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Review

A review of the mandibular and maxillary nerve supplies and their clinical relevance

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ABSTRACT

Mandibular and maxillary nerve supplies are described in most anatomy textbooks. Nevertheless, several anatomical variations can be found and some of them are clinically relevant.

Several studies have described the anatomical variations of the branching pattern of the trigeminal nerve in great detail. The aim of this review is to collect data from the literature and gives a detailed description of the innervation of the mandible and maxilla.

We carried out a search of studies published in PubMed up to 2011, including clinical, anatomical and radiological studies.

This paper gives an overview of the main anatomical variations of the maxillary and mandibular nerve supplies, describing the anatomical variations that should be considered by the clinicians to understand pathological situations better and to avoid complications associated with anaesthesia and surgical procedures.

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1. The trigeminal nerve: a general overview

The trigeminal nerve is the largest of the cranial nerves. It originates from the brainstem at the midlateral surface of the pons, near its upper border, by a smaller motor and a larger sensory root. The afferent fibres transmit information from the face, oral and nasal cavities, and most of the scalp. Most of these fibres have their cell bodies located in the trigeminal ganglion or Gasserian ganglion. With the exception of periodontal ligament mechanoreceptors, the cell bodies of the neurons involved in proprioception and the stretch receptors are located in the mesencephalic nucleus. In addition, the trigeminal nerve also contains visceral efferent fibres for lacrimal, salivary and nasal mucosa glands; these fibres come from facial and glossopharyngeal nerves and run into the trigeminal nerve after an anastomosis with a branch of the facial or glossopharyngeal nerves. Somatic efferent fibres of the trigeminal nerve innervate the masticatory muscles. They originate from the motor nucleus of the trigeminal nerve located in the pons.

The trigeminal nerve gives three branches distal to the trigeminal ganglion. The upper branch of the trigeminal nerve is the ophthalmic nerve (V_1). It passes forward in the lateral wall of the cavernous sinus and gains access to the orbit via the superior orbital fissure. The ophthalmic nerve gives branches to supply sensation to the eyeball, conjunctiva, lacrimal glands, nasal mucosa, skin of the nose, eyelid and forehead. The middle branch is the maxillary nerve (V_2). Maxillary division exits the middle cranial fossa through the foramen rotundum and enters into the pterygopalatine fossa where it gives off several branches for the dura, the maxillary teeth and associated gingiva, the maxillary sinus, the upper lip, the lateral surface of the nose, the lower eyelid and conjunctiva, the skin of the cheek and of the side of the forehead, the nasal cavity and the mucosa of the hard and soft palate. The lower branch is the mandibular nerve (V_3). V_3 runs along the floor of the cranium then exits through the foramen ovale into the infratemporal fossa and innervates the dura, the temporomandibular joint, the skin over the side of the head above the ears, the auricle, the tongue and its adjacent gingiva, the muscle of the floor of the mouth, the mandibular teeth and associated gingiva, the mucosa and skin of the cheek, the lower lip and the chin and the muscles of mastication.

Given that the aim of this study is to describe the anatomical variations of the branches of the trigeminal nerve, which may have clinical implications during anaesthesia and surgical procedures in dental and maxillofacial practice, we have described the branching pattern of the mandibular and the maxillary nerves in detail.

1.1. *Review methodology*

Literature about the anatomical variations of mandibular and maxillary nerve was selected through a search of Medline, PubMed and Google Scholar databases up to 2011. Additionally, a manual search in the major anatomy, dental implant, prosthetic and periodontal journal and books were performed. The publications were selected by including clinical, anatomical and radiological studies.

2. The mandibular nerve

The mandibular nerve is the third and inferior division of the trigeminal nerve. Unlike the ophthalmic and maxillary divisions, which contain only afferent fibres, the mandibular division contains both afferent and efferent fibres. It runs from the trigeminal ganglion through the foramen ovale down towards the mandible in the region of the infratemporal fossa giving off several branches. The main trunk divides into the nervus spinosus, a recurrent meningeal branch and the medial pterygoid nerve. Then, it divides into a small anterior and a large posterior trunk; the masseteric nerve, the deep temporal nerve, the long buccal nerve and the lateral pterygoid nerve originate from the former; from the posterior division the auriculotemporal nerve, the lingual nerve and the inferior alveolar nerve originate. The inferior alveolar nerve gives off the mylohyoid nerve before it enters the mandible through the mandibular foramen on the medial surface of the mandibular ramus and gives two terminal branches: the mental nerve and the incisive nerve.

2.1. *Anatomical variations of the mandibular nerve supply*

Variations in the branching pattern or topographical relations of the mandibular nerve often account for failure to obtain adequate local anaesthesia in routine oral and dental procedures and for unexpected injury to branches of the nerve during oral/maxillofacial surgery.[1–5] To date, anatomical variations of the mandibular nerve and its branches have been described by several authors.[6–9]

2.1.1. *Anatomical variations of the inferior alveolar nerve and its branches*

The inferior alveolar nerve is the largest branch of the mandibular nerve. It runs into the infratemporal fossa and before entering the mandibular foramen originates a collateral branch, the mylohyoid nerve for the innervation of the mylohyoid and anterior belly of the digastric muscles. Then, it enters the mandibular foramen and runs with the inferior alveolar artery into the mandibular canal constituting the inferior alveolar neurovascular bundle (Fig. 1). In the canal, the nerve gives off two terminal branches: the mental nerve, a larger branch that emerges from the mental foramen and innervate the skin of the chin and the skin and the mucosa of the lower lip and the incisive nerve, a smaller branch, which

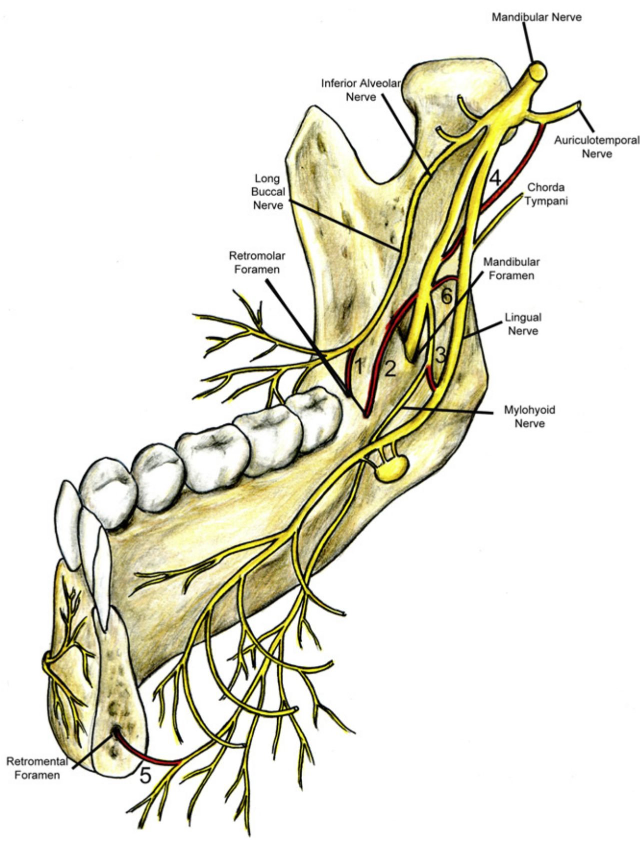

Fig. 1 – Schematic representation of the mandibular nerve and its branches. Some anatomical variations are reported: (1) additional branches of the long buccal nerve; (2) additional branches of the inferior alveolar nerve; (3) communication between the mylohyoid nerve and the lingual nerve; (4) communication between the inferior alveolar nerve and the auriculotemporal nerve; (5) innervation of the incisor teeth by the mylohyoid nerve; (6) communication between the inferior alveolar nerve and the lingual nerve. Nerves are shown in such a way as to summarise optimally the main communication branches of the mandibular nerve, although this may have resulted in details of some of the nerve orientations being modified.

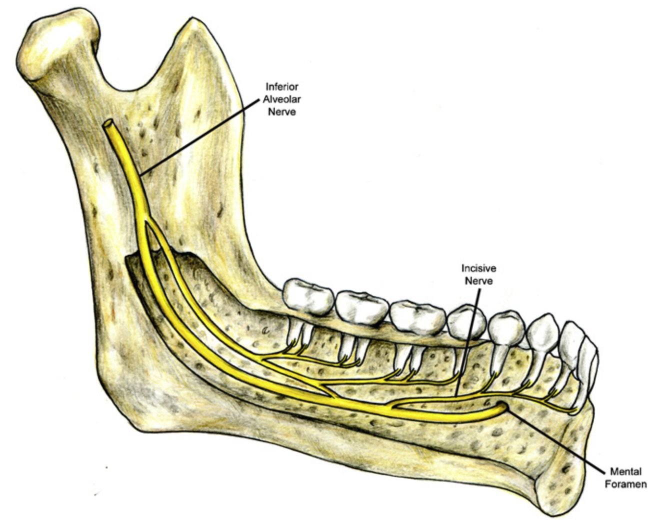

Fig. 2 – Schematic representation of extraosseous multiple branches of the inferior alveolar nerve showed after osteotomy of the inner surface of the mandibula.

continues to travel in the mandible and provides sensory innervation to the premolar, canine, incisor teeth and their associated gingiva.

Here we have reported the following: the anatomical variations of the inferior alveolar nerve compared to its extraosseous and intraosseous branching pattern and its relation with the maxillary artery, the anatomical variations of the mental and incisive nerves and the anatomical variations of the mylohyoid nerve.

2.1.1.1. Anatomical variations of the inferior alveolar nerve. The inferior alveolar nerve can give multiple (extraosseous) branches before it enters the mandibular canal. Within the bony canal it may give rise to multiple intraosseous branches also. Throughout its course the inferior alveolar nerve may support communicating branches with other named parts of the mandibular division – such as the mylohyoid nerve, the lingual nerve, the long buccal nerve and the auriculotemporal nerve. All of these features will be discussed in the relevant paragraphs. It may also show anatomical variations in its relation with the maxillary artery.

2.1.1.1.1. The inferior alveolar nerve: extraosseous multiple branches. The inferior alveolar nerve, before entering the mandible, can give multiple branches. This variation is associated with the presence of accessory foramina and multiple canals so, understanding the mandible accessory foramina can offers valuable insights into determining the location of multiple branches (Figs. 1 and 2).

Several authors reported the presence of multiple foramina in the mandible and the important role of these accessory foramina either in vascularisation or innervation has been suggested.[10–23] Supporting this concept, Nortjé et al.[24] found a bifurcation of the nerve with bifid mandibular canals in 0.9% (33/3612) of subjects, concluding that the mandibular canals are usually, but not invariably, bilaterally symmetrical, and most hemimandibles contain only one major canal. In addition, Grover and Lorton[25] performed a similar study showing only 0.1% (4/5000) radiographs with this anomaly. Furthermore, Langlais et al.[15] evaluated routine panoramic radiographs of 6000 patients and found 57 cases (0.95%) of bifid mandibular canals, 19 in males and 38 in females. Moreover, Sanchis et al.[17] showed a prevalence of 0.35% from the analysis of 2012 panoramic radiographs. Nevertheless, Naitoh et al.[26] by reconstructing 122 two-dimensional images of the mandibular ramus region, observed bifid mandibular canals in 65% of patients and classified it as retromolar, dental, forward and buccolingual canals. De Oliveira-Santos et al.[27] also reported 19% of bifid mandibular canals using cone beam computed tomography exams (CBCT). Cases of trifid mandibular canal and bilateral bifid mandibular canal were also described.[20]

Changes in the location of the mandibular foramen with age should also be considered. Regarding this point, the position of the mandibular foramen with age has been described considering different landmarks. Kilarkaje et al.[28] reported that the distance between the mandibular foramen and different landmarks, (i.e., the head of the mandible, third molar, anterior border of the ramus, angle of the mandible, symphysis menti and lowest point on the mandibular notch), gradually increased with advancing age. Moreover, compared to the occlusal plane and the alveolar crest plane the mandibular foramen was described moving upward with age.[29] For greater accuracy in anaesthetic procedures, dentists should know the locational changes in the mandibular foramen with age when performing block anaesthesia for the inferior alveolar nerve.

The presence of accessory foramina was also associated with the presence of additional branches of the inferior alveolar nerve. In particular, branches of the inferior alveolar nerve can be high in the infratemporal fossa and travel to the base of the coronoid process to enter the mandible through the retromolar foramina providing sensory innervation to the molar teeth.[14,30,31]

These conditions can lead to complications when performing mandibular anaesthesia. In particular, since the bifurcation occurs before the nerve enters the mandibular foramen, a normal inferior alveolar nerve block may be insufficient to block stimulus conduction for both branches, whilst alternative methods can be more effective.[1,4]

The common method for inferior alveolar anaesthesia is the Halstead method, which has a success rate between 71% and 87%.[5,32] This approach is performed in the infratemporal fossa, before the nerve enters the mandibular foramen.[5] If the Halstead method fails, alternative methods to block the inferior alveolar nerve and the supplementary nerves that could innervate the mandibular teeth could be used, e.g., buccal and lingual infiltrations, intraligamentary injection, the Gow-Gates mandibular nerve block, the Vazirani-Akinosi closed mouth mandibular block.[33] In particular, the Vazirani-Akinosi method can be useful when the patient cannot open the mouth wide. In this case, in fact, the inferior alveolar nerve is located far from the medial surface of the mandibular ramus. On the contrary, the Gow-Gates method is performed near the mandibular condyle, where the mandibular nerve is not yet divided into its terminal branches.

Nevertheless, we should note that the presence of accessory foramina could be related to the presence of blood vessels only.[4,24] This possibility could explain why the presence of accessory mandibular canals and foramina based on panoramic radiographs is not always associated with difficulty in obtaining mandibular anaesthesia.

2.1.1.1.2. *Variations in the intraosseous course of the inferior alveolar nerve*. Even if the inferior alveolar nerve enters the mandible by a single foramen, it can have several variations during its course into the mandibular canal.[34]

(1) The nerve can enter the mandibular foramen and run into the mandibular canal as a single trunk giving branches for molar and premolar teeth. In the premolar region, the nerve gives the incisive nerve for premolar, canine and incisor teeth and the mental nerve.

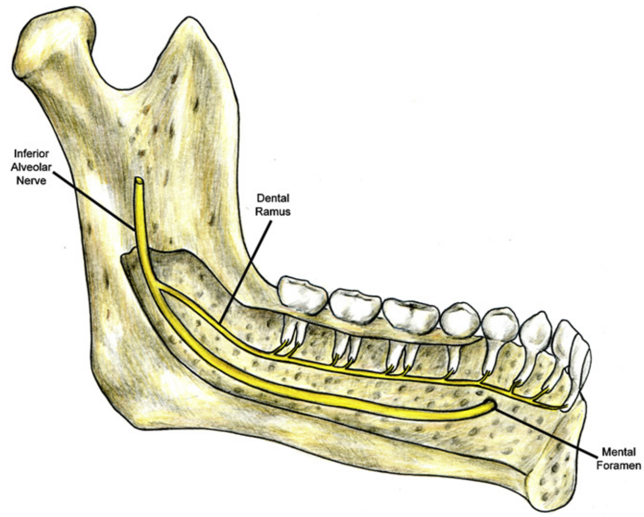

Fig. 3 – Schematic representation of intraosseous multiple branches of the inferior alveolar nerve showed after osteotomy of the inner surface of the mandibula.

(2) The nerve can give a major and minor trunk near the mandibular foramen; the major trunk runs into the mandibular canal and emerges from mental foramen, whereas the minor trunk (*dental ramus*) innervates molar and premolar teeth and then becomes the incisive nerve (Fig. 3).
(3) The nerve gives three branches near the mandibular foramen for molar and premolar teeth, for canine and incisor teeth and for mental foramen.

2.1.1.1.3. *Relation between the inferior alveolar nerve and the maxillary artery*. The maxillary artery is the larger terminal branch of the external carotid artery arises in the parotid gland behind the neck of the mandible and crosses the infratemporal fossa to enter the pterygopalatine fossa through the pterygomaxillary fissure. It crosses the inferior alveolar nerve and the lingual nerve and runs along the lower border of the lateral pterygoid muscle.

Unusual variations in the relation between the inferior alveolar nerve and the maxillary artery, have been observed by several authors.[7,35,36] Roy et al.[7] reported that, in one specimen of 40 human heads analysed, the inferior alveolar nerve originated from the posterior division of the mandibular nerve by two distinct roots, without any communication with other branches of the mandibular nerve. These branches joined to form a single trunk and incorporated between them the second part of the maxillary artery. Recently, Khan et al.[37] found a similar pattern in the second part of the maxillary artery which passed through the inferior alveolar nerve, splitting the nerve into superficial and deep divisions, which rejoined inferior to the maxillary artery. There was an additional case in which the inferior alveolar nerve had three roots and the maxillary artery passed between two of them.[38]

Moreover, other anatomical variations concerning the relation between the inferior alveolar nerve, the maxillary artery and other surrounding structures have also been reported. Anil et al.[3] examining 20 dissections of the infratemporal fossa, found in two specimens that the maxillary artery was entrapped within a loop formed by the root of the inferior alveolar nerve and a connecting nerve branch originating from the auriculotemporal nerve versus the inferior alveolar nerve. Moreover, an unusual relation where the maxillary artery was located between the inferior alveolar nerve and the lingual nerve has been described recently.[39]

In addition, the maxillary artery was reported to pierce only the lingual nerve or a common trunk formed by the inferior alveolar nerve and the lingual nerve.[40]

These anatomical relations could explain certain trigeminal pain conditions and must be considered for dental, oncological, reconstructive surgery of the infratemporal fossa and for adequate anaesthesia.[7] The vascular compression of the afferent fibres of the inferior alveolar nerve by the pulsating maxillary artery may cause pain and numbness without any neurological symptoms. Moreover, sensory alterations could be caused by intravascular puncture of the maxillary artery following local anaesthetic; the procedure can cause a haematoma that exerts soft pressure on the closed anatomical structures.

2.1.1.2. Anatomical variations of the mental nerve. The mental nerve is one of the terminal branches of the inferior alveolar nerve. It emerges through the mental foramen and branches out into three parts; one of them descends to the skin of the chin and the other two ascend to the skin and mucosa of the lower lip. The mental foramen lies below the level of premolar teeth. The location and emergence of this nerve have been described in several studies and their changes in relation with aged and the teeth presence was also reported.[41,42]

2.1.1.2.1. Additional branches of the mental nerve and accessory mental foramina. Contradictory data concerning the presence of accessory mental foramen have also been reported. Some authors report that accessory foramen is located apical or proximal to the mental foramen and contains mental nerve fibres. Shankland[43] reported a 6.62% prevalence of accessory mental foramina, Parameswaran and Udayakumar[44] recorded a considerably smaller percentage (2.5%) and Grover and Lorton[25] found no accessory foramina in series of 5000 panoramic X-rays. A higher percentage was recently reported by Naitoh et al.[45] by using CBCT. Moreover, the presence of accessory mental foramen located in the lingual cortical bone of the mandible[46] and a case of triple mental foramina has recently been describe.[47]

The presence of accessory foramina can be associated with additional branches of the mental nerve. A rare case of two mental nerves emerging from two different mental foramina has been reported reported[48,49]: the two nerves were almost the same diameter and the accessory mental foramen was located adjacent to each other on the same side of the mandible.

The oral and maxillofacial surgeon should consider the importance of adequate preoperative radiological examination and should be careful during surgical procedures, in surgery below the second premolar tooth, to prevent possible nerve damage.

2.1.1.2.2. Different pattern of emergence of the mental nerve. Whilst the emphasis of some research has been on the exact positioning of the mental foramen, a number of studies have addressed the path of emergence of the mental neurovascular bundle.[41,42,50]

Serman[51,52] produced evidence for a mental foramen complex in which the nerve re-enters the mandible through a more anterior foramen after a short extraosseous course. This hypothesis was supported by Pogrel et al.,[53] who suggested a crossover innervation of incisors from the contralateral mental nerve.

Some investigators described an anterior loop to the nerve before its emergence from the mental foramen. The existence of this loop was challenged by Rosenquist.[54] Support for this study was given by Kieser et al.[55] who reported that the mental nerve most frequently emerges in a posterior orientation and that the most common patterns of emergence observed were either a Y- or T-shaped divergence between the mental and incisive nerves, with non-distinct anterior loops.

The reason for this is unclear, but it is argued that the change in the orientation could be ascribed to forward growth of the mandible, which dragged the neurovascular bundle along with it.[56] Warwick[57] first suggested that the posterior inclination of the foramen was related to the development of the human chin. This view was supported by Montagu[42] who suggested that the gradient of the growth of the mandible was directed posteriorly and hence, the foramen could be expected to open in the same direction. In addition, the work of De Villiers[58] offered empirical support showing that the mental foramen emerged with an anterior inclination in the cases of unerupted first deciduous molars.

Interest in the emergence and location of the mental nerve has been rekindled by the need for accurate pre-operative surgical planning for the placement of mandibular implants and for all surgical procedures that need osteotomy near the mental nerve emergence.

2.1.1.2.3. Cross innervation of the incisor teeth by the contralateral mental nerve. Some evidence suggest that branches of the mental nerve could cross the midline and re-enter in the mandible through accessory foramen providing innervation to the contralateral incisor teeth.[51,53] This variation should be considered for anaesthetic procedures. Indeed, in this situation, the Halstead method, i.e., the mental nerve block and the infiltration near the tooth apex could not provide adequate anaesthesia and supplementary injections, such as bilateral inferior alveolar or mental nerve block, or a labial infiltration, may be necessary.

2.1.1.3. Anatomical variations of the incisive nerve. The incisive nerve is one of the terminal branches of the inferior alveolar nerve. It continues within a bone canal or constitutes the incisive plexus providing the innervation to the premolar, canine, incisor teeth and their associated gingiva.

2.1.1.3.1. Cross innervation of the incisor teeth by the contralateral incisive nerve. It is widely accepted that the incisive nerve is extensively branched and also innervates the contralateral side.[59] This variation was demonstrated by mapping an area of anaesthesia after the inferior alveolar block: in 8 on 19 cases. Stewart and Wilson[60] noted that the midline of the body may not correspond exactly with the midline for the nerve. On the contrary, other authors did not observe this variation and found that the incisive nerve did not cross the midline.[10,61]

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The reason for this could be ascribed to the origin of the mandible, which is formed by the fusion of the bilateral first pharyngeal arches, creating the possibility of crossover innervation.

2.1.1.4. Anatomical variations of the mylohyoid nerve. The mylohyoid nerve originates from a small posterior branch of the inferior alveolar nerve before the latter enters the mandibular foramen (Fig. 1). It originates at variable distances superior to the mandibular foramen.[62,63] After branching from the inferior alveolar nerve, the mylohyoid nerve courses downward and anteriorly within mylohyoid groove on the medial surface of the mandible providing innervation to the mylohyoid and the anterior belly of the digastric muscles. Nevertheless, some fibres could enter the mandibular through the retromandibular foramina and provide innervation to premolar, canine and incisor teeth.[5,13,33,63–65]

2.1.1.4.1. Additional innervation of the mandibular teeth by the mylohyoid nerve. The anatomy of the mylohyoid nerve is variable in relation to its level of branching, course through the mylohyoid groove, branch numbers to the mylohyoid and digastric muscles and terminal branching in the submental region.

Numerous studies indicate the mylohyoid nerve as an alternate ‘‘escape route’’ for pain in the mandibular teeth.[5,12,62,65–67] In particular, the presence of accessory mandibular foramina explains the potential innervation of the mandibular teeth by the mylohyoid nerve.

Some authors[5,62,65,67] described the presence of mylohyoid branches into the mandible by entering the retromental foramina, which are accessory foramina (superior and inferior) that occur on the lingual surface of the mandible in an area superior to the genial tubercles and at the inferior border of the mandible. In addition, intraosseous dissections of the mylohyoid nerve shows that its branches could terminate directly in the incisor teeth or connecting with the ipsilateral or contralateral incisive nerve (Fig. 1).[62,65] Moreover, Carter and Keen found that the mandibular teeth are innervated by a nervous plexus constituted by the mylohyoid nerve and the dental branch of the inferior alveolar nerve.[12] The mixed nature of the mylohyoid nerve was confirmed by a study that described the presence of both $A\delta$ fibres (afferent) and $A\alpha$ fibres (efferent) in this nerve.[68]

An important factor related to the additional sensitive branches of the mylohyoid nerve fibres is the presence of the teeth. Indeed, the number of fibres is reported to decrease in edentulous patients, reinforcing the idea that the mylohyoid nerve is involved in the teeth innervation.[69,70]

Regarding the clinical implications of the teeth innervation by the mylohyoid nerve, it could be explained by incomplete anaesthesia during routine oral and dental procedures.[5,71] In addition, the surgeons must be aware of this variation for a correct interpretation of unexpected findings after oral nerve injury. The administration of anaesthetic solution near the mandibular foramen may have effect only on the inferior alveolar nerve. Therefore, to provide adequate anaesthesia to mandibular teeth, the mylohyoid nerve block performed near the retromental foramina is recommended.

2.1.2. Anatomical variations of the lingual nerve

The lingual nerve is a terminal branch of the posterior division of the mandibular nerve. It enters the mouth between the medial pterygoid muscle and the ramus of mandible and then passes anteriorly under cover of the oral mucosa, just inferior to the third molar tooth. It is a sensory nerve to the anterior two-thirds of the tongue, the floor of the mouth and lingual gingiva. Moreover, it contains parasympathetic fibres from the facial nerve for the sublingual and submandibular glands.

The lingual nerve runs anterior to the inferior alveolar nerve, so it is often anesthetised during inferior alveolar nerve block. Moreover, because of its anatomical location, lingual nerve injury is possible during oral surgery, such as third molar extraction, mandibular trauma management, periodontal procedures and excision of neoplastic lesions.[72,73]

2.1.2.1. Relation of the lingual nerve with the third molar region. A significant complication of third molar removal is lingual nerve injury. Some data has reported that the frequency of lingual nerve injuries during oral and maxillofacial procedures varies between 0.6% and 2%.[74–76] These injuries often result in anaesthesia, paresthesia or hypesthesia of the anterior part of the tongue and it can affected taste. However, permanent damage to the nerve is uncommon[77] and there is little detailed data on the spontaneous recovery rate.[78–80]

Consequently, the precise anatomical knowledge of its location in the third molar region plays an important role in planning and performing surgical procedures in this area.[81] Cadaveric dissections, clinical and radiographic observations could provide useful information to localize this nerve. In particular, the mean values of the distance of the lingual nerve to the lingual plate and crest in the third molar region could be an useful index during surgical procedures and help the maxillofacial surgeon to prevent lingual nerve damage.[75,82–84] Quantitative studies on the position of the lingual nerve in the third molar region report that the mean horizontal distance of the nerve from the lingual plate ranges from 0.58 mm to 3.45 mm, whereas the mean vertical distance of the lingual nerve below the alveolar crest is between was 2.28 mm and 8.32 mm.[82,83] Some years later, Karakas et al.[75] found similar data and reported that the mean vertical and horizontal distances of the nerve to the lingual crest and lingual plate of the mandible were 9.5 ± 5.2 mm and 4.1 ± 1.9 mm respectively. Discrepancies in measurement data could be related to race, genetic and individual constitution. On the other hand, the presence or absence of teeth in the retromolar area and the loss of muscle tone and connective tissue tension with advancing age has no statistical relation to the nerves position or relation to the crest of the lingual plate.[83,85]

2.1.2.2. Communication between the inferior alveolar nerve and the lingual nerve. The communication between the inferior alveolar nerve and the lingual nerve has been described by several authors (Fig. 1). Racz et al.[6] in a study of lingual nerve made in 48 half-heads of 24 cadavers, found communication between the lingual nerve and the inferior alveolar nerve in 25% of cases. This finding was also reported by Khaledpour[86] but with an incidence of about 7%. More recently, during the dissection of 24 head halves of 12 Japanese cadavers, a communicating branch between these two nerves was frequently observed proximal to the originating point of the mylohyoid nerve.[87]

The communication between the two nerves suggests: (1) the contribution of the afferent and parasympathetic fibres from the lingual nerve to the inferior alveolar nerve respectively for supplementary innervation to the teeth and the innervation of the lower labial salivary glands; (2) the contribution of afferent fibres from the inferior alveolar nerve for the regions innervated by the lingual nerve.

This supplementary innervation must be considered during the anaesthesia.

2.1.2.3. Communication between the mylohyoid and the lingual nerve. A communicating branch between the mylohyoid and lingual nerve has been reported. In particular, branches of the mylohyoid nerve could contribute to the sensory innervation of the tongue by the presence of anastomosis between this nerve and the lingual nerve (Fig. 1).

Racz et al.[6] studying 48 human half-heads, described a communication branch between the mylohyoid nerve and the lingual nerve in 33% of examined cases. More recently, Kim et al.[73] described communication between the mylohyoid and the lingual nerve in 12.5% of examined cases and they first mentioned that this communication could provide another route for collateral sensory transmission to the tongue. Sassoli Fazan et al.[88] reinforced this idea, indicating that some of the afferent fibres of the mylohyoid nerve might also innervate the tongue.

The anastomosis between the mylohyoid and the lingual nerves was found to occur after that the lingual nerve passes close to the third molar region, making it susceptible to injury during the third molar extraction.[89] Moreover, the presence of a communication between the mylohyoid and the lingual nerves could help in lingual nerve function recovery after third molar removal, since the mylohyoid nerve could be contributing to the sensory innervation of the tongue.[88,89]

2.1.2.4. Collateral branches from the lingual nerve. Lingual nerve has often several additional branches. Kim et al.[73] reported that collateral nerve branches originated from the lingual nerve and innervated the lingual gingiva around the lower third molar and the retromolar region. These were observed in 81.2% of examined cases, indicating that this anatomical variation could be considered a normal innervation pattern variation, as previously suggested by other works.[90,91] This collateral innervation may explain the incomplete anaesthesia during the mandibular nerve block anaesthetic procedure.

2.1.3. *Anatomical variations of the long buccal nerve*

The long buccal nerve, a branch of the mandibular division of the trigeminal nerve, arises quite high in the infratemporal fossa, runs between the two heads of the lateral pterygoid muscle and then descends in a forward direction in association with the maxillary artery and medial to the tendon of the temporalis muscle and Bichat's fat pad. It connects with the buccal branch of the facial nerve and reaches the skin over the buccinator muscle. The long buccal nerve also carries afferent fibres to the lower buccal gingiva, lower buccal sulcus and the mucosa of the cheek and may contribute to the extraoral cutaneous supply of the cheek.

2.1.3.1. Additional innervation of the teeth by the long buccal nerve. The innervation of the molar teeth could be ascribed to the long buccal nerve, a branch of the anterior division of the mandibular nerve.[4,92] Indeed, branches of this nerve could enter in the retromolar foramina (Fig. 1).[33] This variation could be responsible for the failure of the traditional inferior alveolar nerve block.[4,31,93]

2.1.4. *Anatomical variation of the auriculotemporal nerve*

The auriculotemporal nerve runs medial to lateral behind the neck of the mandible, gives off parotid branches and then turns superiorly, posterior to its head and moving anteriorly, giving off anterior branches to the auricle. Then, it crosses over the root of the zygomatic process of the temporal bone, deep to the superficial temporal artery. In literature, some cases of a connection between the auriculotemporal nerve and the inferior alveolar nerve have been described (Fig. 1).[3,6,8,86]

Variations in the anatomy of the auriculotemporal nerve are of great interest for regional anaesthesia.[94,95] Indeed, anastomosis between the fibres of the auriculotemporal nerve and the inferior alveolar nerve could compromise the efficacy of the inferior alveolar nerve block.

2.1.5. *Cervical plexus: additional innervation of the mandibular region*

Branches of the cervical plexus could provide additional innervation of the mandibular region. The great auricular nerve arises from the cervical plexus and provides sensory innervation of the skin over the parotid gland, the mastoid process and the outer ears. In particular, the anaesthesia of the great auricular nerve that arises from the cervical plexus was reported in a case of third molar extraction when conventional anaesthesia failed, suggesting an involvement of great auricular nerve in the innervation of the angle of the mandible (Fig. 4).[96] Consequently, a separate infiltration may be needed to achieve total analgesia of the mandibular region.

3. The maxillary nerve

The maxillary nerve is a sensory nerve. After its origin from the trigeminal ganglion, the maxillary nerve passes through the cavernous sinus below the ophthalmic nerve, exits through the foramen rotundum and enters into the pterygopalatine fossa. In the fossa, several sensory branches are given off the meningeal branches, the superior alveolar nerves, the zygomatic and infraorbital nerves. The other branches originate from the pterygopalatine ganglion: the nasal and palatine nerves.

3.1. *Anatomical variations of the maxillary nerve supply*

Detailed knowledge of the anatomical variations of the maxillary nerve is necessary for a surgeon whilst performing maxillofacial surgery and regional block anaesthesia. In the literature, there is little data concerning the maxillary nerve component. Siéssere et al.[9] dissected 20 human heads to study

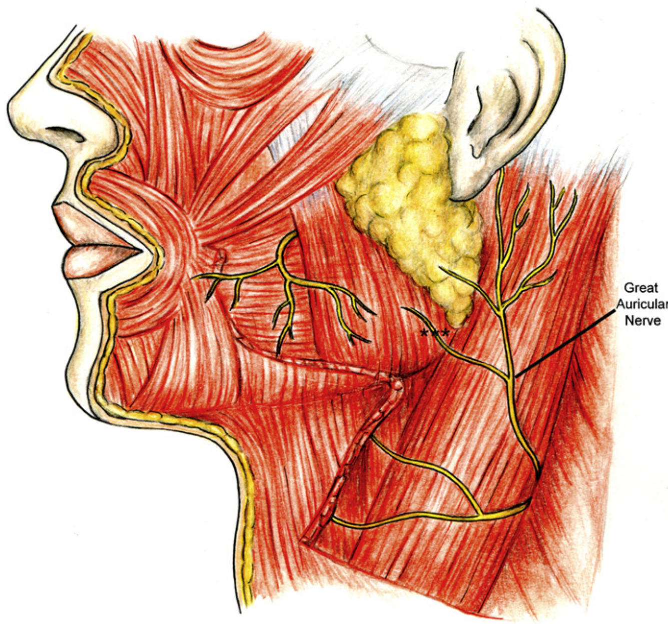

Fig. 4 – Schematic representation of the great auricular nerve from the cervical plexus. ***Branch supplying the innervation to the angle of the mandible.

their structures from an external, medial and endocranial view and they observed no significant variations relating to the ophthalmic and maxillary nerves. On the contrary, anatomical variations were found in 20% of cases in relation with the mandibular nerve and its branches.

3.1.1. *Anatomical variations of the infraorbital nerve*

The infraorbital nerve is a direct extension of the maxillary division of the trigeminal nerve (Fig. 5). It courses anteriorly through a canal within the bone of the orbital floor and provides superior alveolar nerves for the sensory innervation of the maxillary teeth. The infraorbital nerve then emerges from the infraorbital foramen and gives 4 branches, the inferior palpebral, the external nasal, the internal nasal and the superior labial branches for the sensory innervation to the skin of the eyelid, nose, cheek and upper lip.

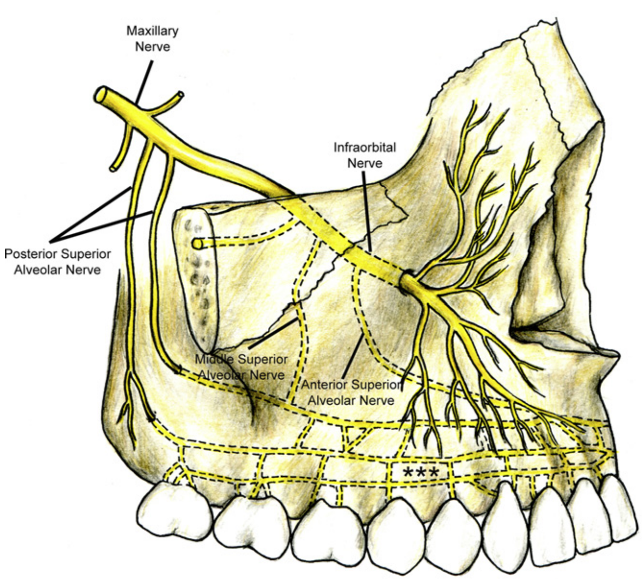

Fig. 5 – Schematic representation of the maxillary nerve and its branches. ***Dental plexus.

The infraorbital foramen is usually (90–97%) single nevertheless, several studies have underlined the presence of two or three foramina.[97–103] Aziz et al.[99] reported a 15% incidence of accessory infraorbital foramina. A low percentage (4.7%) was observed during a study on 1064 skulls, with a higher frequency on the left side, both in male and in female skulls.[101] In addition, an incidence of 1.3% was found by Gupta.[102] Moreover, a case of bifid foramina associated with a bifid infraorbital nerve was found during a cadaver dissection of a 69-year old man.[103] Normally, the distance from the infraorbital foramen to the inferior border of the orbital rim is from 4.6 to 10.4 mm[99,100,104,105] depending on the landmarks chosen for measurements.

Since the infraorbital nerve block is often used to achieve regional anaesthesia of the face, the study of frequency and position of accessory infraorbital foramen are useful to reduce anaesthetic and surgical complications, especially in trunk block of the infraorbital nerve.

3.1.2. *Anatomical variations of the superior alveolar nerve*

The superior alveolar nerve is given off from the maxillary nerve in the pterygopalatine fossa, runs in the infraorbital canal and divides into branches, which supply the maxillary teeth. Traditionally, researchers and clinicians have understood that there are three alveolar nerves: the anterior, middle and posterior superior alveolar nerves that carry sensation to the maxillary teeth; nevertheless, the middle superior alveolar nerve could be absent, consequently it is often considered an anatomical variant.

The contribution of the three alveolar nerves to the maxillary teeth innervation has been reported being different. The superior molar teeth are normally innervated from the posterior superior alveolar nerve and occasionally from the middle superior alveolar nerve, whereas there is no innervation to the first molar from the anterior superior alveolar nerve.[106,107] Regarding the superior premolar teeth, it is interesting to observe that some patients have only two maxillary alveolar nerves and that the middle superior alveolar nerve, the innervation ascribes to the premolar teeth was often missing[107,108] and was provided by the posterior superior alveolar nerve. The innervation of the canine and incisor teeth is normally due to anterior superior alveolar nerve; nevertheless, Robinson and Wormald[109] showed that there was a wide variation to the branching pattern of the anterior superior alveolar nerve and the middle superior alveolar nerve within the anterior face of the maxilla.

Unfortunately, there are no anatomical predictors of the innervation pattern. Therefore, clinicians may have to modify their approach to avoid anaesthetic procedure failure.

3.1.2.1. *The posterior superior alveolar nerve*. The posterior superior alveolar nerve originates from the maxillary nerve just before it enters the infraorbital groove (Fig. 5). It descends on the tuberosity of the maxilla and gives off several branches to the gingival and the mucosa of the cheek. Then it enters the posterior alveolar canal on the infratemporal surface of the maxilla and gives off branches to the membrane of the maxillary sinus and the molar teeth. Several variations in the branching pattern of this nerve have been reported; in particular, it could be found as a single or a multiple nerve branches.

McDaniel[110] found that the posterior superior alveolar nerve had one branch in 21%, two branches in 30% and three branches in 25% of specimens. Where multiple branches were present, the branches entered the highest foramen and supplied the anterior teeth.

Even if the branching pattern of this nerve should be considered during anaesthetic procedures in this region, the different origins of the posterior superior alveolar nerve compared to the middle and the anterior branches offers the possibility to anesthetise only the posterior branch. Indeed, the posterior superior alveolar nerve is approached near the maxillary tuberosity, whereas the anterior superior alveolar nerve in the region of infraorbital foramen.

Moreover, occasionally, the posterior superior alveolar nerve block may not cause complete maxillary molar anaesthesia due to the presence of branches from the palatine nerve that could innervate the molar and premolar teeth.[33] In this case, the greater palatine nerve block could be associated to the posterior superior alveolar nerve block to enhance the anaesthetic effects. Alternative to the greater palatine nerve block could be plexus anaesthetic injection on the palatal aspect.

3.1.2.2. *The middle superior alveolar nerve*. The middle superior alveolar nerve is given off from the infraorbital nerve, during its course in the infraorbital canal, and runs in the lateral wall of the maxillary sinus to supply the premolar teeth (Fig. 5).

McDaniel[110] reported that the middle superior alveolar nerve followed the classical description in only 30% of examined cases whilst the majority of middle branch entered the formation of a nerve plexus that supplied the teeth. When the middle branch was absent, the innervation of the premolar teeth may be provided by secondary branches of the anterior superior alveolar nerve, by the posterior superior alveolar nerve or by a nervous plexus between these two nerves. Even if this situation is not easily detectable, this variation should be considered during anaesthetic procedures.

3.1.2.3. *The anterior superior alveolar nerve*. The anterior superior alveolar nerve comes from the infraorbital nerve at variable distances from the infraorbital foramen. The nerve arises from the middle and anterior thirds of the infraorbital nerve and courses in the infraorbital canal. After entering the anterior face of the maxilla, it courses across the maxilla towards the canine fossa before branching and forming the superior dental plexus located in the maxillary alveolar process (Fig. 5). The anterior superior alveolar nerve was present as a single trunk in 75%, of cases as reported by McDaniel[110]; in 35% there was a diffuse fine plexus of the anterior superior alveolar nerve branches overlying the canine fossa. The presence of a superior dental plexus appears to be favoured by multiple posterior branches and by the presence of a middle branch or an anterior branch with multiple main branches.

It is important to monitor facial sensation preoperatively and to carefully identify the nerve course during preoperative radiologic evaluation because injury to it may have implications on the patient's quality of life post-operatively. Traumatic or iatrogenic injury to this nerve may result in hypesthesia, paresthesia, or pain in this area. Computed tomography with triplanar reconstruction has enhanced our ability to delineate the course of the infraorbital nerve through its bony canal.

3.1.3. *Anatomical variations of the palatine nerve*

The greater palatine nerve is the anterior branch of the palatine nerve; it runs in the inferior area of the hard palate and innervates the palatal gingiva and the hard palate. The palatine nerve is distributed to the roof of the mouth, soft palate, tonsil, and lining membrane of the nasal cavity. Most of its fibres derive from the sphenopalatine branch of the maxillary nerve. In older textbooks, it is usually categorized as anterior, middle, and posterior palatine nerve. More recent textbooks simplify the distribution into the greater palatine nerve and the lesser palatine nerve.

Variations of the location of greater palatine foramen have been reported.[111,112] The first description of the location of the greater palatine foramen was reported by Matsuda.[113] In particular, it was opposite the maxillary second or third molar[114] or anywhere between the maxillary second and third molar.[115] A recent study[112] confirmed the presence of the foramen opposite the maxillary third molar (54.87%) distal to the maxillary third molar (38.94%) and between the maxillary second and third molar (6.19%).

Variations were also described for nerve supply; indeed, the greater palatine nerve can sometimes gives additional branches for the molar and premolar maxillary teeth. This variation has to be considered for a complete and adequate superior alveolar nerve block.

3.1.4. *Anatomical variations of the nasopalatine nerve*

The nasopalatine nerve is a branch of the sphenopalatine nerve; it enters the nasal cavity through the sphenopalatine foramen, passes across the roof of the nasal cavity and runs obliquely downward and forward; it descends to the roof of the mouth through the incisive canal and it emerges from the nasopalatine foramen. Anatomical variations of this nerve are related to the pattern of innervation. It usually provides innervation to the palate and palatal gingiva near the canine teeth. Nevertheless, in some cases it could give some branches for the innervation of the incisor teeth.[116] Consequently, the nasopalatine nerve block should be necessary to completely anesthetise the central incisor.

4. Conclusion

This review summarises data in the literature concerning anatomical variations of mandibular and maxillary nerve supplies in order to provide an update of the main anatomical variations concerning these nerves and consequently, to give detailed anatomical basis for a better understanding of clinical and surgical practice related to oral and maxillofacial area. The knowledge of the branching patterns of the trigeminal nerve, the additional innervation and the presence of accessory canals and foramina should be carefully considered for choosing the best plan and consequently for optimizing anaesthetic and surgery procedure during oral and maxillofacial procedures.

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