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COMMUNICATION

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A marginal process of the zygomatic bone predicts a lateral exit of the zygomaticotemporal nerve: An anatomical study with application to surgery around the midface

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Abstract

Previous studies have not verified the contents of accessory foramina of the zygomatic bone on dry skulls and thus could not conclude whether they carried accessory zygomaticofacial nerve branches or branches or the entire trunk of the zygomaticotemporal nerve (ZTN). Therefore, the aim of the current study is to present findings from cadaveric dissections to clarify this relationship. Fifty, fresh frozen, adult cadaveric sides underwent dissection of the ZTN. When identified, these nerves were quantified and their relationship to the zygomatic bone further documented by dissecting through the bone following the course of the nerve from a superficial to deep perspective. Additionally, 100 dry, adult, human skulls were analyzed looking for lateral foramina on the zygomatic bone. On three cadaveric sides (6%), the ZTN was found to pierce the zygomatic bone deeply and exit its superficial lateral surface. For dry skull specimens, a lateral zygomaticotemporal foramen (ZTF) was identified on nine sides (4.5%). For both groups, the presence of a strong marginal process of the zygomatic bone was strongly correlated to a ZTF exiting the lateral surface of the zygomatic bone. Although relatively uncommon, the ZTN can pierce the lateral aspect of the zygomatic bone and thus can be located superficial to the cheek. Such findings should be borne in mind during surgical or other invasive procedures in this area in order to minimize iatrogenic injury to the ZTN.

KEYWORDS
anatomy, cadaver, zygomatic bone, zygomaticotemporal foramen, zygomaticotemporal nerve

1 | INTRODUCTION

The zygomaticotemporal nerve (ZTN) is a branch of the maxillary division of the trigeminal nerve. It emerges from the zygomatic nerve in the floor of the orbit and bifurcates into zygomaticofacial and zygomaticotemporal branches on the lateral wall of the orbit. The ZTN runs along the inferolateral wall of the orbit, traversing a groove and bony canal in the zygomatic bone, communicates with the lacrimal nerve, and passes through the zygomaticotemporal foramen (ZTF) on the temporal (posteromedial) surface of zygoma near the base of the frontal process. It then enters the temporal fossa (Govsa et al., 2009; Schmidt-Erfurth & Kohnen, 2018; Tomaszewska et al., 2015). Anatomical variations of the pathway of the ZTN have been highlighted in previous studies, which evaluated its relationship to the inferior orbital fissure, the location and frequency of the ZTF, and variations in the number of branches (Hwang et al., 2004; Mangal et al., 2004).

Understanding the variations in frequency and location of the zygomatic foramina and the zygomatic nerve branches is important for preventing iatrogenic injuries during craniofacial and orbital procedures that involve osteotomies and anesthetic injections in the zygomatic region (Mangal et al., 2004). Orbitozygomatic craniotomy and osteotomy are becoming widely popular approaches to skull base surgery as they provide broad and multidirectional access to vascular and neoplastic lesions in the region; this involves successive cuts to liberate the orbit and zygomatic arch (Lemole et al., 2003; van Furth et al., 2006). Knowledge of the precise location of the ZTN and its branches is also crucial during surgical management of zygomaticomaxillary fractures (Govsa et al., 2009). Neurovascular structures close to the zygomatic region should be preserved when a transmaxillary approach to the orbit is used during removal of infraorbital tumors and in orbital decompression (Gönül et al., 2003).

In essence, most authors describe the location of the ZTF as on the deep temporal surface of the zygomatic bone. However, one previous dry skull study showed a variable number of zygomatic foramina (Figure 1), and also showed that some ZTFs were superficially located (Loukas et al., 2008). However, previous studies have not verified the contents of these foramina and thus could not conclude whether they carried accessory zygomaticofacial nerve branches or branches or the entire trunk of the ZTN (Figure 1). Therefore, the aim of the current study is to present findings from cadaveric dissections exhibiting a branch of the ZTN in a superficial position traversing a superficial ZTF and compare this to bony skull anatomy. Knowledge of the existence of a superficially positioned ZTF and ZTN is of significance during orbitozygomatic and maxillary facial surgeries and zygomatic fracture reductions, and for administering anesthesia to prevent or minimize iatrogenic injuries that can lead to paresthesia and weakness or culminate in protracted pain if there is nerve entrapment.

2 | MATERIALS AND METHODS

Twenty-five cadavers (50 sides) underwent dissection of the ZTN. The specimens were fresh-frozen and were derived from 31 male and 19 female cadavers with a mean age at death of 79 years (range 45–101 years). The specimens were dissected using a surgical microscope (Zeiss, Germany) using microsurgical techniques. Specifically, we documented nerves that traveled through the zygomatic bone and exited the superficial surface of the bone. When identified, these nerves were quantified and their relationship to the zygomatic bone further documented by dissecting through the bone with a drill and bone rongeurs following the course of the nerve from a superficial to deep perspective.

Additionally, 100 dry, adult, human skulls (200 sides) were analyzed looking for lateral foramina on the zygomatic bone. Specifically, any foramen that was posterior to the zygomaticofacial foramina (ZFF) was

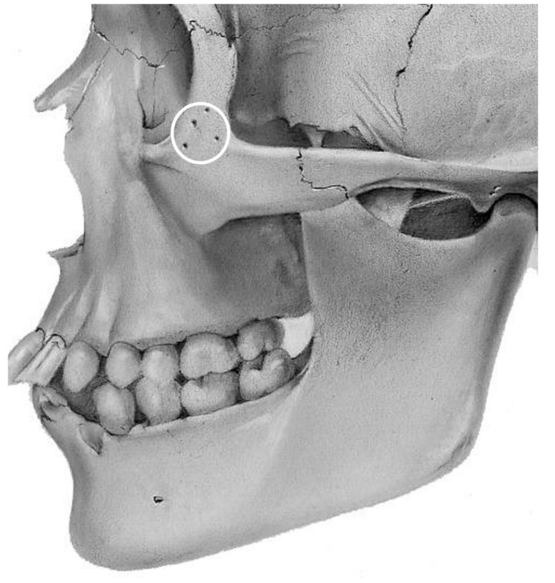

FIGURE 1 Schematic drawing of multiple "zygomatic foramina." In the past, these were termed primarily accessory zygomaticofacial foramina as it was assumed that the zygomaticotemporal nerve (ZTN) penetrated the temporal surface of the zygomatic bone and not its superficial surface as does the zygomaticofacial foramen.

examined under the surgical microscope. Small acupuncture needles were inserted into these foramina to determine their medial course and to verify if they originated in the infratemporal fossa, that is, ZTN or orbit, that is, zygomaticofacial nerve. Statistical analysis between sides was performed using student *t* tests with significance set at $p < 0.05$.

3 | RESULTS

On three cadaveric sides (6%), the ZTN was found to pierce the zygomatic bone deeply and exit its superficial lateral surface. These were all identified on two left sides and one right side and all were from male specimens ($p = 0.0001$) (Figures 2–4). All three of these ZTNs pierced the frontal process of the zygomatic bone with two of these piercing the bone at the posterior margin of the zygomatic bone at its junction with the marginal process. One ZTN pierced the zygomatic bone just distal to the marginal process (Figure 4), one just proximal to the process (Figure 3) and one, just anterior to the process (Figure 2). One of these three ZTNs, after piercing the frontal process of the zygomatic bone, traveled in a groove on the surface of the zygomatic bone (Figure 3). All ZTN that perforated the zygomatic bone were determined to be the nerve's main trunk as no additional branches were identified.

For dry skull specimens, a laterally placed ZTF was identified on nine sides (4.5%) (four left and five right sides) (Figure 5). One bony specimen (0.5%) had a ZTF on the right side that was located more superior to the ZFF (Figure 6). One bony specimen (0.5%) was found to have duplicated ZTF and ZFF on the left side (Figure 7).

No statistical significance ($p > 0.05$) was found comparing the presence or placement of the ZTF on the dry skull specimens. For both groups, the presence of a prominent marginal process of the zygomatic bone was strongly correlated ($r = 0.855$; $p < 0.01$) to a ZTF exiting the lateral surface of the zygomatic bone (Figures 5 and 8).

4 | DISCUSSION

A thorough understanding of the pathway of the ZTN and its anatomical variations in terms of frequency and location of the ZTF is crucial for preventing iatrogenic injury during surgical manipulation in the region and for increasing the percentage of successful outcomes in neuro, plastic, and maxillofacial surgeries. However, there have been few studies of its anatomy, and reports in the literature rarely focus on the nerve and its topography (Tezer et al., 2017; Tubbs et al., 2012).

Kim et al. studied the intraosseous course of the ZTN three-dimensionally using microcomputed tomography on Korean subjects and noted that about 71.4% of zygomaticotemporal canals (ZTCs) originated from the intraosseous canal along the course of zygomaticofacial canals, while 28.6% of ZTCs opened through each corresponding foramen. An average of 2.2 foramina per zygomatic bone was also reported (Kim et al., 2013). Another assessment of 192 Korean skulls showed zygomatic foramina located on the body of the zygomatic bone in a substantial number of cases, while they were found on the frontal process or on the margins of the frontal process and body in other cases (Kim et al., 2013). The average number of ZTFs was 0.8 (Kim et al., 1997). A study by Zhao et al. on 62 skulls of

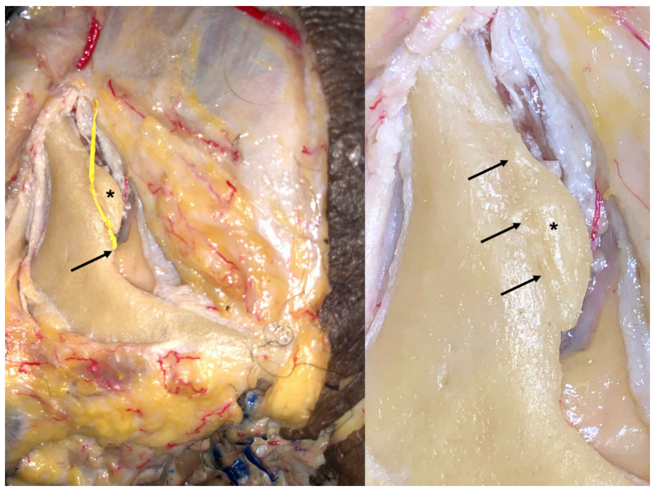

FIGURE 3 Left: A left-sided zygomaticotemporal nerve (ZTN) (yellow) that pierced (arrow) the posterior aspect of the zygomatic bone and traveled superiorly (right image) in a groove (arrows) located just anterior to the marginal process (*).

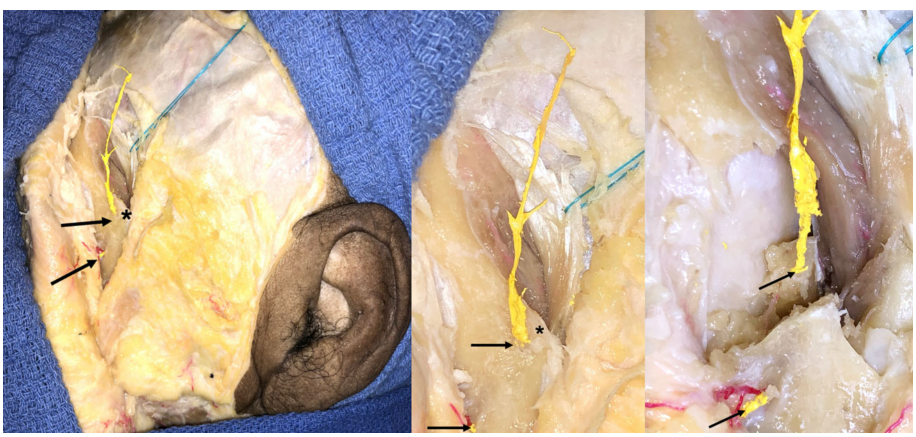

FIGURE 2 Left dissection of the zygomaticotemporal nerve (ZTN) (yellow nerve ascending over the temporal fascia) in which the nerve pierced (upper arrows) the lateral surface of the zygomatic bone. Note the marginal process of the zygomatic bone (*) and more inferiorly located zygomaticofacial nerve (lower arrows). The middle panel is a zoomed in image of the first panel and the third panel shows dissection through the zygomatic bone and identifies the penetration site of the ZTN from a temporal to lateral course.

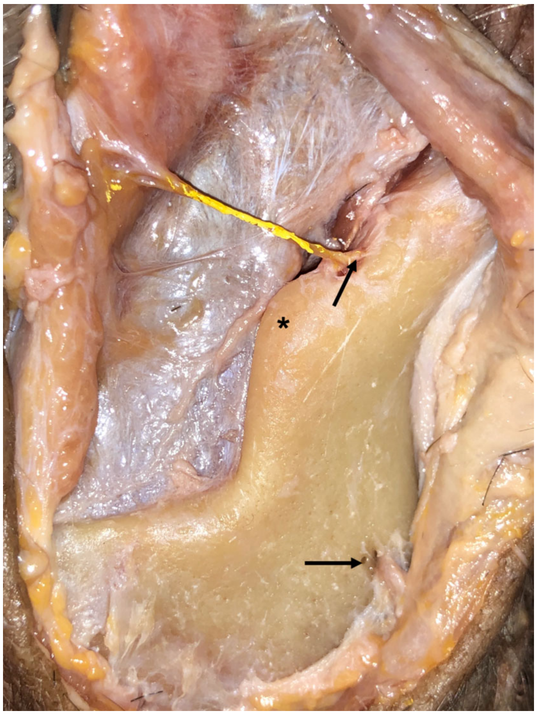

FIGURE 4 A right-sided zygomaticotemporal nerve (ZTN) (yellow) that pierced (upper arrow) the posterior edge of the temporal process of the zygomatic bone just superior to the marginal process (*). For reference, not the exiting zygomaticofacial nerve (lower arrow).

African American descent showed an average number of 1.98 ± 0.93 zygomatic foramina. There were more foramina on the right (2.13 ± 0.98) than the left (1.68 ± 0.79). They concluded that African Americans have a higher average number of zygomatic foramina than other populations, and nerves should be preserved during subperiosteal dissection 5 mm below the inferolateral orbital rim as there is a greater density of zygomatic foramina in this area (Zhao et al., 2018). The inconsistency and divergence in the size and contour of the zygomatic bone and in the frequency and location of foramina can be ascribed to ethnic differences, which are often used by the anthropologists as non-metrical markers for identifying different populations (Loukas et al., 2008; Mangal et al., 2004). The fact that ethnicity can potentially be significant is corroborated by several studies manifesting such discrepancies in various populations. For example, Brazilian studies showed a relative predominance of single or double zygomatic foramina, while absence of a zygomatic foramen was prevalent among Argentinian skulls. Four foramina were observed in 5.5% of Western Anatolian skulls and two zygomaticofacial foramina were frequent in South Africans (Gonzalez et al., 2002; Keyser, 2000; Loukas et al., 2008; Zhao et al., 2018).

Janis et al. examined 50 cadaveric head sides and reported the location of the ZTF on the lateral wall of the zygomatic portion of the orbit, 6.7 mm lateral to the lateral orbital rim and 7.88 mm cranial to nasion-lateral orbital margin line. Interestingly, some ZTFs were identified as posterolateral to the edge of the lateral orbital margin rather than on its surface. Some specimens also had two branches of the ZTN a finding we did not observe in cadaveric specimens but in only one dry skull specimen (Janis et al., 2010). Totonchi et al. measured the distance of the emergence site of the ZTN from the palpebral commissure as 16.8 mm (range, 12–31 mm) in the posterolateral direction and 6.4 mm (range, 4–11 mm) in the cranial direction on the left; and 7.1 mm (range, 15–21 mm) in the lateral direction and 6.65 mm (range, 5–11 mm) in the cranial direction on the right. Interestingly, these authors observed three accessory nerves related to the main ZTN, which were superior, lateral and immediately adjacent to the major branch. However, they rendered the findings less reliable by making the measurements after dissection of the temporal region (Totonchi et al., 2005). A distance of 23.81 ± 4.8 mm between the exit point of the ZTN and the lateral canthus was found by Tezer et al. during examination of 28 hemifaces of embalmed and fresh cadavers (Tezer et al., 2017). Last, based on our findings, we believe that some previous studies (Hauser & De Stefano, 1989) have misinterpreted a laterally exiting ZTF as a "high" zygomaticofacial foramen.

During embryological development of the face, the zygomatic nerve is prone to becoming entrapped in the mesenchyme at various locations along its course in the orbit and zygomatic bone as it gives off its branches (Mangal et al., 2004). The nerves and vessels of the zygomatic bone develop during the third month between the orbital and remaining parts of this bone (Hauser & De Stefano, 1989). Another potential embryological explanation for the variable number of zygomatic foramina is the varying number of ossification centers related to the zygoma, described as one to three by various authors (Hauser & De Stefano, 1989; Loukas et al., 2008; Zhao et al., 2018). Furthermore, according to recent findings, the variation in the number of foramina can be credited to continuous division of all three branches of the maxillary nerves as the cranium develops and matures (Mangal et al., 2004). Iwanaga et al. speculated that accessory mental foramina are fashioned when bone is incorporated in the periphery of the branching point, as opposed to the traditional addition of bone proximal to the branching points. This could be extrapolated to the ZTF: if bone is added after the nerve gives off its branches, multiple ZTFs can develop (Iwanaga et al., 2017). This point is supported by our findings that a more prominent marginal process (apophysis pyramidalis, Sommering's process) of the zygomatic bone was strongly correlated to a ZTF on the lateral surface of the zygomatic bone. Some have considered this protuberance of the zygomatic bone as being due to the pull of the temporal fascia or due a separate ossification center (Hauser & De Stefano, 1989).

Precise details regarding the intraosseous course of the ZTN are unknown (Kim et al., 2013). Clinically, the locations of various zygomatic foramina and nerve branches are of paramount significance for surgeons and anesthesiologists during numerous facial surgical procedures conducted in the zygomatic region. The location of a superficial ZTF is important during stabilization of zygomatic fractures as deployment of screws proximally to the ZTF, or potentially within it, can injure the nerve. Transecting the neurovascular structures housed in the foramen during surgical dissections can induce hypesthesia or paresthesia in the nerve distribution and intraoperative bleeding and hematoma formation. Care should be taken to avoid the nerves, as

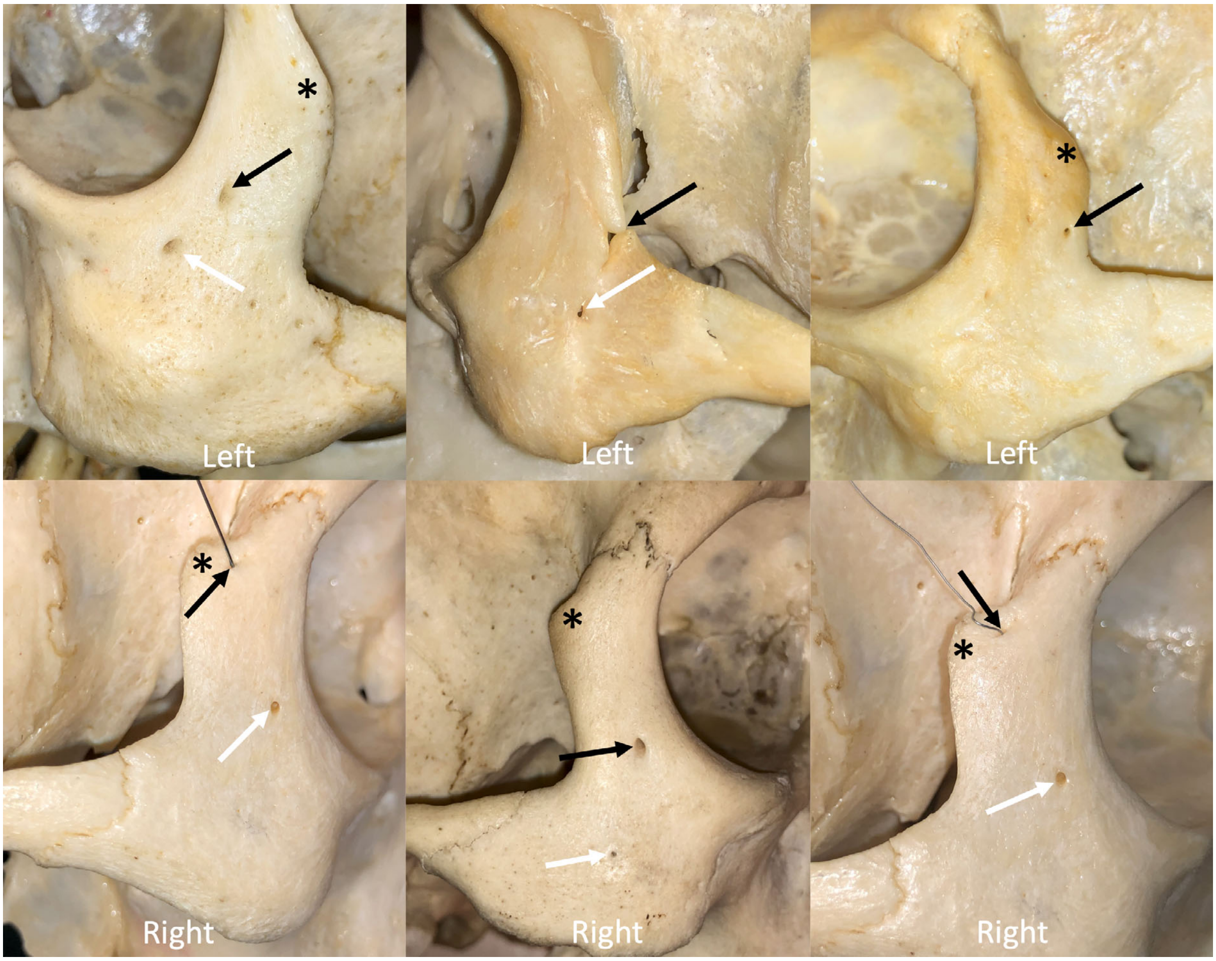

FIGURE 5 Examples of skulls with zygomaticofacial foramina (ZFF) (white arrows) and laterally placed zygomaticotemporal foramina (ZTF) (black arrows). The marginal process of the zygomatic bone is noted at the *. Note that a prominent marginal process of the zygomatic bone (*) is strongly correlated to the presence of a laterally placed ZTF. The ZFF is absent in the right image of the upper panel.

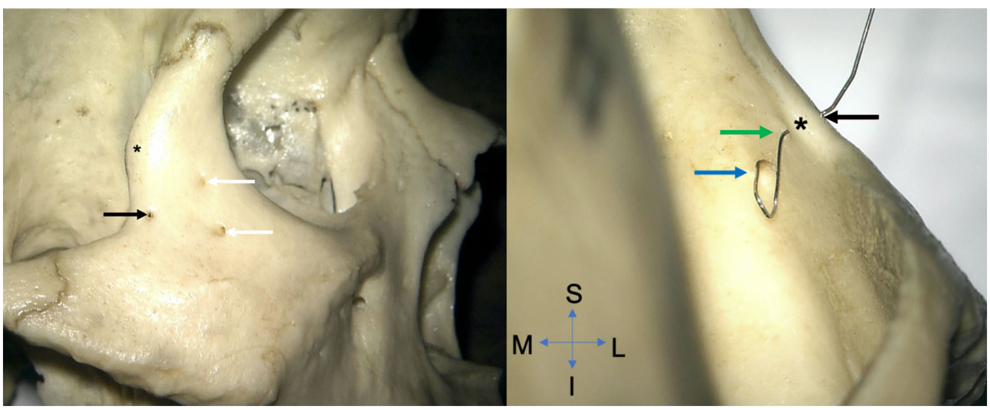

FIGURE 6 Left: Skull noting two zygomaticofacial foramina (ZFF) (white arrows) and a laterally located zygomaticotemporal foramina (ZTF) (black arrow). Note the marginal process (*) of the zygomatic bone. Right: Zoomed in posterior view of the specimen seen to the left. The wire is exiting the posterior aspect of the zygomatic bone as the zygomaticotemporal nerve (ZTN) (blue arrow) and penetrates the temporal (deep) surface of the zygomatic bone (green arrow) adjacent to the marginal process (*) to exit the lateral surface of the zygomatic bone (red arrow). I, inferior; L, lateral; M, medial; S, superior.

entrapment during manipulation of the lateral orbital wall, reduction of zygomatic fractures, subperiosteal facelift and craniotomies can cause protracted pain. Nerves can be injured during parallel osteotomy of the medial zygomatic body during malarplasty, various cosmetic procedures, facial fracture repair, and administration of anesthetic nerve blockade (Center et al., 2019; Ghosh & Narayan, 2021;

Hwang et al., 2004; Loukas et al., 2008; Zhao et al., 2018). Therefore, precise localization of the ZTF and the superficial branches of the ZTN is necessary to alleviate morbidities associated with surgical manipulation in the zygomatic region.

Last, in the works of Janis et al. (2010) and Totonchi et al. (2005) discussed how an improved knowledge of the topography/variations of the ZTN and/or its branches might be used for treating patients with migraine headaches where the ZTN is thought to be involved. Therefore, the findings of the current study could also be applied to this patient population.

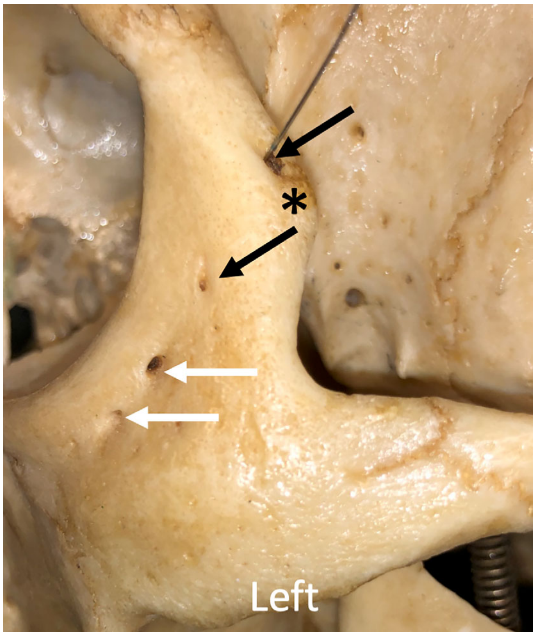

FIGURE 7 Examples of skulls with duplicated laterally placed zygomaticotemporal foramina (ZTF) (black arrows) and zygomaticofacial foramina (ZFF) (white arrows). Note that a marginal process of the zygomatic bone (*) is prominent in this case.

5 | CONCLUSIONS

Although relatively uncommon, the ZTN can pierce the lateral aspect of the zygomatic bone and thus can be located superficial to the cheek region. This anatomical variation should be added to the list of known variations of the ZTN and zygomatic bone (Zytkowski et al., 2021). Based on our findings, a prominent marginal process of the zygomatic bone might predict a ZTF on the lateral surface of the zygomatic bone. Such findings should be borne in mind during surgical procedures in this area such as orbitozygomatic craniotomies, zygomatic fracture repair, and lateral orbital surgeries so that postoperative complications, for example, sensory loss in the temporal region are avoided.

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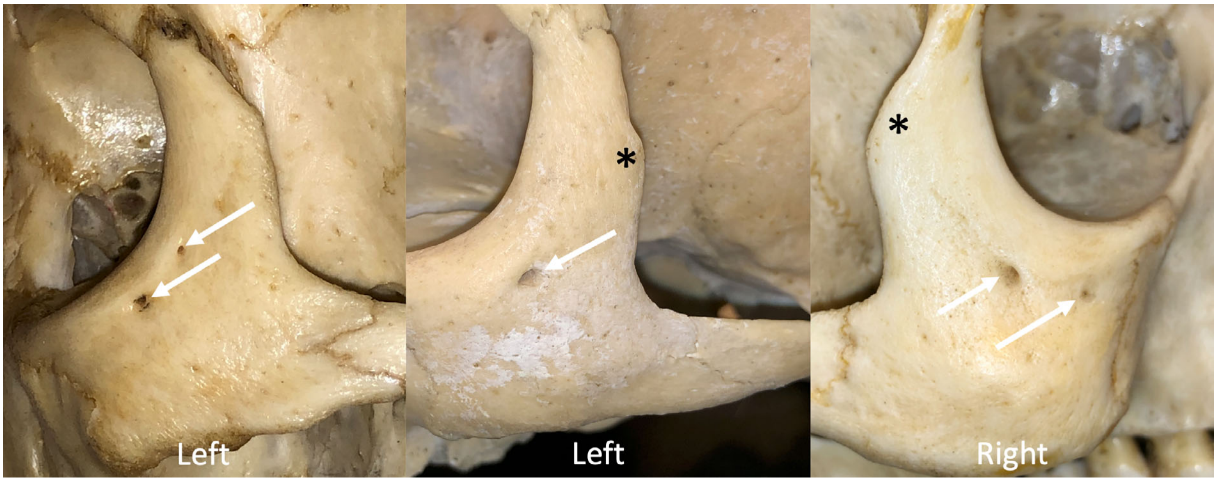

FIGURE 8 Examples of skulls with no laterally placed zygomaticotemporal foramina (ZTF) but zygomaticofacial foramina (ZFF) (white arrows). Note that a marginal process of the zygomatic bone (*) is not prominent in these cases.

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