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REVIEW ARTICLE

Clinical anatomy of the chorda tympani: a systematic review

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Abstract

Objective: The chorda tympani is at risk of iatrogenic injury throughout its course. This paper reviews the clinical anatomy of the nerve in adults.

Design: Systematic literature review.

Method: Relevant English-language articles were identified using five electronic databases and one search engine. Data from approximately 70 scientific papers were supplemented with information from selected reference texts.

Results: The anatomy of the chorda tympani differs from standard descriptions, particularly regarding its exit from the middle ear and area of lingual innervation. Whilst it is known to convey taste sensation from the anterior two-thirds of the tongue and parasympathetic innervation to the submandibular and sublingual salivary glands, the chorda tympani probably has additional sensory and secretomotor functions.

Conclusion: A detailed understanding of the anatomy of the chorda tympani may help to reduce the risk of iatrogenic injury during head, neck and middle-ear surgery, and to explain the variable consequences of such injury.

Key words: Anatomy; Ear, Middle; Chorda Tympani Nerve; Otologic Surgical Procedures

Introduction

This review describes the normal anatomy of the adult chorda tympani, aiming to provide a thorough understanding of its course and functions relevant to head and neck surgery. Whilst anatomical variants are included, most congenital malformation syndromes and pathology are beyond the scope of this review.

Search strategy

A systematic literature review was undertaken using the electronic databases Medline, Embase, PubMed, Web of Science, and Cochrane Library and the search engine Google Scholar. The aim was to identify all papers describing the clinical anatomy of the chorda tympani. English-language and human studies were selected, using the search term 'chorda tympani' and its subheadings; a few foreign language articles with English abstracts, and relevant animal studies, were also included. Secondary references were retrieved from primary sources, together with evidence-based observations within selected anatomy, physiology and other reference texts.

Central connections

The chorda tympani contains nerve fibres associated with two brainstem nuclei: (1) the superior salivary nucleus, housing the cell bodies of secretomotor preganglionic parasympathetic neurons; and (2) the solitary nucleus, the upper part of which is the gustatory nucleus. The latter receives the central processes of unipolar taste neurons which have their cell bodies in the ganglia of the three cranial nerves conveying taste.[1] After synapsing in the gustatory nucleus, secondary axons ascend in the medial lemniscus to relay in the thalamus. The pathway then passes via the posterior limb of the internal capsule to reach the primary gustatory cortex, located within the face area of the somatosensory cortex between the insula and parietal operculum.[2] It is uncertain whether this pathway is crossed[3,4] or mostly uncrossed,[5] and whether taste is perceived bilaterally in humans.[2] Other projections from the thalamus pass to the hypothalamic nuclei and the limbic system.[1]

Within the facial canal

The smaller 'sensory' root of the facial nerve, the nervus intermedius (of Wrisberg), conveys special

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sensory fibres from taste buds on the anterior tongue and soft palate (cell bodies in the geniculate ganglion), together with secretomotor fibres to salivary glands below the oral fissure.[6–8] After exiting the brainstem, the nervus intermedius is typically adherent to the vestibulocochlear nerve for a variable distance, before separating to lie adjacent to and finally merge with the facial nerve within the internal auditory meatus.[9] After fusion of its 'motor' and 'sensory' roots, the facial nerve enters its own Z-shaped canal, the facial (Fallopian) canal, with its labyrinthine, tympanic and mastoid segments.[10,11] Typically, the facial nerve gives off the chorda tympani in the vertical mastoid segment, just before it exits the skull at the stylomastoid foramen. At this point, the facial nerve is composed mostly of large, myelinated fibres, with the smaller (approximately 2–3 μm) fibres of the chorda tympani distributed throughout[6,12,13] rather than aggregated into a discrete bundle as in animals.[13] Rarely, facial nerve motor fibres travel with an enlarged chorda tympani,[14] although this concept has been disputed.[15]

From facial nerve to tympanum

The chorda tympani is the largest intrapetrous branch of the facial nerve,[7] arising anterolaterally[16] below the nerve to stapedius. It passes anterosuperiorly in the posterior canaliculus, accompanied by a branch of the stylomastoid artery[7,17] sometimes referred to as the posterior tympanic artery.[18] The posterior canaliculus opens into the middle ear via an aperture situated in the angle between the posterior and lateral walls of the tympanic cavity, just medial to the fibrocartilaginous annulus of the tympanic membrane. This opening is variously described as being level with the upper end of the handle of the malleus[1] and the round window.[17] The posterior canaliculus is approximately 0.3–0.5 mm in diameter[19] and arises at a mean angle of 22° from the facial canal.[20]

The chorda tympani is subject to numerous anatomical variations, consistent with the aphorism 'the hallmark of the temporal bone is variation'.[17,21] After branching off the facial nerve, the chorda tympani accompanies it for a variable distance before entering the posterior canaliculus,[18] which joins the facial canal on average 4–5 mm proximal to the stylomastoid foramen,[11,12] near the level of the lower margin of the bony tympanic ring (Figure 1).[22] This branching point is variable (Table I), in part because some studies have measured the point at which the chorda tympani leaves the facial nerve whilst others have recorded the junction between the posterior canaliculus and the facial canal (Table I). In congenital malformations, the chorda tympani may arise more proximally, even at the geniculate ganglion.[25] The posterior canaliculus is between 3 and 14 mm long; in approximately 10 per cent of individuals, it is a sulcus on the posterior wall of the external acoustic meatus rather than a true canaliculus.[18]

The true prevalence of an extratemporal origin of the chorda tympani is uncertain. In the two largest studies, this prevalence varied between 2[12] and 5 per cent.[18] There may be ethnic differences. In a study of 30 temporal bones from Chinese cadavers, the chorda tympani had an extratemporal origin in 53 per cent, which the author attributed to a difference in mastoid morphology, with a more 'proximal' stylomastoid foramen.[24] When the chorda tympani originates outside the temporal bone, the posterior canaliculus is entirely separate from the facial canal.[17,26] Rarely, the chorda tympani has a bifid origin from the facial nerve.[21] An extratemporal origin of the chorda tympani is readily understood if its development is considered. In the fetus and young infant, the chorda tympani leaves the facial nerve outside the skull,[11] but with postnatal growth of the mastoid it migrates to a more proximal position (i.e. the facial canal grows more than the mastoid segment of the nerve),[22,23] resulting in the chorda tympani typically diverging from the facial nerve within the facial canal by one year of age.[11]

Across the tympanum

The chorda tympani arches upwards to cross the pars flaccida of the tympanic membrane, medial to the upper part of handle or neck of the malleus and above the insertion of tensor tympani.[17,18] It lies just medial to the inner mucosal layer of the tympanic membrane, adjacent to the posterior and anterior mucosal folds of the malleus (Figure 2).[17,27] Occasionally, in infants at least, the chorda tympani is suspended from the latter within its own mucosal fold. In contrast to some reports,[14,28] there is no firm evidence to suggest that the chorda tympani innervates the mucosal surface of the tympanic membrane.[29]

A few anatomical variants of the tympanic segment of the chorda tympani have been described. Two cases have been reported of the chorda tympani lying in a transtympanic bony sheath, associated with conductive hearing loss.[30,31] Lateral displacement of the chorda tympani has been found in association with congenital deformity of the malleus.[32] Unilateral or bilateral duplication of the chorda tympani is rare, but in such cases one component may pass lateral to the neck of the malleus within the tympanic membrane.[14]

Electron microscopy shows that the tympanic segment of the chorda tympani consists of about 5000 nerve fibres, two-thirds of which are myelinated.[13] In the rat, most of these myelinated fibres are sensory afferents, whilst the unmyelinated fibres are secretomotor efferents.[13]

From tympanum to infratemporal fossa

The chorda tympani exits the tympanum via a separate bony canal, the anterior canaliculus (canal of Huguier), which runs within the medial part of the slit-like petrotympanic fissure.[33] The entrance to this canal is through a foramen immediately above the petrotympanic fissure.[33,34] Accompanying the chorda tympani in the petrotympanic fissure are the anterior tympanic

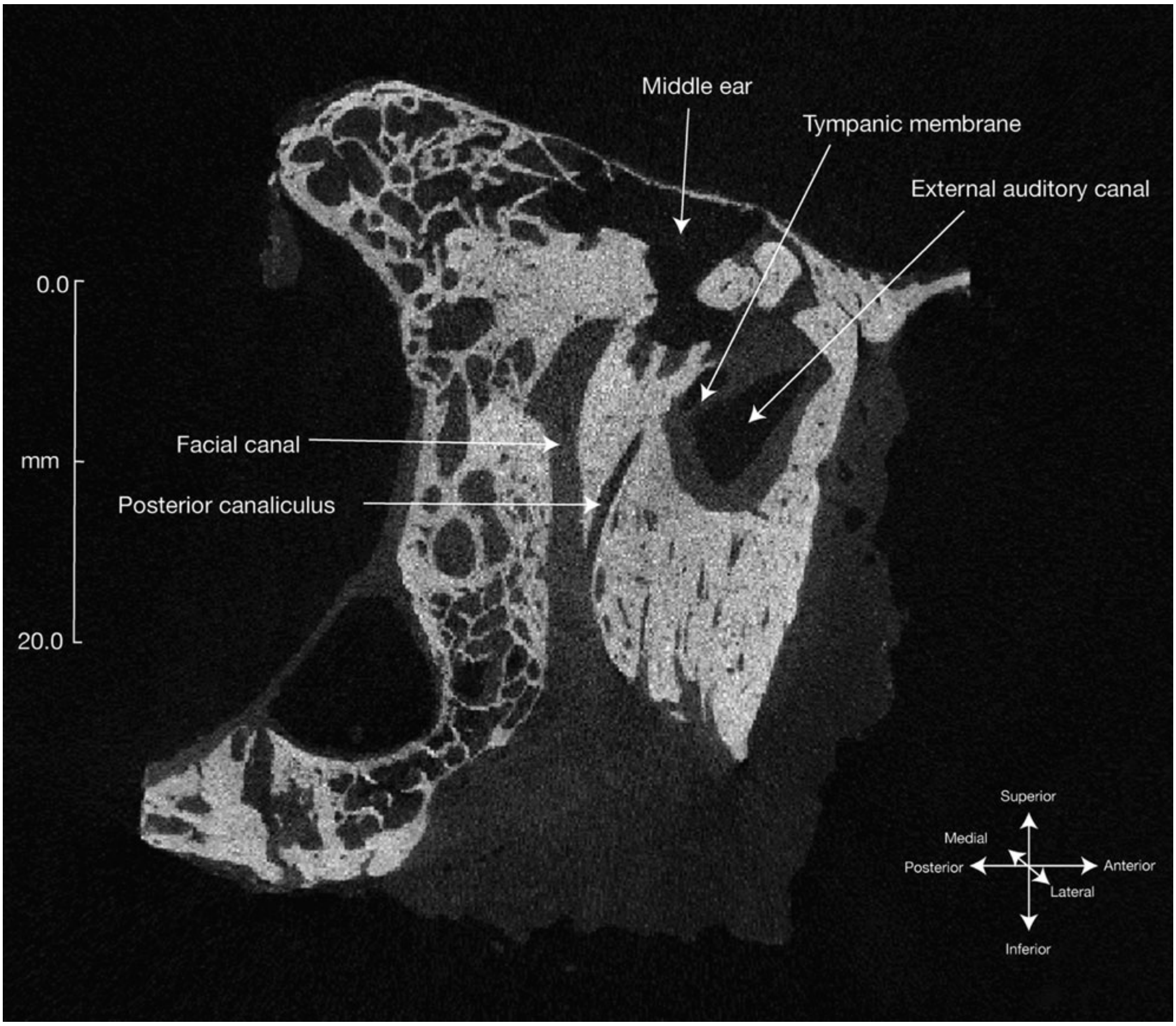

FIG. 1
Sagittal micro-computed tomography scan through a cadaveric temporal bone (from a 64-year-old man), showing the facial canal and the posterior canaliculus.

TABLE I
STUDIES ON ORIGIN OF CHORDA TYMPANI FROM FACIAL NERVE

Study		Mean distance from SF	Range	Methodology
Author(s)	Country			
Jeppsson[3]	Sweden	3.1 mm proximal	0.3–8.9 mm proximal (n = 18), Distal (n = 1)	Dissection of 19 temporal bones; measurement technique not stated
Kullman *et al.*[12]	USA	5.3 mm proximal	10.9 mm proximal to 1.2 mm distal	Microdissection of 100 temporal bones; posterior canaliculus measured with callipers
Kulczynski & Wozniak[18]	Poland	2.7 mm proximal	8.7 mm proximal to 1.2 mm distal	Microdissection of 78 adult temporal bones; nerves measured with dividers
Muren *et al.*[20]	Sweden	4.8 ± 5.2 mm proximal	0–10 mm proximal	64 polyester casts of temporal bones; posterior canaliculus measured under magnification
Fujita *et al.*[23]	USA	4.0 mm proximal	2.1–6.9 mm proximal	Computer-aided 3D reconstruction of histological sections of 5 adult temporal bones; nerves measured
Low[24]	Singapore	3.2 mm proximal (n = 14; 47%), Distal (n = 16; 53%)	0.5–6.0 mm proximal*	Microdissection of 30 adult[†] temporal bones; nerves measured with callipers

*Extratemporal distances unknown. [†]Chinese. SF = stylomastoid foramen; 3D = three-dimensional

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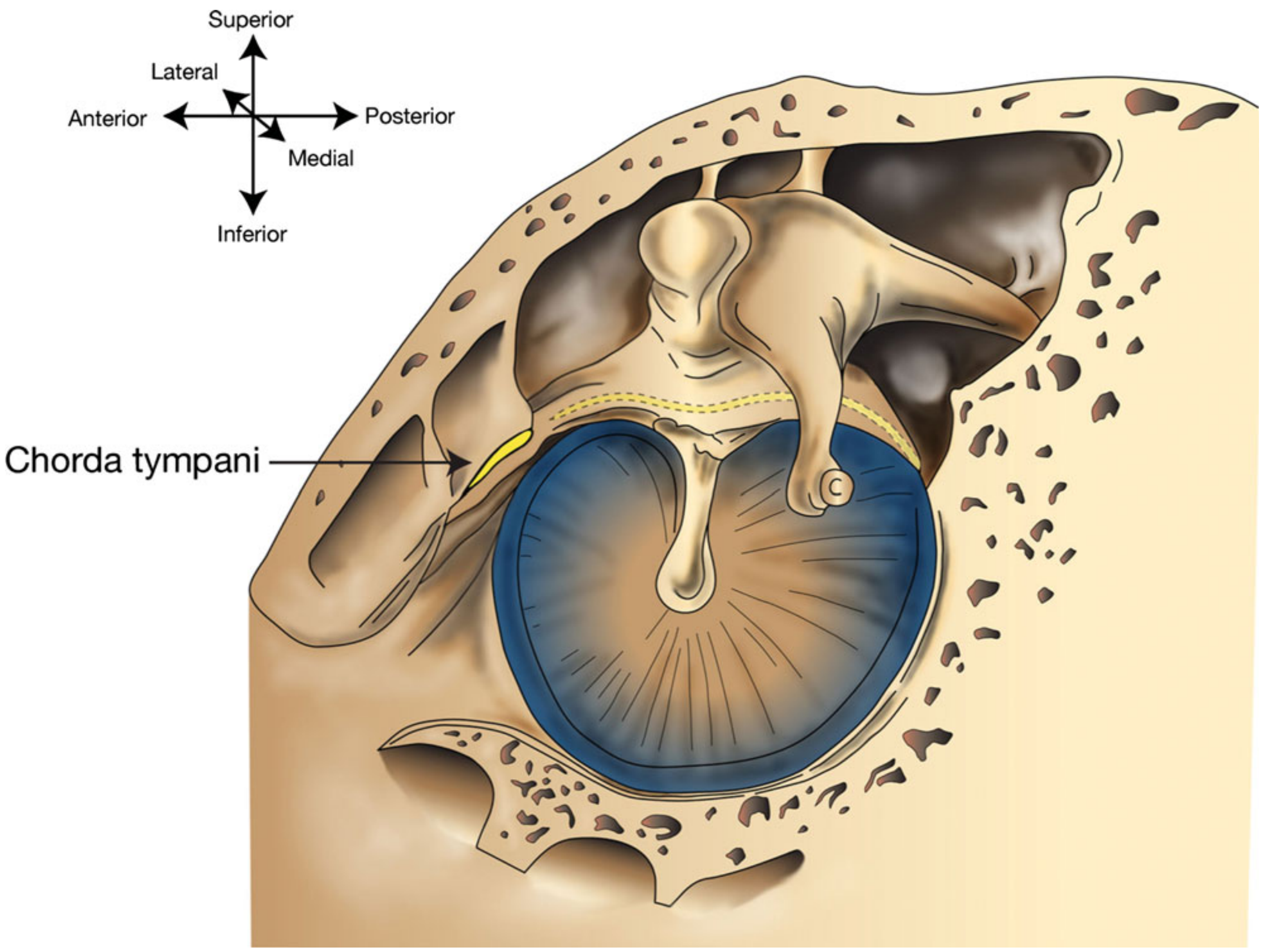

FIG. 2
Illustration of the right middle ear, viewed from the tympanum laterally. The chorda tympani traverses the tympanic membrane from posterior to anterior.

branch of the maxillary artery,[7,35] lymphatics,[35] and two wedge-shaped ligaments, namely the anterior malleolar ligament (which connects the anterior aspect of the neck of the malleus to the sphenomandibular ligament) and the discomalleolar ligament (which runs between the malleus and the capsule and intra-articular disc of the temporomandibular joint (TMJ)).[36] The chorda tympani is the most medial of these structures, and the two ligaments are separated by a bony, septum-like ridge.[36,37] The anterior canaliculus runs parallel and anterior to the pharyngotympanic tube.[33,34] It crosses the temporo-sphenoidal suture and exits the skull by a minute foramen behind the base of the spine of the sphenoid;[34] it does not directly communicate with the mandibular fossa[33] but is closely related to the medial surface of the TMJ.[38] As it exits the sphenoid bone, it frequently gives off a branch to the cartilaginous part of the pharyngotympanic tube.[18,28] The anterior canaliculus is not fully formed until five years of age; before this, the chorda tympani lies in a groove in the petrous part of the temporal bone.[33] If the canal remains open laterally, TMJ activity may precipitate a variety of symptoms.[33]

From the infratemporal fossa distally

The chorda tympani descends medial to the spine of the sphenoid and angles forward to join the lingual nerve approximately 1–2 cm below the base of the skull, just above the lower border of the lateral pterygoid muscle (Figure 3).[8,39] Communications between the chorda tympani and the lesser petrosal nerve or otic ganglion have been reported.[18,28]

The lingual nerve descends anteriorly between the lateral surface of the medial pterygoid muscle and the mandible, grooving the medial surface of the mandible between the posterior attachment of the mylohyoid muscle to the mylohyoid line and the mandibular attachment of the superior constrictor to the pterygomandibular raphe.[1] It then continues forward medial to the posterior root of the mandibular third molar tooth,[39,40] where it occupies a variable position covered only by gingival mucosa.[41] After crossing the superior aspect of the deep part of the submandibular gland, the lingual nerve loops under the submandibular duct in the floor of the mouth, from lateral to medial, to enter the tongue. The diffuse distribution of chorda tympani nerve fibres within the fascicles of

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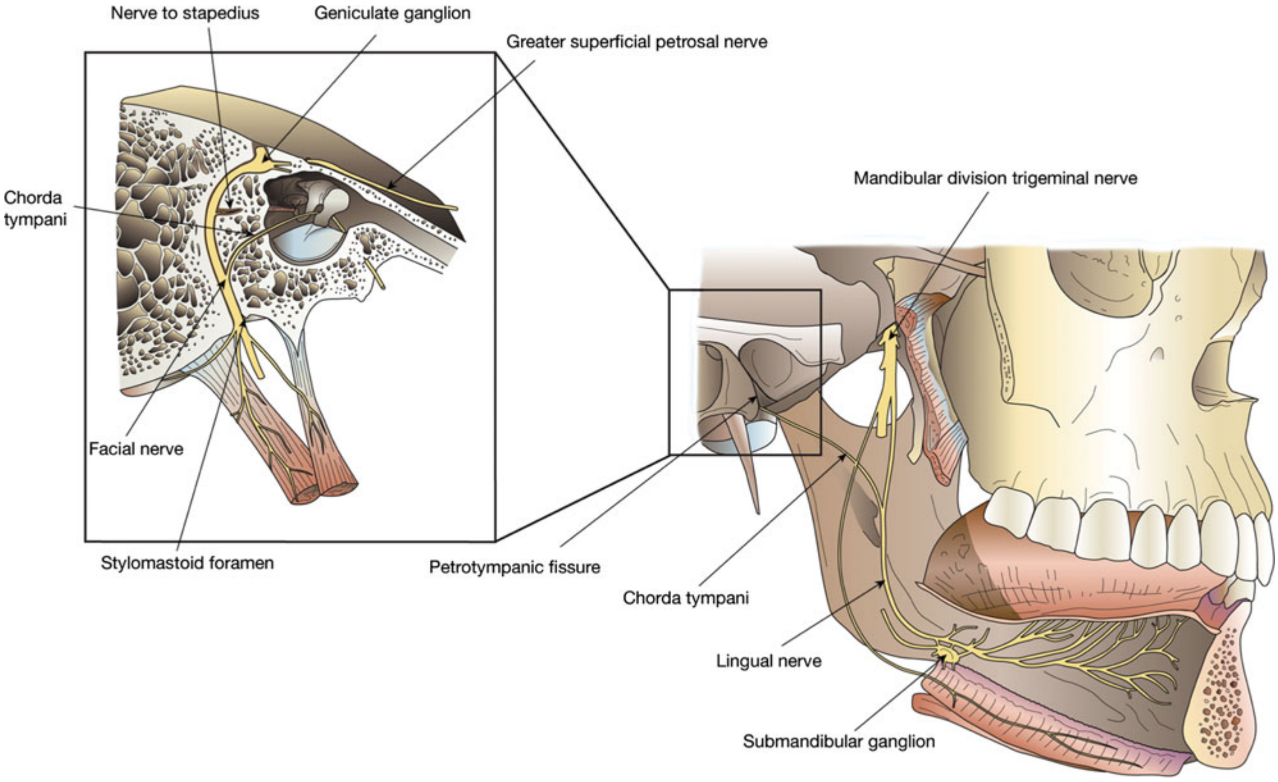

FIG. 3

Schematic illustration of the course of the chorda tympani from the facial nerve to the lingual nerve. Inset shows an oblique vertical slice through the temporal bone. The anterior two-thirds of the tongue are a lighter shade to indicate the area innervated by the chorda tympani.

the lingual nerve probably accounts for the poor recovery of taste function after lingual nerve repair.[42]

The submandibular ganglion lies on the surface of the hyoglossus muscle, above the deep part of the gland, suspended from the lingual nerve by several filamentous branches. Preganglionic parasympathetic nerves from the chorda tympani synapse in the ganglion, and postsynaptic fibres either pass directly to the submandibular gland and its duct or rejoin the lingual nerve to innervate the sublingual salivary gland. A few preganglionic fibres traverse the ganglion and relay in ganglion cells at the hilum of the submandibular gland.[1,8,43]

Imaging the chorda tympani

Both the posterior canaliculus and the course of the chorda tympani across the middle ear can be seen *in vivo* with conventional[16] and high-resolution computed tomography,[44] particularly modern 64-slice scans which allow three-dimensional reconstruction.[45] The anterior canaliculus is not visible. We could find no reports of magnetic resonance imaging of the normal chorda tympani.

Other anatomical variants

Major anatomical variations of the chorda tympani appear to be rare, apart from those described above, except in the presence of severe congenital malformation.[14] There is one report of the chorda tympani arising from the facial nerve outside the skull and running forward lateral to the styloid process to join the lingual nerve, without entering the temporal bone, but this was in association with a major congenital ear malformation.[46] All or part of the chorda tympani may be duplicate; if one of these nerves arises extratemporally, it may enter the temporal bone by its own separate foramen rather than via the stylomastoid foramen.[21] We found only one reference to complete absence of the chorda tympani; this was in children with severe ear anomalies.[47]

Functions of the chorda tympani

The chorda tympani conveys taste sensation from the anterior two-thirds of the tongue and secretomotor innervation to the salivary glands in the floor of the oral cavity. It has been suggested that the chorda tympani also conveys nerve fibres serving additional functions: general sensation (including pain and temperature) from the anterior two-thirds of the tongue; secretomotor fibres to the parotid gland; and efferent vasodilator fibres to the tongue.

Taste

Each taste bud comprises numerous gustatory receptor cells innervated by multiple nerve fibres.[1] Taste buds are found throughout the oral cavity and pharynx, but are particularly plentiful on the papillae of the presulcal

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dorsal and lateral regions of the tongue. Taste is conveyed centrally via several cranial nerves, as follows:

(i) The lingual nerve carries general sensation and taste from the anterior two-thirds of the tongue,[3,48] excluding the region of the circumvallate papillae. Taste fibres travel with the chorda tympani. Although these generally convey ipsilateral taste sensation, electrogustometric studies indicate that there is bilateral innervation of the tip of the tongue.[49,50] This is supported by detailed dissections of the lingual nerve which show a unilateral distribution, except at the tip of the tongue where there is also contralateral innervation.[51]
(ii) The glossopharyngeal nerve transmits general and taste sensation from the posterior one-third of the tongue, the circumvallate and foliate papillae,[52] and the oropharynx.[1]
(iii) Vagal taste fibres are less well characterised, but taste buds are present on the epiglottis.[53,54]
(iv) Finally, the lesser palatine (maxillary division of the trigeminal nerve) and greater petrosal nerve (facial nerve) convey taste sensation from the soft palate.[55]

However, the anatomy is more complex. Some studies have identified anastomoses between the lingual and glossopharyngeal nerves, and found that the glossopharyngeal nerve projects more anteriorly than the posterior third of the tongue.[56,57] Electrogustometric studies conducted following injury to the chorda tympani during middle-ear surgery suggest that the circumvallate and foliate papillae may be dually innervated by the chorda tympani and glossopharyngeal nerve,[50] and that the area innervated by the chorda tympani varies widely between individuals.[49] Studies in which the chorda tympani was anaesthetised in healthy volunteers noted only a modest impairment in taste, prompting the suggestion that the facial nerve may normally inhibit taste perception transmitted by the glossopharyngeal nerve.[58,59] This mechanism helps to compensate for the loss of taste sensation: damage to the chorda tympani reduces its central input, thereby releasing inhibition on other taste nerves.[60] Finally, one report suggested that in some cases the greater petrosal nerve may also transmit some taste fibres from the anterior two-thirds of the tongue.[48]

Salivation

The chorda tympani carries efferent preganglionic parasympathetic fibres to the submandibular and sublingual salivary glands, which induce salivary secretion.[61] Stimulation of the chorda tympani causes vasodilation in these glands. It is possible that the salivary glands also receive secretory fibres via other pathways.[62] This is supported by the observation that citric acid can still elicit secretion from the submandibular gland, albeit considerably reduced, after the chorda tympani has been severed.[62–64] This reflex secretion is inhibited by local anaesthesia of the hypoglossal and glossopharyngeal nerves.[65] Unlike other glands, salivary secretion can occur in response to parasympathetic or sympathetic stimulation,[1,66] but it is unlikely that sympathetic activity is responsible for this ongoing submandibular gland secretion, since stellate ganglion blockade does not reduce the response.[65]

General sensation

Action potential recordings from a transected chorda tympani in one patient (accessed at middle-ear surgery) suggested a response to tactile stimulation of the tongue.[67] Some patients experience numbness, tingling or pain after manipulation, stretching or transection of the chorda tympani. Perez *et al.*[68] objectively assessed general lingual sensation in a prospective, controlled study of 15 patients undergoing middle-ear surgery. Almost half the patients complained of numbness and tingling in the tongue soon after the operation, and were found to have a small but significant reduction in light touch sensation and two-point discrimination on the operated side; these abnormalities resolved within three months. Interestingly, in this study no sensory deficit was recorded in the single patient with a transected chorda tympani. Thus, the chorda tympani may convey general sensation in at least some individuals, but its contribution is small in comparison to the lingual nerve. Alternatively, the chorda tympani may modulate trigeminal sensitivity.[50,69]

Pain

Based on observations in a single patient who reported touch, pain and taste sensation on electric stimulation of an intact chorda tympani, Costen *et al.*[70] hypothesised that the chorda tympani transmits pain. No other studies have reported similar findings. Other authors have suggested that the chorda tympani inhibits pain perception via the lingual nerve, such that damage to the chorda tympani causes the perception of pain from the corresponding area of the tongue affected by loss of taste.[60,71]

Temperature

Gustatory thresholds are affected by temperature.[72] Weak detection of thermal stimuli by the chorda tympani has been reported in a variety of animals[73,74] and in humans.[67] In these experiments, water at different temperatures was applied to the tongue, which may have stimulated taste perception. However, Ogawa *et al.*[74] showed that a single chorda tympani fibre can respond to both gustatory and thermal stimuli, and a detailed analysis of these results suggested that temperature is detected independently of taste.[75] More recently, it has been demonstrated that heating or cooling small regions of the tongue can induce taste sensation.[76] The authors suggested that this 'thermal taste' is due to temperature-sensitive neurons in the chorda tympani encoding taste rather than temperature.

Parotid gland secretion

It has been postulated that the chorda tympani contains secretomotor fibres to the parotid gland.[77,78] This would not be surprising, considering that the superior and inferior salivatory nuclei, which are the origin of preganglionic parasympathetic fibres within the facial and glossopharyngeal nerves, are contiguous.[1,61] Therefore, some fibres from the inferior salivary nucleus destined for the parotid may run in the chorda tympani. Furthermore, the chorda tympani has been shown to communicate with the lesser petrosal nerve and otic ganglion in up to one-third of individuals.[18]

Diamant and Wiberg[77] measured salivary secretion in response to citric acid on the tongue. In seven of 10 cases in which the chorda tympani had been unilaterally severed or damaged, they found that parotid secretion was reduced by up to 50 per cent on the operated side. This may be explained by an impaired salivatory reflex response due to a reduction in afferent signals from the chorda tympani. However, unilateral lingual anaesthesia in two patients with normal taste function did not decrease ipsilateral parotid secretion.

Tongue vasodilation

In cats, electrical stimulation of the chorda tympani or lingual nerve beyond the point at which it is joined by the chorda tympani has been shown to induce vasodilation in the tongue. Erici and Uvnas[79] have suggested that this is due to vasodilator fibres in the chorda tympani. This finding has not yet been demonstrated in humans.

Conclusion

This critical appraisal of the clinical anatomy of the chorda tympani highlights the fact that it is more complex than reference anatomy texts indicate. The chorda tympani appears to possess a range of less commonly known functions, in addition to conveying taste sensation from the anterior two-thirds of the tongue and parasympathetic innervation to the submandibular and sublingual salivary glands. This helps to explain the variable effects of transection or damage to the nerve.

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References

1 Standring S, ed. *Gray's Anatomy: the Anatomical Basis of Clinical Practice*, 40th edn. Edinburgh: Churchill Livingstone, 2008
2 Onoda K, Kobayakawa T, Ikeda M, Saito S, Kida A. Laterality of human primary gustatory cortex studied by MEG. *Chem Senses* 2005;**30**:657–66
3 Jeppsson PH. Studies on the innervation of taste buds. *Acta Otolaryngol* 1967(suppl 224):140–8
4 Lee BC, Hwang SH, Rison R, Chang GY. Central pathway of taste: clinical and MRI study. *Eur Neurol* 1998;**39**:200–3
5 Shikama Y, Kato T, Nagaoka U, Hosoya T, Katagiri T, Yamaguchi K *et al*. Localization of the gustatory pathway in the human midbrain. *Neurosci Lett* 1996;**218**:198–200
6 Malone B, Maisel RH. Chapter 2: Anatomy of the facial nerve. *Am J Otol* 1988;**9**:494–512
7 Monkhouse WS. The anatomy of the facial nerve. *Ear Nose Throat J* 1990;**69**:677–87
8 McMinn RMH, ed. *Last's Anatomy: Regional and Applied*. New York: Churchill Livingstone, 1994
9 Rhoton A, Kobayashi S, Hollinshead WH. Nervus intermedius. *J Neurosurg* 1968;**29**:609–18
10 Kerr AG, ed. *Scott-Brown's Otolaryngology*, 6th edn. London: Butterworths, 1997
11 Weiglein AH. Postnatal development of the facial canal. An investigation based on cadaver dissections and computed tomography. *Surg Radiol Anat* 1996;**18**:115–23
12 Kullman GL, Dyck PJ, Cody DT. Anatomy of the mastoid portion of the facial nerve. *Arch Otolaryngol Head Neck Surg* 1971;**93**:29–33
13 Ylikoski J, Gamoletti R, Galey F. Chorda tympani nerve fibers in man. *Acta Otolaryngol* 1983;**95**:291–6
14 Durcan DJ, Shea JJ, Sleeckx JP. Bifurcation of the facial nerve. *Arch Otolaryngol* 1967;**86**:619–31
15 Jahrsdoerfer RA. The facial nerve in congenital middle ear malformations. *Laryngoscope* 1981;**91**:1217–25
16 Martin-Duverneuil N, Lafitte F, Chiras J. Cross-sectional anatomy of the facial nerve. *JBR-BTR: Organe de la Societe Royale Belge de Radiologie* 1999;**82**:301–5
17 Anson BJ, Donaldson JA, Shilling BB. Surgical anatomy of the chorda tympani. *Ann Otol Rhinol Laryngol* 1972;**81**:616–31
18 Kulczynski B, Wozniak W. Variation of the origin and course of the chorda tympani. *Folia Morphol* 1978;**37**:237–41
19 Noble JH, Warren FM, Labadie RF, Dawant BM. Automatic segmentation of the facial nerve and chorda tympani in CT images using spatially dependent feature values. *Med Phys* 2008;**35**:5375–84
20 Muren C, Wadin K, Wilbrand HF. Anatomic variations of the chorda tympani canal. *Acta Otolaryngol* 1990;**110**:262–5
21 Donaldson JA, Anson BJ. Surgical anatomy of the facial nerve. *Otolaryngol Clin North Am* 1974;**7**:289–308
22 Yasumura S, Takahashi H, Sando I, Aoki H, Hirsch BE. Facial nerve near the external auditory meatus in man: computer reconstruction study – preliminary report. *Laryngoscope* 1993;**103**:1043–7
23 Fujita S, Nakashima S, Sando I, Takahashi H. Postnatal developmental changes in facial nerve morphology. Computer-aided 3-D reconstruction and measurement. *Eur Arch Otorhinolaryngol* 1994;**251**:434–8
24 Low WK. Surgical anatomy of the facial nerve in Chinese mastoids. *ORL J Otorhinolaryngol Relat Spec* 1999;**61**:341–4
25 Fowler EP, Edmund P. Variations in the temporal bone course of the facial nerve. *Laryngoscope* 1961;**71**:937–46
26 Nager GT, Proctor B. Anatomic variations and anomalies involving the facial canal. *Otolaryngol Clin North Am* 1991;**24**:531–53
27 Palva T, Northrop C, Ramsay H. Aeration and drainage pathways of Prussak's space. *Int J Pediatr Otorhinolaryngol* 2001;**57**:55–65
28 Bosman DH. The distribution of the chorda tympani in the middle ear area in man and two other primates. *J Anat* 1978;**127**:443–5
29 De Lara Galindo S, Segura M, Avella G, Alaminos IL, Rosas JL. Semimacroscopic studies of the chorda tympani. *Acta Anat* 1972;**83**:372–81
30 Kraus P, Ziv M. Incus fixation due to congenital anomaly of chorda tympani. *Acta Otolaryngol* 1971;**72**:358–60
31 Ozmen OA, Sarac S, Sennaroglu L, Turan E. Bony sheathed chorda tympani: a unique case of incudomalleolar fixation. *Otol Neurotol* 2007;**28**:345–7
32 Gerhardt HJ. One hundred and seventy-five surgically treated malformations of the external and middle ear: findings and results. *Auris Nasus Larynx* 1988;**15**:81–7
33 Toth M, Moser G, Patonay L, Olah I. Development of the anterior chordal canal. *Ann Anat* 2006;**188**:7–11
34 Gray O. The chorda tympani. *J Laryngol Otol* 1953;**67**:128–38

35 Anagnostopoulou S, Venieratos D, Antonopoulou M. Temporomandibular joint and correlated fissures: anatomical and clinical consideration. *Cranio* 2008;**26**:88–95
36 Kim HJ, Jung HS, Kwak HH, Shim KS, Hu KS, Park HD *et al*. The discomallear ligament and the anterior ligament of malleus: an anatomic study in human adults and fetuses. *Surg Radiol Anat* 2004;**26**:39–45
37 Sencimen M, Yalcin B, Dogan N, Varol A, Okcu KM, Ozan H *et al*. Anatomical and functional aspects of ligaments between the malleus and the temporomandibular joint. *Int J Oral Maxillofac Surg* 2008;**37**:943–7
38 Siessere S, Vitti M, Semprini M, Regalo SC, Iyomasa MM, Dias FJ *et al*. Macroscopic and microscopic aspects of the temporomandibular joint related to its clinical implication. *Micron* 2008;**39**:852–8
39 Erdogmus S, Govsa F, Celik S. Anatomic position of the lingual nerve in the mandibular third molar region as potential risk factors for nerve palsy. *J Craniofac Surg* 2008;**19**:264–70
40 Du Toit DF. Nervus lingualis: applied anatomical relevance to dental practice and oral surgery. *SADJ* 2003;**58**:207–12
41 Pogrel MA, Renaut A, Schmidt B, Ammar A, Kiesselbach JE. The relationship of the lingual nerve to the mandibular third molar region: an anatomic study. *J Oral Maxillofac Surg* 1995;**53**:1178–81
42 Girod SC, Neukam FW, Girod B, Reumann K, Semrau H. The fascicular structure of the lingual nerve and the chorda tympani: an anatomic study. *J Oral Maxillofac Surg* 1989;**47**:607–9
43 Blatt IM, Bunto WG. The structure of nerve elements in the major salivary glands of the human. *Ann Otol Rhinol Laryngol* 1960;**69**:375–86
44 Parlier-Cuau C, Champsaur P, Perrin E, Rabischong P, Lassau JP. High-resolution computed tomography of the canals of the temporal bone: anatomic correlations. *Surg Radiol Anat* 1998; **20**:437–44
45 Noble JH, Dawant BM, Warren FM, Labadie RF. Automatic identification and 3D rendering of temporal bone anatomy. *Otol Neurotol* 2009;**30**:436–42
46 Altman F. Problem of so-called congenital atresia of the ear. *Arch Otolaryngol* 1949;**50**:759–88
47 Saito R, Watanabe S, Fujita A, Fujimoto A, Inokuchi I, Ogura Y. Temporal bone pathology in congenital anomalies of the oval window and the facial nerve. *Auris Nasus Larynx* 1985;**12**: 139–48
48 Schwartz HG, Weddell G. Observations on the pathways transmitting the sensation of taste. *Brain* 1938;**61**:99–115
49 Tomita H, Ikeda M, Okuda Y. Basis and practice of clinical taste examinations. *Auris Nasus Larynx* 1986;**13**(suppl 1):S1–15
50 Berteretche M-V, Eloit C, Dumas H, Talmain G, Herman P, Tran Ba Huy P *et al*. Taste deficits after middle ear surgery for otosclerosis: taste somatosensory interactions. *Eur J Oral Sci* 2008;**116**:394–404
51 Rusu MC, Nimigean V, Podoleanu L, Ivascu RV, Niculescu MC. Details of the intralingual topography and morphology of the lingual nerve. *Int J Oral Maxillofac Surg* 2008;**37**:835–9
52 Yanagisawa K, Bartoshuk LM, Catalanotto FA, Karrer TA, Kveton JF. Anesthesia of the chorda tympani nerve and taste phantoms. *Physiol Behav* 1998;**63**:329–35
53 Jowett A, Shrestha R. Mucosa and taste buds of the human epiglottis. *J Anat* 1998;**193**:617–18
54 Kano M, Shimizu Y, Okayama K, Kikuchi M. Quantitative study of ageing epiglottal taste buds in humans. *Gerodontology* 2007;**24**:169–72
55 Ikeda M, Ikui A, Tomita H. Gustatory function of the soft palate. *Acta Otolaryngol Suppl* 2002;**546**:69–73
56 Toure G, Bicchieray L, Selva J, Vacher C. The intra-lingual course of the nerves of the tongue. *Surg Radiol Anat* 2005;**27**: 297–302
57 Doty RL, Cummins DM, Shibanova A, Sanders I, Mu L. Lingual distribution of the human glossopharyngeal nerve. *Acta Otolaryngol* 2009;**129**:52–6
58 Catalanotto FA, Bartoshuk LM, Ostrom KM, Gent JF, Fast K. Effects of anesthesia of the facial nerve on taste. *Chem Senses* 1993;**18**:461–70
59 Lehman CD, Bartoshuk LM, Catalanotto FC, Kveton JF, Lowlicht RA. Effect of anesthesia of the chorda tympani nerve on taste perception in humans. *Physiol Behav* 1995;**57**: 943–51
60 Bartoshuk LM, Snyder DJ, Grushka M, Berger AM, Duffy VB, Kveton JF. Taste damage: previously unsuspected consequences. *Chem Senses* 2005;**30**(suppl 1):i218–9
61 Getchell TV, Doty RL, Bartoshuk LM, Snow JB, eds. *Smell and Taste in Health and Disease*. New York: Raven Press, 1991
62 Chilla R, Bruner M, Arglebe C. Function of submaxillary gland following iatrogenic damage to chorda tympani nerve. *Acta Otolaryngol* 1979;**87**:152–5
63 Chilla R, Nicklatsch J, Arglebe C. Late sequelae of iatrogenic damage to chorda tympani nerve. *Acta Otolaryngol* 1982;**94**: 461–5
64 Diamant H, Enfors B, Holmstedt B. Salivary secretion in man elicited by means of stimulation of the chorda tympani. *Acta Physiol Scand* 1959;**45**:293–9
65 Laage-Hellman J-E, Strom-Blad CR. Secretion from human submaxillary gland after section of the chorda tympani. *J Appl Physiol* 1960;**15**:295–7
66 Koeppen BM, Stanton BA, eds. *Berne and Levy Physiology*. Philadelphia: Mosby/ Elsevier, 2008
67 Oakley B. Taste responses of human chorda tympani nerve. *Chem Senses* 1985;**10**:469–81
68 Perez R, Fuoco G, Dorion JM, Ho PH, Chen JM. Does the chorda tympani nerve confer general sensation from the tongue? *Otolaryngol Head Neck Surg* 2006;**135**:368–73
69 Just T, Steiner S, Strenger T, Pau HW. Changes of oral trigeminal sensitivity in patients after middle ear surgery. *Laryngoscope* 2007;**117**:1636–40
70 Costen JB, Clare MH, Bishop GH. The transmission of pain impulses via the chorda tympani nerve. *Ann Otol Rhinol Laryngol* 1951;**60**:591–609
71 Tie K, Fast K, Kveton J, Cohen Z, Duffy V, Green B *et al*. Anesthesia of chorda tympani nerve and effect on oral pain. *Chem Senses* 1999;**24**:609
72 McBurney DH, Collings VB, Glanz LM. Temperature dependence of human taste responses. *Physiol Behav* 1973;**11**:89–94
73 Zotterman Y. Has water a specific taste? *Nature* 1959;**183**: 191–2
74 Ogawa H, Sato M, Yamashita S. Multiple sensitivity of chorda tympani fibres of the rat and hamster to gustatory and thermal stimuli. *J Physiol* 1968;**199**:223–40
75 Andersen HT, Hartmann AO. Specificity of sensory messages mediated through chorda tympani fibres with multiple sensitivity to gustatory and thermal stimuli. *Acta Physiol Scand* 1971;**83**:150–5
76 Cruz A, Green BG. Thermal stimulation of taste. *Nature* 2000; **403**:889–92
77 Diamant H, Wiberg A. Does the chorda tympani in man contain secretory fibers for the parotid gland? *Acta Otolaryngol* 1965; **60**:255–64
78 Jeppsson PH. Studies on the structure and innervation of taste buds. An experimental and clinical investigation. *Acta Otolaryngol Suppl* 1969;**259**:1–95
79 Erici I, Uvnas B. Efferent and antidromic vasodilator impulses to the tongue in the chorda-lingual nerve of the cat. *Acta Physiol Scand* 1952;**25**:10–4

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