Neural Interconnections of Extracranial Nerves in Headache Surgery: Anatomical Landmarks and Clinical Implications: A Review of the Literature

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Summary: Headache disorders (HDs) remain a nationwide challenge for the US health care system, affecting nearly 60% of the US population. Surgical deactivation of the peripheral trigger site, also referred to as headache surgery, represents an effective treatment for patients with refractory HD pain or nonresponse to pharmacologic regimens. Research stemming from other surgical specialties has underlined the clinical relevance of neural interconnections in refining diagnostic algorithms, adapting surgical techniques, and improving overall patient outcomes. Different HD trigger points have been identified, but there is a paucity of studies discussing the mostly sensory neural interconnections between these trigger points in a comprehensive fashion. The authors provide an overview of the specific nerves involved in HD and synthesize the literature on HD nerve interconnections to deduce clinical implications. Overall, this line of research may help refine the perioperative workflow and enhance HD patient care. *(Plast. Reconstr. Surg. 155: 183e, 2025.)*

Headache disorders (HDs) represent a persistent burden for the US health care system, affecting nearly 60% of the US population.[1,2] Worldwide, more disability-adjusted life-years are attributable to HD than to all other neurologic disorders combined.[2,3] A plethora of pharmaceutical (eg, triptans, nonsteroidal anti-inflammatory drugs, antidepressants) and nonpharmaceutical (eg, neurostimulation) HD treatments are US Food and Drug Administration–approved, but nearly 40% of patients do not have adequate response, and only 2% to 14% of eligible individuals use their prescribed HD medication consistently.[4–11]

Nerve compression or irritation in the head and neck region is one underlying reason for medical nonresponse, and has been implicated in refractory HD. A recent study found that 15% of patients presenting with HD have occipital neuralgia.[12] Surgical deactivation of peripheral trigger sites, also referred to as headache surgery, is an effective surgical therapy for patients with HD presenting with neuralgia.[13–17]

The etiology of headaches remains incompletely understood, but headaches are postulated to be a neurological disorder stemming from a combination of genetic, environmental, and neurologic factors. During a headache attack, there is

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evidence of altered neuronal excitability, abnormal neurotransmitter release, and disrupted neuronal signaling.[18–20] Although refined screening algorithms help maximize outcomes of headache surgery, profound knowledge of surgical anatomy in this region remains pivotal for surgical success.[21–23] Anatomical variations in terms of neural interconnections between extracranial nerves implicated in headache surgery have been largely neglected. However, the routes of communication between these nerves may play a crucial role for the success of headache surgery. To date, no study has attempted to shed light on the implications of neural interconnections of extracranial nerves in headache surgery.

In this article, we summarize the available literature on neural interconnections in the head and neck region, delineate anatomical landmarks, and deduce clinical implications. By filling this knowledge gap, headache surgeons may hone preoperative planning, refine the perioperative workflow, and optimize overall postoperative outcomes.

COMMON TRIGGER SITES IN HEADACHE SURGERY

The most common trigger sites in headache surgery include the supratrochlear, supraorbital, greater occipital nerve (GON), lesser occipital nerve (LON), frontal nerve, zygomaticotemporal nerve, and auriculotemporal nerve (ATN), as well as rhinogenic and nummular pain sites. Gfrerer et al.[24] and Seyed Forootan et al.[25] reported that the majority of patients with headache have multiple trigger sites. A detailed overview of neural interconnections between these trigger sites is summarized in the following.

NEURAL INTERCONNECTIONS OF EXTRACRANIAL NERVES INVOLVED IN HEADACHE SURGERY

Major Occipital Nerve Interconnections

Compression and irritation of the major occipital nerves (ie, GON, LON, and third occipital nerve [TON]) play a crucial role in the pathophysiology of HDs. These nerves possess multiple interconnections with each other and adjacent nerves in the posterior neck region.

While traversing through the superficial fascia along with the occipital artery, the GON gives off numerous branches that communicate with the LON and the TON to supply the skin.[26] A study by Becser et al.[27] identified communicating branches of the GON with the LON in 60% of cases (12 out of 20 hemifacial sides) and with the TON in 8.3% of cases (1 out of 12 hemifacial sides). Natsis et al.[28] reported fusion of the GON with the LON at the level of the occiput in 80% of investigated cases. As the LON courses over the occiput, multiple connecting branches forming a communication with the GON have been reported.[29–32] A cadaveric dissection study conducted by Tubbs et al.[33] reported the presence of a small medial branch traversing from the GON to the TON 1 cm superior to the horizontal line connecting the external occipital protuberance (EOP) in all but 3 cadaveric sides. Likewise, in all but 2 cadaveric sides, a small communicating nerve branching off of the TON just inferior to the EOP and coursing laterally to connect with the GON was identified. After traveling deep to the semispinalis capitis muscle, the TON gives off this communicating branch to the GON, which has passed the obliquus capitis inferior muscle and the rectus capitis posterior muscle, pierced the semispinalis capitis muscle, and passed the trapezius muscle before receiving it.[27,33–36] The TON sends multiple connecting branches to the terminal branches of both the GON and the LON.[34,35,37] Delicate neural branches connecting the TON of both sides with each other were found in the midline inferior to the EOP in 67% of investigated cases.[33,35] Cesmebasi et al.[36] highlighted that due to the multiple interconnections among the GON, LON, and TON, "it can sometimes be difficult to determine which nerve is primarily responsible for a specific area's painful symptoms" (Figs. 1 and 2).

Posterior Cervical Plexus (Cruveilhier Cervical Plexus)

Below the suboccipital musculature (ie, rectus capitis posterior major/minor, obliquus capitis superior/inferior muscles), neural loops connect the first (suboccipital nerve) and second dorsal ramus (GON and LON), as well as the second and third dorsal ramus (TON), sometimes reaching up to the fourth dorsal ramus, to form the posterior cervical plexus together with the suboccipital nerve.[34,38] In a cadaver dissection study by Tubbs et al.,[35,39] neural intercommunicating branches between the upper cervical dorsal ramus and their medial branches were found in 87% of cases. Connections between C1 and C2 were found in 65%, between C2 and C3 in 54%, and between C3 and C4 in 15% of cases. Due to their deep topographic location adjacent to facet joints, anatomical variability of nerves and their interconnections may be the root of therapy-recalcitrant pain after

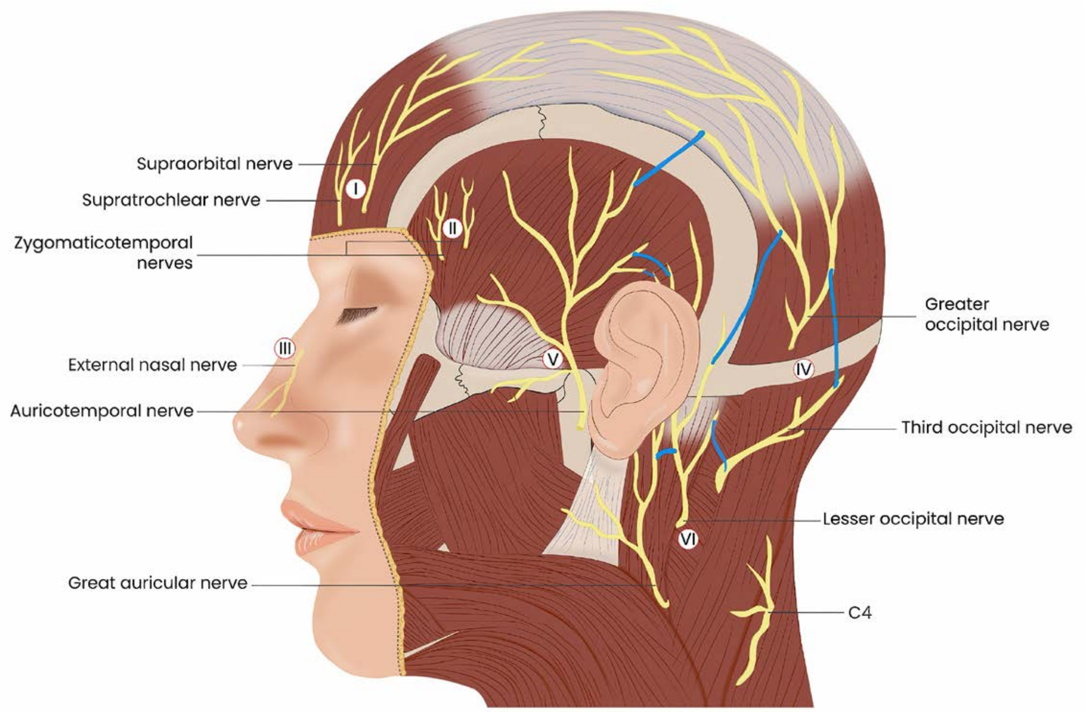

Fig. 1. Illustration of the anatomy of extracranial nerves commonly affected in HD. Described headache trigger zones are marked with *white circles* and *roman numerals*. Neural interconnections are shown as *blue* branches.

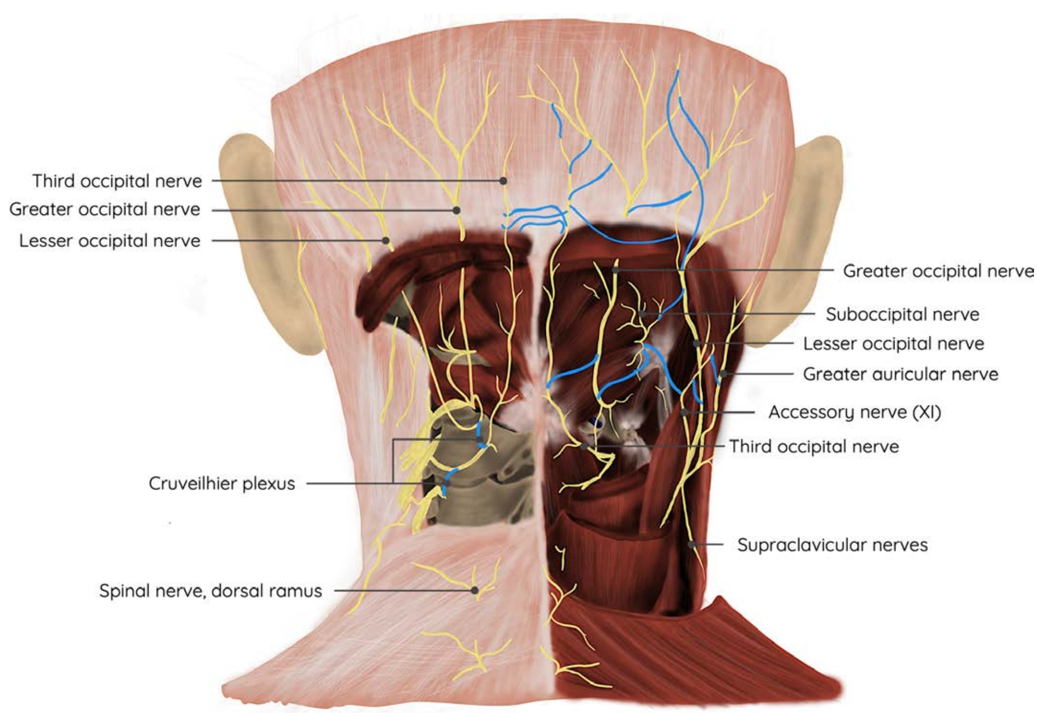

Fig. 2. Illustration of the anatomy of extracranial nerves and their neural interconnections in the occipital region in different depths. Neural interconnections are shown as *blue* branches.

ablative procedures, as articular branches arising from the TON and its neural interconnections has been described.[35,40] These communications are being formed deep to the semispinalis capitis muscle near the bony vertebrae.[35] The deep neural circuitries of the Cruveilhier plexus are further supplied by the SON, which also forms connections with the GON, the LON, and the spinal accessory nerve.[41–43]

Trigeminocervical Interconnections

The functional connectivity of the major occipital nerves and the trigeminal nerve due to their convergence at the caudal part of the trigeminal nucleus has been studied extensively, but the literature on the extracranial anatomical interconnections is scarce.[44–48] Communicating branches of the GON with the ATN, a branch of the mandibular nerve of the trigeminal nerve (cranial nerve [CN] V3), have been described in 10% of cases (2 out of 20 specimens) in a dissection study by Becser et al.[27] The authors also reported communication between the LON and ATN in 10.5% of cases (2 out of 19 specimens). Gebara et al.[49] further substantiated such communication between the LON and the ATN. These specific neural interconnections could potentially play a role in the pathogenesis of treatment-resistant auriculotemporal neuralgia, suggesting a new avenue for understanding and managing this condition.

Trigeminofacial Interconnections

All 3 divisions of the trigeminal nerve (CN V) show plexiform connections with the terminal motor branches of the facial nerve (CN VII):

(1) Two research groups have documented the existence of neural interconnections between the supraorbital nerve, as a branch of the ophthalmic nerve (CN V1), and the temporal branch of the facial nerve, at a frequency ranging between 44% and 86%.[50,51] The supratrochlear nerve was reported to anastomose with the temporal and buccal branches of the facial nerve in 57% and 50%, respectively.[51] Neural interconnections were also reported between the infratrochlear nerve (as a branch of the nasociliary nerve coming from CN V1) and the buccal as well as zygomatic branches of the facial nerve.[52,53] Such interconnections are likely linked to a range of clinical manifestations. For instance, patients with trigeminal neuralgia may experience complications such as hemifacial spasms.[45,47]

(2) Won et al.[52] documented further neural interconnections between the infraorbital nerve, as a branch of the maxillary nerve (CN V2), and the buccal and zygomatic branches of the facial nerve in 100% and 29% of cases, respectively. Tansatit et al.[54] specified single (10%), double (63%), and triple (25%) communications between the infraorbital nerve and the buccal branch of the facial nerve. In addition, up to 2 branches of the temporal branch of the facial nerve were reported to penetrate the superficial layer of the deep temporal fascia to communicate with the zygomaticotemporal nerve as a branch of the maxillary nerve (CN V2), with a reported prevalence of 82%.[55] Communicating branches were also described between the zygomaticofacial nerve as another branch of the maxillary nerve (CN V2) and the zygomatic branch of the facial nerve, albeit with a rarer rate (42% of investigated cases).[51] Generally, the zygomatic branch of the facial nerve appears to be well connected, with further branches to the supraorbital and supratrochlear nerves (both branches of CN V1) as well as to the buccal nerve of the mandibular nerve (CN V3).[56,57]

(3) Namking et al.[58] classified the connection of the ATN as a branch of the mandibular nerve (CN V3) with the facial nerve into 4 types based on the number of communicating ATNs (CATNs) joining the facial nerve: (I) 1 branch (21%), (II) 2 branches (60%), (III) 3 branches (15%), or (IV) several branches (4%). They reported that some branches of the CATN innervated the orbicularis oculi muscle, prompting the authors to hypothesize that the CATN might carry proprioceptive information of this muscle.[58] This particular connection might, among other causes, explain clinical phenomena such as referred eyelid pain or twitching, which are commonly reported by patients with headache. Tansatit et al.[59] further analyzed the topographic anatomy of these communications: up to 3 branches—most commonly 2 branches, in half of all cases—coming from the ATN join the zygomatic and buccal branches of the facial nerve. These branches are commonly located superficial to the superficial temporal artery and deep to the superficial temporal vein within the parotid tissues.[59,60] In line with this finding, Kwak et al.[61] documented that the

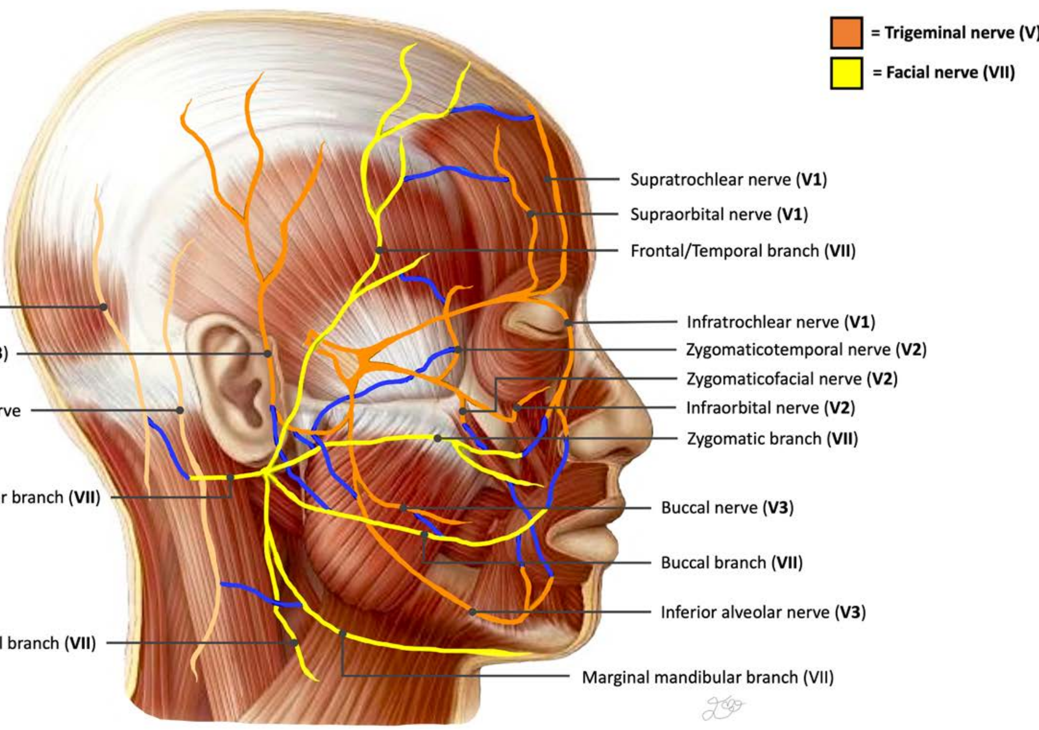

Fig. 3. Illustration of the anatomy of the trigeminofacial connections described in the literature. The trigeminal nerve and its branches is depicted in *orange*; the facial nerve and its branches is depicted in *yellow*. Neural interconnections are shown as *blue* branches.

parotid tissue is the typical site of communication between the ATNs and facial nerve, with 93% of CATNs joining the facial nerve posteriorly at the upper part of the parotid gland. Yet, in contrast to Namking et al.,[58] the authors did not find a single-branched CATN pattern; instead, the number of branches varied from 2 to 4, with triple-branched CATN communication being the most common (47%). Almost 3 decades ago, Shimada et al.[53] documented 2 more trigeminofacial interconnections: although a neural route between the mental branch of the inferior alveolar nerve of the mandibular nerve (CN V3) and buccal as well as marginal mandibular branches of the facial nerve was noted, the buccal branch of the mandibular nerve (CN V3) and buccal branches of the facial nerve were also found to communicate in the area of the buccinator and orbicularis oris muscles (commonly through the so-called communicating buccal nerve).[56] The interconnection between the marginal mandibular branch of CN VII and the mental nerve of CN V3 was validated by various researchers and might elucidate the clinical observations of patients reporting teeth pain during symptom flare-ups.[51,56,62,63]

The ATN has also been reported to occasionally anastomose with the inferior alveolar nerve of the mandibular nerve (CN V3) as well as with the zygomaticotemporal branch (Fig. 3).[64–68]

Neural Interconnections in the Temporal Region

After ascending superoposteriorly toward the auricle, the greater auricular nerve (GAN) gives off a mastoid (posterior) branch communicating with the auricular branch of the LON.[33,36,69–72] It has been reported that the auricular branch connecting with the GAN may also originate from the GON instead of the LON.[49,73,74] In addition, the GAN has been reported to exhibit branches to other extracranial nerves, such as the facial nerve (CN VII) and the accessory nerve.[31,75,76] Both the presence of anterior and posterior communicating nerves of the GAN connecting with the facial nerve has been reported. Furthermore, communication between the GAN and the auricular branch of the vagus nerve was described.[77] Interconnections between the GAN and the auriculotemporal branch of the facial nerve were also reported to form in close vicinity to the parotid gland. However, neural interconnections of the GAN with the facial nerve were observed more commonly than with the ATN.[78,79]

Other Cranial Nerves

A further connection of the LON has been described by Tubbs et al.[76] In their dissection study of 56 cadaver heads, the authors showed that in 1.8% of cases (2 out of 112 sides), the LON arose directly from the accessory nerve, and in 5.4% of cases (6 out of 112 sides), communicated with the accessory nerve. Chabot et al.[80] confirmed this origin in their case presentation, where the posterior branch of the spinal accessory nerve was found to give off an ascending branch superficial to the splenius capitis muscle, identified to be the LON. In one instance, a variation of the LON giving off a connecting branch to the accessory nerve was seen. Interestingly, the authors emphasized that no other nerves of the cervical plexus communicated with this nerve.[80,81] In 44% of cases investigated in a cadaveric study by Johal et al.[82] and Tubbs et al.,[83] a connection between the accessory nerve and the C1 dorsal rootlet was reported. In several studies, the LON has been reported to form intercommunicating branches with the auricular branch of the facial nerve.[26,31,84] Furthermore, nerves implicated in occipital neuralgia were reported to show neural connections with the vestibulocochlear (CN VIII), glossopharyngeal (CN IX), and vagus (CN X) nerves.[38,85,86] Communicating branches were consistently reported to form between the GAN and marginal mandibular branch as a branch of the facial nerve (CN VII).[73,87] (**See Table, Supplemental Digital Content 1**, which shows an overview of neural interconnections of extracranial nerves involved in headache surgery, ***http://links.lww.com/PRS/H302***.)

PERIOPERATIVE IMPLICATIONS AND PITFALLS FOR HEADACHE SURGEONS

Neural Interconnections in Preoperative Patient Selection for Headache Surgery

Headache surgeons use a gamut of diagnostic tools, including neuromodulator injections, diagnostic nerve blocks, and pain drawings, when screening patients with headache for eligibility for nerve decompression.[21,88–90] However, research from other surgical specialties suggests that neural interconnections may interfere with the predictive values of diagnostic pathways for such neuropathologies. For example, Sraj et al.[91] reported the case of a patient who presented with the typical symptoms of carpal tunnel syndrome but a negative Tinel sign and Phalen test. The authors found that the test results might be due to the transfer of sensory nerve fascicles from the ulnar nerve to the median nerve. In accordance, nerve stimulation in the epitrochlear-olecranon groove triggered symptoms indicative of carpal tunnel syndrome. In addition, Becser et al.[27] dissected 10 cadavers and deduced that linked ineffective (therapeutic) blockades of the GON and LON might be linked to LON–GON or GON–LON interconnections. While the role of neural interconnections in patient eligibility for headache surgery remains to be established in large-scale prospective studies, topographic and anatomical knowledge of such neural communications may help interpret aberrant diagnostic findings (ie, persisting pain after nerve blocks or uncommon pain referral patterns) and ultimately guide clinical decision-making.

Neural Interconnections in Perioperative Planning and Surgical Technique Adaptation

One of the most important perioperative implications associated with these neural interconnections is the imperative to modify the surgical approach to account for potential anatomical variations. Surgeons should be sensitized to the potential presence of such interconnections and undertake precautionary measures during the procedure to avoid inadvertent injury or disruption to these neural pathways, with eventual severe sequelae. In accordance, surgeons should exercise utmost caution and use meticulous techniques to minimize the risk of unintended damage to these interconnections, as their disruption could lead to significant postoperative complications.[92–94] In addition, the surgeon must be prepared to extend the initial surgical incision if an interconnection is identified, allowing for its proper release and avoidance of any compromise to the neural pathway.[95,96]

The presence of neural interconnections can substantially complicate the surgical dissection process, potentially necessitating additional time and effort to precisely identify and separate these interconnected nerve branches. This might result in extended anesthesia time in the operating room, which poses well-documented risks.[92] In this context, the use of intraoperative neurophysiologic monitoring, including somatosensory evoked potentials and electromyography, can provide real-time feedback to guide surgical dissection and avoid damage to interconnected nerve branches.[95]

Neural Interconnections in Postoperative Therapy–Refractory Headache

Mechanical compression of neural interconnections can result in an unexpected pattern of neural transmission and pain referral.[97] Thus, through the referral of pain, these pathways can disguise the actual trigger site. For instance, pain arising from an irritated LON can be experienced in the region characteristic of the GON if neural interconnections between both nerves are present. Owing to the myriad possible interconnections between nerves implicated in headache surgery that have not been described sufficiently hitherto, surgeons ought to be attentive throughout the entire treatment. In patients in whom the performed surgical procedure did not specifically target and release the mechanically compressed neural interconnections causative of the pain, patients may continue to experience headaches due to the persistence of neural pathways that were not adequately decompressed. This underscores the importance of preoperative assessment and meticulous surgical planning to identify and target all relevant nerves forming interconnections with the nerve hypothesized to be causative of pain.[98]

In patients who experience postoperative complications due to unanticipated neural interconnections, further interventions may be warranted to address unresolved pain. These interventions may encompass additional procedures, targeted nerve blocks, or alternative therapies aimed at modulating the neural activity in the affected interconnected circuits,[99,100] with additional risk of complications. The development of comprehensive treatment strategies that account for these rare interconnections is therefore pivotal in improving patient outcomes and reducing the incidence of therapy-refractory HD.

These nerve interconnections should not confuse or intimidate clinicians performing headache surgery. In the overwhelming majority of patients, these interconnections do not influence the outcomes when the practical steps outlined in articles based on extensive clinical experience are followed.[25,90] Indeed, in most clinical presentations, vessels irritate the distal branches of the nerves and removal thereof yields remarkable positive outcomes. However, knowledge of these interconnections could help manage suboptimal or unexpected outcomes.

This descriptive study, despite being comprehensive in its literature review and identification of knowledge gaps concerning neural interconnections in the head and neck area, is not without limitations. The clinical implications derived from this review need future validation. Considering the intricate neural interconnections identified, this study suggests the possibility of reevaluating surgical approaches in the head and neck region. The necessity and nature of any modifications to surgical techniques remain subject to future research; however, these findings hint at the potential benefits of exploring less-invasive incisional patterns to reduce the likelihood of unintentional nerve damage. Furthermore, the adoption of intraoperative monitoring tools like somatosensory evoked potentials and electromyography may warrant further investigation, as their use could offer valuable intraoperative insights. All surgeons must be aware of the described anatomical variations in this area. This knowledge will enable the surgeon to identify patients with headache with atypical clinical presentations that could be linked to uncommon neural interconnections. Recognizing these patterns will aid in accurately tracing back such symptoms to their potential neural origins, ultimately improving diagnostic and treatment strategies.

CONCLUSIONS

The identification of different HD trigger nerves, with understanding of the anatomy and topography of neural interconnections, can add to the refinement of preoperative diagnostics, guide intraoperative decision-making, and improve postoperative HD outcomes. This line of research may serve as an evidence-based foundation for future prospective studies determining the exact role of neural interconnections in headache surgery.

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