THE SURGICAL ANATOMY OF THE EXTRA-TEMPORAL PORTION OF THE FACIAL NERVE IN RELATION TO PAROTIDECTOMY

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ABBREVIATIONS

AO	Aorta
APG	Accessory Parotid Gland
AT	Auditory Tube
BA	Branchial bar
BR	Branchial cleft/trema
CC	Carotid Canal
CCA	Common Carotid Artery
EAM	External Auditory Meatus
ECA	External Carotid Artery
EJV	External Jugular Vein
FA	Facioacoustic primordium
FO	Foramen Ovale
FL	Foramen Lacerum
GAN	Great Auricular Nerve
GON	Greater Occipital Nerve
HN	Hypoglossal Nerve
I	First arch
IAM	Internal Auditory Meatus
ICA	Internal Carotid Artery
II	Second arch
Inf. Ob.	Inferior Oblique
iv vent.	Fourth ventricle
JF	Jugular Foramen/Fossa
Lin	Lingual Nerve
LLSAN	Levator Labii Superioris Alaeque Nasi
LON	Lesser Occipital Nerve
LS	Levator Scapulae
M	Meckel's cartilage
MA	Maxillary Artery
MAC	Mastoid Air Cells
Man. Fossa	Mandibular Fossa
Man.P	Mandibular Process
Max.P	Maxillary Process
MM	Masseter Muscle
MP	Mastoid Process
MV	Maxillary Vein
OA	Occipital Artery/Groove for the occipital artery
OC	Optic Cup
OOc	Orbicularis Oculi
OOr	Orbicularis Oris
Ot	Otocyst
P	Platysma

PAA	Posterior Auricular Artery
PAV	Posterior Auricular Vein
PBD	Posterior Belly of Digastric muscle
PF	Petrosal Foramen
PG	Parotid Gland
PH	Pharyngeal division
PRI/PRE	Pretrematic branches
Prom.	Promontory
PRT	Pretrematic branch
PST	Posttrematic branches
R	Reichert's cartilage
RMV	Retromandibular Vein
R+TG	Root and Trunk Ganglion
SCM	Sternocleidomastoid Muscle
SHD	Stylohyoid muscle
SMF	Stylomastoid Foramen
SP	Styloid Process
Spl.	Splenius
Sq.Temp	Squamous part of the temporal bone
SS	Sigmoid Sinus/Sulcus
STA	Superficial Temporal Artery
STV	Superficial Temporal Vein
TM	Temporalis Muscle
TMS	Tympanomastoid suture
TP	Tragal Pointer
TR	Tympanic ring
Trap.	Trapezius
Tymp. Plate	Tympanic Plate
V	Trigeminal Nerve/ganglion
Vn. And tract	Spinal tract of the trigeminal nerve and its nucleus
VI	Abducent nerve
VIn	Abducent nucleus
VII	Facial Nerve
VIIn	Facial motor nucleus
Zmj	Zygomaticus Major

DEDICATION

I would like to dedicate this thesis to both my parents Nancy and Paul and to my dearest brother Jaimie.

Your unconditional love and belief in me has been a tower of strength in my life and despite all that happens, to still have you there by my side means the world.

All my love.

DECLARATION

I hereby declare that this thesis has been composed by myself, that it has not been submitted in any previous application for a degree, either at this University or any other, and that the general matter of this thesis is my own general composition.

No benefit has been received by the author from any commercial party towards this thesis.

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PREFACE

The facial nerve passes through the substance of the parotid gland and therefore, surgery on this gland (commonly for parotid tumours) places the nerve at great risk. The facial nerve needs to be preserved as it supplies the muscles of facial expression and therefore damaging it will have severe cosmetic and functional consequences.

There has been dispute in the past as to whether to locate the facial nerve during parotid gland surgery from an anterograde approach, where the main trunk is identified early in the procedure (Corcione and Califano, 1990) or, by a retrograde approach, where the peripheral branches are identified first (Yu, 2001).

In Glasgow, the facial nerve is identified in parotidectomy by the anterograde approach. This means that the facial nerve is identified after it leaves the skull at the stylomastoid foramen but before it enters the parotid gland. A landmark at this point which can be used to identify the facial nerve is the tympanomastoid suture, although other landmarks have been used in the past (Holt, 1996; Conley, 1978; Hecneman, 1975 and Boswell, 1959).

The null hypotheses which are to be tested are that in parotid surgery:

- **The tympanomastoid suture is not a reliable landmark to use to locate the extra-temporal portion of the facial nerve.**
- **The tympanomastoid suture is not a safe landmark to use to locate the extra-temporal portion of the facial nerve.**
- **The tympanomastoid suture is not any more reliable in locating the extra-temporal portion of the facial nerve compared to other landmarks which have been used in the past.**

To test this proposition the following work will be undertaken:

- To test the **reliability** of using the tympanomastoid suture in locating the facial nerve:
    1. **The tympanomastoid suture will be identified in the cadaver.**
    2. **The suture will be used to identify the facial nerve.**
    3. **The distance will be measured from the tympanomastoid suture to the main trunk of the facial nerve (ie. its extra temporal portion) and this will be repeated on a series of cadavers.**

- To test the **safety** of the tympanomastoid suture in locating the facial nerve:

1. **The relationship of the suture line to the facial nerve and other surrounding structures will be examined.**
2. **The facial nerve will be traced distally and surrounding structures to it will be examined.**
3. **A parotidectomy (which involves identifying the facial nerve early in the operation) will be carried out on the cadaver to see the other structures which may be at risk.**

- To test the **reliability** of the tympanomastoid suture against other landmarks:
    1. **Three other surrounding landmarks will be identified: the "tragal pointer", the posterior belly of digastric muscle and the junction of the cartilaginous and bony external auditory canal to examine their relationship to the facial nerve.**
    2. **Distances will be measured from the main trunk of the facial nerve to each of these landmarks and serial measurements will be undertaken.**

- Finally, the identification of the facial nerve at operation will be observed to judge the safety and reliability of identifying the main trunk early in the operation and to see if any other complications arise. It is hoped these types of measurements above may also be useful in the future in terms of computer-guided surgery.

SECTION 1

INTRODUCTION

1.1 HISTORY AND GENERAL DESCRIPTION OF THE FACIAL NERVE

The facial nerve has had a remarkably rich and intriguing history in its anatomy and surgery. Although the work of many has constructed our present day knowledge of the facial nerve, perhaps the two greatest contributors have been Gabriel Fallopius (1523-1562) and Sir Charles Bell (1774-1842).

The first person to contribute to facial nerve anatomy was Gabriel Fallopius (1523 - 1562) who was appointed to the Chair of Anatomy and Botany at the University of Padua in 1551 and is regarded as the founder of the Italian School of Anatomy. He described the three auditory ossicles, the two windows, the chorda tympani, the promontory and the canal which contains the intra-temporal facial nerve and bears his name, the Fallopian canal (Shah and Jackler, 1998). He also divided the inner ear into two parts: the labyrinth and cochlea and noted the communication between the mastoid cells and tympanic cavity. Fallopius also suggested that the facial and acoustic nerves were separate, breaking with the tradition of his contemporaries at that time.

Sir Charles Bell contributed substantially to anatomic and functional knowledge of the face. In 1829 he provided clinical correlations in relation to trauma of the facial nerve. This work included a man who was wounded by the horn of an ox which entered under the angle of the jaw and came out before the ear, thus tearing the facial nerve. Bell said from this that "the seventh nerve of the face controlled the motions (voluntary or involuntary) such as breathing, sucking, swallowing and speaking, with all the varieties of expression" (Bell, 1829).

In Figure 1, reproductions of the drawings by Sir Charles Bell, taken from his work entitled "The Anatomy and Philosophy of Expression", can be seen to reveal the complexity of the facial muscles and the variety of emotions which they can show.

Figure 1: Illustrations drawn by Sir Charles Bell from his work on "The Anatomy and Philosophy of Expression" (1872). Taken from Ballance and Duel (1932). A=Laughter, B=Weeping, C=Fear, D=Pain, E=Jealousy, F=Remorse and G=Madness.

The next period in facial nerve surgery and anatomy was the era of facial nerve repair. If it was damaged, perhaps due to the cavalier approach to suppurative mastoiditis, the facial nerve was reconnected with another nerve. The first case of this was Drobnik in 1879 who joined the facial nerve with the spinal accessory nerve. The hypoglossal and glossopharyngeal nerves have also been used with varying degrees of success (Shah and Jackler, 1998).

Intra-temporal facial nerve repair then increased in popularity in the late 19th and early 20th century. Ballance repaired the intra-temporal portion of the facial nerve directly in 1894, but this failed due to sepsis (Ballance and Duel, 1932). Other significant contributors in the field of intra-temporal repair include Bunnel and Duel who noted the superior result with direct repair of the intra-temporal portion of the facial nerve (Shah and Jackler, 1998).

Modern advances in facial nerve surgery have included facial nerve decompression and facial reanimation. Direct nerve suturing and crossover anastomosis have also been performed. Even today, studies are taking place to find suitable "donors" for facial nerve anastomosis in the treatment of facial nerve paralysis (Brenner and Schoeller, 1998). Indirect hypoglossal facial nerve anastomosis is also an expanding area which has been shown to be successful if the central stump of the facial nerve is unavailable. It may also help when the facial nerve has been preserved but has not yet regained function and the mimetic muscles are still viable, say after cerebellopontine angle or temporal bone surgery (Manni et al 2001). Also, different procedures over time, have been developed for reaching the intra-temporal portion of the facial nerve (May and Schaitkin, 2000).

With advances on the approach to parotid tumours and the on-going dispute as to the most effective way to identify the extra-temporal portion of the facial nerve (Corcione and Califano, 1990 and Yu, 2001), a detailed knowledge of facial nerve anatomy is required. This is because the facial nerve actually passes through the substance of the parotid gland and any operations on this gland could cause the nerve to be damaged.

This long and exciting history shows that the facial nerve is a very important nerve from a clinical viewpoint, and also has considerable research potential.

1.2 EMBRYOLOGY AND MORPHOLOGY

The complexity of the facial nerve can be explained by examining its development from an embryological view-point.

During the fourth and fifth weeks of development, the wall of the anterior part of the foregut, the future pharynx, develops a series of pouches (Johnson and Moore, 2000). These pharyngeal pouches extend outwards until the endoderm of the pharynx meets the surface ectoderm to form a closing membrane. As the pouches develop one behind the other, they divide the mesoderm lying between the pharynx and the ectoderm in to a series of bars, the pharyngeal, or branchial arches. On the outer surface of the embryo, the depressions between the arches are the branchial clefts. The mesoderm contained within each arch develops:

- An aortic arch artery
- A skeletal element
- A branchial muscle mass supplied by a cranial (branchial) nerve composed of sensory and motor fibres.

According to the classical scheme of head segmentation the ten "true" cranial nerves (III-XII) are each equivalent to a ventral or dorsal root of a spinal nerve, with the facial (VII) being dorsal.

The facial nerve is associated with the second branchial arch and carries sensory fibres, visceral motor (to glands) and motor fibres to the pharyngeal arch musculature ie. the muscles of facial expression.

As Smith discussed in 1959, each pharyngeal arch nerve has a pretrematic branch (visceral sensory (which has two rami – external and internal)), a posttrematic branch composed of both motor and sensory fibres (mixed) and a pharyngeal branch. This is summarised in the following diagram:

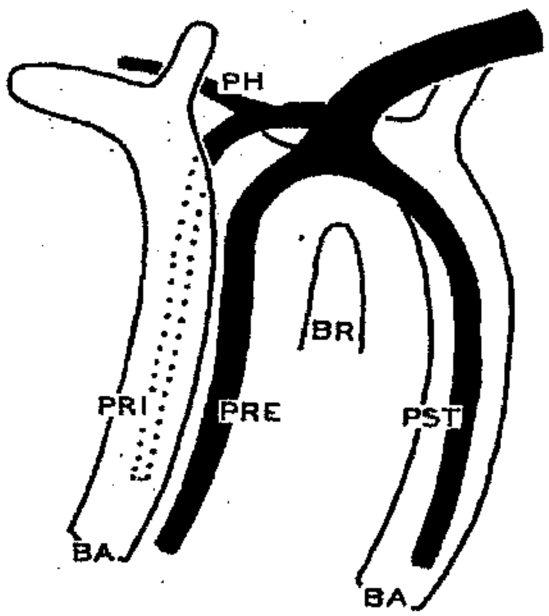


Figure 2: Diagram of the branchial arches, clefts and nerves. BA= Branchial Bar, BR= Branchial cleft/ trema, PH= Pharyngeal division, PRI/PRE=Pretrematic branches, PST=Posttrematic branches. Taken from R.D. Smith, 1959.

The facial nerve takes origin from the dorsal central nervous system and courses lateral to the skeletal axis and aorta as it approaches the branchial arch. The facial nerve courses lateral from the central nervous system to enter the internal auditory meatus, and since the aorta (internal carotid) is coursing through the petrous temporal bone, the nerve crosses the artery here.

The carotid artery emerges from the medial end of the temporal bone and the internal auditory meatus is lateral. The facial nerve has crossed dorsal to the aorta and now lies lateral to it.

The pretrematic branch passes ventrally and medial to Meckel's cartilage (cartilage of the first arch), the posttrematic branch passes ventrally, lateral to the cartilage of the second arch (Reichert's cartilage) and the pharyngeal branch passes cranially, medial to Meckel's cartilage.

The facial nerve, as a dorsal nerve, has two ganglia associated with it at the third week of life: the more proximal (root ganglion) which is derived from the neural crest cells and the distal (trunk ganglion) is derived from the epibranchial placode (Smith, 1959). The facioacoustic primordium then moves to the deep surface of the epibranchial placode on the dorsal and caudal aspect of the first branchial groove (Larsen, 1997).

Then, the aorta passes dorsal to the trema (branchial cleft) reaching a position cranial to it. At the same time Meckel's cartilage shrinks (to later become the malleus and sphenomandibular ligament) whereas Reichert's cartilage reduces but not to the same extent.

The pretrematic branch is medial to Meckel's cartilage, yet lateral to Reichert's cartilage. The posttrematic branch is lateral to the aorta. This is all summarised in Figure 3.

Then, the root and trunk ganglion fuse thus forming the genicular ganglion. Also, at the same time, the nervus intermedius appears and a small branch is given off to the posterior digastric muscle mass. This occurs at weeks 5-6 (Sataloff, 1990).

From the ganglion, the pharyngeal branch becomes the greater superficial petrosal nerve. This nerve then courses ventrally and rostrally to the lateral aspect of the developing internal carotid artery, where it joins the deep petrosal nerve and continues as the nerve of the pterygoid canal. This terminates in a group of cells, later to become the pterygopalatine ganglion (Larsen, 1997).

The genicular ganglion (and otic vesicle) become surrounded by the mesodermal otic capsule and eventually go on to be completely enclosed by the cartilaginous precursor of the temporal bone. This also incorporates the nerve of the second branchial arch and the dorsal extensions of the branchial pouches which go on to form the Eustachian tube, the tympanic cavity and the mastoid antrum and air cells (which are endodermally lined). This explains the complex relations in the temporal bone.

The pretrematic nerve, the chorda tympani, passes lateral to the Reichert's cartilage and medial to the Meckel's cartilage and dorsal to the trema.

The chorda tympani passes ventral to the first pharyngeal pouch to enter the mandibular arch by joining with a branch of the first branchial arch nerve, the mandibular. It does this by traversing the central mesodermal portion of the tympanic membrane. This is the site at which the ectodermally lined first branchial cleft comes closest to the endodermally lined first branchial pouch. The pouch and cleft separate the mesoderm of the first and second branchial arches, which are thus connected only by the very thin precursor which will be the tympanic membrane.

The posttrematic nerve (the rest of the facial nerve) remains posterior to the trema and lateral to the Reichert's cartilage.

The final position can be summarised in the following diagrammatic representation.

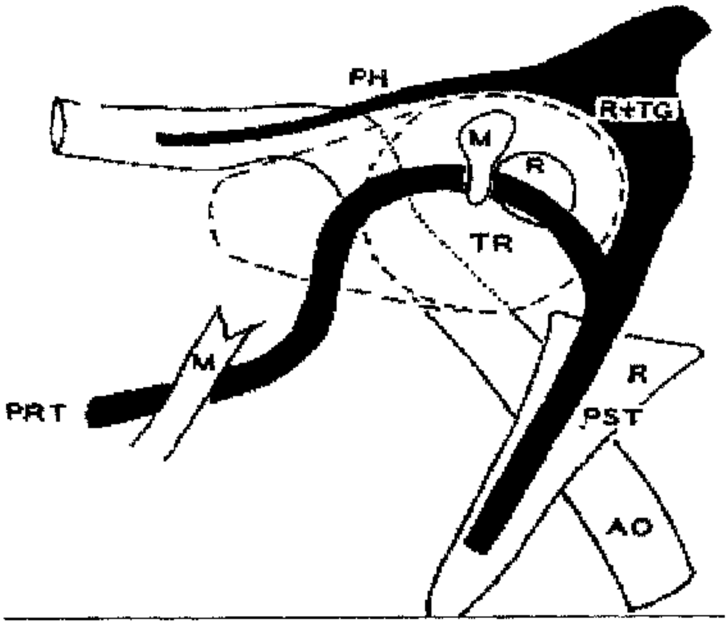


Figure 3: The final layout and complex pattern of the facial nerve and its relations. AO=Aorta, M=Meckel's cartilage, PH=Pharyngeal branch (greater superficial petrosal nerve), PRT=Pretrematic branch (chorda tympani), PST=Posttrematic branch (main trunk of the facial nerve), R=Reichert's cartilage, R+TG=Root and Trunk Ganglion, TR=Tympanic Ring.

Taken from R.D. Smith, 1959.

The main trunk of the nerve supplies the muscles which are derived from the second branchial arch mesoderm, which are generally known as the muscles of facial expression. Other muscles which develop from the second arch, besides those of which are integrated into superficial tissues of the face, are occipitofrontalis, the auricular muscles, stylohyoid, the posterior belly of digastric, and the stapedius (as stapes is a derivative of the second arch mesoderm). As these muscles develop in association with the pharynx (which is lined by endoderm), they are innervated by neurons that appear in the visceral area of the motor part of the hindbrain (Monkhouse, 1990). They are therefore referred to as branchiomotor (or special visceral efferent) neurons. For the facial nerve, the neurons are situated in what will develop into the facial motor nucleus.

Many of the muscles of the second branchial arch migrate into the superficial layers of the head and neck. They are attached to the deeper layers of the integument, thus moving it, and encircling the eyes and mouth. However, the posterior belly of digastric, stapedius and stylohyoid retain their attachments to the skeletal elements of the arch.

It has to be noted that the second arch has several layers of mesenchyme and from these layers, various muscles develop. From 8-20mm, sheet like collections form of premyoblasts and early myoblasts extend from the superficial part of the arch into temporal, occipital, cervical and mandibular regions (Gasser, 1967).

The superficial layer of the second arch mesenchymal lamina spreads to make occipital lamina, cervical lamina (giving the cervical part of platysma), mandibular lamina (giving depressor labii inferioris, mentalis, risorius, depressor anguli oris and the inferior part of orbicularis oris) and temporal lamina. The deep layer of the second arch mesenchymal lamina gives the digastric complex (giving stapedius, posterior belly of digastric, digastric tendon and the stylohyoid muscles). This occurs at 10-18mm (Sataloff, 1990 and Larsen, 1997).

At seven weeks (18mm) the posterior auricular nerve divides into cranial and caudal branches. The caudal branches communicate with C2 and C3. The other branches go to the platysma myoblastic lamina, the angle of the mouth, the mandibular arch and the infraorbital rim.

All of the peripheral branches lie close to the deep surfaces of the myoblastic laminae that will form the facial muscles.

At 18mm, the parotid bud can be seen appearing as an evagination from the lateral oral cavity and although it is the first of the salivary glands to develop, it is the last to become encapsulated (Silvers and Som, 1998).

At seven weeks (22mm), a branch from the geniculár ganglion near the greater superficial petrosal nerve that developed earlier, is reduced to a communication as the tympanic plexus and lesser petrosal nerve develop from the glossopharyngeal nerve. At the end of week seven (26mm), the nerve branches increase in size and number. All the peripheral branches can be identified and anastomoses are well established with the infraorbital, buccal, auriculotemporal and mental branches of the trigeminal nerve. Also, the superficial layer of second arch mesenchyme differentiates into two more laminae through the seventh to eighth week (20-45mm): infraorbital (giving zygomaticus major and minor, levator labii superioris alaeque nasi, superior part of orbicularis oris, compressor nares, depressor septi, orbicularis oculi and frontalis) and occipital platysma laminae.

At 26mm, the first order ductules of the parotid primordium appear next to the masseter muscle (Sataloff, 1990). The temporal, zygomatic and upper buccal branches lie superficial to the parotid primordium whereas the lower buccal, mandibular, and cervical branches are deep to it. The posterior auricular nerve migrates to the occipital area.

Week eight sees the development of the Fallopian canal and into week ten (58mm), there is extensive branching and communication with the trigeminal nerve and this is especially so in the periorbital and infraorbital regions.

At week eleven, the external petrosal nerve arises from the facial nerve distal to the genicular ganglion, travelling with a branch from the middle meningeal artery. Branches which arise from the facial nerve between the stapedius and chorda tympani nerves join with branches of the glossopharyngeal and vagus nerves to provide sensory innervation to the external auditory canal, though variations in this have been documented (Tanaka and Mizukami, 1991).

Communication with the zygomatico-temporal nerve has begun and branches from cervical nerves have now become communications with the lesser occipital and transverse cervical nerves.

At fourteen to fifteen weeks the genicular ganglion is fully developed but the facial nerve remains associated with the mesenchyme which will differentiate into the labyrinth and mastoid.

The facial nerve transmits axons of neurons in another visceral motor area of the hindbrain, the superior salivatory nucleus. This is similar to the lateral grey column of the spinal cord and the neurons are lateral to the branchiomotor area and originally were ventral to the sulcus limitans of the neural tube.

The dorsal portion of the neural tube, which is sensory, contains a group of neurons which gives rise to the special visceral afferent area. This gives rise to the tractus solitarius and the central connections are established by processes from the genicular ganglion.

During development, the branchiomotor nucleus of the facial nerve migrates caudally and ventrally and this process is explained by neurobiotaxis and this will be discussed later.

In late foetal life, the facial canal is closed by bone except at the facial hiatus in the floor of the middle cranial fossa. However, at least 25% of Fallopian canals have dehiscences with more recent work showing that a high frequency of dehiscence occurred at the oval window (60%) and the pyramidal section (54%) and the anterior segment of the tympanic segment had a rate of 20% (Perez et al, 1997).

At birth, the anatomy of the facial nerve is approximately that of an adult, except for its exit through the superficially located stylomastoid foramen. With increasing age, especially after birth, the facial nerve runs further and further downward before turning forwards (Yasumura et al, 1993). This is also related to the developing mastoid tip.

The mastoid portion of the temporal bone at birth is flat and the tympanic ring shallow and they are almost subcutaneous. The mastoid portion grows forward and downward and the tympanic ring grows laterally, thus causing the stylomastoid foramen to be on the inferior surface of the temporal bone. The facial nerve remains vulnerable until the third year of life, when the mastoid portion is then known as the mastoid process and becomes palpable (Monkhouse, 1990).

1.3 THE FACIAL NERVE: NUCLEI OF ORIGIN AND FUNCTIONAL COMPONENTS

The facial nerve is the seventh cranial nerve and has four components each with very distinct functions (Kiernan, 1998). These are:

- Branchial motor: Supplying the posterior belly of digastric, occipital belly of occipitofrontalis, stylohyoid muscle, stapedius and the muscles of facial expression.
- Visceral motor: Parasympathetic innervation to the lacrimal, submandibular and the sublingual glands as well as the mucous membranes of the nasopharynx and hard and soft palate.
- Special sensory: Taste sensation from the anterior two thirds of the tongue and the hard and soft palate.
- General sensory: General sensation from the skin of the concha of the auricle and from a smaller area behind the ear.

The primary function of the facial nerve and the most important from the clinical standpoint is the motor innervation of the muscles of facial expression. In this regard, the nerve contains, as does any other motor nerve, the axons of neurons on which the cell bodies lie in the appropriate nucleus in the central nervous system. In the case of the facial nerve, its nucleus lies in the upper medulla. In addition to these fibres, the facial nerve contains a number of parasympathetic, special sensory and general sensory fibres and these will be discussed at a later stage.

The facial nerve possesses both a motor and sensory root, the latter being called the nervus intermedius (Williams in Gray's Anatomy, 1995). The two roots appear at the caudal border of the pons lateral to the recess by the inferior cerebellar peduncle and the olive.

The following diagram shows the position of the motor nucleus with respect to the other surrounding structures in the brain stem.

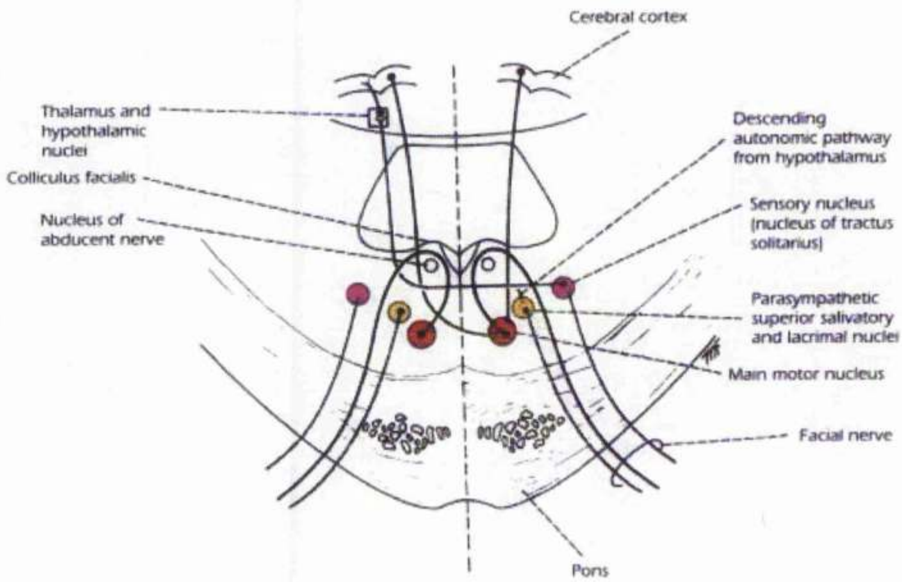


Figure 4: The origin of the facial nerve at the ponto-medullary junction.

1.3.1 FACIAL MOTOR NUCLEUS

The motor component of the facial nerve is generally believed to be more important as it supplies the muscles of the face, scalp, auricle, buccinator, platysma and stapedius, posterior belly of digastric and stylohyoid.

The motor nucleus is where most of the components of the facial nerve are derived. It lies rostral to the nucleus ambiguus in the caudal portion of the pons as a column 4mm in length in the lateral part of the reticular substance, dorsal to the superior olive and medial to the nucleus of the spinal tract of the trigeminal nerve (Brodal, 1981).

The cells present are typical multipolar neurons with coarse Nissl granules. Topographically the facial motor nucleus is a group of lateral, intermediate and medial, which have been identified in various mammals including man (Papez, 1927 and Williams, 1995). Based on work with guinea pigs, rats and dogs, Papez (1927) experimented by removing isolated branches of the facial nerve of these animals and then studying the facial motor nucleus for degenerative changes and changes in staining. In general, the work showed that the fibres that supply the lower portion of the face were shown to arise in the dorsal part of the nucleus and those supplying the upper part, in the more ventral part.

In humans, it is generally accepted that the lateral sub-nucleus innervates the buccal musculature, the intermediate sends axons into the temporal, orbital and zygomatic facial branches, and the medial into the posterior auricular and cervical rami and probably into the stapedial nerve (Williams, 1995).

The fibres of the facial motor nucleus pass towards the floor of the fourth ventricle forming a bulge called the facial colliculus. The fibres then go over the caudal end of the abducent nucleus, run forward along the medial side, and loops again over the rostral end forming the internal genu. This pattern is explained because the abducent and facial nuclei are intermingled at an early embryonic stage. They obtain a position on the medial side of the abducent nuclear complex and then under the control of neurobiotactic influence (the migration of neurons towards a major source of stimulation) of the spinal tract of the trigeminal nerve, it begins to move ventrolateralward (Crosby, 1962). The nucleus of the abducent nerve then moves forward to the position of the other eye muscle nuclei and carries in front of it the root fibres of the facial nerve.

The facial motor nucleus also receives three afferent sources (Kiernan, 1998):

- Tectobulbar: From the superior colliculus to complete the pathway for reflex closure of the eyelids.
- Fibres from the trigeminal sensory nuclei in the corneal reflex.

- Fibres from the superior olivatory nucleus for reflex contraction of the stapedius muscle in response to loud noises.

1.3.2 SENSORY COMPONENT

The sensory component of the facial nerve is involved with the genicular ganglion. The cell bodies of primary sensory neurons are here and it is situated at the bend of the nerve as it traverses the facial canal in the petrous temporal bone at a site of very complex surgical anatomy (Proctor, 1991), which will be discussed later.

Gustatory fibres

The peripheral processes of cells for taste, which compose most of the ganglion, enter the chorda tympani branch of the facial nerve which joins with the lingual branch of the mandibular nerve. The chorda tympani arises from the main trunk of the facial nerve approximately 6mm above the stylomastoid foramen (Monkhouse, 1990). It then runs a complex course passing across the tympanic membrane, passing through the petrotympanic fissure. It passes on the medial side of the spine of the sphenoid, lateral to the levator palati muscle, medial to the middle meningeal artery and the auriculotemporal nerve, and medial to the inferior alveolar nerve, and joins the lingual nerve (from the mandibular division of the trigeminal nerve). The fibres are distributed to taste buds on the anterior two thirds of the tongue. The glossopharyngeal nerve innervates the posterior one third and the vagus nerve carries impulses from the taste buds on the soft palate, epiglottis, and posterior wall of the pharynx. Taste buds are renewed continuously, but, because a bud degenerates if its nerve supply is interrupted and new buds are formed with restoration of an intact nerve supply, the integrity of a bud depends on its innervation (Smith and Breathnach, 1990).

The fibres for palatal taste have their sensory fibres in the greater petrosal branch from the geniculár ganglion. From here it turns anterior and medially leaving the temporal bone via the petrosal foramen and entering the middle cranial fossa. It passes deep to the trigeminal ganglion to enter the foramen lacerum. It traverses the foramen and enters a canal at the base of the medial pterygoid plate in conjunction with the sympathetic fibres (deep petrosal nerve) branching from the plexus following the internal carotid artery. The parasympathetic and sympathetic fibres together make up the nerve of the pterygoid canal. It is joined by palatine branches of the maxillary division of the trigeminal nerve. The palatine fibres provide general sensation in the palate and inner surface of the gums, whereas the facial nerve fibres terminate in taste buds of the hard and soft palate.

The central processes of the genicular ganglion subserving taste enter the brain stem in the nervus intermedius so called because it lies between the motor root and the vestibulocochlear nerve, or adhering to the latter, to enter the brain stem (Williams in Gray's Anatomy, 1995). This, and the gustatory fibres from the glossopharyngeal and vagus nerves, terminate in the solitary nucleus. From here fibres go to the ventral posterior nucleus of the thalamus which projects to the cortical area for taste.

Cutaneous fibres

These are distributed to the skin of the concha of the auricle, a small are behind the ear, the wall of the external auditory meatus, and the external surface of the tympanic membrane and sensation from here is conveyed in a branch of the facial nerve called the sensory auricular branch (Eshragi et al, 2002). It arises from the vertical segment of the facial nerve between the second genu and the chorda tympani origin. The central processes enter the nervus intermedius and continue into the spinal tract of the trigeminal nerve.

1.3.3 PARASYMPATHETIC NUCLEI

The superior salivatory nucleus contains the cell bodies of preganglionic neurons which leave the facial nerve in the chorda typmani nerve joining the lingual nerve then terminating on the submandibular ganglion. Short postganglionic fibres are distributed to the submandibular and sublingual glands, where they stimulate secretion and cause vasodilatation (Brodal, 1981).

The lacrimal nucleus contains cell bodies of preganglionic fibres which lead into the pterygopalatine ganglion via the greater petrosal nerve. Postganglionic fibres from here travel with the zygomatic branch of the maxillary nerve. The fibres terminate in the lacrimal glands causing secretion here (Crosby et al, 1962).

1.4 THE EXTRA TEMPORAL COURSE AND DISTRIBUTION

After leaving the ponto-medullary junction, the facial nerve passes with the nervus intermedius and the vestibulocochlear nerve to enter the internal auditory meatus.

The facial nerve passes into the anterosuperior segment of the internal auditory meatus. From the internal auditory meatus, the facial nerve takes its first horizontal course to the genicular ganglion. It then takes its first turn with an acute angle passing posterolaterally then runs a second straight course that runs near the top of the tympanum. The second turn of the facial nerve is with a curvature with a large radius and is directed vertically downward. The third and last straight portion is directed inferiorly and a little posterior to end at the stylomastoid foramen (Proctor, 1991). This site of complex anatomy is very important with respect to Bell's palsy.

Peripheral seventh cranial nerve palsy, the most frequent cranial neuropathy, may be due to traumatic, compressive, ischaemic, infective or inflammatory conditions (Steiner and Mattan, 1999, Devriese, 1974 and Unlu et al 2003). However, the majority of cases remain without an identified aetiology and will be diagnosed as an idiopathic paralysis, or Bell's palsy (Longmore et al 2001).

The signs and symptoms include taste impairment, retroauricular pain, dry eyes, facial weakness/paralysis, hyperacusis and decreased salivary secretion (Collier and Longmore, 2003).

After the facial nerve passes through the petrous temporal bone, it leaves the skull through the stylomastoid foramen.

This is situated just posterior to the base of the styloid process, between it and the anterior limit of the mastoid notch, which is the groove where the posterior belly of digastric attaches. After leaving the skull through this aperture, the facial nerve turns anterolaterally, passing for approximately 1cm before becoming intimately associated with the parotid gland (Monkhouse, 1990). As descending, it gives off the posterior auricular nerve, the digastric branch and the stylohyoid branches.

1.4.1 POSTERIOR AURICULAR BRANCH

This arises close to the stylomastoid foramen, running upwards in front of the mastoid process to communicate with the auricular branch of the vagus, the lesser occipital nerve and the great auricular nerve. It divides into an occipital branch (supplying the occipital belly of occipitofrontalis) and auricular branch (supplying auricularis posterior and the intrinsic muscles on the cranial surface of the auricle).

1.4.2 DIGASTRIC BRANCH

This arises close to the stylomastoid foramen, dividing into several filaments which supply the posterior belly of digastric muscle. One of these filaments joins with the glossopharyngeal nerve (Williams in Gray's Anatomy, 1995).

1.4.3 STYLOHYOID BRANCH

This branch frequently arises in conjunction with the digastric branch. It is long and slender and enters the stylohyoid muscle in its mid-portion (Proctor, 1991).

After giving off these branches, the facial nerve descends and passes in an anterolateral direction. It descends through a triangle formed by the mastoid, the angle of the mandible and the cartilaginous ear canal (Carlson, 2000). It courses laterally around the styloid process and follows the lateral surface of the posterior belly of digastric muscle for a variably short distance before piercing the posterior capsule of the parotid gland.

The nerve then continues within the substance of the parotid gland on a very superficial plane (with the retromandibular vein at a deeper level and the external carotid artery at a deeper level still). The main trunk splits into two principal divisions, the temporofacial and cervicofacial portions.

McCormack et al (1945) had shown, the point of bifurcation of the main trunk of the facial nerve occurs 5-7mm dorsal to the ramus of the mandible and an average of 3.4cm above the external angle of the mandible. Converted into a surgical value, "the point of bifurcation of the facial nerve lies posterior and slightly medial to the ramus of the mandible and superiorly two-thirds of the distance between the external angle of the mandible and the palpable temporomandibular articulation".

After the facial nerve bifurcates, it divides into temporal, zygomatic, buccal, marginal mandibular and cervical branches. Considerable variation exists in the precise interrelations and specific distribution of these divisions as documented in an extensive study by Davis et al (1956) where the types of branching of the facial nerve was examined in 350 cervicofacial half heads.

1.4.4 TEMPORAL BRANCH

This branch passes superficial to the auriculotemporal nerve and the superficial temporal vessels. It passes over the zygomatic arch continuing in a gentle curve across the temporal region, passing near the upper outer point of the eyebrow. Furnas (1965) showed that the temporal branch was found to cross the superior border of the zygomatic arch at a point that intersected a perpendicular line drawn from the anterior temporal hairline and crossed the forehead at the superior and lateral aspect of the eyebrow. Drawing perpendicular lines extending posterior and superior to the trajectory of the facial nerve, there is a safe area extended to 1cm above the perpendicular line drawn at the superior aspect of the zygomatic arch, and to within 2 cm above the perpendicular line drawn at the lateral aspect of the brow.

As the temporal branch courses over the superficial surface of the zygomatic arch, it is within the temporoparietal fascia, or superficial temporal fascia. The temporoparietal fascia represents a cephalad extension of the superficial musculo-aponeurotic system (SMAS) and is in continuity with the galea above, the frontalis anteriorly, and the occipitalis posteriorly. The superficial temporal artery also runs in the same anatomic plane as the temporal branch of the facial nerve and the frontal branch of this artery parallels the course of the nerve, lying directly superior to it (Stuzin et al., 1989).

As Rudolph (1990) showed, at 5 cm away from the parotid edge, the temporal branch was 2.3+/-0.6mm deep to a subcutaneous face lift plane, whereas the remaining nerves had a mean of 4.4-6.7mm deep to this plane of dissection 5 centimetres from the parotid edge. This study showed that the temporal branch of the facial nerve is the most superficial of the facial nerve branches on proceeding distally from the parotid edge.

1.4.5 ZYGOMATIC BRANCH

Freilinger et al (1987) commonly observed two zygomatic rami, with the superior ramus being the thinner of the two. The superior ramus crossed superficial to the upper one third of the zygomaticus major muscle to innervate the inferior portion of the orbicularis oculi. The thicker inferior zygomatic ramus crossed deep to the lower one third of the zygomaticus major. This ramus further subdivides into branches that innervated the zygomaticus major and levator labii superioris muscles at their deep surfaces, and the buccinator and levator anguli oris muscles at their superficial surfaces.

1.4.6 BUCCAL BRANCH

Freilinger et al (1987) also showed that two buccal branches were observed to cross the masseter, where they communicated with each other, as well as the marginal mandibular and zygomatic rami. The upper buccal branches joined the zygomatic branch to innervate buccinator at its superficial surface, whereas the lower buccal branch joined the marginal mandibular ramus to innervate the depressor anguli oris at its deep surface.

Both the zygomatic and buccal branches have been noted by Rudolph to have a mean depth of 5.7 and 6.7mm deep respectively, 5 cm anterior to the parotid edge which is more than twice that of the temporal branch (2.3mm). Therefore, these branches are considerably deeper than the temporal and are less likely to be damaged in surgical procedures. There is still dispute regarding the fascial relationships of the buccal and zygomatic branches upon leaving the anterior edge of the parotid gland as noted by Gosain (1995).

1.4.7 MARGINAL MANDIBULAR BRANCH

This branch leaves the parotid gland 1cm below the angle of the mandible, then to run deep to the platysma to innervate the depressor anguli oris (with buccal branches) and the depressor labii inferioris muscles at their deep surfaces and the mentalis at its superficial surface (Freilinger et al, 1987). One or more of these rami extend below the angle of the mandible. As it courses anteriorly, it passes lateral to the facial artery as it crosses the inferior border of the mandible (Wetmore, 1991).

1.4.8 CERVICAL BRANCH

This arises from the lower part of the parotid gland, running forward and downwards under the platysma to supply it and communicate with the transverse cutaneous cervical nerve.

Other finer branches of the facial nerve have been documented eg. the ansa of Haller and its lingual branch but these have been inconstant in findings as documented by Proctor (1991).

1.5 BLOOD SUPPLY AND VENOUS DRAINAGE

The blood supply to the extra-temporal portion of the facial nerve is derived from the stylomastoid artery, though the exact origin of this artery has been open to dispute. A recent study by Moreau et al (2000) stated that the origin of the stylomastoid artery was from the posterior auricular artery in 70% of cases, the occipital artery in 20% and from the external carotid artery in 10% of cases whereas others have disputed this (Blunt, 1954). The stylomastoid artery passes on the medial side of the facial nerve as it ascends into the stylomastoid foramen and anastomoses with the petrosal artery (from the middle meningeal artery) to form a complete arcade within the temporal bone.

At and below the level of the genicular ganglion, the nerve is surrounded by a tough connective tissue sheath and this encloses both the facial nerve and the arterial arcade, and in its substance lies a well developed venous network which drains anteriorly, into veins accompanying the petrosal artery and inferiorly, into the venae comitantes of the stem vessel from which the stylomastoid artery is derived (Blunt, 1954).

1.6 THE PAROTID GLAND

Salivary tissue consists of glands divided according to size into major and minor glands. The parotid gland is the largest of the paired salivary glands and opens into the oral cavity opposite the second upper molar tooth releasing almost exclusively a serous secretion (Burkitt and Quick, 2001).

Embryologically, the parotid gland is an outgrowth of the buccal cavity. At the beginning of the sixth week, solid epithelial buds of ectodermal origin from the wall of the primitive mouth and invaginate into the surrounding mesenchyme. A groove that later becomes a tunnel develops. The future parotid gland is formed in the blind end of the tunnel by proliferation, budding length and extensive branching (Carlson, 2000). The parotid gland then extends back towards the ear and in doing this it envelops the facial nerve. From the deep surface, it goes between the branches of the nerve in an irregular fashion. This means that the facial nerve does not lie in a plane as such in the parotid gland (Martin, 1952). This line of thought had been pursued by McKenzie (1948) when he stated that "the possibility of being able to define lobes of the gland …is very remote" and his analogy of the parotid gland as it moved backwards towards the ear (during development) when it wraps around the facial nerve was like "a creeper weaving itself into the meshes of a trellis-work fence".

The parotid gland is an irregular, wedge-shaped organ that wraps over the posterior aspect of the ascending ramus of the mandible. Nearly 80% of the gland lies on the outer surface of the masseter muscle and the ascending ramus and the angle of the mandible (Silvers and Som, 1998).

Its superficial surface extends medially to cover a portion of the masseter muscle. Laterally, it is covered by the superficial musculo-aponeurotic system, which extends from the frontalis muscle superiorly (and is also continuous with the superficial temporalis fascia), platysma inferiorly, the mimetic muscles anteriorly and the perichondrium of the tragal cartilage and the sternocleidomastoid muscle on the mastoid posteriorly as described by Thaller, et al (1990).

The parotid gland is enclosed by fascia and is derived from the cervical fascia. The superficial part is very dense and is attached to the zygomatic arch whereas the deep part is attached to the styloid process, tympanic plate and mandible, and blends with the fibrous sheaths of the surrounding muscles (Robertson and Blake, 1984). A portion of fascia which is attached to the styloid process and the angle of the mandible is called the stylomandibular ligament.

The body of the gland fills the space between the mandible and the surface bounded by the external auditory meatus and the mastoid process. Deep to the ascending ramus, the gland extends forward to a variable degree, lying in contact with the medial pterygoid muscle. Just below the condylar neck, above the attachment of the medial pterygoid to the bone, the gland extends between the two. At the condyle, the gland lies between the capsule of the temporomandibular joint and the external auditory meatus. Laterally, at the junction of the mastoid process and the sternocleidomastoid muscle, the gland lies directly on the posterior belly of digastric muscle, the styloid process, and the stylohyoid muscle. The tip of the transverse process of the atlas also is in the medial wall of the parotid bed. These structures separate the gland from the internal carotid artery, internal jugular vein and the cranial nerves IX to XII. Practically, these form the parotid bed, which is related to the so-called "deep lobe" (Carlson, 2000).

Much dispute has occurred in the literature about whether there are lobes or if an isthmus exists and as discussed by McKenzie (1948) "communications between the superficial and deep portions of the gland may occur through any gap in the plexus of the facial nerve and, further, that the exact manner in which the gland interdigitates with the nerve is not constant". There is not a clear definition as to the superficial and deep lobes but merely referred to as superficial if it is above the facial nerve and deep if it is below the facial nerve as detailed in Gray's by Williams, 1995.

The duct of the parotid, sometimes known as Stensen's duct, emerges from the anterolateral edge of the parotid gland over the masseter muscle. At the anterior edge of this muscle, it turns medially to pierce the buccinator muscle and enters the oral cavity at the level of the upper second molar tooth. In about 20% of people there is an accessory parotid gland, which can be found overlying the masseter muscle, usually cranial to Stensen's duct (Silvers and Som, 1998).

The saliva from the parotid gland is almost exclusively serous. It is produced in the terminal unit or the secretory unit. In the parotid, the terminal units are tubulo-acinar and they produce a serous fluid. Also, they have been shown to produce a secretory piece which combines with IgA from the plasma cells in the interstitium to form secretory IgA (Weiss, 1988).

The terminal units then merge to form larger intercalated ducts which are also lined by secretory cells. These then pass into the striated ducts – so called because of the vertical orientation of the mitochondria in slender compartments formed by the infoldings of the basal membrane (Fawcett, 1994).

The striated ducts (tall columnar epithelium) then unite together and eventually become the parotid duct, which allows the saliva to then enter the oral cavity (and at the opening there is stratified squamous epithelium).

The facial nerve is the most superficial structure to pass through the substance of the parotid gland. Then, deep to the facial nerve is the retromandibular vein and the deepest structure in the parotid gland is the external carotid artery.

1.6.1 THE FACIAL NERVE IN THE PAROTID GLAND

The facial nerve is the most superficial structure which traverses the parotid gland and is at great risk of being damaged if the parotid gland is being operated on. Before entering the parotid gland, the facial nerve gives off three branches. These are the posterior auricular, posterior belly of digastric and a branch to the stylohyoid. It then enters the upper part of the gland on the posteromedial surface, passes forwards and downwards behind the posterior border of the ramus of the mandible and splits into two main divisions. The finer branches are the temporal, zygomatic, buccal, marginal mandibular and cervical branches. These exit from the gland at the anteromedial surface and go to supply the muscles of facial expression.

The parotid gland is an outgrowth from the buccal cavity and it extends towards the ear. As it does this, it covers the facial nerve, but from the deep surface, extensions of the gland pass between the branches of the nerve in an irregular manner.

1.6.2 THE RETROMANDIBULAR VEIN IN THE PAROTID GLAND

This vein is formed by the union of the superficial temporal vein and the maxillary vein which enter the upper part of the gland at the point where the corresponding arteries leave. It leaves the inferior portion of the parotid gland and joins the posterior auricular vein to form the external jugular vein but it also gives off a communicating branch that joins the facial vein. The retromandibular vein generally lies between the facial nerve (superficially) and the external carotid artery (deeper) although variations have been found in the relationship especially between the facial nerve and the vein as shown by Kopuz et al (1995). This showed that in 90% of cases, the retromandibular vein was located on the medial side of both the upper and lower trunks of the facial nerve, whereas in 10% the retromandibular vein was lateral to the lower trunk and medial to the upper trunk.

1.6.3 THE EXTERNAL CAROTID ARTERY IN THE PAROTID GLAND

This artery enters the inferior aspect of the gland, dividing into a superficial temporal artery and a maxillary artery at the junction between the middle and upper third of the gland. The superficial temporal artery gives off a branch called the transverse facial artery. The maxillary artery goes on to the infratemporal fossa.

1.6.4 THE LYMPHATICS OF THE PAROTID GLAND

The pre-auricular lymph nodes (or superficial parotid lymph nodes) in the superficial fascia drain the temporal scalp, the upper half of the lateral surface of the auricle and the anterior wall of the external auditory meatus (Williams, 1995). Lymph nodes within the substance of the parotid gland (or deep parotid lymph nodes) drain the gland itself, nasopharynx, palate, middle ear, and external auditory meatus. These then drain into the internal jugular and spinal accessory nodes (Carlson, 2000).

1.6.5 THE NERVE SUPPLY OF THE PAROTID GLAND

The parotid gland is innervated by both sympathetic and the parasympathetic fibres. The sympathetic supply is derived from the plexus on the external carotid artery. Parasympathetic secretomotor fibres to the parotid gland arise from the inferior salivatory nucleus and reach the otic ganglion via the tympanic nerve of Jacobson and the tympanic plexus. Postganglionic fibres travel in the auriculotemporal nerve to reach the parotid gland. Also travelling in the auriculotemporal nerve is postganglionic sympathetic secretomotor fibres which pass to the sweat glands of the face (Hall-Craggs, 1990). The importance of this will be seen later.

1.6.6 STRUCTURES RELATED TO THE PAROTID GLAND

Muscles

The styloglossus, stylohyoid, and stylopharyngeus pass anterior to the transverse process of the atlas but in surgery of the parotid gland, only the stylohyoid is easily seen.

The stylohyoid passes downwards and anteriorly from the posterior surface of the styloid process to attach to the body of the hyoid bone. The muscle or its tendon is pierced by the intermediate tendon of digastric near the hyoid bone (Gosling et al, 1996). Stylohyoid elevates the hyoid bone.

The superficial portion of the parotid gland overlaps the masseter muscle. This muscle extends from the zygomatic arch to the lower lateral surface of the mandibular ramus and the periphery of the angle of the mandible.

Nerves

The great auricular nerve is a sensory nerve that has its origin in the second and third spinal nerves. It becomes superficial in the posterior border of the sternocleidomastoid muscle. From here, it ascends to the parotid region where it divides into an anterior branch (supplying parotid parenchyma and pre-auricular skin), a posterior superficial branch (to the auricle) and a posterior deep branch which passes along the sternocleidomastoid muscle (Vieria et al 2002).

The auriculotemporal nerve is a branch of the posterior division of the mandibular nerve. It passes back and slightly down on the medial surface of the lateral pterygoid muscle. It bends outward behind the neck of the mandibular ramus and runs upwards through or deep to the parotid gland. This nerve gives secretomotor fibres to the parotid gland and conveys sensation from the temporal region, the upper half of the pinna and most of the external auditory meatus.

Blood Vessels

The external carotid artery runs deep to the stylohyoid and digastric muscles but superficial to the deeper styloid muscles. At first it is separated from the deep surface of the parotid gland by the stylohyoid and digastric muscles then it curves gently outwards and enters the parotid gland.

The superior thyroid, lingual and ascending pharyngeal arteries branch from the external carotid artery and arise well below the posterior belly of digastric muscle and lie below the dissection field for parotidectomy.

The occipital artery runs upwards and backwards under the cover of the digastric muscle, it grooves the surface of the mastoid process medial to the origin of digastric and turns posteriorly away from the parotid gland. It runs a tortuous course with hairpin bends and even great variation exists thereafter in its course even varying between left and right sides of the same person (Schmidt and Adelmann, 2001).

1.6.7 DISCUSSION OF PAROTID PATHOLOGY

Salivary gland neoplasms account for about 3% of head and neck tumours and they affect major salivary glands more often than minor salivary glands (Larson, 2001). Approximately 75-85% of these neoplasms occur in the parotid gland yet 70-80% are benign (Leverstein et al, 1997).

Table 1 below highlights the classification of disorders which can affect the parotid gland. It is subdivided into benign and malignant conditions but also ranks from most to least common on each category.

BENIGN	MALIGNANT
PLEOMORPHIC ADENOMA	MUCOEPIDERMOID CARCINOMA
WARTHIN'S TUMOUR	ADENOID CYSTIC CARCINOMA
ONCOCYTOMA	ACINIC CELL CARCINOMA
MONOMORPHIC ADENOMA	SQUAMOUS CARCINOMA
	MIXED MALIGNANT

Table 1: Pathologies affecting the parotid gland. Adapted from: Oxford Textbook of Surgery, 2000. Second Edition.

As well as the above, parotitis can also affect the parotid gland (Bron and O'Brien, 1997). This can be caused by infections, the most common being mumps.

Sjögren's syndrome is an autoimmune disorder which is characterised by chronic lymphocytic infiltration of the lacrimal and salivary glands, including the parotid gland.

This syndrome is classified into primary Sjögren's (Sjögren's without an associated connective tissue disorder) and secondary Sjögren's (Sjögren's with an associated connective tissue disorder). This disease is generally only seen in adults although it has also been reported in children (McGuirt et al 2002).

Pleomorphic Adenomas

Pleomorphic adenomas are more common in women than in men, and the peak incidence is in the fifth decade. They are slow growing tumours and not well encapsulated. They generally occur in the tail of the parotid, with the majority of tumours lying superficial to the facial nerve (McGurk, 1997). Although they are benign, they can recur again. It has been shown that younger patients tend to develop recurrences more often than older patients (Laskawi et al, 1998).

A pleomorphic adenoma is composed of epithelial and myoepithelial cells and can be sub-classified depending on its morphological pattern. This involves classification into a cell rich type, a classic type (composed of an equal balance of epithelial, myoepithelial and stroma components) and a myxoid (stroma-rich) type.

Histologically, there are islands of neoplastic epithelial cells separated by a myxomatous connective tissue stroma which may contain areas which appear to be immature cartilage. This led early pathologists to believe that it was a neoplastic tumour composed of both epithelial and connective tissue origin, hence generating the misleading name of mixed salivary tumour (Burkitt, 2001).

The majority of pleomorphic adenomas show a focally thin capsule although more than two-thirds of pleomorphic adenomas of the myxoid type and at least half of all tumours show a focal absence of a capsule (Stennert et al. 2001). This shows that simple enucleation of the tumour would be insufficient and recurrences are more likely to happen as tissue may be left behind at operation.

Stennert also showed that satellite cells and pseudopodia were present in up to 25% of all pleomorphic adenomas therefore, again increasing the risk of recurrence.

However, Leverstein et al (1997) showed that a partial parotidectomy is a very effective treatment for the majority of pleomorphic adenomas. It has also been shown that there is no apparent risk of increased recurrence of benign tumours, or even low-grade malignant tumours, if only a partial parotidectomy is done, provided that the tumour removal required a less than complete lobectomy or total parotidectomy (Lee Rea, 2000).

Witt (2002) has shown that more complete parotidectomy for pleomorphic adenoma resulted in higher rates of transient facial nerve dysfunction and Frey's syndrome. Also, he showed that focal capsular exposure occurred in virtually all cases for resections for parotid pleomorphic adenomas.

However, if there is a pleomorphic adenoma in the tail of the parotid gland then removal of the inferior half of the superficial lobe is sufficient treatment (Myssioreck, 1999).

Warthin's Tumour

This is the second most common benign tumour, can be bilateral and is also known as a papillary cystadenoma lymphomatosum or cystadenolymphoma. It is thought to arise from ectopic epithelial salivary tissue within lymph nodes external to or within the parotid gland.

It has two components: a double layered oncocyte epithelial component, which develops cysts and papillary projections, and a stroma component with lymphoid tissue similar to a lymph node (Teymoortash et al, 2001).

This study by Teymoortash also showed that there could be a role of endocrine factors (specifically progesterone), which may help to explain the preponderance of this tumour in men. Only very rarely can a Warthin's tumour turn malignant (Yamada et al 2002).

It has been shown that the best treatment is actually a local excision instead of a superficial parotidectomy as this has a shorter operating time, less facial deformity, less facial nerve damage, lower incidence of Frey's syndrome and better function of the parotid gland (Yu, 1998).

Pleomorphic adenomas and Warthin's tumours are by far the most common benign tumours affecting the parotid gland but malignant disease can also affect this gland.

Malignant Disease

Malignancy of the parotid gland is rare but includes adenoid cystic carcinoma, mucoepidermoid carcinoma, adenocarcinoma, acinic cell carcinoma, squamous carcinoma and mixed malignant tumours.

A study by Calearo et al (1998) of 167 malignant parotid tumours showed that adenoid cystic carcinoma and mucoepidermoid carcinomas were by far the most common.

Calearo also stated that the mucoepidermoid and acinic cell carcinomas had the best prognosis compared with the other types but Harbo et al (2002) found in his study that adenoid cystic carcinomas and the acinic cell carcinomas had the best prognosis.

Both authors agreed, as do others, that the most relevant factors in prognosis are tumour stage and grade, histological classification, facial nerve involvement and local extension.

Hocwald et al (2001) also showed that other important predictors for prognosis were lymph node involvement and perineural invasion.

Investigations

To make a formal diagnosis of a parotid tumour, the clinician requires a full history (pain, swelling or tenderness) and examination of the patient. Fine needle aspiration cytology (FNAC), computed tomography (CT) or magnetic resonance imaging (MRI) help in staging the tumour.

It has been noted that MRI is a reasonable choice over CT if there is a suspected tumour as there is potential for improved tissue contrast at the tissue margins whereas if a mass may be inflammatory then CT would be more appropriate (Casselman and Mancuso, 1987).

1.7 APPLIED ANATOMY - PAROTID SURGERY

The primary aim of parotid surgery for tumours, is the complete removal of diseased tissue with preservation of the facial nerve.

The first known attempt to excise the parotid because of a tumour was made by Warren of Boston, in 1804 (Boswell, 1959). Early attempts to remove tumours and protect the facial nerve simultaneously were hampered by insufficient knowledge of the distribution of the nerve, the anatomy of the parotid gland and also the types of pathology affecting the gland. This practice led to enucleation of the tumour rather gingerly. This resulted in recurrence rates of 20-45% for parotid tumours (McGurk, 1997). Consequently, parotid surgery fell into disrepute and was avoided both by patient and surgeon.

Complete parotidectomy, with preservation of the facial nerve, has been practiced for less than a century. The first account of this procedure came from Carwadine in 1907 (Kidd, 1950).

Over the years since then, different view-points have been put forward in treating parotid pathology, identification of the facial nerve and the relevance of radiotherapy.

Among pioneering authors in this field include Adson and Ott (1923), Janes (1943), Furstenberg (1945) and Martin (1952).

Adson and Ott (1923) outlined the principles of parotid surgery by stating that tumours of the parotid gland should be enucleated early and completely, and that the facial nerve should be preserved when carrying out radical dissections.

Janes (1943) believed in approaching the facial nerve by locating the marginal mandibular branch first then removing as much of the gland around the tumour as was required. Radiotherapy in malignant lesions was "probably indicated".

Furstenberg (1945) thought that the facial nerve could be preserved, even when performing extensive surgery, and that if it were traumatically damaged, it could be anastomosed end-to-end.

Martin (1952) advocated that only a small margin of normal tissue should be removed around a tumour and that the external carotid artery should be removed if a total parotidectomy is needed, say for advanced tumour spread.

1.7.1 COMPLICATIONS OF PAROTIDECTOMY

The main complications of removal of the parotid gland are as follows:

- Facial nerve weakness. This very much depends on the extent of the surgery for the pathology concerned. For superficial parotidectomies, transient paresis occurs in about 30% of patients (McGurk, 1997). Within this group, most people gain full recovery of facial nerve function. The likelihood of temporary facial weakness increases with the extent of surgery, tumour deep to the facial nerve, previous parotid surgery, a diagnosis of sialadenitis and additional neck dissection (Bron and O'Brien, 1997). Permanent facial nerve damage occurs in about 1% of superficial parotidectomies, and slightly more in total parotidectomy (McGurk, 1997). Permanent damage to the facial nerve is generally associated with radical neck dissection, and even then, it is the marginal mandibular branch which is commonly affected (Bron and O'Brien, 1997).
- Secondary bleeding is bleeding which occurs after closure of the operating site. After parotidectomy, this is generally a rare complication.
- Local saliva accumulation or salivary fistula is an occasional complication following parotid surgery, causing saliva to leak onto the face at meal times. It can occur in about 13% of cases of parotidectomy (Dulguerov et al 1999) but usually resolves after several months.

- Loss of sensation to the earlobe (due to the posterior division of the great auricular nerve being damaged).
- Frey's syndrome, which is also described as gustatory sweating.

Frey's syndrome

This is a condition in which there are episodes of unilateral gustatory hyperhidrosis, pain or flushing over the cutaneous distribution of the auriculotemporal nerve. This syndrome was first described in 1757 by Duphenix, then by several others, when there was gustatory sweating over the cheek area in patients with previous parotid infections and incisions for drainage (Nicolai J-PA, 1985 and Linder et al 1997). In 1923, Lucy Frey, a French neurologist, described a case of gustatory sweating occurring after a bullet injury to the parotid gland. Frey used the term of the "auriculotemporal syndrome" to describe the patients malady but it has been known as Frey's syndrome ever since. Gustatory sweating was first recognised as a possible sequel to parotidectomy in 1932 (Linder et al, 1997).

The inferior salivatory nucleus has fibres which pass via the tympanic nerve of Jacobson and the tympanic plexus to the otic ganglion. From here postganglionic parasympathetic fibres travel to the parotid gland via the auriculotemporal nerve. The sweat glands of the face are supplied by postganglionic sympathetic fibres and these arise originally in the superior cervical ganglion but also travel in the auriculotemporal nerve. During parotidectomy, it is believed that the nerve fibres to both the parotid gland and the sweat glands are divided, and this leads to the aberrant regeneration so that fibres intended for the parotid gland supply the sweat glands instead.

Frey's syndrome has been reported from 10.6% after follow up from parotidectomy (Corcione and Califano, 1990) to a 96% rate with testing by the Minor starch-iodine test (Linder et al 1997). It has been shown that despite there being a high objectively positive Frey's syndrome after parotidectomy, there is a very low reporting of symptoms suggestive of Frey's syndrome (Farrell and Kalnins, 1991).

To minimise this complication, a number of procedures have been undertaken. One such procedure includes sternocleidomastoid muscle transfer to fill the site where the parotid gland has been removed by rotating parts of the sternocleidomastoid muscle into the defect site. Also the superficial musculo-aponeurotic system (SMAS) can be plicated to prevent the aberrant regeneration of fibres to the skin surface (Casler and Conley, 1991). This means that after the parotid tumour has been removed, the existing SMAS can be pulled over the defect site to prevent the aberrant regeneration of fibres to the skin surface.

Other types of procedures to reduce the incidence of Frey's include variations in the use of the superficial musculo-aponeurotic system (Moulton-Barrett et al 1996), a temporoparietal fascial flap (Rubinstein et al 1999) or both the temporoparietal fascia and the fascia of the temporalis muscle (Ahmed and Kohle, 1999) to place between the parotid gland and the cheek skin flap.

Other methods include subcutaneous implants (Dulguerov et al 1999) or using 2% topical glycopyrrolate (May and Mcguirt, 1989) to injecting Botulinum toxin A (after diluting with sodium chloride) to the affected area of the face. These injections actually show promising reductions in Frey's syndrome (Beerens and Snow 2002). Botulinum toxin has also been shown to work in both Frey's syndrome but also gustatory epiphora ('crocodile tears') (Hofmann, 2000).

The most important complication to be aware of in parotid surgery, is facial nerve damage.

1.7.2 FACIAL NERVE IDENTIFICATION IN PAROTIDECTOMY

Damage to the facial nerve is a possibility during parotid gland surgery because it runs through the substance of the gland. The effects may range from a mild palsy to full loss of function of the mimetic muscles of the face. The technical difficulties of operating on the parotid gland after previous surgery are well known and there is an increased risk of damage to the facial nerve if a complete removal of the tumour has to be undertaken eg. for recurrent pleomorphic adenoma (Olsen and Daube, 1994). Therefore, an accurate way to identify the facial nerve early in operation had to be known.

Up until the 1940's, the retrograde technique was advocated in identifying the facial nerve. This involved finding a peripheral branch early in surgery and tracing it back to the main trunk (Monte-Purcelli, 1963). Some surgeons still prefer to carry it out this way today (Yu, 2001). This way has been found to be time consuming, especially when the tumour is large, if there has been distortion of the intra parotid facial nerve plexus by bulky infiltrating tumours, or when scarring has occurred due to previous procedures (Martin, 1952). However, it may have to be done if the search for the facial nerve in the retromandibular fossa is hazardous, perhaps due to scar tissue.

In 1940, Janes described exposing the main trunk of the facial nerve early in the operation (Heeneman, 1975). This has been echoed by other authors like Cocke, 1978 and Corcione and Califano, 1990. Since then various structures have been used to locate the facial nerve after it has left the stylomastoid foramen.

The upper body of the posterior belly of digastric and its attachment to the mastoid process has been used (Boswell, 1959). The nerve is found at approximately 1.5cm anterocranial to this point. Also, the facial nerve is found, after emerging from the stylomastoid foramen, to be on average 9mm from the digastric muscle (Holt, 1996).

The "tragal pointer", a portion of the tragal cartilage, is said to point to the nerve which lies 1-2cm deep to the 'tip' (Conley, 1978). It has been shown on both CT and MRI scans to be 10 to 15mm caudal to the pointer (Casselman and Mancuso, 1987).

Although these results have been documented, it has to be remembered that these are not bony landmarks. Bony landmarks have been shown to be more appropriate for anatomical guides because they are more rigid and less likely to fluctuate in their position relative to surrounding structures (Nishida and Matsuura, 1993).

The mastoid process has been used to find the main trunk of the facial nerve. If one index finger is placed flush with the lowermost tip of the mastoid process on top of, and parallel to, the fibres of the sternocleidomastoid muscle, the other finger is placed on the lateral surface at an angle of 90 degrees with the first finger, and in doing this, points directly forwards. The facial nerve has been said to be found deep and slightly anterior to the centre of the fingertip (Beahrs, 1977). The difficulty with this approach is that using the fingertip is that it provides only a rough guide and the dissection is effectively blind.

The main trunk of the facial nerve has been found to be between two bony landmarks (Britnall et al 1955). Superiorly, it lay near a bony ridge at the anteroinferior margin of the external auditory meatus of the skull. Inferiorly, it was found at the blunt anterior end of the mastoid process of the temporal bone. Between these two landmarks lies the V -shaped sulcus. This is one of the first references to the fissura tympanomastoidea, or the tympanomastoid fissure/suture. The main trunk is found close to this suture at 3-4mm deep to the bony edge of the tympanomastoid suture (Reid, 1989).

The tympanomastoid suture seems to be an accurate landmark for identification of the facial nerve (Alexander de Ru et al, 2001 and Hogg and Kratz, 1958). Maynard (1978) also found that the main trunk of the facial nerve was constantly related to the apex of the V shaped sulcus. An analysis of this and the other landmarks for their accuracy in finding the main trunk of the facial nerve accurately has to be done and this forms the rest of this work documented hereafter.

During procedures involving the facial nerve and surrounding structures, a facial nerve stimulator can be used to confirm the presence, or otherwise, of structures in the operating field which are believed to be the facial nerve. The muscles of facial expression are observed for their contraction if the facial nerve has been stimulated. As well as being used in parotid surgery, this approach combined with video-monitoring can also be used in other otologic or neurosurgery which may involve the facial nerve being in the operating field (Filipo et al, 2000 and Silverstein and Rosenberg, 1991).

Although the facial nerve stimulator helps confirm the presence of the facial nerve, it does not initially localise the nerve. Therefore, a very reliable landmark for the safe identification of the facial nerve has to be sought. It also has to be highly accurate and subject to least variability.

SECTION 2

MATERIALS AND METHODS

Twenty-six adult human heads (including neck) were selected from the regular stock at the Anatomy Department of the University of Glasgow.

The specimens consisted of 15 females and 11 males with the mean age being 83, and a range from 59 to 98 years old (APPENDIX 1).

Twenty-six of the specimens had been perfusion fixed in embalming fluid (APPENDIX 2) and in one of these, the arteries had also been injected with latex (APPENDIX 3).

The specimens were placed into 3 groups for different work to be undertaken.

The first group consisted of three heads being used for dissection to demonstrate the course of the facial nerve (with landmark measurements being taken at a later stage).

The second group consisted of one head being used for dissection to demonstrate the blood supply of the facial nerve (with landmark measurements also taken on this specimen).

The third group consisted of twenty-two heads being dissected by second year dental students from the Anatomy Department at the University of Glasgow. From this group, extensive dissection work anterior to the ear had already been carried out and, therefore, this sample set was used only for the landmark measurements from the main trunk of the facial nerve, which will be detailed later.

2.1 MATERIALS

Specimens and models from the University of Glasgow's Anatomy Department's museum and teaching collection were used to illustrate particular points and are identified, as appropriate, within the text.

ANATOMICAL DISSECTIONS

For dissection, the specimen was prepared by using a Swann Morton No. 22/24 blade on a No. 4 scalpel. Finer dissection work was undertaken with a No. 11 blade with a No. 3 scalpel.

The dissection work was guided by two textbooks, namely Lord Zuckermans "A New System of Anatomy – A Dissectors Guide and Atlas" (1981) and Gosling et al "Human Anatomy" (1996).

At the appropriate time, as detailed later, a Carl Zeiss operating microscope was used with an Eschmann DV 110 High vacuum pump (with water) for suction and drainage.

MICROSCOPIC STUDY

Specimens for microscopy were examined using one of the four types of microscope appropriate to the specimen. The microscopes used were a LEICA $MZ7_5$ (for low power examination of specimens), a LEITZ – WETZLAR microscope for digital photography of slides, an OLYMPUS CH-Z for bench work examination of specimens and a JEOL JSM-T300 scanning electron microscope.

Photographs were taken with a NIKON COOLPIX 995 digital camera and transferred to a VIGLEN CONTENDER 2 PENTIUM II PC and stored as jpeg files. They were then adjusted to the correct size using the "Paint Shop Pro 6.00" programme and labelled. The pictures were transferred to the computer C drive and then placed in Microsoft Word '97.

2.2 ANATOMIC DISSECTIONS

DISSECTION 1: DEMONSTRATION OF THE COURSE OF THE FACIAL NERVE

A pre-auricular incision was made. This was carried under the ear lobe then over the mastoid process. It curved back down over the sternocleidomastoid muscle into the skin crease of the neck which ran parallel to the inferior border of the mandible as shown in Figure 5 below.

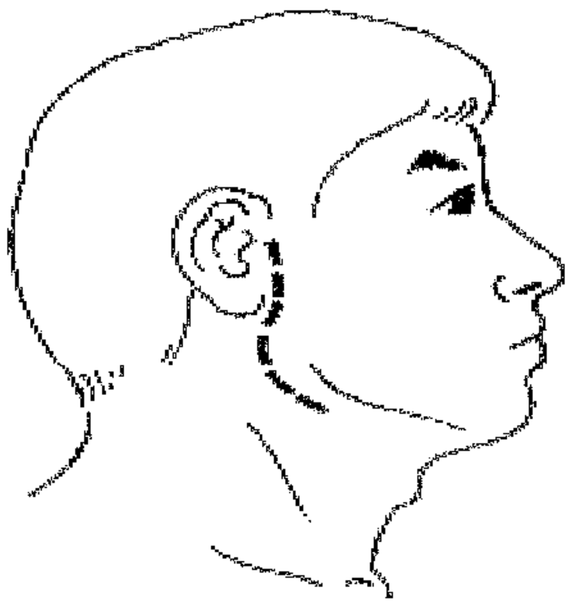


Figure 5: Modified Blair incision. Taken from

http://www.rcsed.ac.uk/journal/vol46_2/4620024.jpg

A skin flap was elevated anteriorly, the ear was reflected superiorly and a skin flap was reflected in the posterior direction also. These were held reflected by using surgical thread through the skin with the distal ends of the thread were attached to clamps. The fascia overlying the parotid gland was left intact but that over the sternocleidomastoid muscle was removed.

Half way along the length of the sternocleidomastoid muscle, the great auricular nerve and external jugular vein were identified. The great auricular nerve was then traced vertically upwards into the parotid to identify three main branches. The external jugular vein was also traced to the inferior margin of the parotid gland.

The anterior border of the sternocleidomastoid muscle was freed from the posterior border of the parotid gland and the muscle was retracted posteriorly.

The ear was retracted as far upwards as possible. This allowed the cartilage of the floor of the external auditory canal to be easily identified due to its cream coloured appearance. At this point, the "tragal pointer" (a portion of tragal cartilage) was clearly noted protruding downward, more prominent than the rest of the tragal cartilage due to its pointed appearance.

The deep fascia enveloping the parotid gland was then dissected away from the perichondrium of the cartilage of the external auditory canal, and also separated from its attachment to the sternocleidomastoid muscle. The parotid gland was then dissected in an anteroinferior direction and dissection proceeded down to the bony external auditory canal.

Identification of the facial nerve

At this stage, the dissection was transferred to a Carl Zeiss operating microscope was used with an accompanying Eschmann DV 110 High Vacuum pump with tap water for suction and drainage. This allowed a finer degree of precision in a clear dissecting field.

Under the microscope, the periosteum over the mastoid process was identified and a vertical incision was made through this. The periosteum was then elevated anteriorly to allow visualisation of the ledge of bone at the beginning of the bony external auditory canal ie. the tympanic plate.

A V shaped sulcus was seen opening forward formed from the sharp ridge of the bony external auditory canal above (from the tympanic plate) and the anterior border of the mastoid process. The tympanomastoid suture was now visualised between these two landmarks.

Directly below this, a great deal of loose fatty tissue was noted. Still using the operating microscope, the tissue was removed in a very careful manner, as the facial nerve would be embedded here.

After careful dissection, the facial nerve was identified as a broad white band of tissue a few mm in diameter descending in an anterolateral direction towards the posterior surface of the parotid gland.

Clearing up the dissection field just inferior to the main trunk of the facial nerve revealed the posterior belly of digastric muscle.

This method of identifying the facial nerve was also used in the cadaver parotidectomy as detailed on page 158.

Resection of the parotid gland

Now that the main trunk of the facial nerve and the posterior belly of digastric muscle were clearly in view, a very fine glistening structure passing from the main trunk of the facial nerve to the posterior belly of digastric muscle was identified: the nerve to the posterior belly of digastric.

The operating microscope was taken away and dissection continued by reflecting the sternocleidomastoid muscle further in a posterior direction. The posterior belly of digastric muscle was followed to the posterior border of the parotid gland.

Now that the dissecting field was clearer, the main trunk of the facial nerve was followed into the parotid gland by blunt dissection using fine artery forceps passed along the nerve. The division into the two main branches of the facial nerve was noted (namely the cervicofacial and the temporofacial divisions) and further anterior dissection, reflecting the parotid gland, allowed clearer visualisation of the peripheral branches of the facial nerve.

Then careful division of the superficial parotid gland lateral to the nerve was undertaken. At this point the great auricular nerve was removed.

After the superficial portion of the parotid gland was removed, the branches of the facial nerve were placed under gentle traction to remove the deep lobe.

Deep to the facial nerve, two vessels could now be identified but at different levels.

Immediately below the facial nerve, the retromandibular vein was noted. It was dissected in a vertical direction to show its tributaries, namely the superficial temporal vein (which crossed the zygomatic arch) and the maxillary vein, coming from mid-way along the angle of the mandible.

The retromandibular vein was then followed in an inferior direction as it ran downwards and backward, crossing over the posterior belly of digastric and sternocleidomastoid muscles obliquely. No posterior auricular vein was identified draining into the retromandibular vein on two of the three dissections in group 1 dissection specimens. In one specimen the posterior auricular vein could be identified draining into the retromandibular vein forming the external jugular vein.

Deep to the retromandibular vein, the external carotid artery could be seen. It was traced superiorly to the origin of the maxillary and superficial temporal arteries.

Tracing the external carotid artery inferiorly revealed a very tortuous course. It was noted to curve medially in direct relation to where the stylohyoid and posterior belly of digastric muscles inserted. On dissecting inferiorly, the next branch to be noted from the external carotid artery was the posterior auricular artery as it passed upwards and backwards superficial to the styloid process (from which stylohyoid could be seen).

On further inferior dissection of the external carotid artery, as it passed medially to the stylohyoid and posterior belly of digastric muscles, the occipital artery was found and could be seen passing to the occiput.

Just inferior to the origin of the occipital artery, the hypoglossal nerve was dissected as it hooked lateral to the external carotid artery and the occipital artery.

Overlying the hypoglossal nerve, an anomalous vein was found on all three specimens in group 1. Lymph nodes were also found at this site.

After the dissection in the neck, the skin was reflected more anteriorly to follow the terminal branches of the facial nerve from the bifurcation. The skin was then removed.

Each of the five main branches of the facial nerve was then traced to the muscles of facial expression which included frontalis, corrugator supercillii, orbicularis oculi, levator labii superioris alaeque nasi, levator labii superioris, zygomaticus major, levator anguli oris, depressor anguli oris, depressor labii inferioris and orbicularis oris which were then dissected.

Buccinator, masseter and temporalis were also seen at this point.

Finally, the ear was removed (but leaving the "tragal pointer") down to the junction between the cartilaginous and bony external auditory canal to allow for the measurements which are detailed later.

The above dissection, to identify the facial nerve, was carried out on two of the three heads in this first group, which also includes the cadaver parotidectomy as detailed on page 158. The other head, which had been latex injected, had a slightly different approach taken on it.

The latex injected specimen

Initially, a pre-auricular incision was made, as previously, extending under the ear lobe, over to the mastoid process and down into the neck. But instead of just creating a skin flap, all of the skin of the face was removed, keeping superficial to the fascia surrounding the parotid gland.

The parotid duct was easily identified emerging from the anterior border of the parotid gland as a white tubular structure running over the masseter muscle and piercing the buccal fat pad before entering into the oral cavity.

After locating this, the branches of the facial nerve could be found in close relation to the parotid duct namely the zygomatic branch above it and buccal branches below. Other branches of the facial nerve were found arising from the anterior border of the parotid gland and these were followed to the termination in the muscles of facial expression.

This dissection allowed the position of the peripheral branches of the facial nerve to be seen as they arise from the parotid gland going to the muscles of facial expression, as they would be in the living subject.

<u>DISSECTION 2:</u> BLOOD SUPPLY OF THE FACIAL NERVE

Only one specimen in which the arterial system had been injected with latex and Indian ink was used for this dissection.

The main trunk of the facial nerve and the surrounding structures (great auricular nerve and external jugular vein) were identified as detailed in dissection 1. It was noted though that on the medial surface of the facial nerve, a glistening structure approximately 2mm wide was seen.

For a clearer view, the ear was removed down to the junction between the cartilaginous and bony external auditory canal. The sternocleidomastoid muscle was reflected and the anterior part of the mastoid process was then drilled away using a small dental drill.

Then, using a Carl Zeiss operating microscope and Eschmann DV 110 high vacuum pump, the stylomastoid foramen was opened from its lateral aspect, again by using the small dental drill. Drilling proceeded vertically into the temporal bone until the chorda tympani could be seen arising from the facial nerve.

Taking away the operating microscope, the sternocleidomastoid and posterior belly of digastric muscles were completely detached from their origin at the mastoid process and removed. Stylohyoid could also be seen and it was also removed.

Medial to the facial nerve, the stylomastoid artery was seen passing into the stylomastoid foramen. It was of approximately 1-2mm in diameter and had a pearly white appearance. Finding it took great time and careful meticulous dissection. On discovering this small calibre artery, it was traced in an inferior direction. It was noted to arise from the very tortuous occipital artery (which itself was seen arising from the external carotid artery).

At this point, the hypoglossal nerve was seen hooking around the external carotid and occipital artery. It was cut and removed to allow easier visualisation of the origin of the arteries in the dissection field.

At the point where the occipital artery gave off the stylomastoid artery, dissection proceeded distally.

This involved first, removing the skin posterior to the ear. Trapezius was identified and removed from its attachment at the superior nuchal line, external occipital protuberance and the spines of the cervical vertebrae. Care was taken not to damage the occipital artery beneath this.

Splenius capitis and other surrounding muscles were removed including levator scapulae, longissimus capitis and the distal fibres of obliquus capitis superior and semispinalis capitis (on which the occipital artery lies on these latter two). Dissection involving these muscles was not specific in identifying the attachments or layout but rather a radical dissection was undertaken as the stylomastoid artery and occipital artery had already been noted. This was exposed to show the distal tortuous course of the occipital artery.

On dissection of the occipital artery, a small mastoid artery was noted going into the mastoid process.

Further defining of the occipital artery after the muscles were removed revealed the greater occipital nerve winding round the artery over the occiput.

Proximally, the external carotid artery and the internal carotid artery were dissected to define their origin from the common carotid artery. Surrounding structures to this were cleared, namely the internal jugular vein, the vagus nerve and the scalene muscles.

DISSECTION 3: LANDMARK MEASUREMENTS

Twenty-two specimens were available for landmark measurements only. This was due to the specimens being used for teaching head and neck anatomy to the second year dental students at the University of Glasgow.

They had been extensively dissected anterior to the ear but the main trunk of the facial nerve, posterior belly of digastric muscle, sternocleidomastoid muscle, ear and posterior auricular surface (eg. mastoid process) were intact.

The main trunk of the facial nerve was clearly visible, as a total parotidectomy had already been carried out by the dental students. The sternocleidomastoid muscle and posterior belly of digastric muscle were cleaned to visualise their relations clearly. This involved removing any fascia still present and tracing the muscles as far proximally to their attachments at the mastoid process as possible.

Then, the ear was reflected superiorly. The loose fatty connective tissue surrounding the main trunk of the facial nerve was removed. This allowed clearer visualisation of the "tragal pointer".

The periosteum was removed from as much of the mastoid process as possible. This was elevated anteriorly so as to visualise the ledge of bone at the beginning of the bony external auditory canal. The tympanomastoid suture, at the V shaped sulcus, was clearly visible.

To allow for clearer visualisation of the landmarks to be made, the ear was removed down to the junction between the cartilaginous and bony canal. The tragal pointer was left intact.

After clear demonstration of the landmarks, Reifler calipers were used and measurements were taken by using a micrometer. The shortest distance was measured from the main trunk of the facial nerve (ie. from its commencement at the stylomastoid foramen to its bifurcation at the pes anserinus) to four landmarks around the dissecting field.

The shortest distance was measured from the main trunk of the facial nerve to the following landmarks:

- TYMPANOMASTOID SUTURE
- POSTERIOR BELLY OF DIGASTRIC MUSCLE
- TRAGAL POINTER
- EXTERNAL AUDITORY MEATUS

The measurements were taken by just touching the main trunk of the facial nerve (after it passed in front of the most anterior part of the mastoid process but before the bifurcation) with the tips of the Reifler calipers. They were then opened out, (not disturbing the position of the facial nerve on one side) until the other half of the tip of the calipers not touching the facial nerve reached the landmark to be assessed. This was done on the same horizontal plane each time. The shortest distance was then recorded. The measurement sites and the landmarks can be seen in Figure 6.

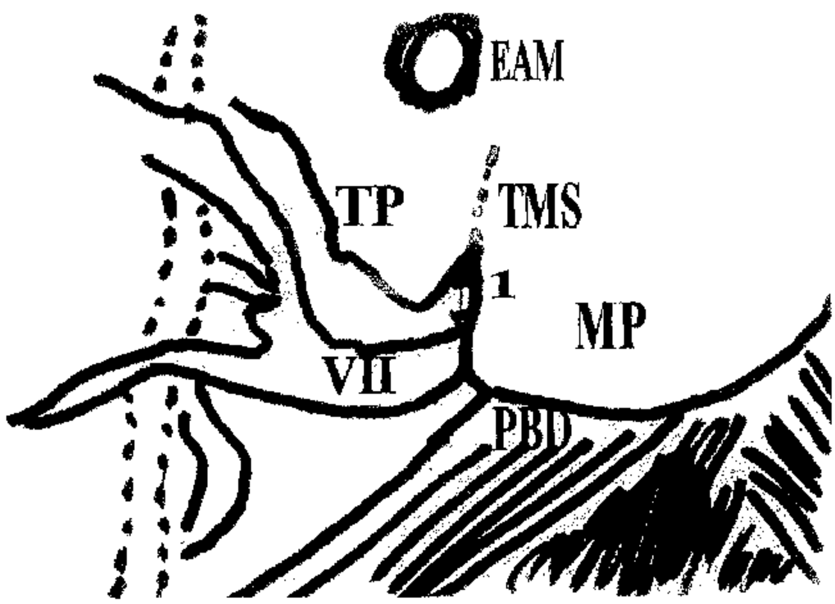


Figure 6a: Diagrammatic representation of the facial nerve in relation to the landmarks. No. 1 on the diagram is the shortest distance from the main trunk of the facial nerve to the tympanomastoid suture. EAM=Junction between the cartilaginous and the bony external auditory canal, MP=Mastoid Process, TMS=Tympanomastoid suture, TP="Tragal Pointer" and VII=Facial nerve.

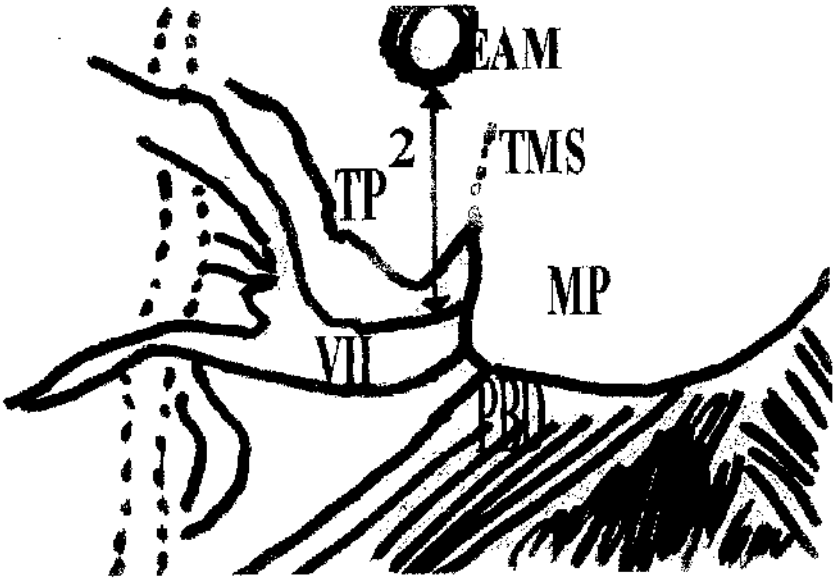


Figure 6b: Diagrammatic representation of the facial nerve in relation to the landmarks. No. 2 on the diagram is the shortest distance from the main trunk of the facial nerve to the junction between the cartilaginous and bony external auditory canal. Abbreviations as before.

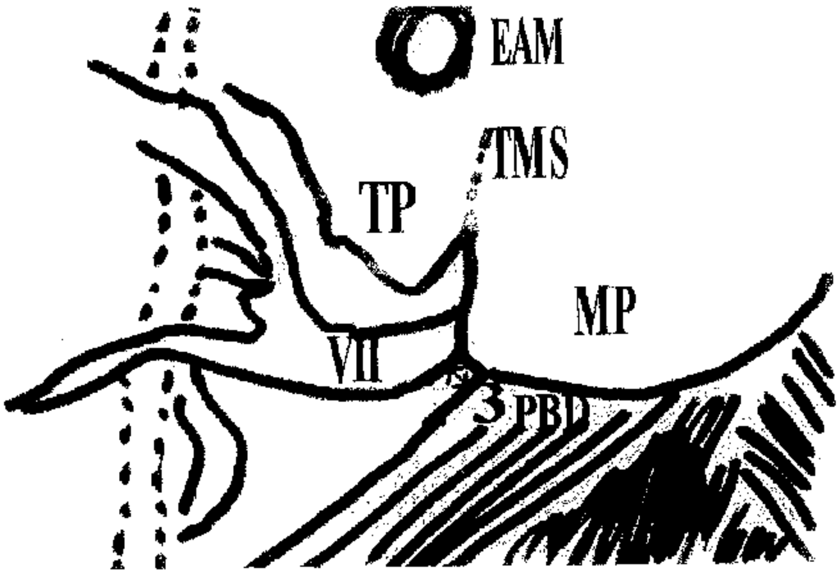


Figure 6c: Diagrammatic representation of the facial nerve in relation to the landmarks. No. 3 on the diagram is the shortest distance from the main trunk of the facial nerve to the posterior belly of digastric muscle. Abbreviations as before.

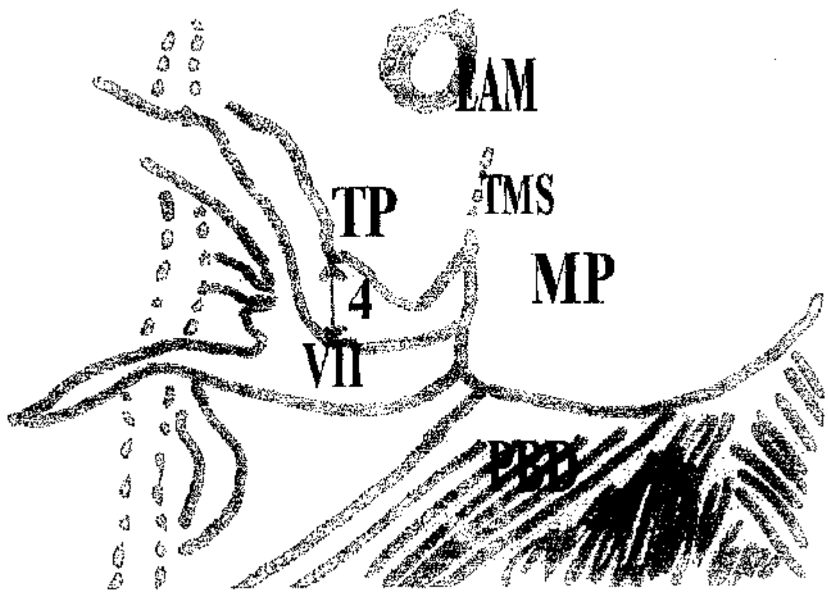


Figure 6d: Diagrammatic representation of the facial nerve in relation to the landmarks. No. 4 on the diagram is the shortest distance from the main trunk of the facial nerve to the "tragal pointer". Abbreviations as before.

Each measurement of the distance of the facial nerve to each of the four landmarks was taken twice and the average calculated. These were then repeated on a sample size of twenty-six cadaver specimens in total. For the purpose of the study, it was the mean result used (after averaging the two results taken for each landmark on each specimen).

There were 26 heads, 15 female and 11 male that were used. This would give a sample set of 52 (left and right side of each head). However, only 48 samples were available. One sample which had the parotid gland removed had disturbed normal facial nerve anatomy so was not suitable for doing landmark measurements on. The second sample had the facial nerve used for light microscopy and scanning electron microscopy. The other two samples had facial nerve anatomy disrupted by second year dental students' dissection work.

With the aid of Minitab (statistics package for the PC), the mean, median and standard deviations of all these measurements were calculated and graphed. Also, comparisons were made to see if there were any male/ female sex differences and left/right side differences with the landmark measurement results.

Boxplots were then used to show the distributional characteristics of the data.

A line is drawn across the box at the median. By default, the bottom of the box is at the first quartile (Q1), and the top is at the third quartile value (Q3). The whiskers are the lines that extend from the top and bottom of the box to the adjacent values. The adjacent values are the lowest and highest observations that are still inside the region defined by the following limits:

Lower Limit: Q1 - 1.5 (Q3 - Q1)

Upper Limit: Q3 + 1.5 (Q3 - Q1)

Outliers are points outside of the lower and upper limits and are plotted with asterisks (*).

Within the boxes, an asterisk (*) indicates the mean.

With the following four sets of results, the 95% confidence interval is also shown in red at the base of the boxplot.

2.3 HISTOLOGY

Two samples were used for this part of the study:

- Main trunk of the facial nerve (ie. after it left the stylomastoid foramen but before the pes anserinus) in cross section for scanning electron microscopy and haematoxylin and eosin (H&E) staining for light microscopy
- Parotid gland in coronal section stained with haematoxylin and eosin to show the facial nerve within the substance of the parotid gland.

All sections for light microscopy were preserved in formalin and prepared in paraffin blocks (APPENDIX 4). Serial sections were then taken using a microtome.

For the main trunk of the facial nerve, a 1cm length was taken from between the stylomastoid foramen and the bifurcation. It was divided into two equal segments. 0.5cm was processed for cross sectional cutting for haematoxylin and eosin staining (APPENDIX 5) and 0.5cm was processed for scanning electron microscopy (APPENDIX 6).

The parotid gland was removed in a single block measuring approximately 4cm x 4cm x 4cm from a 96 year old woman. The parotid gland was cut in coronal section and stained with H&E to demonstrate the facial nerve in the substance of the gland.

2.4 SURGERY ON THE PAROTID GLAND

Mr. G. McGarry, a consultant otorhinolaryngologist at the Glasgow Royal Infirmary and honorary clinical senior lecturer of the University of Glasgow, invited me to attend a parotidectomy he was performing

The patient, who will not be named (to respect patient confidentiality), will be known from here as Mrs X.

Mrs X, a 53-year-old woman, had an eight-month history of a painless lump developing in the region of the parotid gland on the left side. It had been increasing in size but with no other associated symptoms. Mrs X was an otherwise fit woman who smoked on average 10 cigarettes per day.

On attending the ENT outpatient clinic, a fine needle aspirate was taken and sent to pathology for examination. It revealed a pleomorphic adenoma.

Further investigation included an MRI scan to show the extent of the benign tumour.

The tumour was removed in December 2002 and it was this operation that I attended. The surgery was carried out in operating suite 3 in Gartnavel General Hospital.

Mrs X had given informed consent for both the operation and pictures to be taken during the operation. Photographs were taken by a photographer from the Medical Illustration Department at Gartnavel General Hospital.

A general anaesthetic was administered and the patient intubated before being brought into the operating room.

The head was positioned with the face away from Mr. McGarry on the operating trolley. The location of the tumour was confirmed again and the head was held in position with head rings.

Electrodes for the nerve stimulator were placed at various points over the medial aspect of the left side of the face.

The surgeons and theatre nurse scrubbed up. Drapes were placed over the patient's face with sufficient exposure over the left parotid gland. Betadine was then wiped over the entire exposed operating area to maintain sterility.

The incision, with a Swann Morton 12 blade, was S shaped and extended from in front of the pinna, extending over the mastoid process and into the upper skin crease of the neck.

The skin over the parotid gland was then reflected forwards and care was taken to secure haemostasis. The ear was retracted upwards and the sternocleidomastoid muscle and its attachment to the mastoid process was noted. At this point the posterior auricular vein was seen and care was taken not to damage it.

The anterior border of the sternocleidomastoid muscle was freed from the posterior border of the parotid gland. The deep fascia enveloping the parotid gland was then dissected away from the perichondrium of the cartilage of the ear canal and also separated from its attachment to the sternocleidomastoid muscle. Separation of the parotid gland from the sternocleidomastoid muscle was then possible.

The next part of the operation was the crucial stage: identification of the facial nerve.

The sternocleidomastoid muscle was moved in a posterior direction. Dissection continued to the tympanic plate and during this, use was made of the nerve stimulator in the search for the facial nerve. Any connective tissue, which resembled facial nerve, was tested with the nerve stimulator to exclude the nerve.

This stage of the operation involved meticulous dissection and only proceeding at a slow stage as any structure which may have been the facial nerve had to be identified and confirmed as to whether it was nerve or connective tissue.

After careful searching for the facial nerve by using the posterior belly of digastric muscle, the "tragal pointer" and the tympanic plate to aid in locating the nerve, a glistening white band measuring a few millimetres in diameter was at last visible. It had taken almost thirty minutes to locate the nerve. On stimulating the facial nerve with the nerve stimulator, a dramatic contraction of all the muscles of facial expression was noted.

After identifying the facial nerve it was traced in an anterior direction, and the branches close to the tumour were isolated by using fine artery forceps. The tumour was teased out and a small margin of normal parotid tissue was removed with it.

Repeated use was made of the electrical nerve stimulator during the operation in identification and confirmation of the branches of the facial nerve.

After the tumour had been removed, the block of tissue was placed in 10% formalin and sent to the pathology department for histological analysis.

After the removal of the tumour, which in this case was well demarcated, the operating field had to be closed over.

This involved bringing the ends of skin together with interrupted Nylon sutures, either 4/0 or 5/0. A suction drain was also inserted and aspirated initially while under anaesthesia. This has to be left in for 24 hours to allow the passage of blood from the operating site. Surgical staples were then placed to fully seal the skin.

The facial nerve stimulator electrodes were removed, anaesthesia was reversed and immediately after the operation, the patient was taken to the recovery area. When she was conscious from the anaesthetic, she was asked to raise her eyebrows and puff out her cheeks against closed lips to demonstrate any damage to the facial nerve, which in turn would affect the muscles of facial expression.

Fifteen-minute observations of temperature, pulse, respiratory rate and blood pressure are made until the effects of anaesthesia have worn off. Observation for haematoma, infection and nerve injury over the next few days is undertaken. Discharge two to four days after the operation is common.

SECTION 3

RESULTS

3.1 DEVELOPMENT

The facial nerve is the nerve of the second branchial arch. In the diagram below (Figure 7), the position of this arch can be seen in relation to the first arch and other surrounding structures.

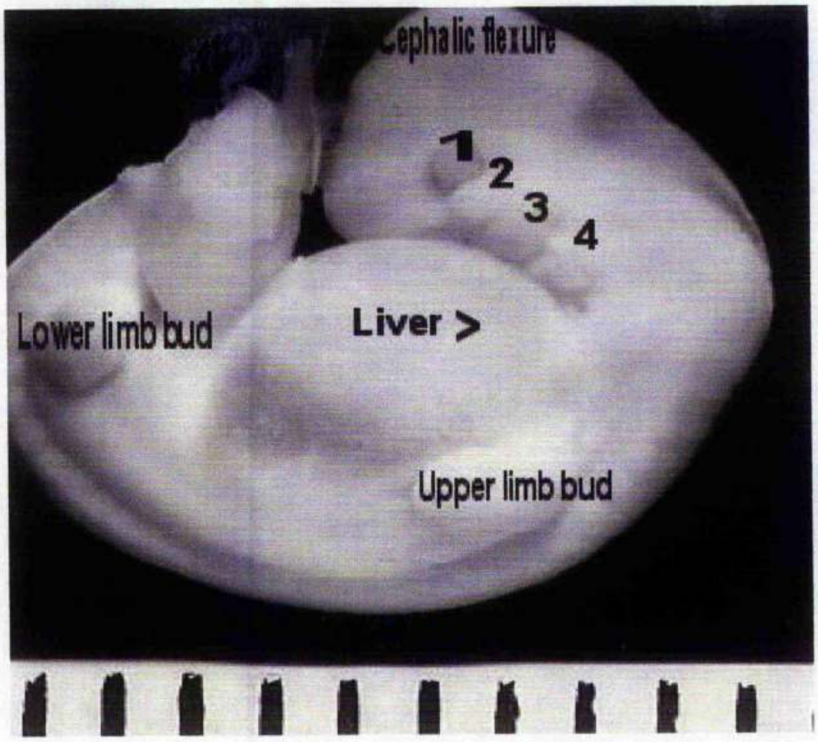


Figure 7: Position of the branchial arches in a sheep embryo at the 10mm stage (similar to humans). Taken from University of Glasgow's Anatomy Department collection of picture sets of embryos. 1=Eye, 2=Maxillary Process, 3=Mandibular Process and 4=II Arch (Hyoid arch)

Figure 7 above is a 10mm sheep embryo. At this stage, the sheep embryo is very similar to the human and for ethical reasons, the sheep embryo from the Anatomy Departments collection of pictures has been used here and not any human samples.

The head, which is relatively large on account of the dominance of the brain, makes a right-angled turn at the cephalic flexure. At the sides of the head are four branchial arches, separated by three branchial grooves. The first branchial arch of each side forks ventrally into two parts. The smaller maxillary process shows signs of fusing with median nasal processes (not seen on this photograph) to form the upper jaw, while the larger mandibular processes form the lower jaw. Next caudad is the prominent second arch (or hyoid arch).

From Figure 7, the position of the liver, and upper and lower limb buds can also be seen in relation to other structures.

Figure 8 is again a sheep embryo. Here, it is a scanning electron microscope image of a 10mm embryo, again showing the position of the first and second pharyngeal arches (which are labelled on the picture).

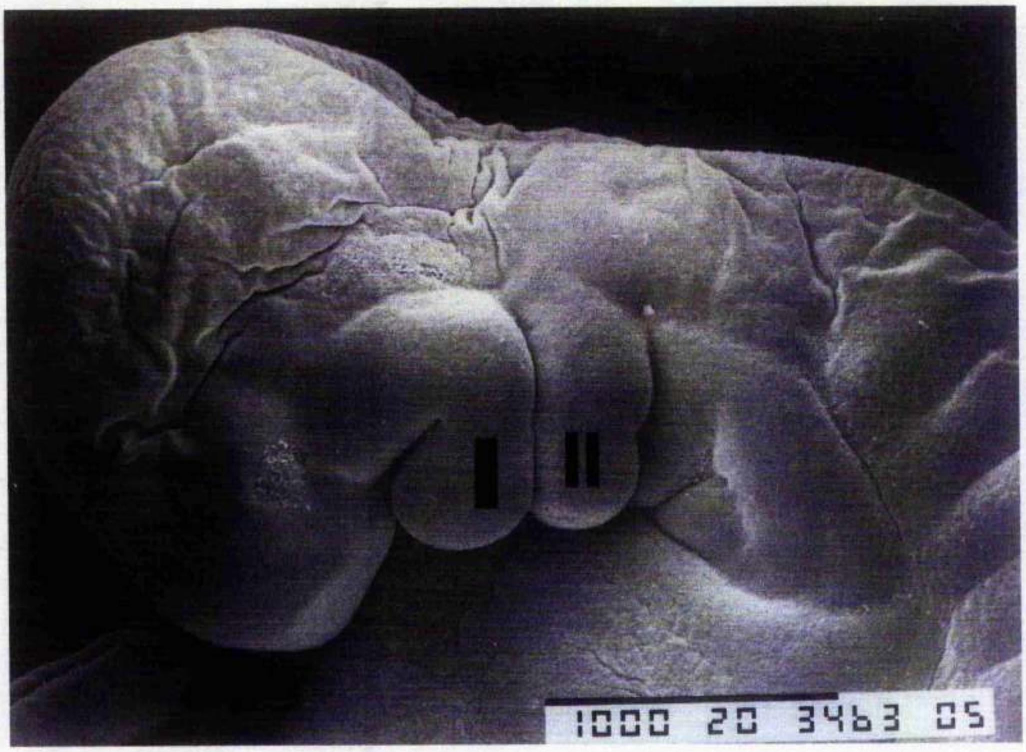


Figure 8: A sheep embryo using scanning electron microscopy. I=Mandibular arch, II=Hyoid arch. Scale shown on the picture. Again, used from the Anatomy Department collection.

In Figure 9, a cross section shows the position of the hyoid arch, or the second pharyngeal arch and its relation to the mandibular process, yet separated from it by the pharyngeal cleft. Also, the relative position of the maxillary process and the optic cup can be seen all in cross section.

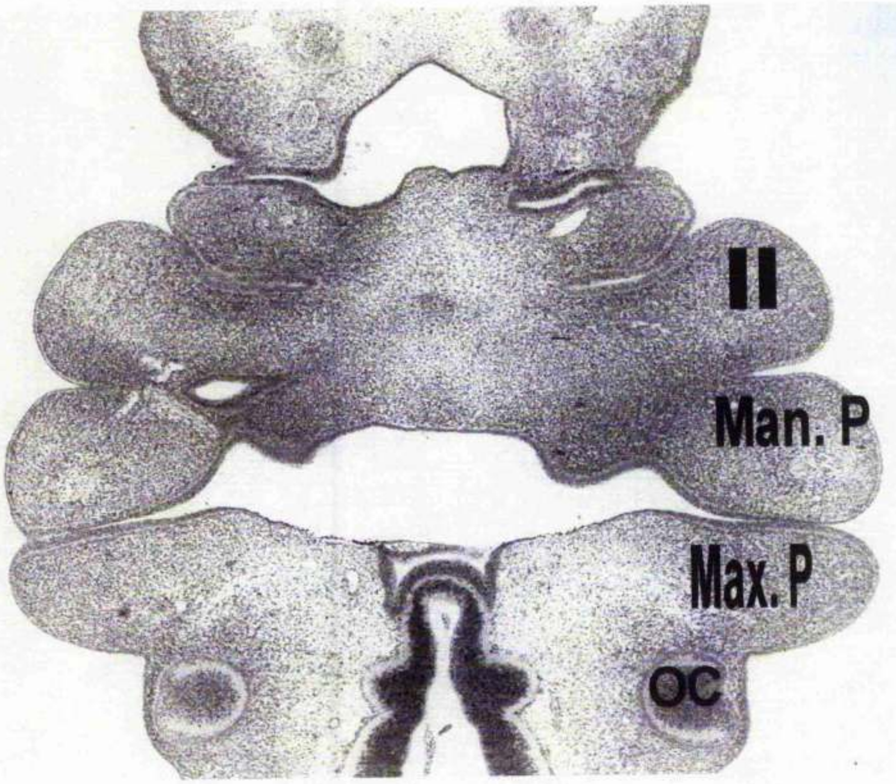


Figure 9: Cross section of an embryo showing the relation of the branchial arches, clefts and pouches, in relation to surrounding structures. The depression on the outer aspect between the arches is the clefts. II=The Second Arch, Man.P=Mandibular Process, Max.P=Maxillary Process and OC=Optic cup. Taken from the Anatomy Departments collection at the University of Glasgow.

Figure 10 demonstrates very clearly the position of the facioacoustic primordium.

Figure 10: The components of the facioacoustic primordium. FA=Facioacoustic primordium, Ot=Otocyst and V=Trigeminal ganglion. Taken from the Anatomy Departments collection at the University of Glasgow.

As the fetus develops, the facial nerve supplies the muscles of the facial expression. For the facial nerve to leave the skull to get to these muscles, it passes through the temporal bone and leaves the skull through a hole called the stylomastoid foramen.

Figure 11 is a fetus at 35 weeks gestation and it shows the developing mastoid from a lateral view.

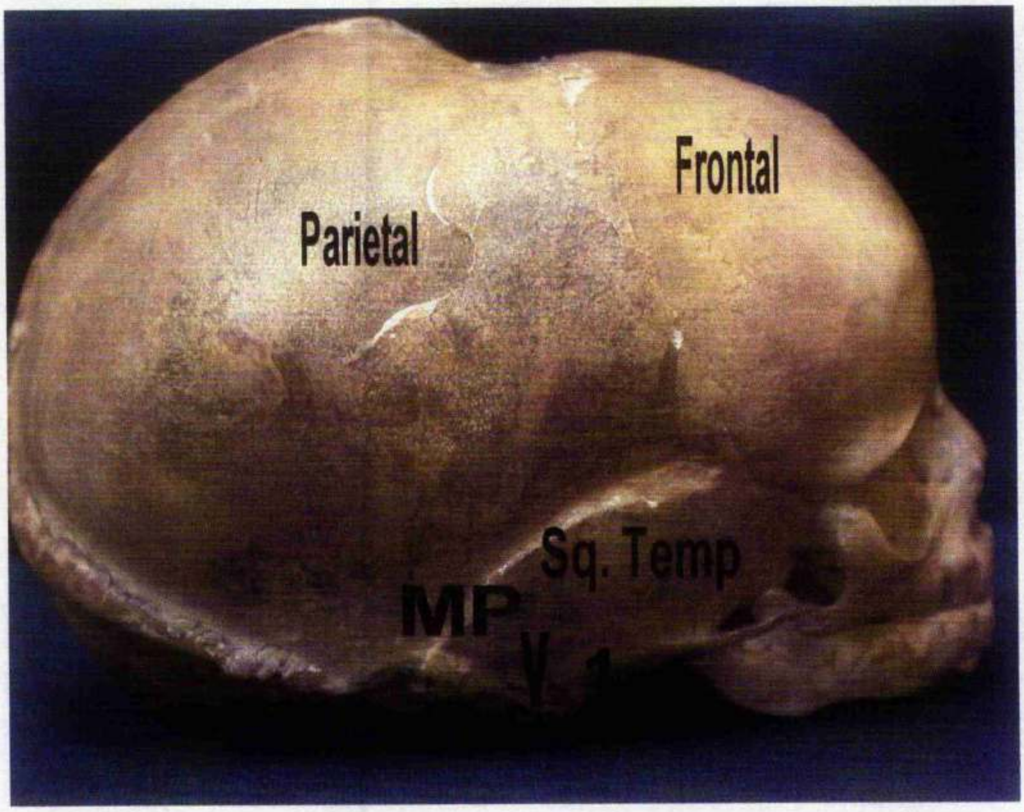


Figure 11: Lateral view of a 35-week gestation fetal skull. The position of the developing mastoid process can be seen (MP). It is not well developed. Other surrounding structures are: FRONTAL=Frontal bone, PARIETAL=Parietal bone and Sq. Temp=Squamous part of the temporal bone. 1= The most anterior site of where the mastoid process is.

The mandibular fossa is very shallow and looks more laterally than downwards.

The developing mastoid process can be seen from a lateral view. It is very flat and in fact the stylomastoid foramen, where the facial nerve leaves the skull, is on the lateral aspect of the skull.

Just anterior to the mastoid process, a darker area is seen. This is the position of the auditory tube and at its lateral surface is the tympanic ring.

The position of the tympanic ring can be seen more clearly in Figure 12.

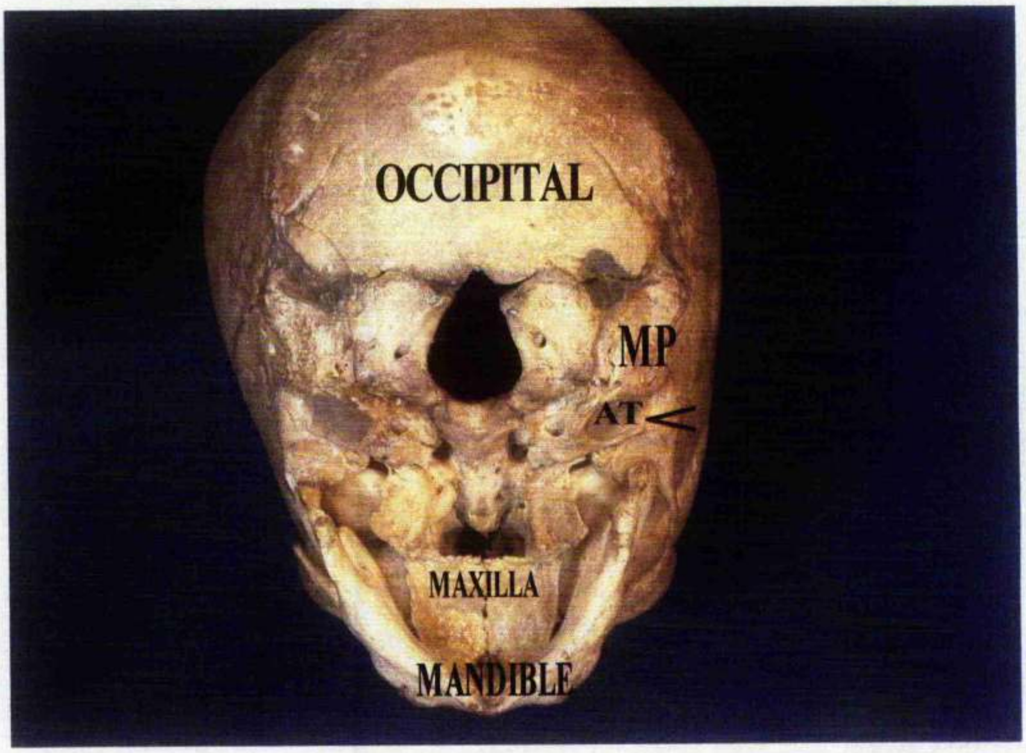


Figure 12: The position of the tympanic ring, indicated by the arrow at the level of the auditory tube (AT). Note the OCCIPITAL bone and the MAXILLA and MANDIBLE.

The developing tympanic ring is an incomplete ring and is not complete in its superior aspect. It is concave and the stylomastoid foramen is just located posterior to it on the lateral surface of the skull.

The term infant can be seen in Figure 13. It can still be seen that the mastoid process is relatively flat. Again, the stylomastoid foramen is located on the lateral aspect.

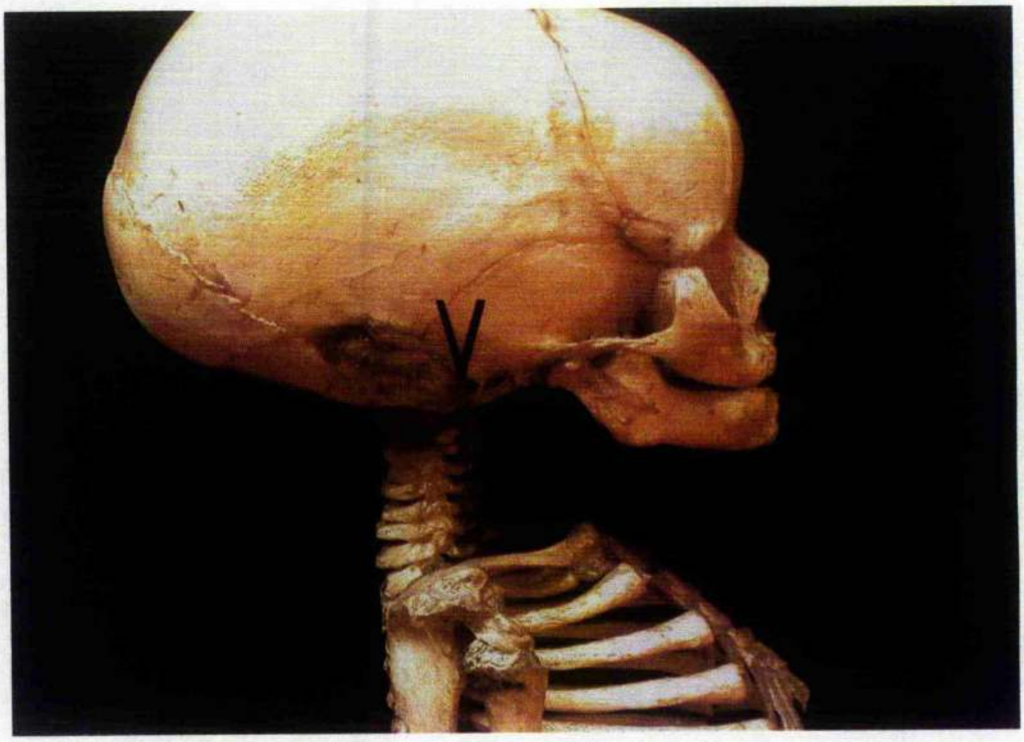


Figure 13: The mastoid region highlighted (by arrow) on a lateral view of a term fetus. Note how it is very flat and not as pronounced as the adult mastoid.

As the child develops, the mastoid air cells develop and the mastoid portion grows downwards and forwards to form the mastoid process, and the styloid process and the stylomastoid foramen come to lie on the under surface of the bone as can be seen in Figure 14-16.

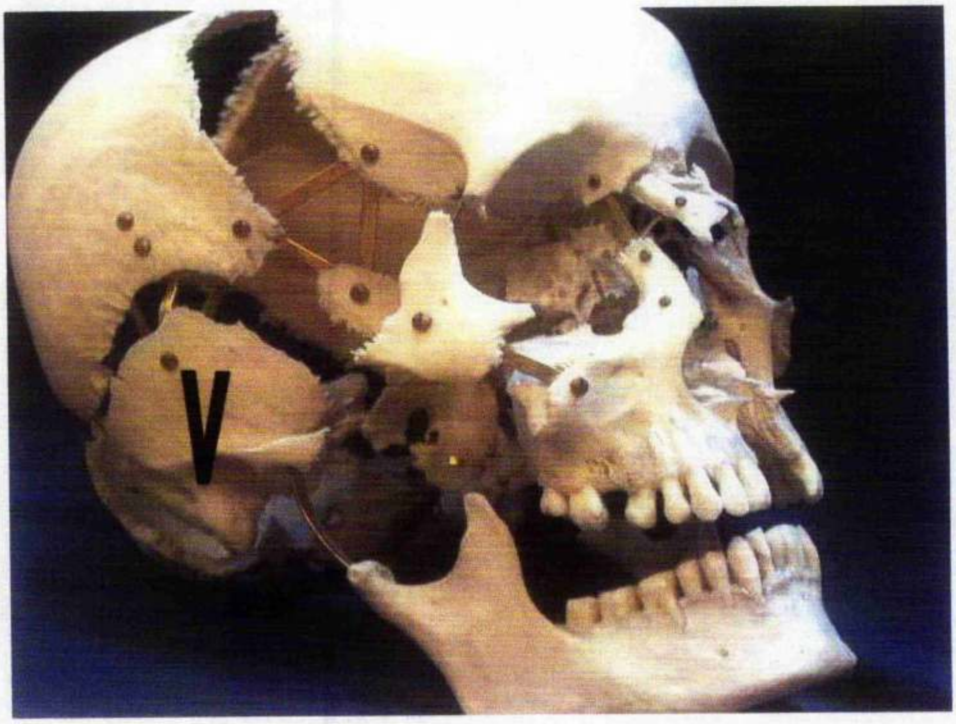


Figure 14: The position of the mastoid process in the adult skull, as indicated at the tip of the arrow. Note it is much more prominent and downward pointing. This specimen is a disarticulated skull from the collection at the Anatomy Museum of the University of Glasgow.

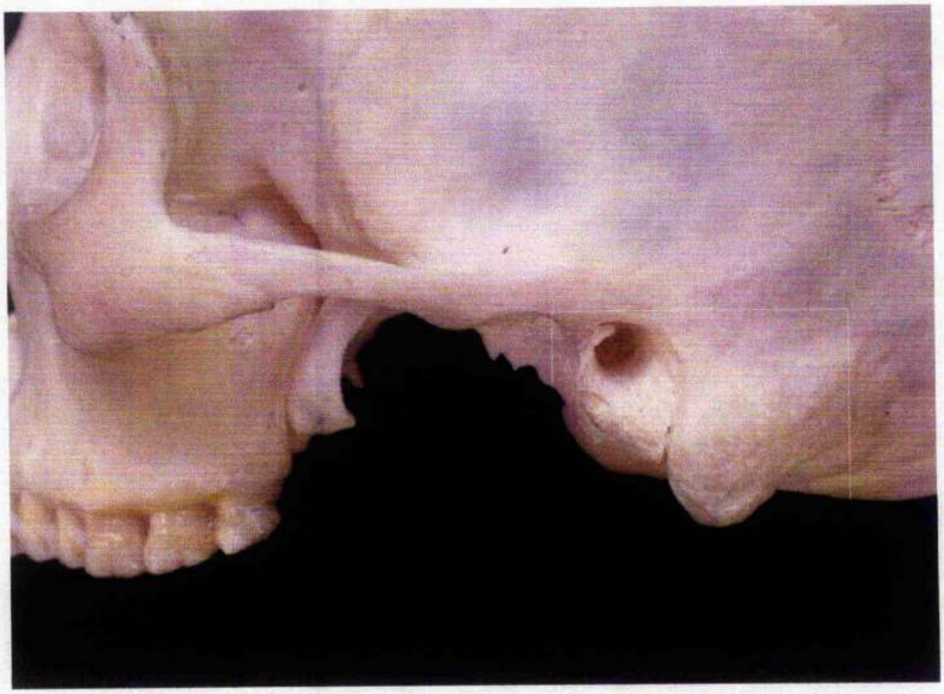


Figure 15: The mastoid region of an adult skull from a lateral view.

The grooves for the insertion of the posterior belly of digastric and, more medially, the occipital artery, are also more pronounced on the adult skull, as shown in Figure 16.

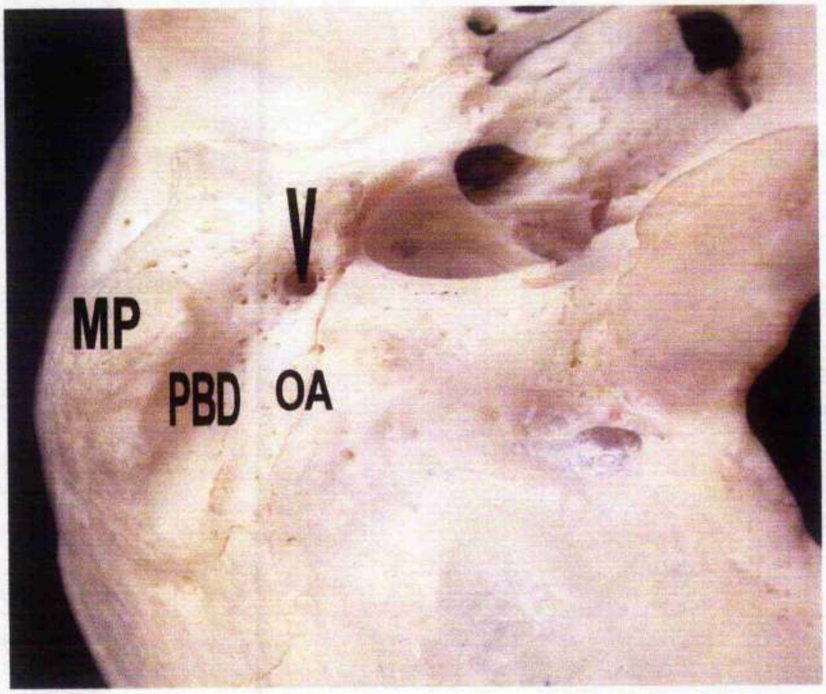


Figure 16: The base of an adult skull (right side) showing the position of the stylomastoid foramen on the inferior surface (indicated by the arrow). MP=Mastoid Process, OA=groove for the occipital artery and PBD =the groove for the posterior belly of digastric muscle.

3.2 DISTRIBUTION OF THE FACIAL NERVE

The facial motor nucleus, the origin of the majority of the fibres in the main trunk of the facial nerve (ie. from commencement at the stylomastoid foramen to the pes anserinus), is situated in the caudal one-third of the ventrolateral part of the pontine tegmentum. This is seen from the picture below of the ponto-medullary junction.

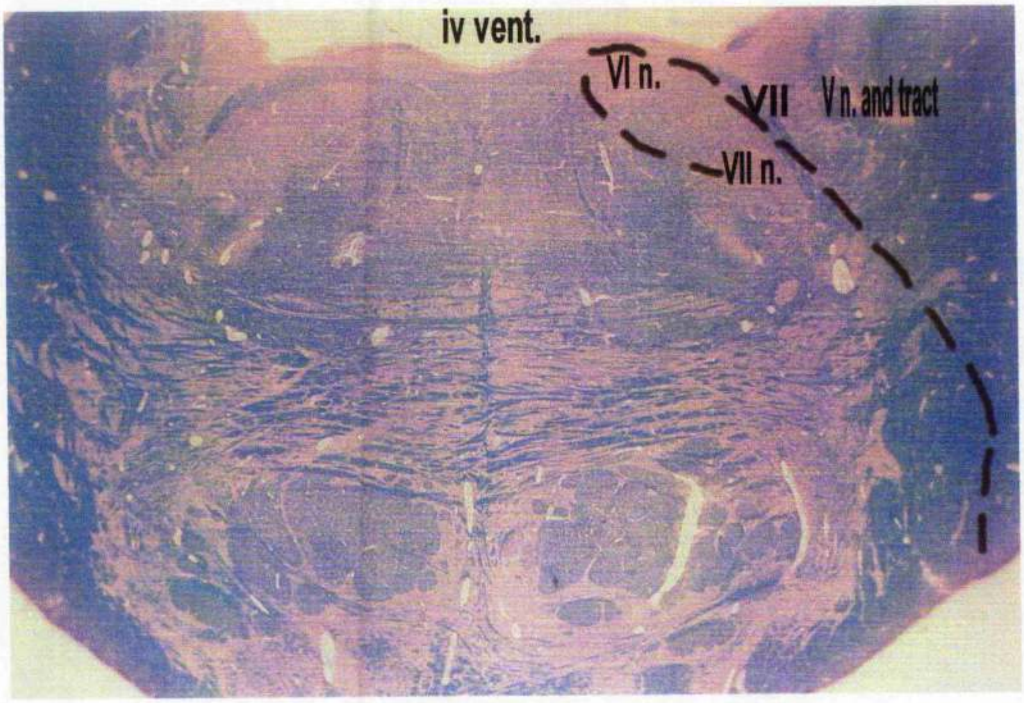


Figure 17: The ponto-medullary junction. The Facial motor nucleus (VII n.). iv vent.=Fourth ventricle, Vn. and tract=Spinal tract of the trigeminal nerve and its nucleus. VI n. =Abducent nucleus and VII=Facial motor nucleus. Kluver-Barrera Luxol Fast Blue MBS x0.8. The path of the facial nerve is highlighted by

the broken line from its nucleus to when it leaves the brainstem. Taken from the Anatomy Department collection.

From the facial motor nucleus (paler region on Figure 17), the fibres pass to the floor of the fourth ventricle, loop around the abducent nucleus (paler stained on Figure 17) thus forming the internal genu. The fibres of the facial motor nucleus then pass between the nucleus of origin and the spinal trigeminal nucleus. They then emerge from the brainstem at the groove between the pons and medulla ie. the ponto-medullary junction. The position of the facial nerve leaving the brainstem can be seen in Figure 18.

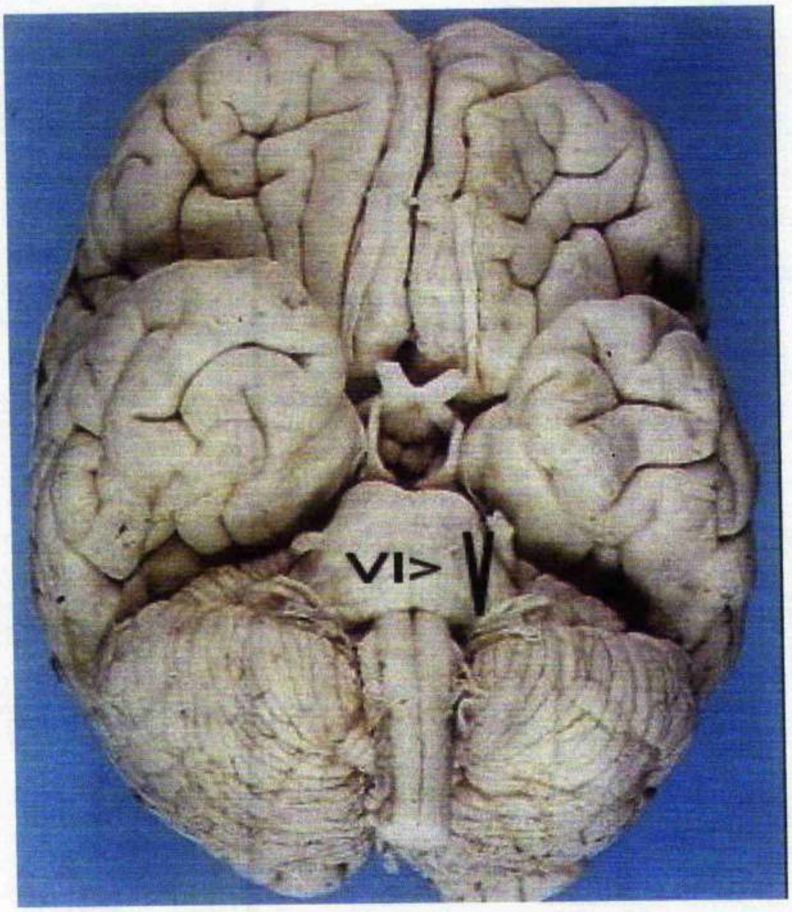


Figure 18: Brainstem – gross view. The facial nerve is leaving at the ponto-medullary junction (arrowed). VI =Abducent nerve. Taken from Williams in Gray's Anatomy, 1995.

Also, a smaller nerve runs alongside the motor root of the facial nerve, the nervus intermedius. It runs in direct association with the motor root of the facial nerve and sometimes can be indistinct from it (see Figure 21).

Both the facial and vestibulocochlear nerves leave the brainstem at the ponto-medullary junction, lateral to the origin of the abducent nerve (Figure 18), with the facial nerve lying more medially of the two.

The facial nerve (including the motor and sensory root) and the vestibulocochlear nerve then course laterally from the brainstem to enter into the petrous temporal bone through an aperture called the internal auditory meatus as can be seen in Figure 19.

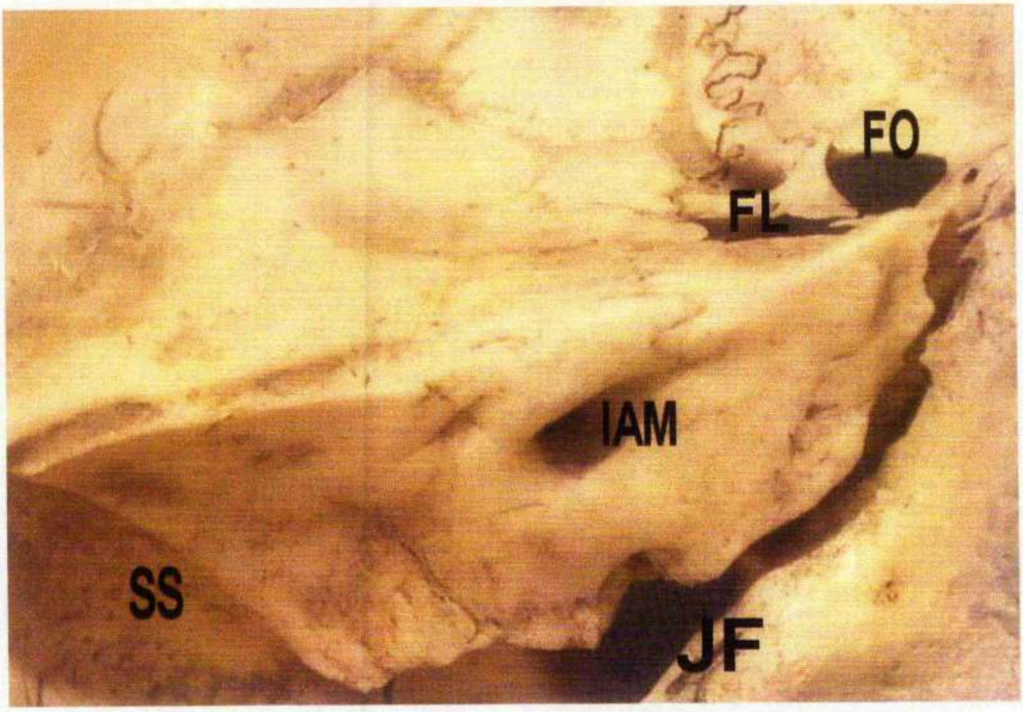


Figure 19: The left petrous temporal bone showing: FL=Foramen Lacerum, FO=Foramen Ovale, IAM=Internal Auditory Meatus, JF=Jugular Foramen, SS=Sigmoid Sulcus.

The posterior surface of the left petrous temporal bone can be seen in Figure 19 and this forms a large portion of the anterolateral wall of the posterior fossa.

The jugular foramen can be seen in the lowermost aspect of the picture. This is directed forwards and medially. The internal jugular vein will pass through here. This in turn is coming from the sigmoid sinus, which would sit in the groove called the sigmoid sulcus, labelled on Figure 19.

Immediately superior to the jugular foramen is the internal auditory meatus. This opening runs transversely in a lateral direction and is approximately 1cm long. The facial, vestibulocochlear nerves, and the nervus intermedius and labyrinthine vessels pass through here.

Just anterior to the anteromedial portion of the petrous temporal bone, the foramen lacerum can be seen, with the foramen ovale just anteromedial to this. The foramen lacerum is bounded behind by the apex of the petrous temporal bone and in front by the body of the sphenoid and the posterior border of its great wing.

The foramen lacerum has a jagged appearance and in vivo, is closed by cartilage and is related to the cartilaginous part of the auditory tube. It also transmits the greater superficial petrosal nerve which leaves the petrosal foramen of the petrous temporal bone as seen in Figure 20.

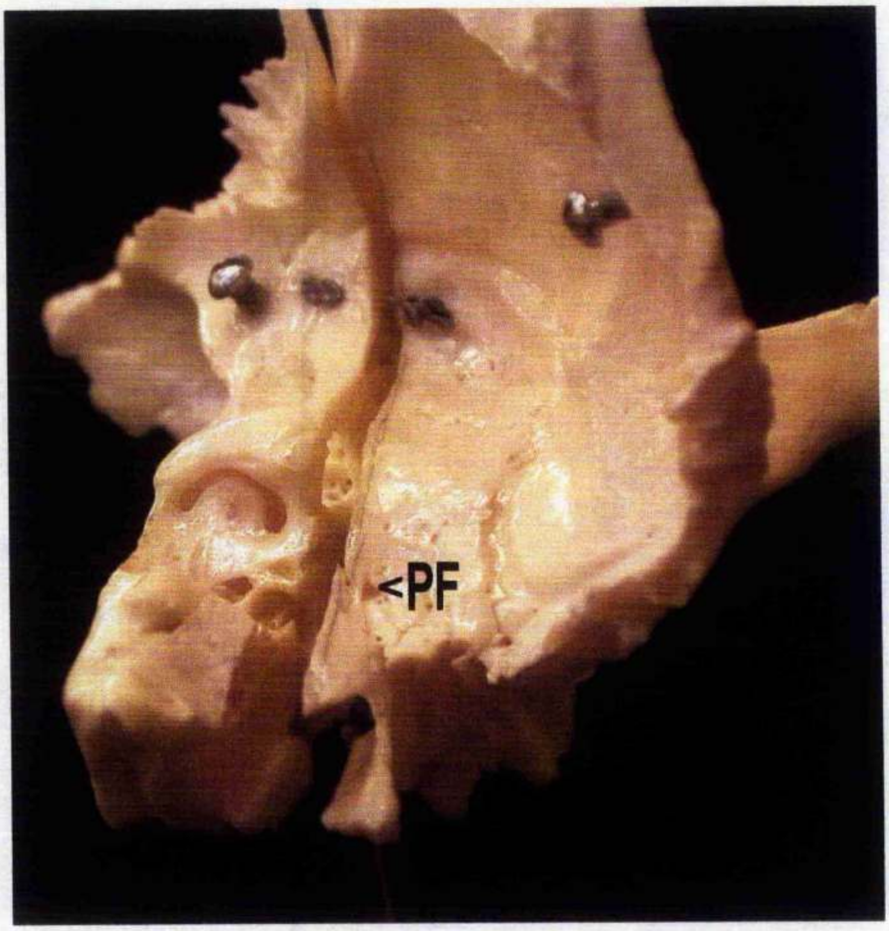


Figure 20: PF= Petrosal Foramen (left of the text on diagram) on the petrous temporal bone.

Returning to the course of the facial nerve, Figure 21 shows a model of the facial and vestibulocochlear nerves entering the internal auditory meatus of the petrous temporal bone. Both the facial and vestibulocochlear nerves pass towards the internal auditory meatus and in Figure 21, the facial nerve is represented by yellow and the vestibulocochlear nerve is blue. After these two nerves pass into the opening, the facial nerve passes into the facial canal and the vestibulocochlear nerve passes inferior to it. In the meatus, the motor root (of the facial nerve) lies in a groove on the upper and anterior surface of the vestibulocochlear nerve, the nervus intermedius being placed between them.

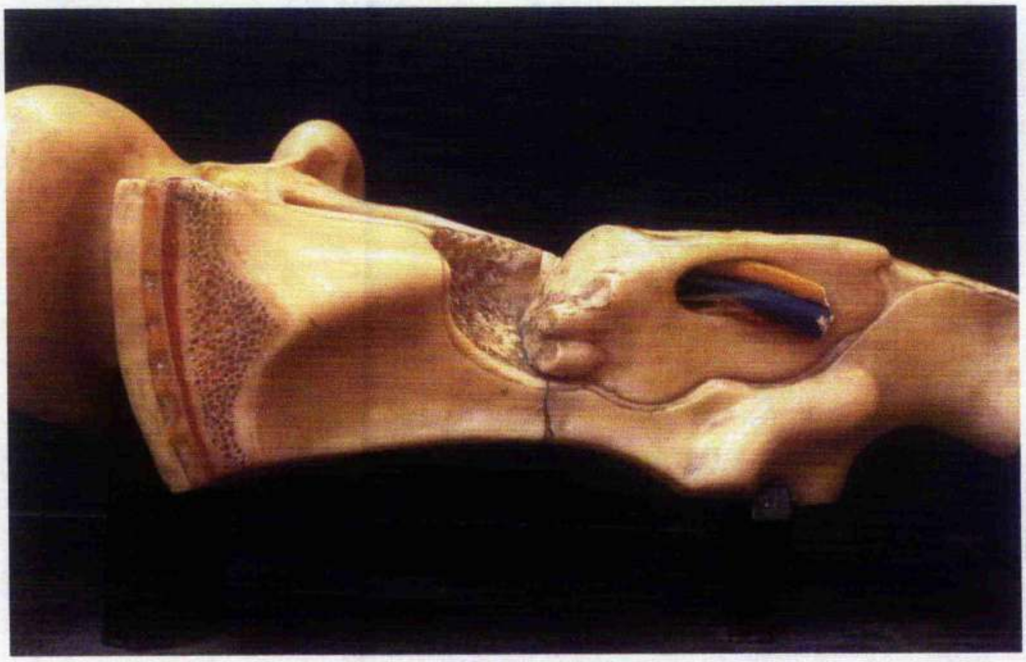


Figure 21: Model of the internal auditory meatus. Yellow=Facial Nerve, Blue=Vestibulocochlear Nerve.

Figure 22 is taken from a hemisected head showing the position and relation of the facial and vestibulocochlear nerve as they enter the internal auditory meatus.

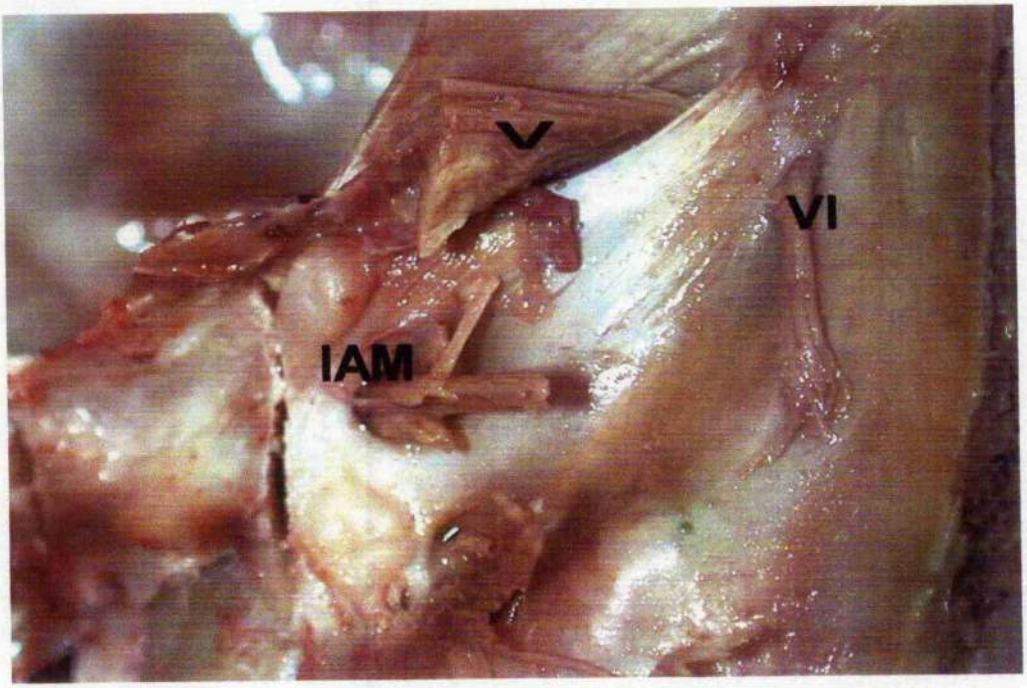


Figure 22: The internal auditory meatus on the cadaver. IAM=Internal Auditory Meatus, V=Trigeminal Nerve, VI=Abducent nerve.

The shiny appearance is due to the overlying dura. Directly superior to the cut facial and vestibulocochlear nerves, a very broad band of nerve tissue can be seen. This is the fifth cranial nerve, the trigeminal nerve. It is passing into Meckel's cave ie. the fold of dura seen in relation to the nerve. Note also the abducent nerve in the field.

At the lateral termination of the meatus, the facial nerve then enters the facial canal. Here, the facial nerve turns laterally above the vestibule and, reaching the medial wall of the epitympanic recess, bends sharply backwards over the promontory (which is the site of the genicular ganglion) and passes downwards in the medial wall of the aditus to the mastoid antrum. It then descends to reach the stylomastoid foramen.

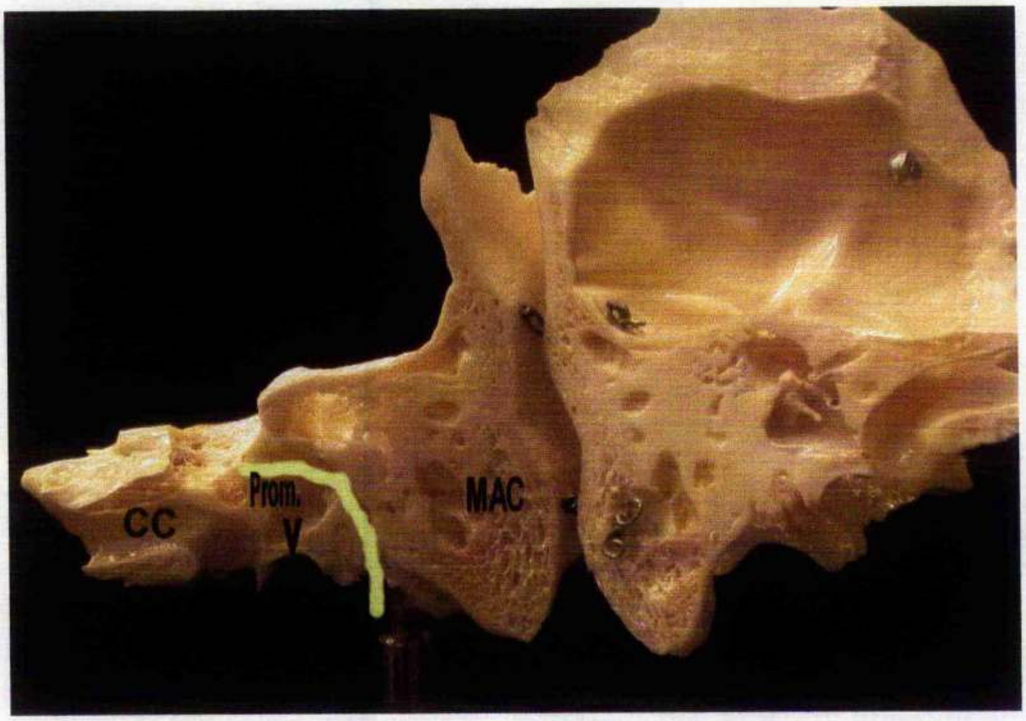


Figure 23: The position of the facial nerve (yellow) as it turns backwards over the promontory (Prom.) and passes downwards in the medial wall of the aditus to the mastoid antrum then descending through the stylomastoid foramen (vertical section) in a left temporal bone. CC=Carotid Canal, MAC=Mastoid Air Cells and the arrow points to the jugular fossa.

As the facial nerve passes through the temporal bone in the facial nerve canal, it can be seen to be closely related to the promontory, a rounded elevation with small grooves for the tympanic plexus.

The position of the carotid canal is just anterior to the horizontal part of the facial nerve, and separated from the vertical segment by the positioning of the jugular fossa, as shown in Figure 23.

The last portion of the facial nerve can be seen in Figure 24 below which shows the facial nerve dissected in the temporal bone as it descends through the stylomastoid foramen.

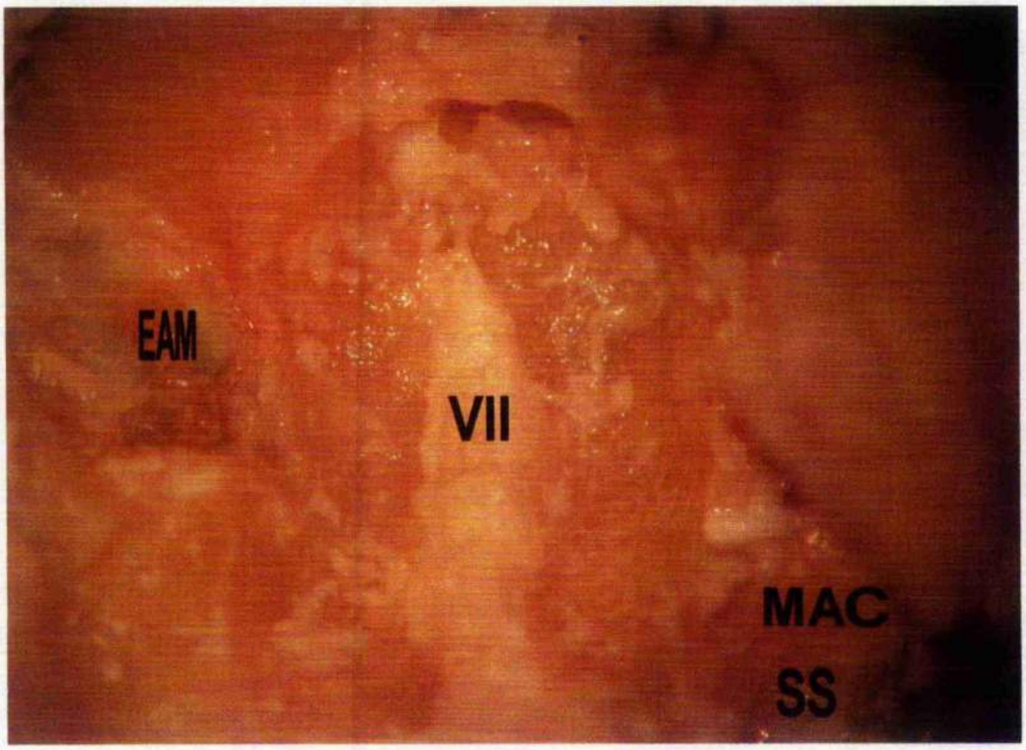


Figure 24: The facial nerve exposed in the stylomastoid foramen (left side) viewed through the operating microscope. The mastoid process has been removed (right side) as has the ear (left side) down to the tympanic membrane. EAM=External

Auditory Meatus, MAC=Mastoid Air Cells, VII=Facial Nerve and SS=Sigmoid Sinus.

Viewed under the Carl Zeiss operating microscope, the pearly appearance of the facial nerve can be seen. This view was obtained by chipping away some of the mastoid process (after removing the attached muscles) to allow the temporal bone to be opened up to show the vertical intra-temporal portion of the facial nerve.

Note also to the left of the picture (anterior) is the auditory canal and tympanic membrane and to the right of the picture the mastoid process is opened with the sigmoid sinus just visible deep to the field of view.

From Figure 25, the stylomastoid foramen can be seen. This is the site at which the facial nerve actually leaves the skull to go on to supply the muscles of facial expression.

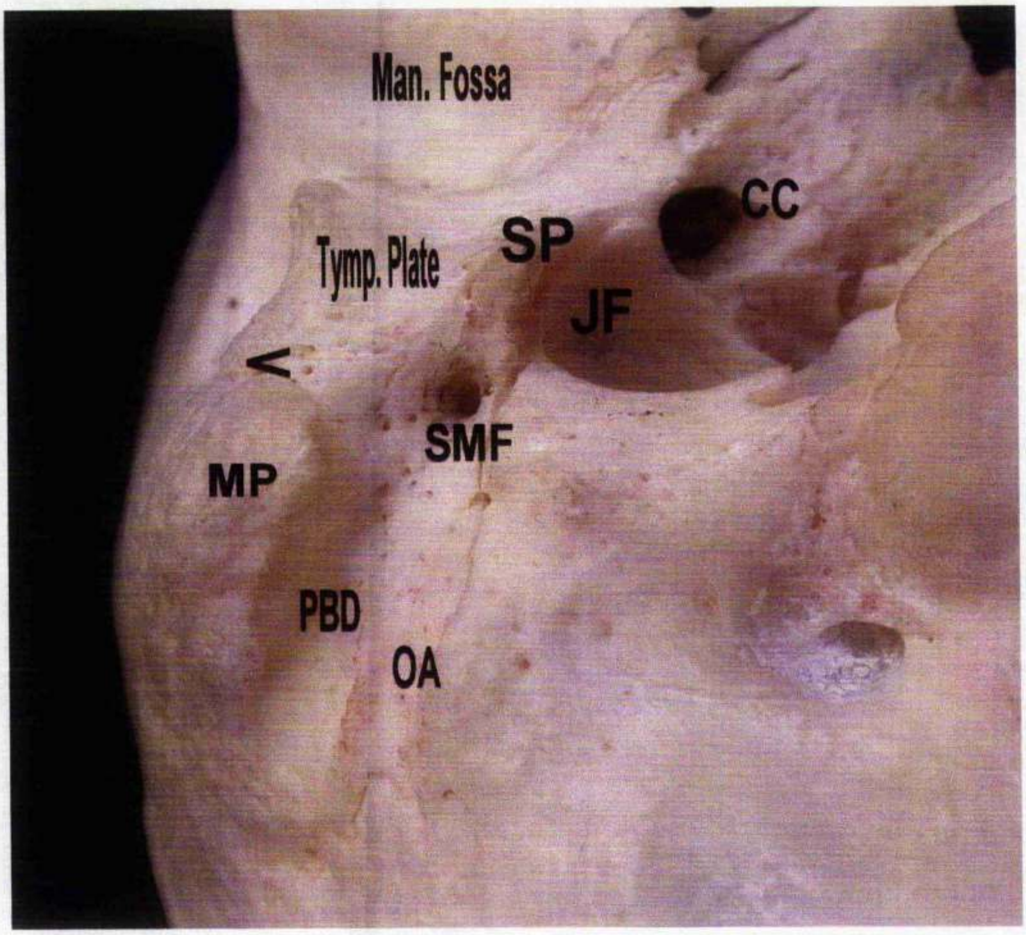


Figure 25: The position of the stylomastoid foramen, base of skull view. CC=Carotid Canal, JF=Jugular Fossa, Man. Fossa=Mandibular Fossa, MP=Mastoid Process, OA=Groove for Occipital Artery, PBD=Groove for Posterior Belly of Digastric, SMF=Stylomastoid Foramen, SP=Styloid Process, Tymp. Plate=Tympanic Plate. The arrow point indicates the position of the most inferior point of the tympanomastoid suture

The stylomastoid foramen is located just above the "SMF" label on Figure 25. It lies behind the root of the styloid process (point of muscle attachment) and at the anterior end of the mastoid notch. A vascular groove also is present crossing the inferior aspect of the posterior part of the temporal bone medial to the mastoid notch/process. Just lateral to the vascular groove for the occipital artery is the groove for the insertion of the posterior belly of digastric muscle.

Note also the inferior point of the tympanomastoid suture can be seen directly lateral to the stylomastoid foramen, the relevance of this will be seen later.

Anteromedial to the stylomastoid foramen, an inferior view can be seen of the jugular foramen/fossa (already seen inside the skull in Figure 19). The carotid canal can be seen traversing the petrous bone and this, in life, transmits the internal carotid artery.

Figure 26 is a model of the temporal bone, with attached ear. It shows the position of the facial nerve as it leaves the stylomastoid foramen. A small twig is seen sweeping laterally, yet just anterior to the mastoid process. This is the posterior auricular nerve.

Various sensory branches (coloured white) distributed over the posterior aspect of the pinna can also be seen here, which are from the facial nerve and also the vagus nerve. Also present are associated branches of the posterior auricular artery (coloured red).

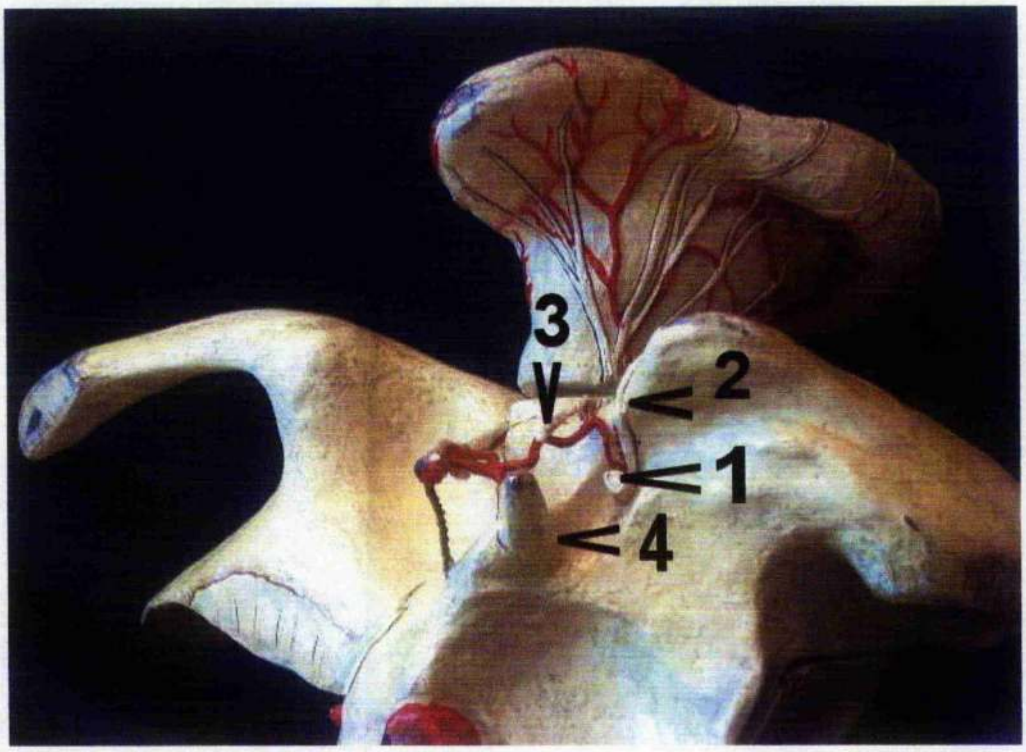


Figure 26: Model of the stylomastoid foramen showing the facial nerve leaving the skull, left side. 1=Facial Nerve, 2=Posterior Auricular Nerve, 3=Posterior Auricular Artery and 4=Styloid Process.

After leaving the stylomastoid foramen, the facial nerve gives off three branches: the posterior auricular nerve, the nerves to posterior belly of digastric and stylohyoid.

The nerve to the posterior belly of digastric can be seen from Figure 27 below.

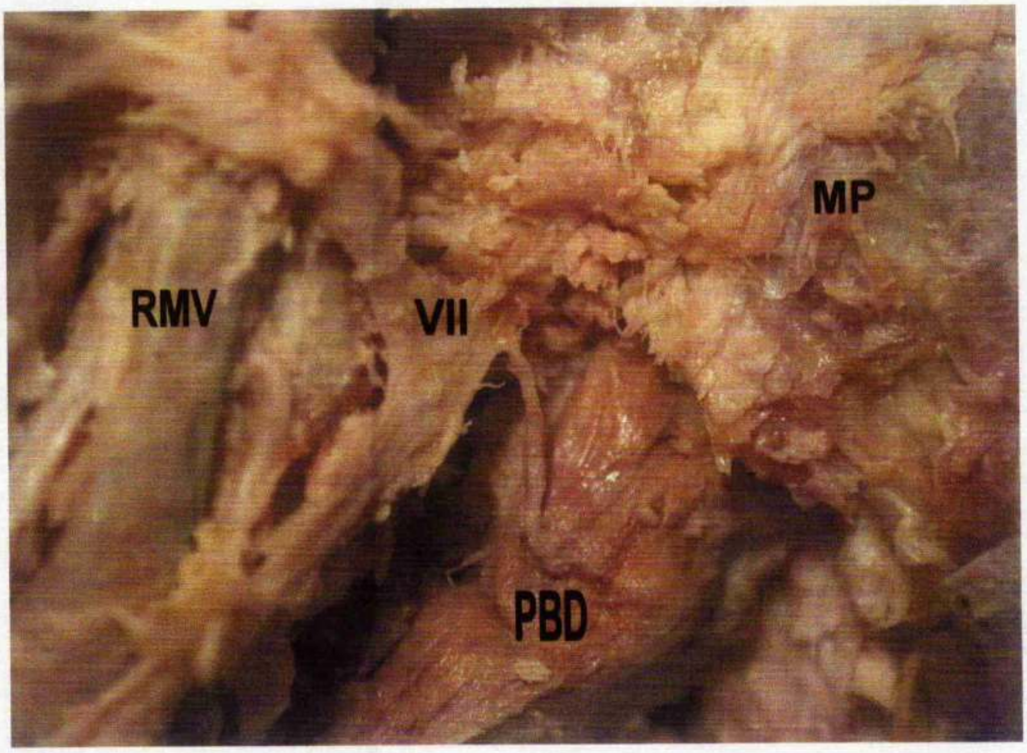


Figure 27: The nerve to the posterior belly of digastric muscle. MP=Mastoid Process, PBD=Posterior Belly of Digastric muscle, RMV=Retromandibular Vein, VII=Facial Nerve.

Note that the sternocleidomastoid muscle and the superficial portion of the parotid gland have been removed. The facial nerve can also be seen to be superficial to the retromandibular vein.

The main trunk of the facial nerve passes in an anterolateral direction on its way to the parotid gland. Early in its extra-cranial course, it appears in front of the digastric muscle, and lateral to the styloid process.

Histologically, the main trunk of the facial nerve (ie. this part after the stylomastoid foramen but before the pes anserinus) in cross section revealed the following, as in Figure 28.

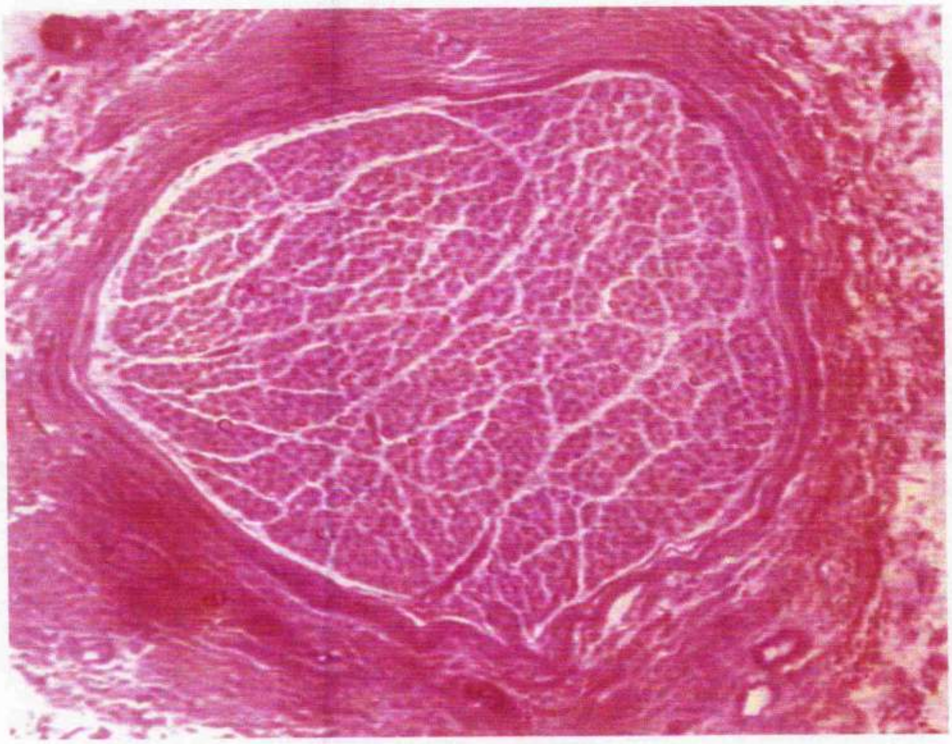


Figure 28: H&E low-power cross section of the facial nerve (main trunk).

This showed that at this point, the facial nerve was monofascicular. A thick epineurium, formed by concentric layers of dense collagenous connective tissue can be seen. This is different from larger peripheral nerves (eg. sciatic nerve) which may have many fascicles, all surrounded by an epineurium. This can be seen in Figure 29 below showing the sciatic nerve in cross section.

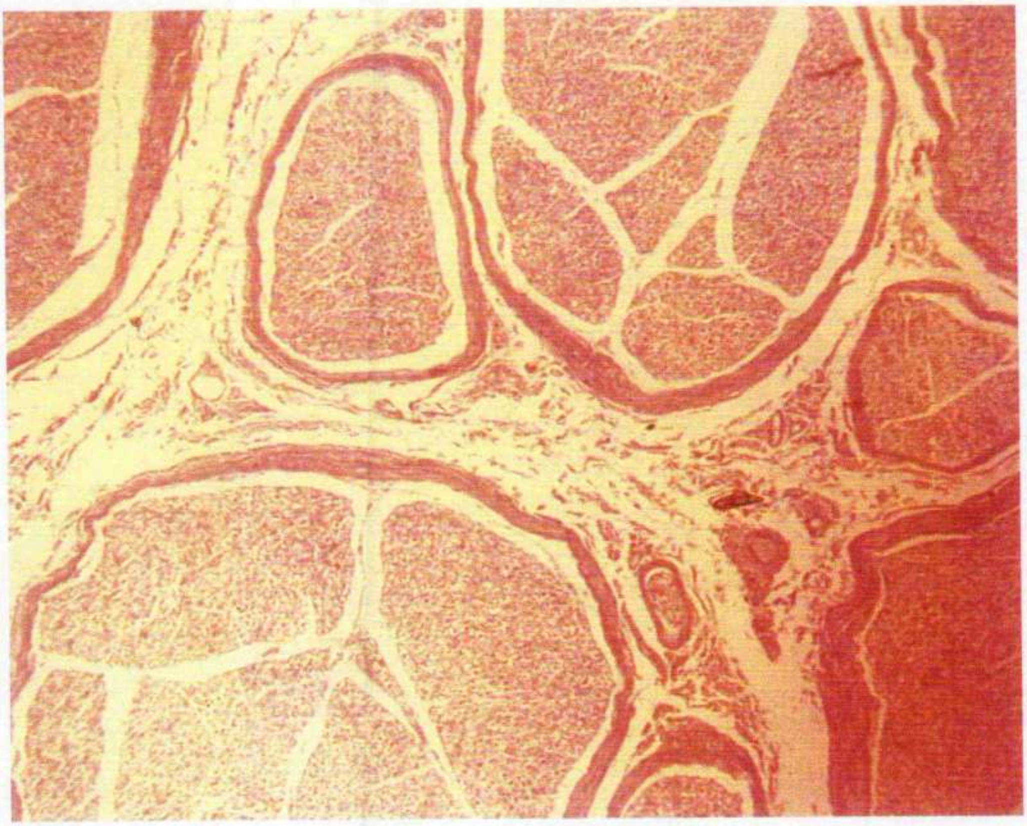


Figure 29: H&E low-power cross section of a peripheral nerve (sciatic nerve). Taken from the University of Glasgow, Anatomy Department collection.

The same region of facial nerve processed for scanning electron microscopy can be seen below in Figure 30.

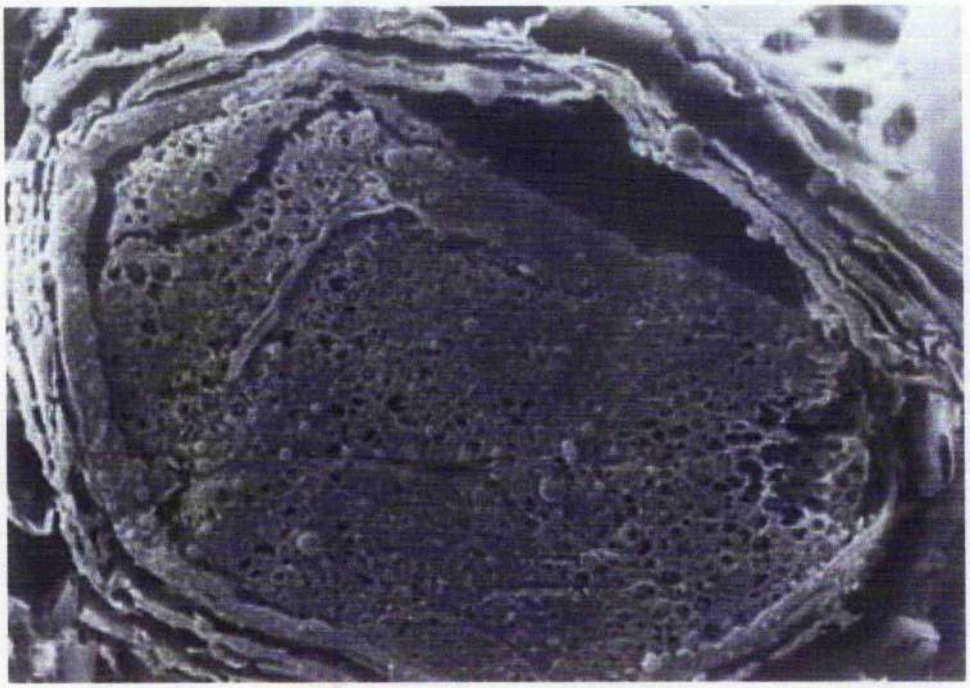


Figure 30: Scanning electron microscopy of the facial nerve in cross section. Note the monofascicular arrangement and the dense surrounding connective tissue (especially at the top right of the field). Scale:

|——————| *=0.1cm*

Again, this demonstrates the monofascicular arrangement, as was shown in Figure 28 previously with H & E staining. The dense connective tissue sheath can be seen arranged concentrically.

Higher power examination of the connective tissue sheath at the edge of the epineurium shows how dense it actually is and its close association with the facial nerve as seen in Figure 31.

Figure 31: Higher power SEM of the dense connective tissue in close association with the epineurium of the facial nerve (bottom left of the picture). Scale:

=0.1cm

The main trunk of the facial nerve then presents a curvilinear course with anterior concavity and courses inferior, anterior and laterally. It pierces the posterior surface of the parotid gland as shown in Figure 32. This field of view is from the Carl Zeiss operating microscope.

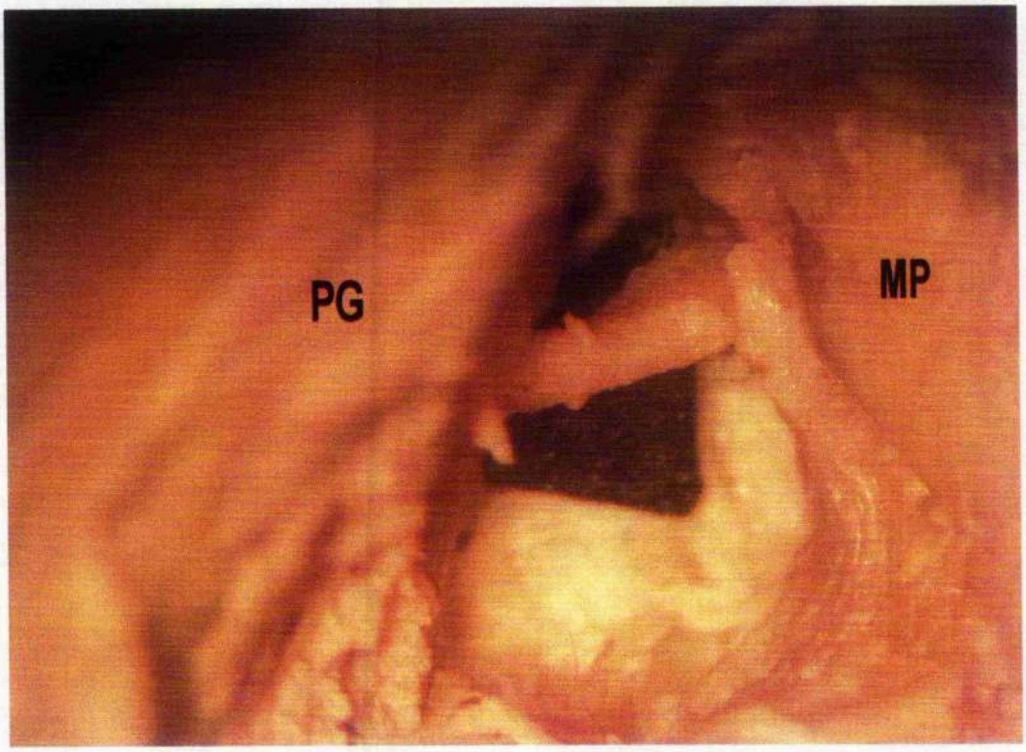


Figure 32: Facial nerve viewed under the operating microscope. The facial nerve is the oblique positioned white structure which is contrasted here by having a black piece of card behind it. MP=Mastoid Process, PG=Parotid Gland.

A small piece of black rectangular paper was placed behind it to highlight it.

Figure 33 shows the gross view of the facial nerve entering the posterior surface of the parotid gland. The posterior belly of digastric muscle can be seen passing from the mastoid tip (deep to sternocleidomastoid muscle) forward and downward under the parotid gland and the external jugular vein. The sternocleidomastoid muscle has been pulled in a posterior direction for ease of access.

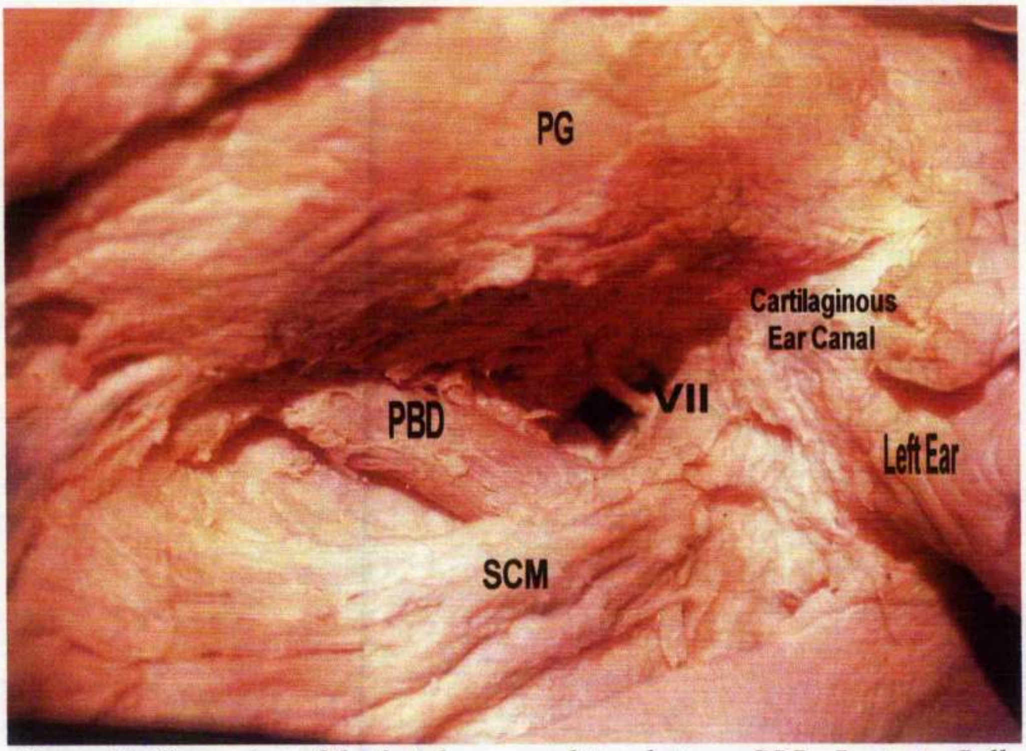


Figure 33: Gross view of the facial nerve and its relations. PBD=Posterior Belly of Digastric muscle, PG=Parotid Gland, SCM=Sternocleidomastoid muscle, VII=Facial Nerve.

The cartilaginous ear canal can be clearly seen to the right of the main trunk of the facial nerve.

The facial nerve actually passes through the substance of the parotid gland. The parotid gland is shown below stained with H&E demonstrating the gland microscopically.

Figure 34: H&E low power: Parotid gland showing a Striated Duct (SD).

The secretory cells are arranged as acini around the smallest branches of the duct system to form individual secretory units. Secretions then pass into the intercalated ducts which are a low cuboidal epithelium. From here the secretion will pass into larger striated ducts, seen above, which have tall cuboidal epithelium. From here the secretion passes into interlobular ducts, which join each other to eventually open into the oral cavity where the epithelium will change to a stratified squamous.

The facial nerve passes through the substance of the parotid gland on its way to the muscles of facial expression as shown in this H&E sample, figure 35.

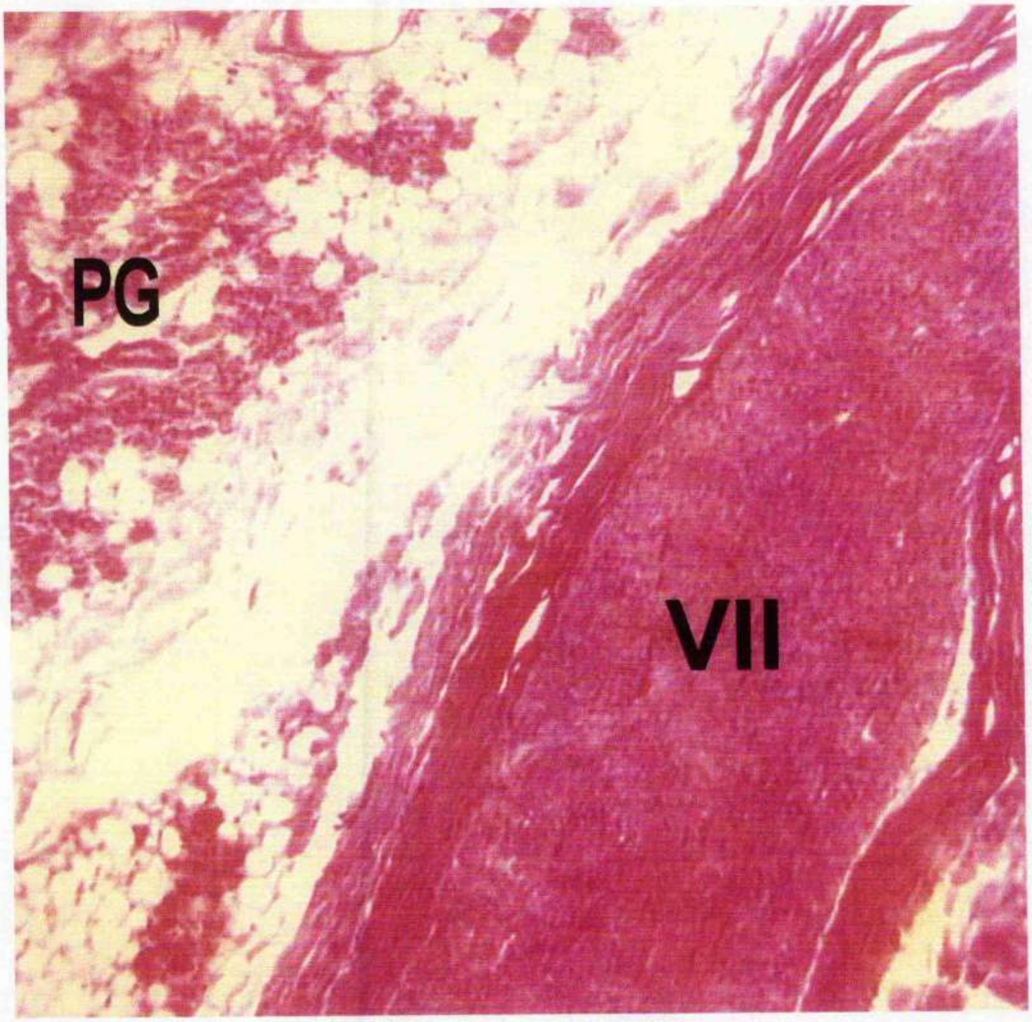


Figure 35: H&E low power: Facial nerve (main trunk) in the parotid gland (cross section). VII=Facial Nerve and PG=Parotid Gland.

The facial nerve can be seen here passing through the parotid gland. This section is the main trunk and is at the point where it has just entered the parotid gland but before reaching the bifurcation. No obvious plane of section was noted as the parotid gland surrounded the facial nerve.

The dense connective tissue surrounding the monofascicular facial nerve can be noted here again.

Tracing of the facial nerve by reflecting the parotid gland superficial to it reveals its two main divisions: the temporofacial and cervicofacial branches as shown in Figure 36.

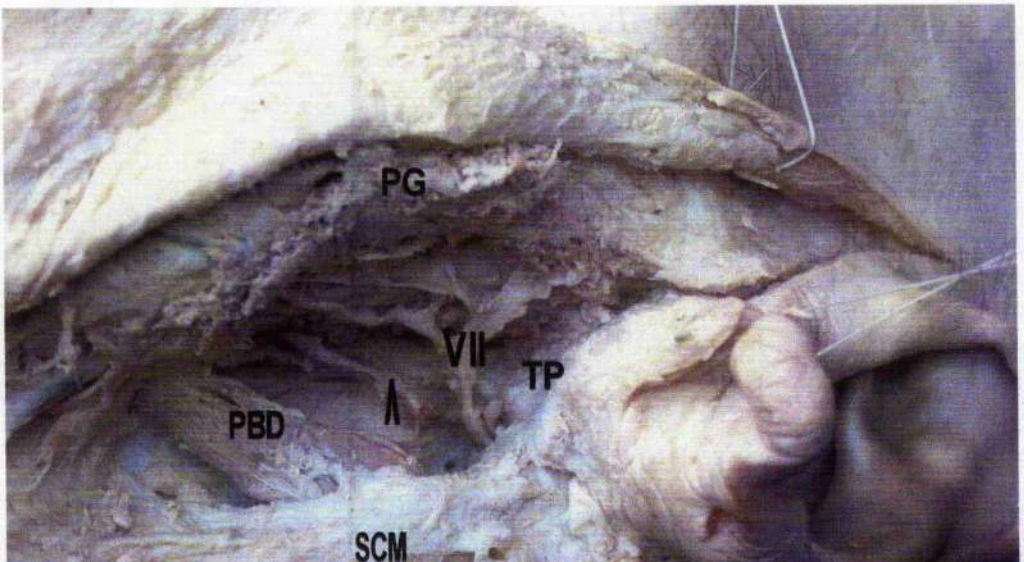


Figure 36: The facial nerve bifurcating. PG=Parotid Gland, PBD=Posterior Belly of Digastric, SCM=Sternocleidomastoid muscle, TP=Tragal Pointer and VII=Facial nerve. The arrow indicates the posterior auricular artery.

Figure 36 shows, after tracing the facial nerve into and through the parotid gland, the bifurcation has been identified.

Just deep to the main trunk of the facial nerve on Figure 36, the posterior auricular artery can be seen (although this was found on only one of the three dissections done for demonstration of the facial nerve course). This artery can be seen to approach the "tragal pointer".

The "tragal pointer" is a portion of the tragal cartilage which can be seen to roughly point in the direction of the facial nerve, is more superficially located than the nerve and is more prominent than the surrounding area, as seen in Figure 36.

Further dissection showed the facial nerve passing over the masseter muscle (Figure 37).

This muscle can be seen to attach to the zygomatic arch and its fibres pass downwards and backwards to the lateral surface of the ramus of the mandible adjacent to the angle.

The branching of the facial nerve can be seen as shown in Figure 37.

Figure 37: The divisions of the facial nerve. RMV=Retromandibular vein, STA=Superficial Temporal Artery, STV=Superficial Temporal Vein, TM=Temporalis muscle, VII=Facial Nerve crossing over masseter.

Removal of the parotid gland, both superficial and deep portions, with further anterior reflection of the skin, revealed blood vessels deep to the facial nerve.

As shown in Figure 37, the facial nerve passes over the retromandibular vein.

The retromandibular vein is formed from the union of the superficial temporal vein and the maxillary vein as seen below.

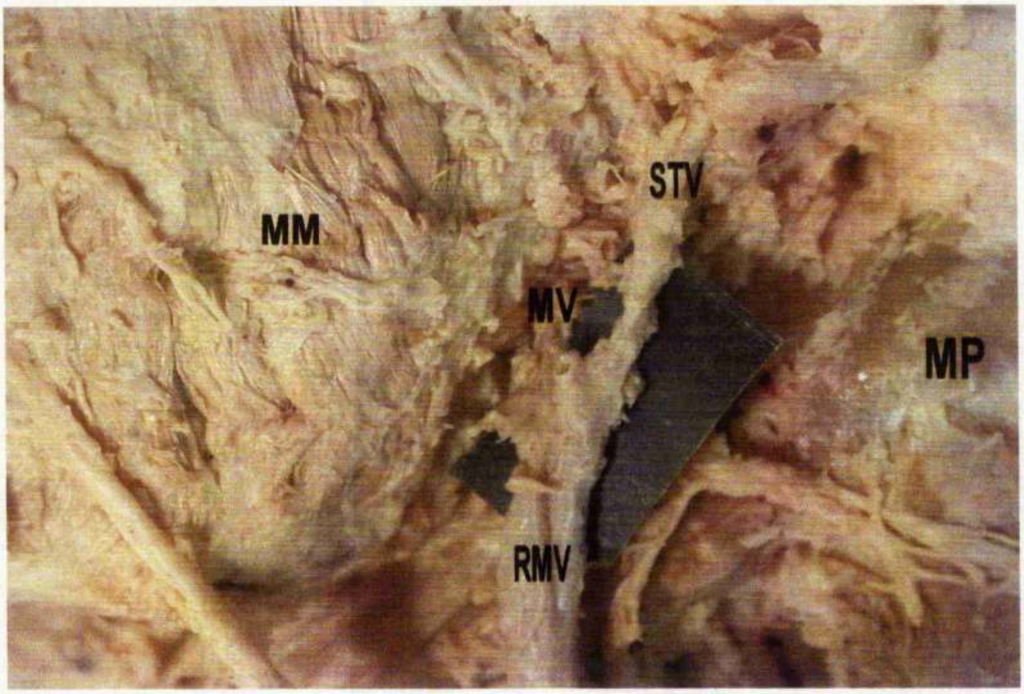


Figure 38: The retromandibular vein, left side: MM=Masseter muscle, MP=Mastoid Process, MV=Maxillary Vein, RMV=Retromandibular Vein, STV=Superficial Temporal Vein.

The superficial temporal vein is draining a wide area of the scalp and passes from the surface of the vertical fibres of the temporalis muscle, crossing over the zygomatic arch, to pass deep to the facial nerve joining up with the maxillary vein.

The maxillary vein can be seen to arise from deeper structures, passing more superficial to join the superficial temporal vein at half way along the length of the angle of the mandible. These features can be seen in Figure 38.

The retromandibular vein then passes downward and backward, crossing the sternocleidomastoid muscle obliquely to become the external jugular vein. No tributaries were noted to join at this level on two of the three specimens dissected for the course of the facial nerve. On figure 38, it shows how one specimen had the facial vein crossing the left of the field to run into the retromandibular vein.

At a deeper level, the external carotid artery could be identified. This lay deeper and slightly posterior to the retromandibular vein as seen in the following picture, Figure 39.

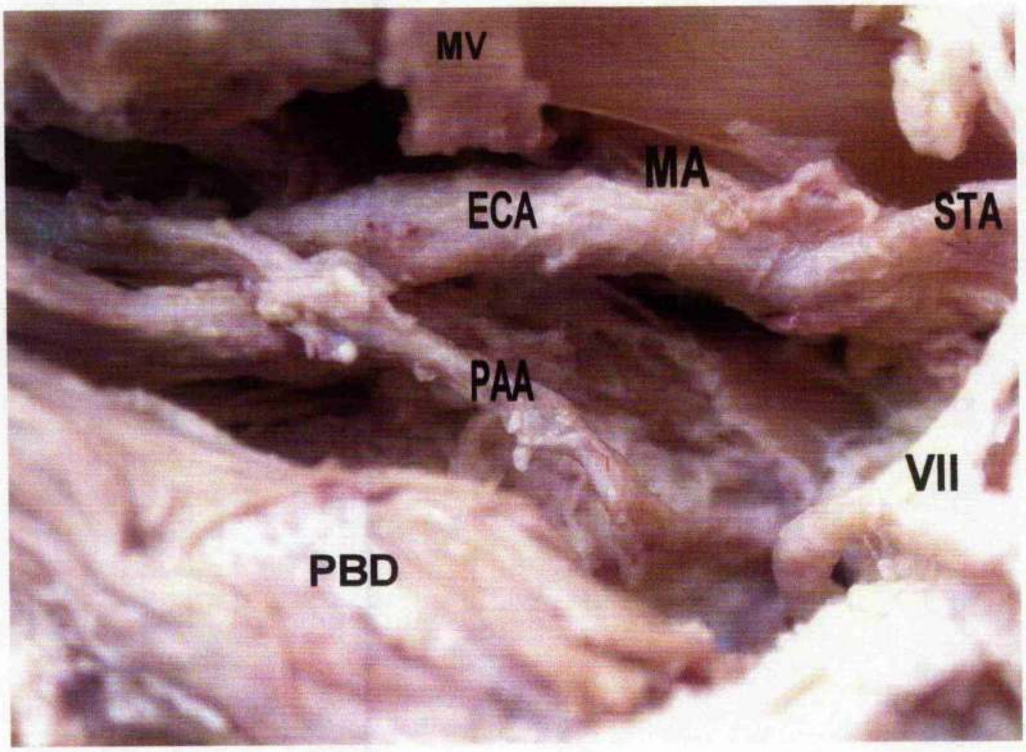


Figure 39: The external carotid artery. Viewed from under the left mandible. The bone at the top is the ramus of the mandible, left side. ECA=External Carotid Artery, MA=Maxillary Artery, MV=Maxillary Vein, PAA=Posterior Auricular Artery, PBD=Posterior Belly of Digastric muscle, STA=Superficial Temporal Artery, VII=Facial Nerve.

The terminal branches of this artery are the superficial temporal artery and the maxillary artery which follow a similar course to the respective veins.

Further down, the external carotid artery runs a very interesting and complex course as seen in Figure 40.

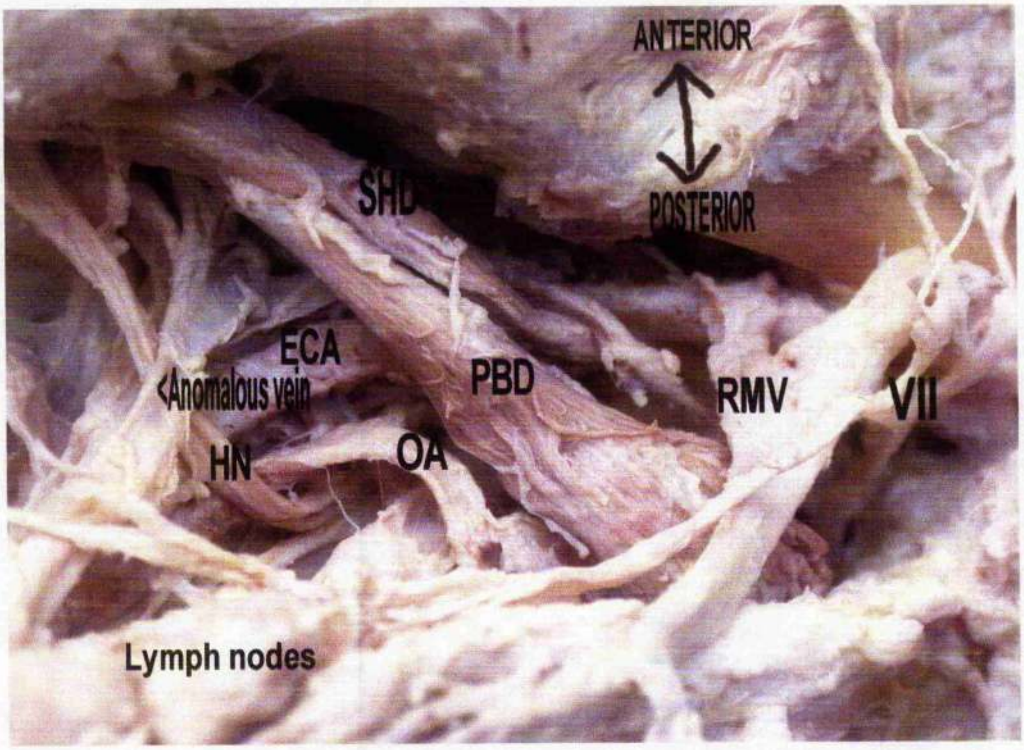


Figure 40: Complex relations of the relations of the facial nerve, below the left mandible: ECA=External Carotid Artery, HN=Hypoglossal Nerve, OA=Occipital Artery, PBD=Posterior Belly of Digastric, RMV=Retromandibular Vein, SHD=Stylohyoid muscle, VII=Facial Nerve.

The external carotid artery is partly overlapped by the sternocleidomastoid muscle, and crossed by the hypoglossal nerve and an anomalous vein. It is at this point that the occipital artery can be seen arising from the posterior aspect of the external carotid artery. From here it can be seen passing on the under surface of the posterior belly of digastric muscle. It then passes just inferior to the posterior belly of digastric muscle then passes medial to it.

On the one cadaver dissected for the blood supply of the facial nerve, the stylomastoid artery was noted to arise from the occipital artery as shown in the following picture.

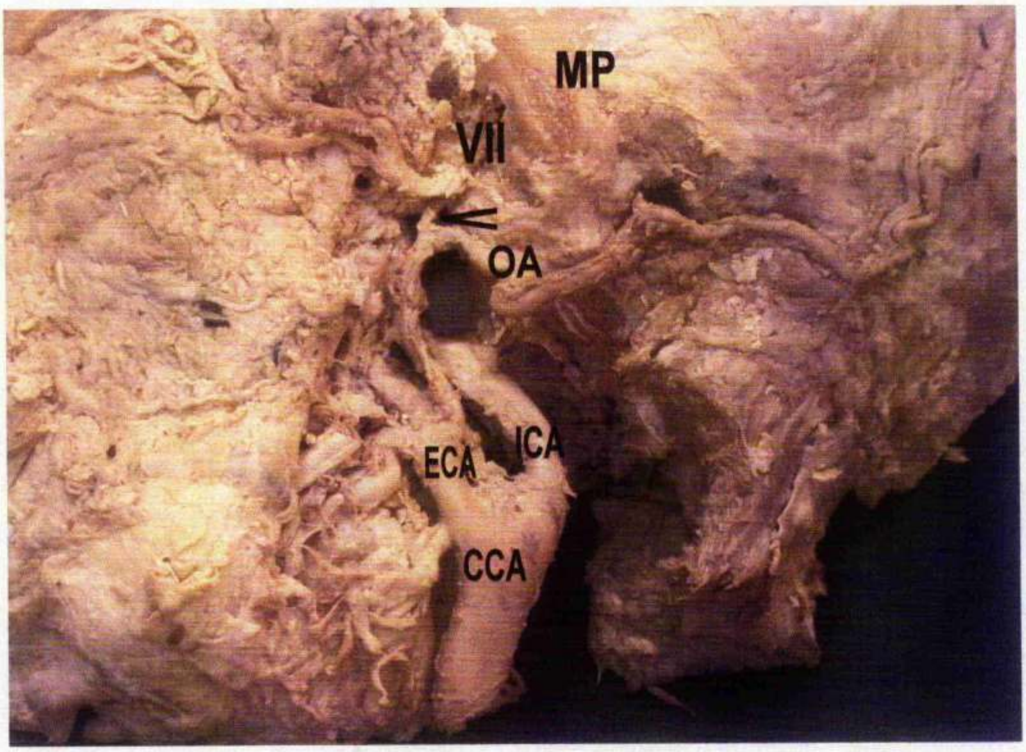


Figure 41: The stylomastoid artery passing medial to the main trunk of the facial nerve (arrow pointing to it). CCA=Common Carotid Artery, ECA=External Carotid Artery, ICA=Internal Carotid Artery, MP=Mastoid Process, OA=Occipital Artery, VII=Facial Nerve.

After giving off the stylomastoid artery, the occipital artery then passes over rectus capitis lateralis, passing onto the occipital groove on the temporal bone as shown.

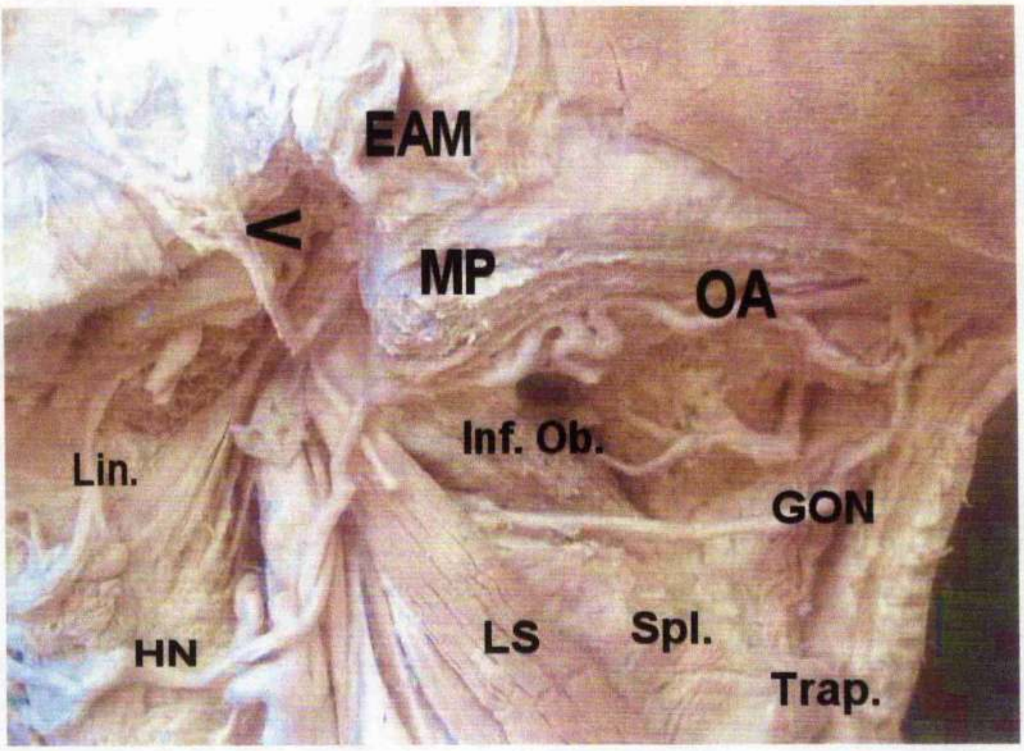


Figure 42: The course of the occipital artery. EAM=External Auditory Meatus, GON=Greater Occipital Nerve, HN=Hypoglossal Nerve, Inf. Ob.=Inferior Oblique, Lin=Lingual Nerve, LS=Levator Scapulae, MP=Mastoid Process, OA=Occipital Artery, Spl.=Splenius and Trap.=Trapezius. The arrow indicates the position of the reflected facial nerve.

It then passes medial to the attachments of sternocleidomastoid muscle, splenius capitis, longissimus capitis and digastric. It turns upwards to the occiput and can be seen in close relation to the greater occipital nerve as seen in Figure 43.

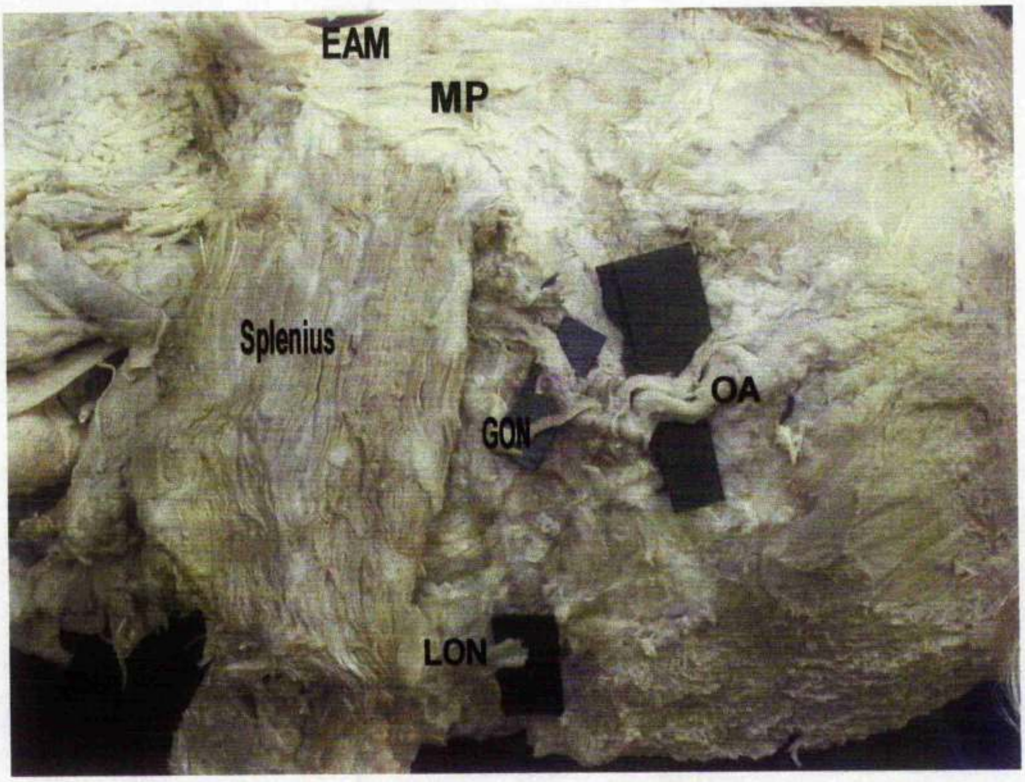


Figure 43: The course of the Occipital Artery (OA) and its relations to the greater occipital nerve (GON). LON=Lesser Occipital Nerve, MP=Mastoid Process and Splenius=Splenius Capitis muscle.

Looking at Figure 44 below (as seen in Figure 36), the posterior auricular artery can also be seen and its direct association with the facial nerve. It runs upwards, backwards, superficial to the styloid process and under cover of the parotid gland. It ends between the mastoid process and auricle, closely related to the main trunk of the facial nerve as seen here. Note that this arrangement was only seen on one of the three specimens dissected for the normal anatomy.

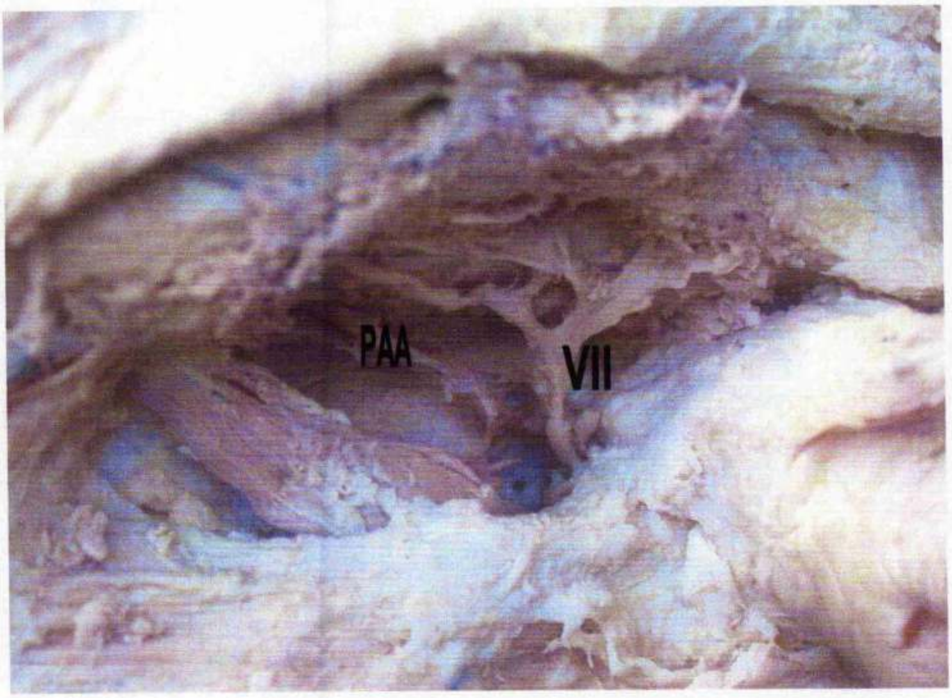


Figure 44: The posterior auricular artery (PAA) in relation to the facial nerve (VII).

The three following pictures (from Figure 45-47) show the course of the facial nerve and the muscles of facial expression.

Figure 45: The muscles of facial expression, parotid intact, left side.

1=Temporalis muscle, 2=Frontalis muscle, 3=Orbicularis oculi, 4=Levator labii superioris alaeque nasi, 5=Levator labii superioris, 6=Levator anguli oris, 7=Zygomaticus major, 8=Parotid duct, 9=Facial artery, 10=Buccinator, 11=Orbicularis oris, 12=Depressor labii inferioris, 13=Depressor anguli oris, 14=Masseter, 15=Platysma and 16=Superficial temporal artery.

Figure 45 shows the intact parotid gland with the peripheral branches of the facial nerve appearing at the anterior end to go on to supply the muscles of facial expression. Many branches exist as the facial nerve goes further from the parotid gland and this has been highlighted by having black card behind each of these branches.

Note at the upper end of the parotid gland, the superficial temporal artery emerges in close relation to some of the branches of the facial nerve and goes on to supply the lateral aspect of the scalp, as it passes superficial to the temporalis muscle.

The parotid duct can be seen to arise from the anterior aspect of the parotid gland, run over the masseter muscle and pass deep, at roughly the level of the zygomaticus major, to gain entry into the oral cavity.

One of the branches of the facial nerve, the marginal mandibular, can be seen to hook under the mandible to then pass back up. This is the lowermost branch which can be seen in close association to the platysma muscle.

The facial artery has also been highlighted and can be seen to pursue a tortuous course over the face and passes beside the marginal mandibular branch of the facial nerve at the level of the mandible.

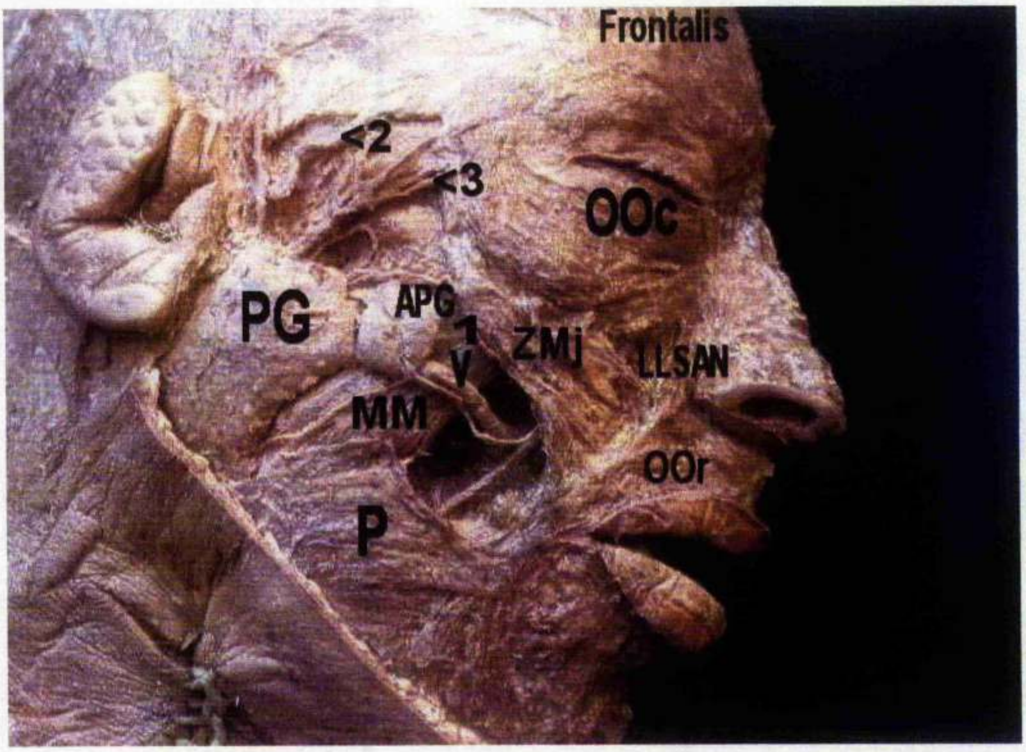


Figure 46: Muscles of facial expression, right side, from the Anatomy Museum at the University of Glasgow. APG=Accessory Parotid Gland, LLSAN=Levator Labii Superioris Alaeque nasi, OOc=Orbicularis oculi, P=Platysma, PG=Parotid Gland, ZMj=Zygomaticus Major. 1=Parotid Duct, 2=Superficial Temporal Artery and 3=Temporal branch of facial nerve.

Figure 46 is taken from the museum at the Anatomy Department of the University of Glasgow.

Again, it demonstrates the complexity of the facial nerve and the muscles of facial expression. The parotid gland has been left intact in this specimen.

An interesting feature to note is the presence of an accessory parotid gland. In this specimen this feature can be seen just anterior to the main parotid gland, and overlies the masseter muscle. It can also be seen to lie on the parotid duct, which is again piercing buccinator at a deeper level to gain entry into the oral cavity.

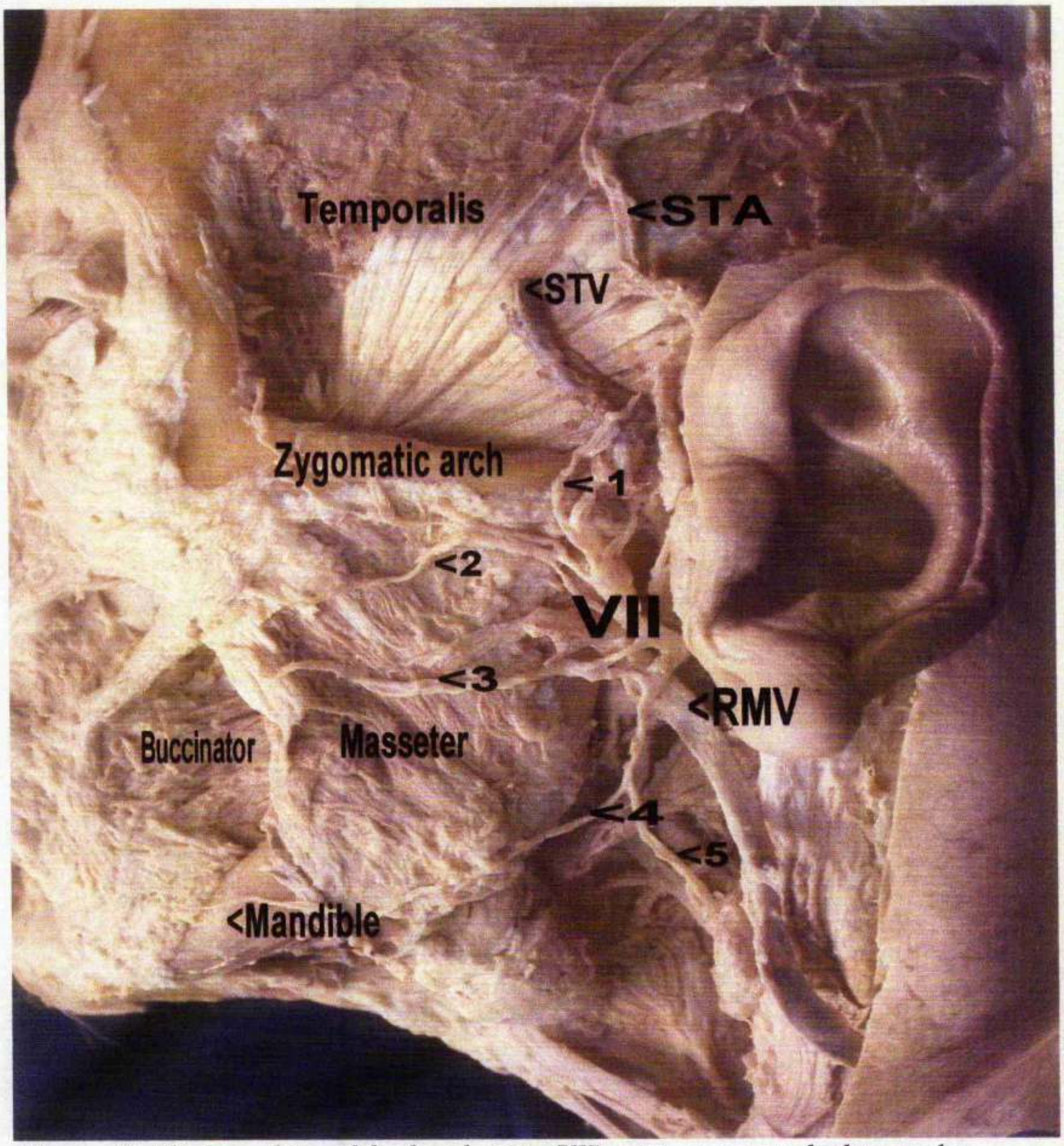


Figure 47: The branching of the facial nerve (VII) going on to supply the muscles of facial expression. RMV=Retromandibular vein, STA=Superficial Temporal Artery, STV=Superficial Temporal Vein. 1=Temporal branch (reflected back), 2=Zygomatic branch, 3=Buccal branch, 4=Marginal mandibular branch and 5=Cervical branch of the facial nerve.

Figure 47 shows the branching pattern of the facial nerve, and in this dissection, the parotid gland has been removed.

The temporal branch (which in this picture has been cut and reflected back) passed towards the lateral aspect of the orbit to supply the orbicularis oculi.

The zygomatic branch in Figure 47 has two branches. They are pursuing a more horizontal course, parallel to the zygomatic arch and are coursing towards the zygomaticus major muscle by passing over the surface of the masseter muscle.

The buccal branch arises from the temporofacial branch (the upper division), and courses horizontally over the masseter muscle at the level of the lowermost part of the pinna. Some of its branches seem to be passing towards the zygomatic branches to pass towards the zygomaticus major muscle and also to pass deep into the site of the buccal fat pad to supply the buccinator.

The marginal mandibular branch is arising from the cervicofacial division and passes just to the angle of the mandible and runs over the lowermost aspect of the body of the mandible, over the masseter muscle and appears to be going on to supply the depressor anguli oris. Note the facial artery has been removed but would be in close association with the facial nerve at this point.

The cervical branch, also arising from the cervicofacial division, has been reflected down and cut. It would go on to supply the platysma muscle, which has been removed to fully demonstrate the course of the marginal mandibular branch of the facial nerve.

All the facial nerve can be seen to pass over the retromandibular vein, which has been formed from the superficial temporal and maxillary veins.

3.3 PAROTIDECTOMY ON THE CADAVER

After the incision was made by a modified Blair incision as shown below, the skin flaps were elevated as detailed previously.

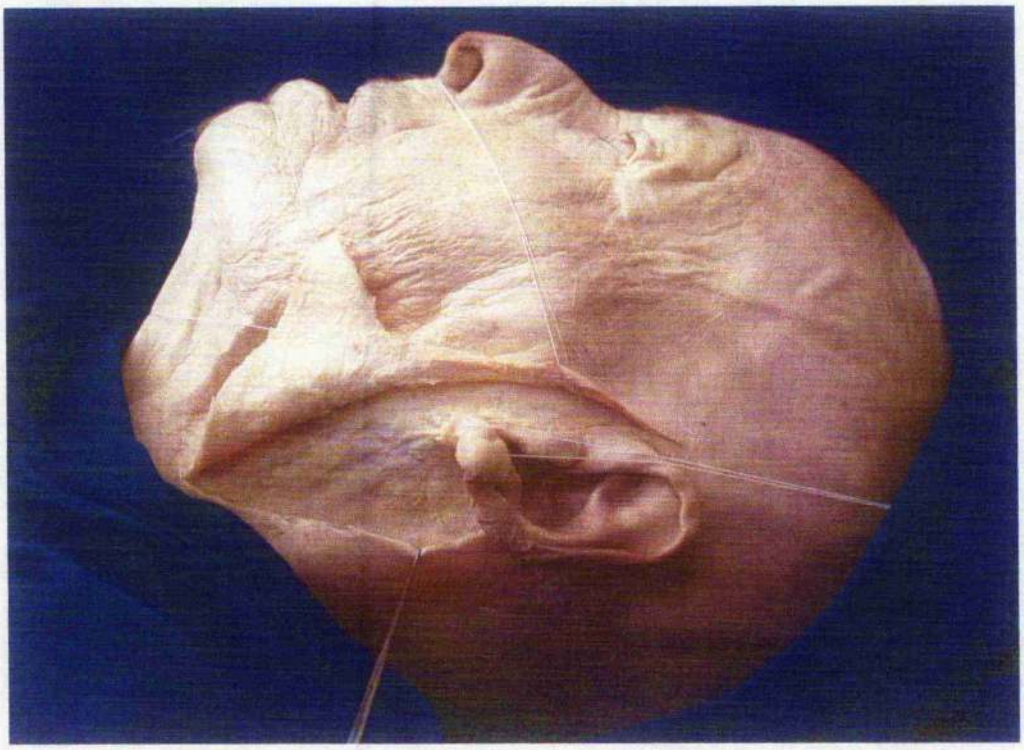


Figure 48: Raising of the skin flap for parotidectomy. A pre-auricular incision extending over the mastoid and down into the skin crease of the neck below the mandible.

The great auricular nerve and external jugular vein were identified lying obliquely over the sternocleidomastoid muscle as shown in Figure 49 below.

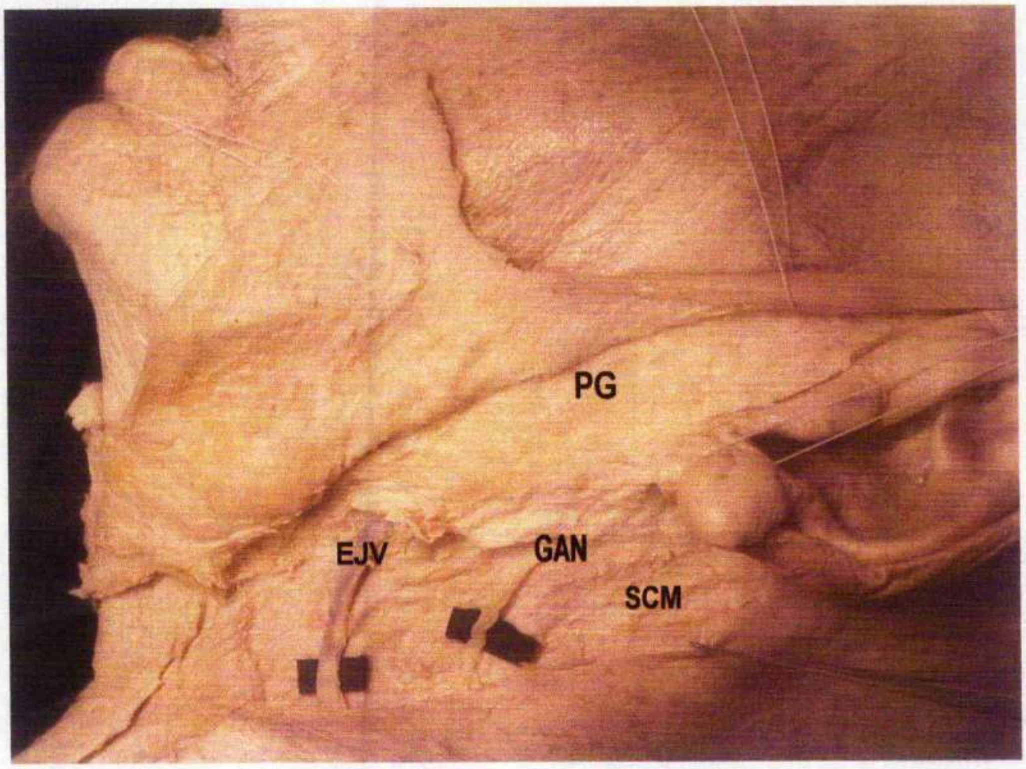


Figure 49: Skin flap raised and superficial structures identified namely: EJV=External Jugular Vein, GAN=Great Auricular Nerve, PG=Parotid Gland, SCM=Sternocleidomastoid muscle.

The great auricular nerve was traced towards the parotid gland and its three main branches were noted, namely the anterior, posterior superficial and posterior deep as shown below in Figure 50. These branches of the great auricular nerve and the presence of the external jugular vein occurred in all three of the specimens dissected for the course of the facial nerve.

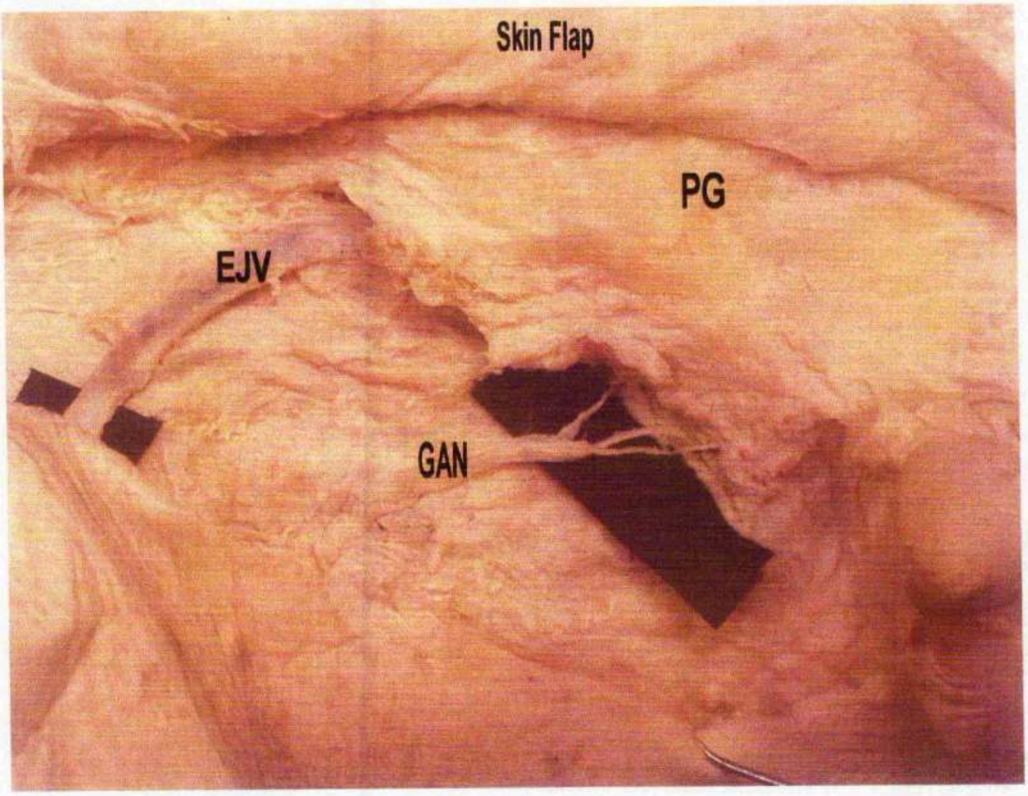


Figure 50: The three branches of the great auricular nerve dissected: anterior, posterior superficial and posterior deep branches. EJV=External Jugular Vein, GAN=Great Auricular Nerve, PG=Parotid Gland.

The facial nerve left the stylomastoid foramen. This was identified as described earlier (starting at page 79), and the facial nerve can be seen entering the posterior surface of the parotid gland as viewed through the operating microscope as shown in Figure 51.

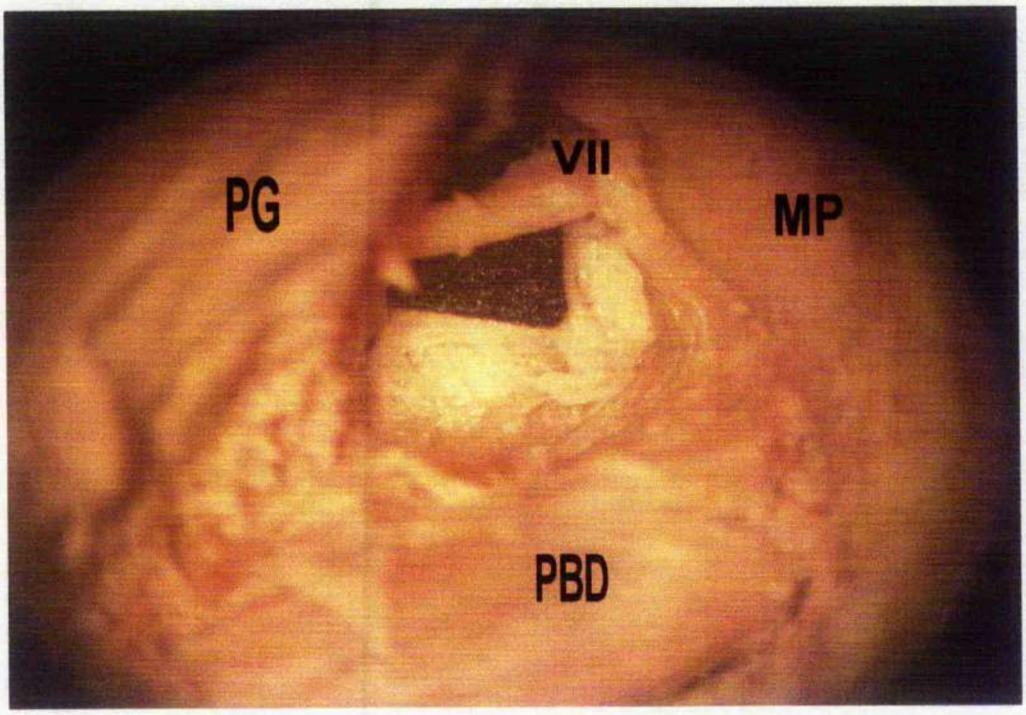


Figure 51: The identification of the main trunk of the facial nerve as viewed in the operating microscope. MP=Mastoid Process, PBD=Posterior Belly of Digastric, PG=Parotid Gland, VII=Facial Nerve.

It always pierced the posterior surface of the parotid gland and overlay the retromandibular vein, with the external carotid artery deep to this as shown earlier.

The facial nerve had an extensive branching pattern which was subject to slight variation with each of the specimens dissected for the course of the facial nerve. The facial nerve always went on to supply the muscles of facial expression.

3.4 THE SURGICAL APPROACH TO THE PAROTID GLAND

One of the pre-operative investigations, which can be used to identify parotid pathology, is a Magnetic Resonance Image (MRI).

Figure 54 shows an MRI scan of a parotid tumour.

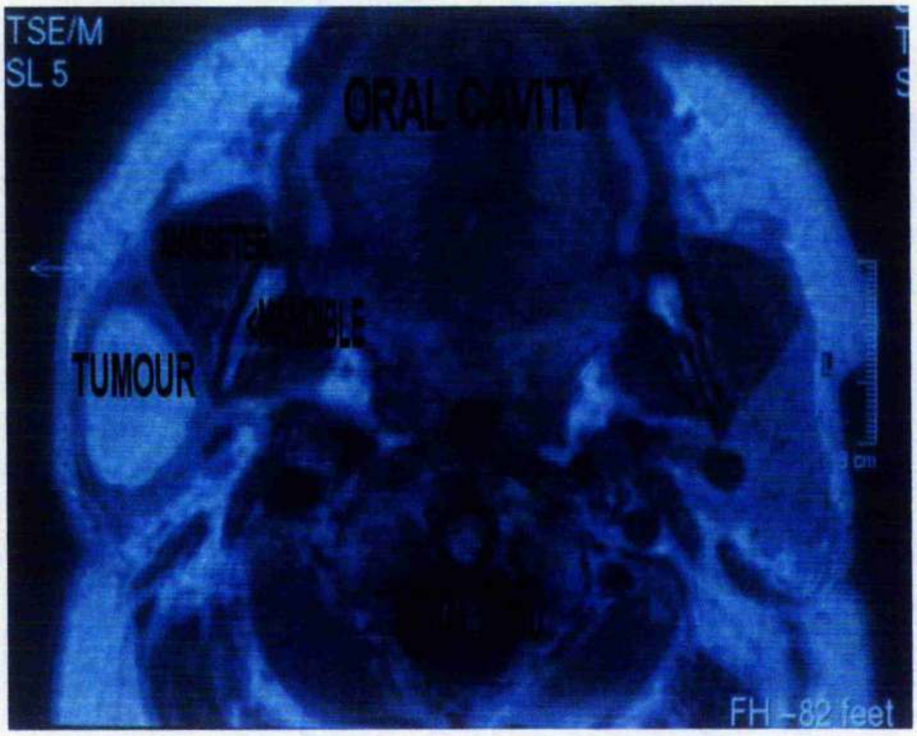


Figure 52: Parotid tumour MRI. This shows tumour in the right parotid gland, courtesy of Mr. G. McGarry, Glasgow Royal Infirmary.

The MRI scan is viewed as though viewing the patient from underneath upwards. Therefore, the left hand side of the picture is the right hand side of the patient and vice versa. From this it can be that the white discrete mass labelled above as TUMOUR is on the right hand side of the patient (though not the patients MRI scan who was observed having the parotidectomy).

The tumour is well defined, with no visible infiltrating components ie. a discrete lesion. It is just posterior and lateral to the mandible. Just medial to the mandible (right on the picture), the oral cavity can be seen.

Directly posterior to this, (or at the bottom of Figure 52), the spinal cord within the vertebral column can be seen.

After confirmation of the type of pathology by FNA sampling, MRI investigation and other pre-operative investigations as necessary, the patient is ready for parotidectomy.

After being anaesthetised, the position of the tumour is reconfirmed and a pen mark is inked onto the side of the face for the line of initial incision. Electrodes are then placed onto the medial aspect of the patient's face ie. just lateral to the nose and mouth. Surgical drapes are then placed over and Betadine is then washed over the face for sterility (hence the orange tinge). This can be seen in Figure 53.

Figure 53: The parotidectomy incision and the electrodes in place (male patient: not the patient observed having the parotidectomy done). Picture courtesy of Mr. McGarry, Glasgow Royal Infirmary.

Note from Figure 53 that there is also an inked line where the angle of the mandible is on this patient so that the surgeon avoids the marginal mandibular branch of the facial nerve.

One of the next steps is the identification of the great auricular nerve, although not formally done in the parotidectomy I observed. If done, it would have the following appearance as seen in Figure 54.

It can be seen to be a white structure which passes perpendicular to the sternocleidomastoid muscle roughly halfway along its length.

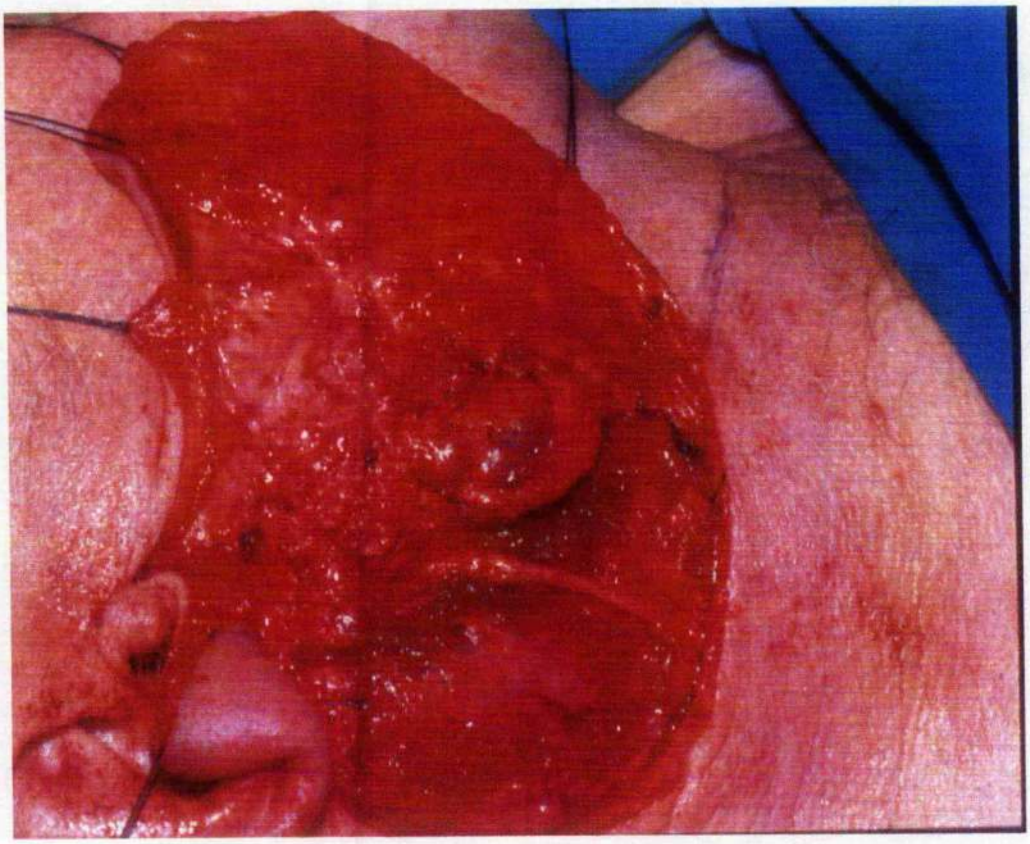


Figure 54: The identification of the great auricular nerve at parotidectomy.

Picture courtesy of Mr. McGarry, Glasgow Royal Infirmary.

Next, the posterior auricular vein was identified as in Figure 55. It descends from behind the earlobe passing obliquely over the sternocleidomastoid from posterior to anterior, to unify with the retromandibular vein to form the external jugular vein.

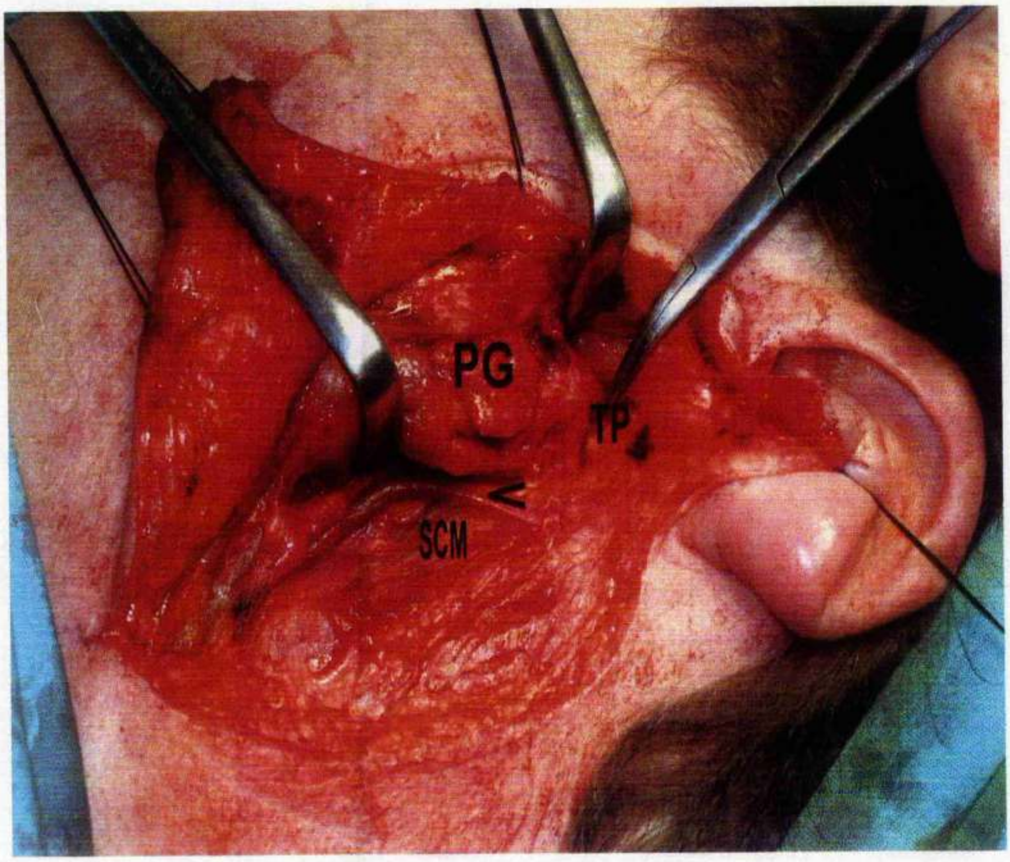


Figure 55: The identification of the posterior auricular vein. The posterior surface of the parotid gland is also retracted from the anterior border of the sternocleidomastoid muscle. PG=Parotid Gland, SCM=Sternocleidomastoid muscle and TP="Tragal pointer".

The ear is held retracted in a superior direction to allow a clearer field to operate in. The posterior surface of the parotid gland was then freed from the anterior border of the sternocleidomastoid muscle. This can be seen in Figure 56 below. Note the closed scissors pointing at the "tragal pointer" at the top of the operating site. The other landmarks which can be used are not visible at this point.

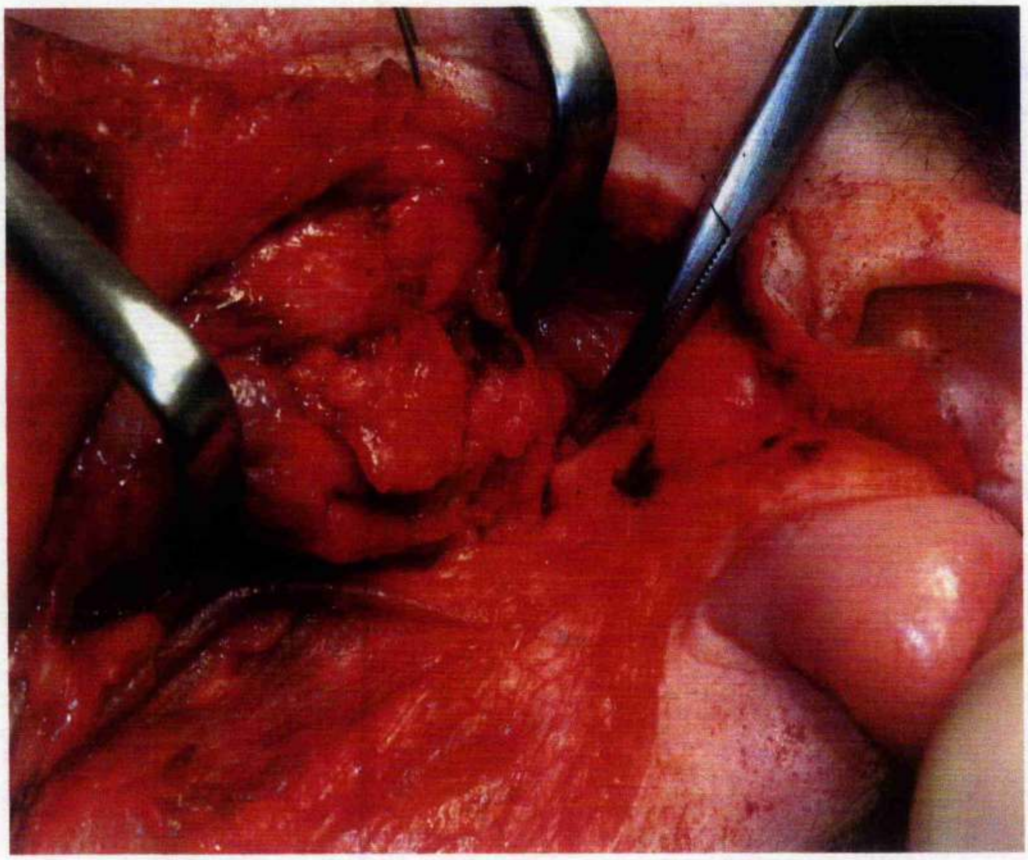


Figure 56: The identification of the "tragal pointer" (where the closed scissors are, top right) and gentle traction of the parotid gland from the sternocleidomastoid muscle.

Clear identification was made of the site of the tumour, and in this case it was located in the superficial portion of the tail of the parotid gland.

The identification of the main trunk of the facial nerve was the most crucial stage of the operation. Mr. McGarry used the tympanic plate, the "tragal pointer" and the posterior belly of digastric muscle to find the main trunk of the facial nerve, assisted with electrical stimulation of any structure which may resemble the facial nerve.

The facial nerve had a pearly white appearance as shown in Figure 57, and once found, great relief was felt in the operating theatre.

The posterior auricular vein was reflected in a posterior direction. This allowed a clearer operating field. The next crucial step was tracing the facial nerve through the parotid gland and safe removal of the tumour as seen in Figure 57.

The facial nerve was traced through the parotid gland by using fine artery forceps, initially closed, and then opening them above the facial nerve to tease away the parotid gland from the nerve.

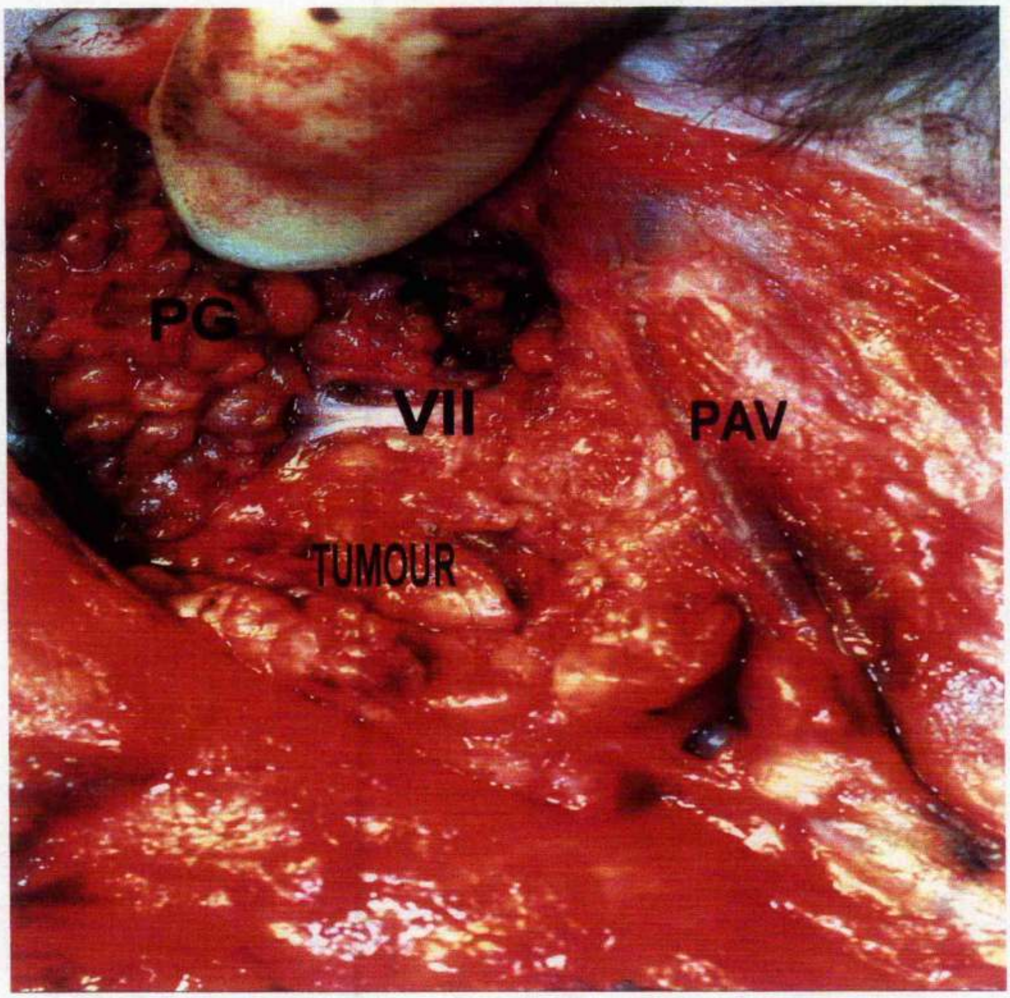


Figure 57: The identification and tracing of the facial nerve through the parotid gland and tumour. PAV=Posterior Auricular Vein, PG=Parotid Gland, VII=Facial Nerve.

The tumour was able to be lifted away from the parotid gland with ease as it was located above the level of the facial nerve but care had to be taken of each fine underlying branch just deep to the tumour. A small margin of normal parotid gland was lifted away with the tumour.

3.5 ASSESSMENT OF LANDMARKS

In the cadaver, the shortest distance was measured from the main trunk of the facial nerve to the following landmarks:

- TYMPANOMASTOID SUTURE
- POSTERIOR BELLY OF DIGASTRIC MUSCLE
- TRAGAL POINTER
- EXTERNAL AUDITORY MEATUS (the most inferior point where the cartilaginous part of the canal met the bony canal).

These relations can be seen in the following diagrams.

Figure 58: The tympanomastoid suture on the skull between the mastoid process and the tympanic plate.

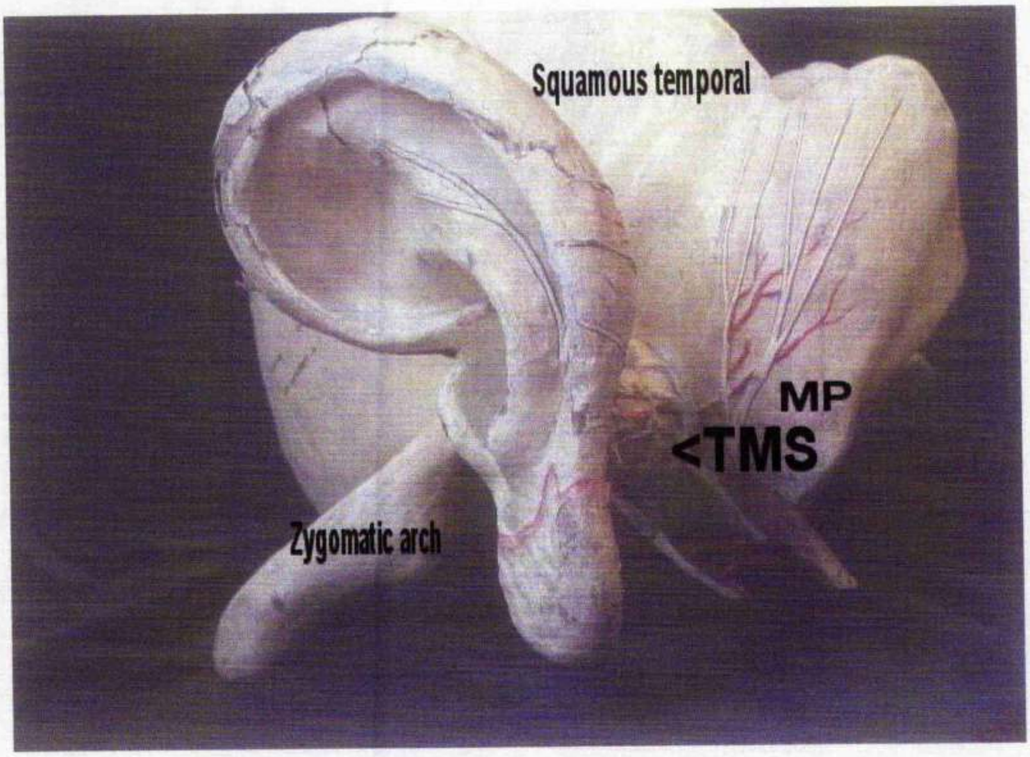


Figure 59: Model showing the position of the tympanomastoid suture. MP=Mastoid Process, TMS=Tympanomastoid suture. Model from the Anatomy Department, University of Glasgow.

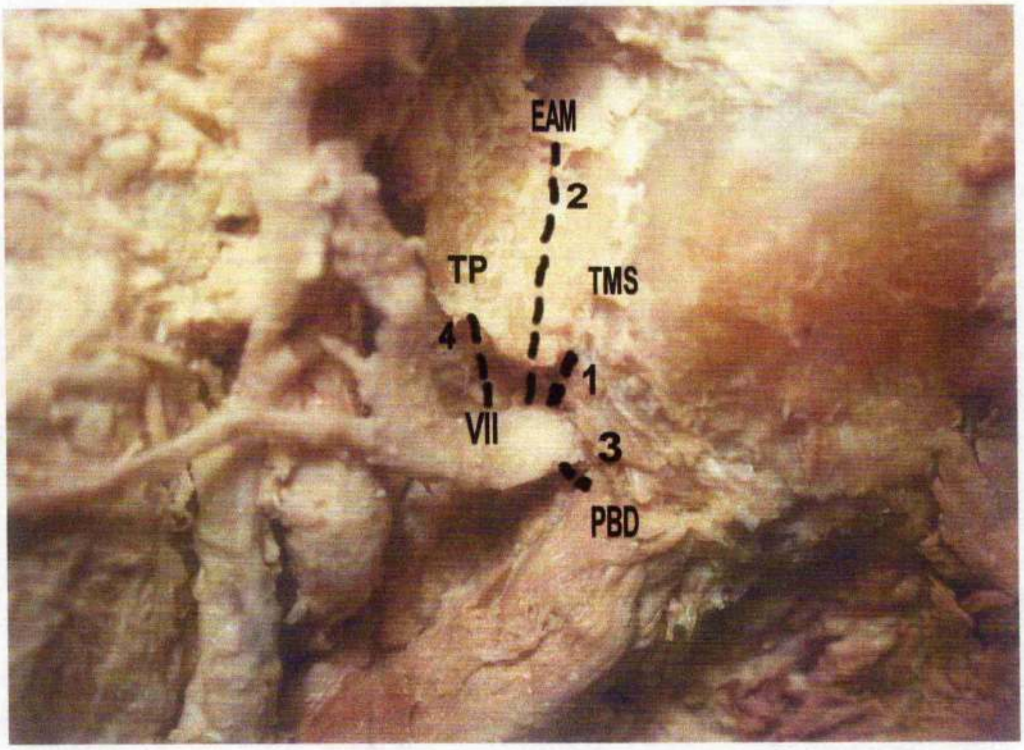


Figure 60: A representation of the landmarks used. The shortest distance from the facial nerve (VII) was measured to each of the landmarks, namely 1=to the Tympanomastoid suture (TMS), 2=to the External Auditory Meatus (EAM) (at the junction between the cartilaginous and bony ear canal), 3=to the Posterior Belly of Digastric muscle (PBD) and 4= to the "Tragal Pointer" (TP). See also page 92-95, Figure 6 for diagrammatic representations of these landmarks.

The individual measurements for each landmark on each specimen can be seen in Appendix 7.

3.5.1 OVERALL RESULTS

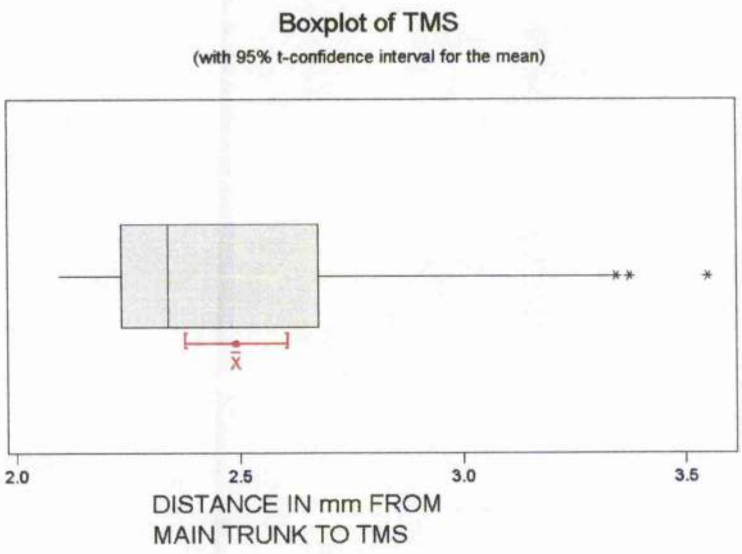
All results can be found in APPENDIX 7. The mean distance from the tympanomastoid suture (TMS) to the main trunk of the facial nerve was 2.49mm. The mean distance from the external auditory meatus (EAM) to the main trunk of the facial nerve was 10.9mm. The mean distance from the posterior belly of digastric muscle (PBD) to the main trunk of the facial nerve was 5.5mm. The mean distance from the "tragal pointer" (TP) to the main trunk of the facial nerve was 6.9mm. All these results are summarised in table 2 below, also showing the standard deviations.

LANDMARK	MEAN DISTANCE (mm) FROM THE FACIAL NERVE (+/- 2SD)
TYMPANOMASTOID SUTURE	**2.49 (+/- 0.78)**
EXTERNAL AUDITORY MEATUS	**10.9 (+/-3.4)**
POSTERIOR BELLY OF DIGASTRIC MUSCLE	**5.5 (+/- 4.2)**
"TRAGAL POINTER"	**6.9 (+/- 3.6)**

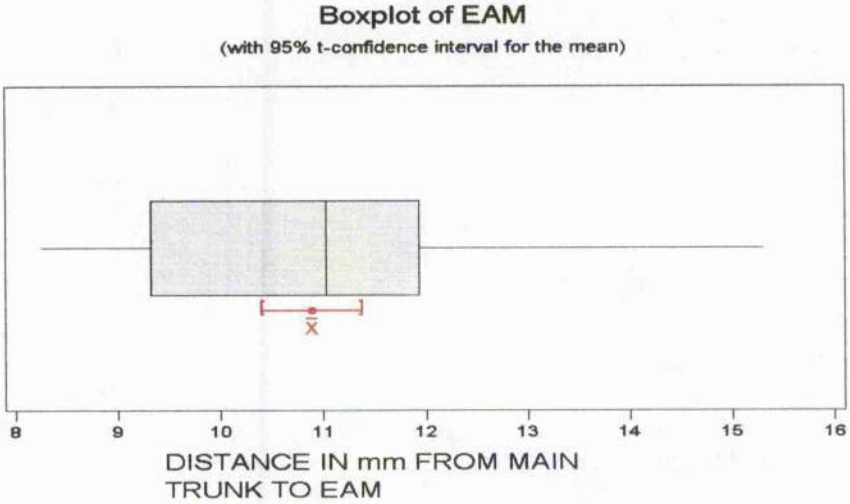
Table 2: Overall landmark measurements from the main trunk of the facial nerve to each of the landmarks showing mean and standard deviation.

These results have been highlighted by using boxplots of each landmark.

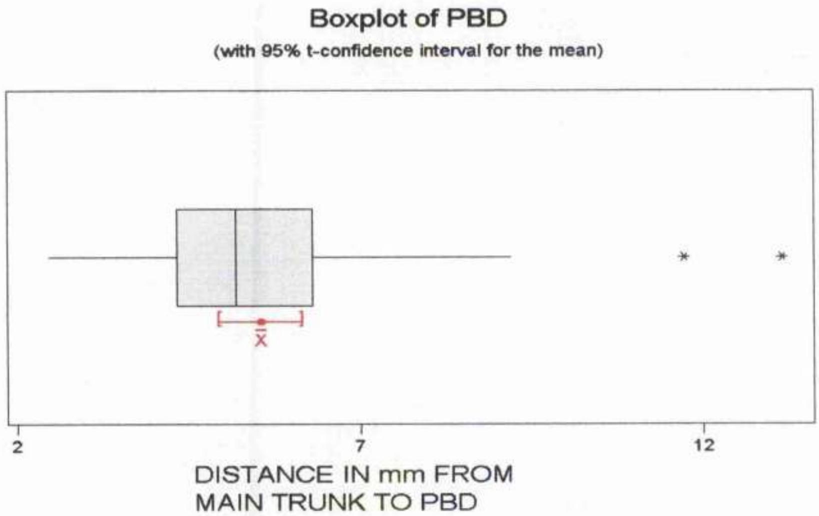
The results are as follows for each of the four landmarks (no sex difference or left/ right side comparisons made at this stage, just all the mean results used for the following four boxplots) with the 95% confidence interval shown in red at the base of the boxplot.



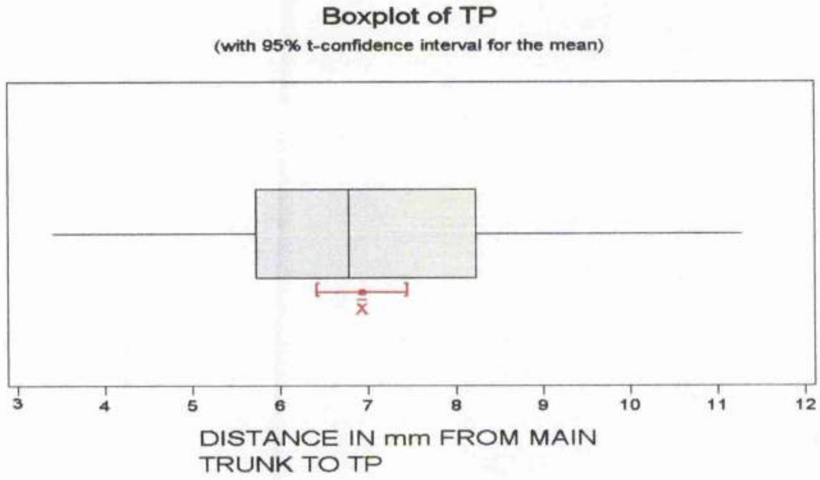
Graph 1: Boxplot of all the mean results from the facial nerve to the tympanomastoid suture (TMS).



Graph 2: Boxplot of all the mean results from the facial nerve to the external auditory meatus (EAM).

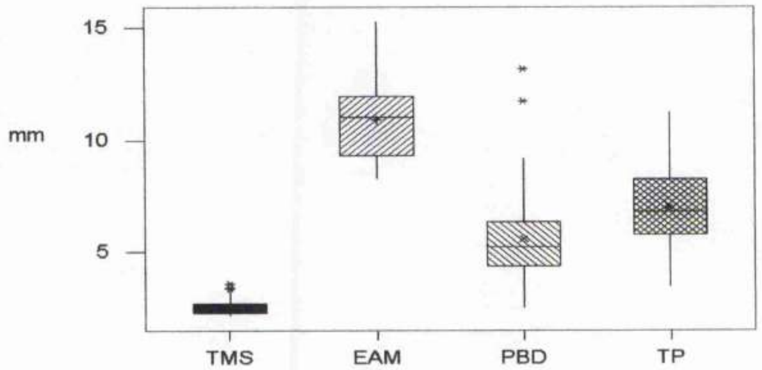


Graph 3: Boxplot of all the mean results from the facial nerve to the posterior belly of digastric (PBD).



Graph 4: Boxplot of all the mean results from the facial nerve to the "tragal pointer" (TP).

These results have all been placed onto the one graph as shown below.



*Graph 5: Boxplot incorporating all the mean results for each of the four landmarks from the facial nerve (Outliers also shown as * and the dark dot in the middle of the box is the mean).*

3.5.2 LEFT/RIGHT COMPARISONS

An examination of the mean results was undertaken with respect to seeing if any differences existed between left/right side of individuals.

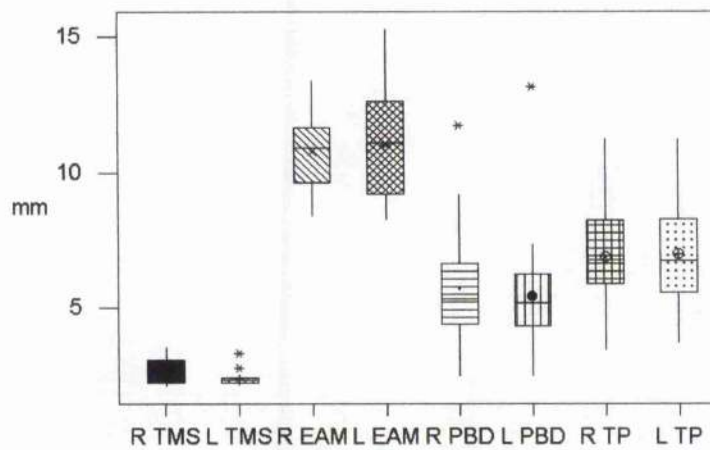
On the samples of the left side, the mean distance from the main trunk of the facial nerve to the TMS was 2.38mm, to the EAM was 11.0mm, to the PBD was 5.4mm and to the TP was 6.99mm.

On the samples from the right side, the mean distance to the TMS was 2.6mm, to the EAM was 10.8mm, to the PBD was 5.7mm and to the TP was 6.89mm.

LANDMARK	MEAN DISTANCE (mm)FROM FACIAL NERVE (+/- 2SD))
R TMS	**2.6 (+/- 0.96)**
L TMS	**2.38 (+/- 0.5)**
R EAM	**10.8 (+/- 2.74)**
L EAM	**11.0 (+/- 3.94)**
R PBD	**5.7 (+/- 4.31)**
L PBD	**5.4 (+/- 4.16)**
R TP	**6.89 (+/- 3.45)**
L TP	**6.99 (+/- 3.79)**

Table 3: Comparison of the left (L) and right (R) side of the specimens for the mean distance from the facial nerve.

These results above can be summarised in the following boxplot which shows the left and right differences for each of these landmarks.



Graph 6: Comparison of the left (L) and right (R) sides of the mean results from the facial nerve to each of the four landmarks. Again, outliers are marked by and the mean is highlighted within the box.*

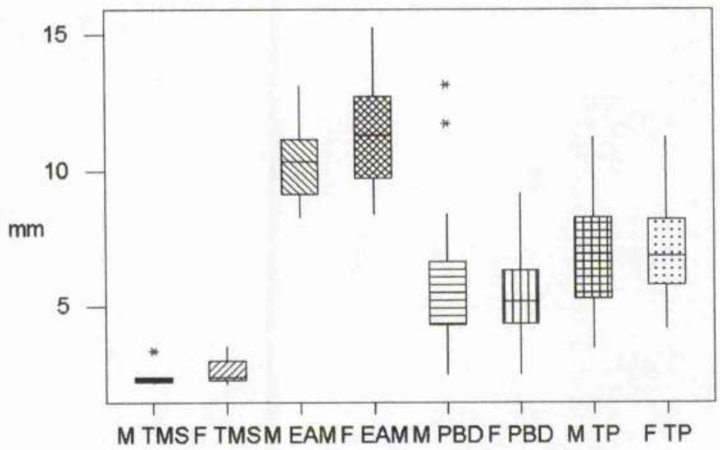
3.5.3 MALE/FEMALE COMPARISON OF LANDMARK MEASUREMENTS

An examination of the mean results was done with respect to seeing if any notable differences occurred between male and female specimens used.

LANDMARK	MEAN DISTANCE (mm) FROM FACIAL NERVE (+/- 2SD)
M TMS	**2.3 (+/- 0.49)**
F TMS	**2.6 (+/- 0.89)**
M EAM	**10.2 (+/- 2.6)**
F EAM	**11.5 (+/- 3.5)**
M PBD	**5.9 (+/- 5.1)**
F PBD	**5.3 (+/- 3.3)**
M TP	**6.7 (+/- 4.4)**
F TP	**7.1 (+/- 3.2)**

Table 4: Male / Female comparisons of the mean distance from the main trunk of the facial nerve to each of the landmarks.

These results have been placed onto a boxplot for easier comparison, as seen in Graph 7.



*Graph 7: Boxplot graph incorporating all mean measurements for each sex (male=M, female=F) from the facial nerve to each of the four landmarks (outliers indicated by *).*

SECTION 4

DISCUSSION

The plan of this discussion is based on recommendations contained in a British Medical Journal Leader article (Smith, 1999).

4.1 STATEMENT OF PRINCIPAL FINDINGS

In relation to the landmarks which surgeons can use to locate the main trunk of the facial nerve in parotidectomy, it was shown by measurement that the tympanomastoid suture had an average shortest distance to the facial nerve of 2.49mm (+/-0.78). The junction between the cartilaginous and bony ear canal had an average shortest distance to the main trunk of the facial nerve of 10.9mm (+/-3.4). The posterior belly of digastric muscle lay on average 5.55mm (+/-4.2) away from the main trunk of the facial nerve. Finally, the "tragal pointer" lay on average 6.9mm (+/-3.6) away from the main trunk of the facial nerve.

Note that the figure in brackets indicates +/- 2 standard deviations from the mean and therefore this encompasses 95% of the results.

No significant differences occurred with the measurements between the sexes or left/right sides of the specimens.

4.2 STRENGTHS AND WEAKNESSES OF STUDY

4.2.1 WEAKNESSES

Difficulties can arise when carrying out investigations on the cadaver and this can lead to problems in the interpretation and relation of the results to the live patient.

The majority of salivary gland neoplasms which affect the parotid gland are benign pleomorphic adenomas and their peak incidence is in the fifth decade of life (Leverstein et. al, 1997). This contrasts significantly with the mean age of the cadavers used for the simulated parotidectomies done in this study which was 83, with a range from 59 to 98 years old.

The texture and pliability of the cadaver tissues differs from tissues of the living individual and there is certainly a lack of elasticity. This may affect the muscles which were examined in this study. As one of the landmarks was the posterior belly of digastric muscle, it may have influenced the measurements which were undertaken.

In relation to the blood supply of the facial nerve, only one dissection of the stylomastoid artery was possible. In this specimen it arose from the occipital artery and as there is still conflict in the literature (Herdman et al 1993, Blunt, 1954 and Moreau et al. 2000), subsequent studies would be required to establish the blood supply of this region.

When the cadaver is embalmed, it lies in the anatomical position. This involves the head orientated facing forward. However, when doing a parotidectomy in the living person, the face is turned away from the operating surgeon. In the preserved cadaver, it was close to impossible to rotate the head away while trying to dissect and take the measurements from the main trunk of the facial nerve to each of the landmarks.

The measurements of the distances from the main trunk of the facial nerve to each of the four landmarks used in this study were made with the ear removed to allow for easier access. This clearly does not represent the situation in the living for a parotidectomy but each of these landmarks can be used in surgery. Also, it was only myself who carried out the measurements. Error could have been minimised by having several people take measurements and then take an average of all of these done.

Also, it is not possible to use callipers or a micrometer in the operating room so this does not reflect the real life clinical scenario.

4.2.2 STRENGTHS

Against these weaknesses that have been detailed, considerable strengths can be gained from this study.

As this study was carried out in the laboratory setting, it was possible to spend time accurately identifying the structures which are seen at operation on the parotid gland.

The regional anatomy could be demonstrated very well as the embalmed cadaver does not bleed. This is in stark contrast to the living subject where bleeding can easily obscure the operating field.

Variability was minimised by carrying out a number of dissections to demonstrate the course of the facial nerve. The landmarks used for surgery were able to be clearly identified which may not always be possible in the operating environment.

A series of measurements were made on 26 cadaver heads. The measurements to each of the landmarks from the main trunk of the facial nerve were taken twice and the average of that result was used to examine the overall variability. The same Reifler calipers and micrometer were used throughout the course of the study so no variability in equipment could occur.

Post mortem artefact may influence the measurements which have been done, but there is no evidence to suggest that it would change one distance more than another and therefore, it would affect the absolute distances rather than the relative distances.

Observation was undertaken of two parotidectomies (although only one was formally recorded) to allow a clearer understanding and clinical correlation of the dissection work undertaken and to give a clearer visualisation of the landmarks which the operating surgeon uses.

4.3 RESULTS IN RELATION TO OTHER STUDIES

On locating the main trunk of the facial nerve when performing a parotidectomy, numerous important structures are first encountered before this crucial point in the operation.

After the initial incision is made just anterior to the ear and carried down into the neck (Figure 53), a skin flap is created (Figure 48).

The first structures encountered are the external jugular vein and the great auricular nerve found half way along the sternocleidomastoid muscle, perpendicular to it (Figure 49 and Figure 54).

The great auricular nerve is very superficial and it ascends to the inferior border of the parotid gland where it divides into its three main branches (Vieria et al, 2002) as shown in Figure 50, although it may not be necessary to formally identify this nerve.

These structures lie on the sternocleidomastoid muscle, and this very structure has a role in treating conditions like Frey's syndrome by plication of it (Casler and Conley, 1991), amongst other treatments, like using the superficial musculo-aponeurotic system (Moulton-Barrett et al, 1996) or temporoparietal fascial flap interpositioning (Rubinstein et al, 1999).

Frey's syndrome is caused by the nerve fibres being divided to both the parotid gland (auriculotemporal nerve) and the sweat glands (Linder et al, 1997). This leads to the aberrant regeneration so that the fibres intended to go to the parotid gland from the auriculotemporal nerve, go instead to the sweat glands, and vice versa.

The auriculotemporal nerve emerges from behind the temporomandibular joint, and ascends posterior to the superficial temporal vessels close to the incision line for parotidectomy (Williams in Gray's Anatomy, 1995) but in this series of dissections, it was unable to be located. This must be a difficult area for the surgeon in minimising Frey's syndrome anatomically with respect to the nerve.

After identifying these structures, the posterior surface of the parotid gland is freed from the anterior border of the sternocleidomastoid muscle and the facial nerve was then located by using the V shaped sulcus (Britnall et al, 1955; Reid, 1989 and Maynard, 1978).

4.3.1 FACIAL NERVE ANATOMY

The facial nerve was located by using the tympanomastoid suture (Nishida and Matsuura, 1993 and Conley, 1978) as seen in Figure 60, and it was directly inferior to this suture line.

At this point, the only structure of note to pass close to the tympanomastoid suture was the posterior auricular artery, as seen in Figure 44. It approached close to the tympanic plate but did not have any direct contact with the suture line intimately. This has not been noted in the surgical textbooks in relation to parotidectomy as a cautionary area (Tardy and Kastenbauer, 1995), and as only one dissection showed this relation of the artery to the suture line, further work would have to be undertaken to confirm, or otherwise, the importance of this finding.

The facial nerve was noted to leave the skull at the stylomastoid foramen. After leaving the skull through this aperture, it turns anterolaterally, passing downward for approximately 1cm (Monkhouse, 1990).

It descends through a triangle formed by the mastoid, the angle of the mandible and the cartilaginous ear canal (Carlson, 2000).

On descent, before passing into the parotid gland, three small branches are given off, namely the posterior auricular, nerve to digastric and the nerve to stylohyoid

(Williams in Gray's Anatomy, 1995). In this study, the nerve to the posterior belly of digastric was identified (Figure 28) although the other two branches were not able to be located.

Histology and scanning electron microscopy of the main trunk of the facial nerve at this point (ie. after it has left the stylomastoid foramen but before the pes anserinus) has shown a monofascicular arrangement, as seen in Figures 28, 30 and 35. This agrees with Devriese (1974), who found that the facial nerve showed a mono-fascicular arrangement in the vertical portion as it approached the stylomastoid foramen.

This is unusual in that it would have been thought that as the facial nerve was a peripheral nerve, it would be multi-fascicular, as in Figure 29 which is a cross section of the sciatic nerve.

It may be thought that the only fibres going to be present are those going on to supply the muscles of facial expression and therefore they are bundled together. This would suggest that they share the same common modality. Also, the section was taken just before entering the parotid gland therefore, the posterior belly of digastric, posterior auricular and the stylohyoid branches have all been given off.

Yet, the main trunk of the facial nerve has still to give off each branch to the various muscles of facial expression and it would be thought that these would be bundled separately for their target destination. It does however seem to be an unusual yet very interesting finding.

The facial nerve is also noted to have a very dense connective tissue sheath associated with it, as seen in Figures 30 and 31. Holt (1996) also noted that at the mastoid tip, the nerve sheath seemed to "blend" into the dense fascia of the surrounding area.

The facial nerve then pierces the posterior surface of the parotid gland.

Cross sectional histology at the point just before the branching of the facial nerve, but within the parotid gland, is shown in Figure 35. Much dispute in the literature has occurred about the nerve lying in a plane but this has been largely disregarded (McKenzie, 1948).

McKenzie (1948) had said that "communications between the superficial and deep portions of the gland may occur through any gap in the plexus of the facial nerve and, further, that the exact manner in which the gland interdigitates with the nerve is not constant".

Also, today in Williams in Gray's Anatomy, 1995 there is not a plane which exists but merely a superficial and deep parotid gland, and this is in relation to if the gland is superficial to the facial nerve or deep to it.

The only relevance this has in parotid surgery is that if the tumour is only in the superficial part of the parotid, it will require less extensive surgery and will have less risk of complications (Leverstein et al, 1997 and Lee Rea, 2000) compared to tumour involving the entire parotid gland, both deep and superficial parts (Witt, 2002).

Within the parotid gland, the facial nerve divides into two main divisions, namely the cervicofacial and temporofacial as seen in Figure 36. This has been noted to occur "posterior and slightly medial to the ramus of the mandible and superiorly two-thirds of the distance between the external angle of the mandible and the palpable temporomandibular articulation" (McCormack, 1945).

The facial nerve then branches into its five main divisions: temporal, zygomatic, buccal, marginal mandibular and cervical as shown by Figure 47. The discussion on the branching will mainly be based on Figure 47.

Temporal branch

In the current study, the temporal branch arose from the temporofacial division. It crossed superficial to the superficial temporal vessels and then passed over the lateral aspect of the zygomatic arch. It was noted to be a very superficial branch, which agrees with Rudolph (1990) who stated that it was the most superficial division of the facial nerve. It then passed towards the lateral aspect of the orbit to supply the orbicularis oculi and the frontal belly of occipitofrontalis.

Furnas (1965) also had stated that this branch crossed the zygomatic arch to pass within the temporoparietal fascia, although that is not obvious from the work contained within Figure 49.

Zygomatic branch

The zygomatic branch, again arose from the temporofacial division. It then passed over the lateral surface of the masseter muscle approaching the zygomatic arch. Just before this point, it bifurcated into two more branches: one running on the under surface of the zygomatic branch, the other running to the zygomaticus major. These finding agree with the work of Freilinger (1987) who stated that there was a superior and an inferior branching pattern. Freilinger also sated that the superior branch was the thinner of the two. This study found that the two branches were approximately the same size.

Buccal branch

The buccal branch was noted to arise from the temporofacial division. It coursed in a horizontal direction as a singular branch of large proportion. It passed deep into the region where the buccal fat pad is located. This disagrees with the work Freilinger (1987) did which stated that there were two buccal branches.

A study by Davis et al (1956), based on 350 cervicofacial half heads, had shown that the buccal branch arises, in the majority, from the cervicofacial division yet a single random dissection has encountered it arising from the temporofacial.

Marginal mandibular branch

This branch arose from the cervicofacial division, ran parallel to the angle of the mandible and then passed over the masseter muscle at the angle of the mandible, then ran along the body of the mandible to terminate on the muscles around the mouth.

However, Freilinger (1987), and also in surgical text books (Tardy and Kastenbauer, 1995), state that the marginal mandibular branch passes below the body of the mandible, then hooks up to the angle of the mouth. This differs to the work carried out here.

Cervical branch

This branch arose from the cervicofacial branch and in Figure 47 it is reflected, but is a single branch.

In general, this branching pattern was similar to the other dissections of the facial nerve but variations were very common. This agrees with work done by Davis et al (1959) who based his work on a large study and grouped the branching into six types.

There was only a loose association with trying to place the dissections done here into one of the specific types created by Davis. This reflects the high degree of branching pattern and variability that the facial nerve has and that not every case can fit into a certain "type" of branching. This should alert the surgeon to the need for careful identification of the facial nerve and not to "assume" the position of any of the branches.

The retromandibular vein

The retromandibular vein is formed from the unification of the superficial temporal vein and the maxillary vein as shown in Figure 38. Kopuz et al (1995) had shown that in 10% of cases, the retromandibular vein was lateral to the lower trunk and medial to the upper trunk. In all dissections in this study, the retromandibular vein always lay medial to the main trunk of the facial nerve for both the upper and lower trunks.

The external carotid artery

Deeper to the facial nerve is the external carotid artery. The terminal branches of this vessel are the superficial and maxillary arteries as shown in Figure 39.

Blood supply of the facial nerve

The stylomastoid artery is seen in Figure 41.

The stylomastoid artery is a small vessel which can be seen to arise from the tortuous occipital artery, which itself has great variability between people (Schmidt and Adelmann, 2001). The stylomastoid artery then passes superior from the occipital artery and then passes along with the facial nerve (medial to it) to enter into the stylomastoid foramen.

The origin of the stylomastoid artery has been disputed in the literature. Herdman (1993) and Blunt (1954) have both shown the stylomastoid artery (in the majority of cases) to arise from the occipital artery. However, a recent study (2000) by Moreau et al showed the stylomastoid artery to arise from the posterior auricular artery in 70% of cases, the occipital artery in 20% of cases and the external carotid artery in 10% of cases.

This shows that there is great variation with the origin of the stylomastoid artery and this study, after only one dissection being undertaken for this purpose, proves this further.

4.3.2 LANDMARK MEASUREMENTS

For the anterograde approach in parotidectomy, first described by Janes in 1940, many landmarks have been used to locate the main trunk of the facial nerve early in the operation.

The present study has examined four landmarks namely, the posterior belly of digastric muscle, the "tragal pointer", the external auditory meatus (junction between the cartilaginous and bony ear canal) and the tympanomastoid suture.

The distances were measured from the lateral aspect of the head. The measurements were taken after the facial nerve had passed anterior to the most anterior part of the mastoid process and all four landmarks could be clearly seen.

The posterior belly of digastric muscle

In 1959, Boswell described using the upper body of the posterior belly of digastric muscle and where it attached to the mastoid process to find the facial nerve. The facial nerve was found to be 1.5cm anterocranial to this point.

Another contributor to using the posterior belly of digastric muscle as a landmark to find the facial nerve is Holt (1996). Holt noted the facial nerve to be 9mm from the anterior border of this muscle.

Within this study, the main trunk of the facial nerve was noted to be 5.5mm (+/-4.2, +/-2SD) from the posterior belly of digastric muscle. This landmark has the greatest variability of all the landmarks used in this study (due to the greatest variation in the standard deviation value).

This is to be expected as it is a muscle mass. The posterior belly of digastric muscle has been shown to vary in its width and its insertion can vary eg. it may be more anterior in its insertion to the mastoid process in some people and more posterior in others, therefore varying the position of the facial nerve in relation to it (Holt, 1996). Holt has also proposed that the angle of insertion to the mastoid process may vary in relation to neck length, which again would have an impact on the distance from it to the facial nerve.

The "tragal pointer"

The "tragal pointer" is a portion of very prominent tragal cartilage which is said to point to the facial nerve which lies 1-2cm deep to the tip of it (Conley, 1978). Casselman and Mancuso (1987) had shown the facial nerve to be 10-15mm caudal to this landmark.

In the present study, the main trunk of the facial nerve lay 6.9mm (+/-3.6, +/-2SD) from the "tragal pointer". During this study, it was noted that the "tragal pointer" was variable in its indication of the direction of the facial nerve. In other words, it did not always "point" to the facial nerve or the direction it was supposed to travel in as it approached the parotid gland, though this was not recorded formally. It was also noted to be the second furthest away from the main trunk of the facial nerve with considerable variability (reflected in the standard deviations). Therefore the "tragal pointer" is not recommended in locating the main trunk of the facial nerve during parotid surgery.

The external auditory meatus

The junction between the bony and cartilaginous ear canal was the site used for this measurement in this present study. It had been used with a reasonable confidence in locating the facial nerve in a study by Alexander de Ru et al, 2001.

The main trunk of the facial nerve was noted to be 10.9mm (+/-3.4, +/-2SD) from the junction between the bony and cartilaginous ear canal.

This landmark is clearly far too far away, in comparison to the other landmarks used and has considerable variability in its location (reflected again by the high number for the standard deviation). Therefore, the external auditory meatus is not recommended in locating the main trunk of the facial nerve in parotid surgery.

The tympanomastoid suture

One of the first references to the tympanomastoid suture is in Britnall et al (1955). It was described as superiorly, lying near a bony ridge at the anteroinferior margin of the external auditory meatus of the skull and inferiorly, found at the blunt anterior end of the mastoid process of the temporal bone. Put simply, it is a V shaped sulcus between the anterior part of the mastoid process and the posterior surface of the tympanic plate.

Reid (1989) also noted that the facial nerve was located 3-4mm deep to this suture. Maynard (1978) found that the facial nerve was constantly related to the apex of the V shaped sulcus. Alexander De Ru et al (2001) also advocated using this landmark in parotid surgery due to its proximity to the facial nerve.

In this study, the main trunk of the facial nerve was 2.49mm (+/-0.78, +/-2SD) from the tympanomastoid suture. This proves that this landmark is the closest to the main trunk of the facial nerve with least variability (reflected by the very small number for the standard deviation) and is therefore the most reliable landmark to locate the main trunk of the facial nerve during parotid surgery.

This would make sense, as the tympanomastoid suture is a bony landmark, least subject to variability as always lies between the tympanic plate and mastoid process, is rigid and therefore more reliable to locate to locate the facial nerve.

This study has therefore compared landmarks used in the past for accessing the facial nerve, but it has also examined the variability of these landmarks in relation to the facial nerve.

It can be concluded that the tympanomastoid suture is the closet to the facial nerve, with least variability, compared to the other three landmarks. Therefore, it can be used to safely and accurately identify the main trunk of the facial nerve.

No structures were found to be intimately related to the tympanomastoid on a gross dissection.

Therefore, the tympanomastoid suture is **safe, reliable** and with **least variability** compared to the posterior belly of digastric muscle, the junction between the cartilaginous and bony external auditory canal and the "tragal pointer".

4.4 MEANING OF RESULTS FOR CLINICIANS

Locating the facial nerve in parotid surgery has always been one of the key steps in the surgery whether that be in the anterograde or retrograde approach.

Generally, the facial nerve is identified in the anterograde approach in parotidectomy, unless there is a large retromandibular mass or too much scar tissue from previous operations in this region.

Locating the main trunk of the facial nerve is the key step in the surgery and many studies have been undertaken to examine the landmarks for their closeness to the facial nerve (Nishida and Matsuura, 1993; Holt, 1996; Robertson and Blake, 1984; Conley, 1978; Beahrs, 1977; Boswell, 1959; Monte-Purcelli, 1963 and Alexander de Ru, 2001) although they have not compared and contrasted and examined the variability as in this study.

For example, Nishida and Matsuura (1993) have stated that bony landmarks, like the mastoid process and the notch between it and the tympanic plate, are very reliable as they are constant without subject to variability in position relative to each other. However, they did not measure or compare directly different landmarks to look at variability.

Holt in 1996 had found that the facial nerve lay 9mm from the posterior belly of digastric. He examined three other landmarks, but did not compare the variability within each set of landmark results.

Conley in 1978 had shown that the "tragal pointer" points to the nerve which lies 1-2mm deep to the 'tip'. However, this present study and work done by Alexander de Ru et al (2001) have shown that the "tragal pointer" does not always point to the facial nerve.

These studies highlighted show that although work has been done on locating the facial nerve by the main trunk in parotidectomy, no work has encompassed looking at surrounding landmarks and assessing variability like this present study.

Facial nerve paralysis is a devastating complication of many otolaryngologic, cosmetic, and oncologic procedures in the head and neck. The complication is well recognised and both surgeons and patients are aware of this. However, with the age of increasing litigation against otorhinolaryngologists, plastic surgeons, oral surgeons and neurosurgeons especially (Lydiatt, 2003), the accurate and safe identification and preservation of the facial nerve is of paramount importance and therefore the best way has to be known to find the nerve.

This study has shown that the tympanomastoid suture is the closest to the main trunk of the facial nerve, is not directly related to any other significant structures around the operating field and is least variable in its position compared to other landmarks (namely the junction between the cartilaginous and bony ear canal, "tragal pointer" and the posterior belly of digastric muscle).

Therefore, the tympanomastoid suture is an accurate and safe landmark to use to find the facial nerve early in parotidectomy, thus avoiding injury to such an important structure.

With the increasing popularity of computer-guided equipment for identifying anatomical structures in surgery, these measurements may become increasingly relevant.

4.5 CONCLUSIONS

The null hypotheses, which was proposed at the beginning of this study, that the tympanomastoid suture is not a reliable or safe landmark, and no more reliable than any other landmark which has been used in the past, can now be rejected.

The principal conclusions of this present study may be summarised as follows:

- The facial nerve is the seventh cranial nerve, is monofascicular in its main trunk and supplies the muscles of facial expression.
- The facial nerve passes through the parotid gland. Deeper in the parotid gland is the retromandibular vein and deeper still is the external carotid artery.
- In locating the facial nerve at its main trunk, no structures are close enough to the tympanomastoid suture to pose a problem (the posterior auricular artery was seen on only one dissection approaching the medial side of the facial nerve but not in direct association with it or the suture line).
- The tympanomastoid suture is the closest to the main trunk of the facial nerve and least variable in its position. It is also a bony landmark and is not subject to positional variability.
- Therefore, the tympanomastoid suture can be used to accurately and safely identify the main trunk of the facial nerve in an anterograde approach parotidectomy.

APPENDICES

<u>APPENDIX 1</u>: DETAILS OF THE SPECIMENS USED

<u>SPECIMEN NUMBER</u>	<u>AGE AT DEATH</u>	<u>SEX</u>
1	86	FEMALE
2	87	FEMALE
3	88	FEMALE
4	90	MALE
5	59	MALE
6	86	FEMALE
7	81	MALE
8	83	MALE
9	77	MALE
10	77	FEMALE
11	85	FEMALE
12	69	MALE
13	84	MALE
14	81	FEMALE
15	88	FEMALE
16	92	MALE
17	77	FEMALE
18	91	MALE
19	79	FEMALE
20	73	FEMALE
21	96	FEMALE
22	98	FEMALE
23	79	MALE
24	78	FEMALE
25	85	MALE
26	96	FEMALE

15 FEMALES, 11 MALES.

APPENDIX 2: EMBALMING OF SPECIMEN

The cadaver is embalmed before dissection work and the following is the University of Glasgow's embalming protocol.

- All hospital and personal items are removed eg. gown, name tag, jewellery etc.
- Head and body hair are removed
- The cadaver is tagged with a year and body number as required by the Anatomy Act.
- An incision is made anterior to sternocleidomastoid to gain access to the common carotid artery into which a wide bore metal cannula is inserted.
- 3 litres of Industrial Methylated Spirits (IMS) is then injected.
- 14-16 litres of embalming fluid is then injected using a Pierce Royal Bond pump at 9psi. Each litre of embalming fluid contains: IMS (625ml), Phenol (125ml), Formaldehyde 37% (75ml) and Glycerol (175ml). Also, the department uses 5ml of phenoexetol (a mould growth inhibitor) to each litre.
- The cadaver is then left overnight.
- The embalming incision is closed and the cadaver is placed in a clear plastic bag and stored in a fridge at 4°C for six weeks before work is undertaken.

APPENDIX 3: LATEX INJECTION

After the initial embalming fluid being injected (as described in Appendix 1), latex can be injected to highlight the blood supply to a region/s.

This involves injecting 200ml of ammonia in 800ml warm water and then injecting 500ml latex solution.

The latex solution is made up of 50ml white latex in 450ml cold water with black Indian Ink added.

APPENDIX 4: PREPARATION OF SPECIMEN FOR LIGHT MICROSCOPY

After the 0.5cm specimen was removed from the main trunk of the facial nerve, it was placed in a histokinette basket and labelled. This was then placed into the histokinette automatic tissue processor for paraffin sections processing. The processor undertook the following series:

• 70% ethanol	2 hours
• 90% ethanol	2 hours
• Absolute ethanol and 2% celloiden	2 hours x 3
• Amyl acetate	2 hours x 3
• Wax bath	4 hours x 2

Specimens were vacuum embedded to ensure that wax impregnation was complete. After embedding plastic moulds were used to produce small wax blocks. They were then cut using the Jung Biocut 2035 at 7μm before being mounted onto slides and then dried for a period of 24 hours at 37°C before the appropriate staining as detailed in Appendix 5.

APPENDIX 5: HAEMATOXYLIN AND EOSIN STAINING

After the specimen has been processed (as detailed in Appendix 4), the sections of the specimen should be left overnight in an oven at 37°C. For staining:

• Slide is placed into Histoclear to dewax	10mins
• Absolute alcohol X2	1min each time
• 90% alcohol	1min
• 70% alcohol	1min
• Wash in water X2	
• Haematoxylin	5mins
• Wash in water	
• Blue in Scott's solution.	
• Wash in water X2	
• Eosin	3mins
• Wash in water X2	
• 70% alcohol	1min
• 90% alcohol	1min
• Absolute alcohol X2	1min each time
• Clear in Histoclear	
• Mounted with Hystomount	

APPENDIX 6: PROCESSING OF SPECIMEN FOR SCANNING ELECTRON MICROSCOPY

The facial nerve sample of an embalmed cadaver used was cut to 1cm long and was found to be 0.4cm in diameter.

Method

1. The specimen was fixed with buffered 5% gluteraldehyde (pH 7.4) overnight
2. Transfer to pH 7.4 Phosphate Buffer 1 hour
3. Post fixed with 1% Osmic acid (OsO_4) 30 minutes
4. Transfer to pH 7.4 Phosphate Buffer 30 minutes
5. Dehydration of the specimen by immersing sequentially in the following:
    - 50% acetone 1 hour
    - 100% acetone 1 hour
    - 100% acetone 1 hour
    - 100% acetone 1 hour
    - Hexamethyldisilazane (HMDS) 1 hour
    - Hexamethyldisilazane (HMDS) 1 hour
6. The specimen was coated in gold in a Polaron Sputter coater (To reflect the electron beam).

APPENDIX 7: LANDMARK MEASUREMENTS

The shortest distance from the main trunk of the facial nerve to the following landmarks (in mm): TMS= TYMPANOMASTOID SUTURE

PBD= POSTERIOR BELLY OF DIGASTRIC MUSCLE

EAM= EXTERNAL AUDITORY MEATUS

TP= TRAGAL POINTER

R. HALF/ L. HALF: RIGHT HALF/ LEFT HALF OF HEAD

R. MEAN/L. MEAN: RIGHT MEAN/LEFT MEAN OF THE 2 RESULTS GIVEN FOR EACH LANDMARK.

No. 1	TMS	EAM	PBD	TP
R. HALF	2.28	11.1	3.0	6.1
	2.25	11.5	3.1	6.5
R. MEAN	**2.265**	**11.3**	**3.05**	**6.3**
L. HALF	2.4	12.0	4.5	7.4
	2.2	12.4	4.7	7.5
L. MEAN	**2.3**	**12.2**	**4.6**	**7.45**
No. 2				
R. HALF	3.7	11.8	9.23	6.26
	3.4	11.7	9.14	6.31
R. MEAN	**3.55**	**11.75**	**9.19**	**6.29**
L. HALF	2.39	15.2	7.41	9.16
	2.27	15.4	7.35	9.20
L. MEAN	**2.33**	**15.3**	**7.38**	**9.18**
No. 3				
R. HALF	3.00	13.5	4.38	8.30
	31.2	13.0	4.47	8.32
R. MEAN	**3.06**	**13.25**	**4.425**	**8.31**
L. HALF	3.33	12.1	5.14	9.45
	3.27	12.4	5.17	9.50

APPENDIX 7: LANDMARK MEASUREMENTS CONTINUED

No. 3	TMS	EAM	PBD	TP
L. MEAN	**3.30**	**12.25**	**5.155**	**9.475**
No. 4				
R. HALF	2.25	12.0	4.40	11.2
	2.31	11.9	4.35	11.34
R. MEAN	**2.28**	**11.95**	**4.375**	**11.27**
L. HALF	2.26	13.3	5.15	9.31
	2.18	13.0	5.21	9.40
L. MEAN	**2.22**	**13.15**	**5.18**	**9.355**
No. 5				
R. HALF	2.15	11.32	4.32	8.25
	2.12	11.27	4.29	8.23
R. MEAN	**2.135**	**11.295**	**4.305**	**8.24**
L. HALF	2.20	11.0	7.35	8.32
	2.17	11.31	7.40	8.29
L. MEAN	**2.185**	**11.155**	**7.375**	**8.305**
No. 6				
R. HALF	3.0	13.45	5.45	8.18
	2.97	13.39	5.37	8.23
R. MEAN	**2.985**	**13.42**	**5.41**	**8.205**
L. HALF	2.40	14.1	4.4	11.25
	2.35	13.7	4.37	11.32
L. MEAN	**2.375**	**13.9**	**4.385**	**11.285**
No. 7				
R. HALF	2.3	11.4	5.00	8.4
	2.27	11.27	5.1	8.37
R. MEAN	**2.285**	**11.335**	**5.05**	**8.385**
L. HALF	2.43	11.0	4.4	9.38
	2.37	11.0	4.2	9.4
L. MEAN	**2.4**	**11.0**	**4.3**	**9.39**
No. 8				
R. HALF	2.31	9.21	4.37	6.34

APPENDIX 7: LANDMARK MEASUREMENTS CONTINUED

No. 8	*TMS*	*EAM*	*PBD*	*TP*
	2.4	9.15	4.4	6.37
R. MEAN	**2.355**	**9.18**	**4.385**	**6.355**
L. HALF	2.42	11.12	6.1	5.32
	2.39	11.19	6.05	5.27
L. MEAN	**2.405**	**11.155**	**6.075**	**5.295**
No. 9				
R. HALF	2.23	9.4	8.44	6.43
	2.3	9.37	8.37	6.38
R. MEAN	**2.265**	**9.385**	**8.405**	**6.405**
L. HALF	2.35	9.05	7.1	5.2
	2.30	9.14	6.9	5.25
L. MEAN	**2.325**	**9.095**	**7.0**	**5.225**
No. 10				
R. HALF	3.35	12.0	9.25	7.04
	3.31	11.74	9.17	7.1
R. MEAN	**3.33**	**11.87**	**9.21**	**7.07**
L. HALF	NO	SAMPLE	AVAILABLE	
No. 11				
R. HALF	1.93	11.4	3.34	4.15
	2.26	10.7	4.02	4.1
R. MEAN	**2.095**	**11.05**	**3.705**	**4.125**
L. HALF	2.28	13.04	4.30	7.14
	3.23	14.3	4.35	9.25
L. MEAN	**2.755**	**13.67**	**4.325**	**8.195**
No. 12				
R. HALF	3.24	8.09	4.33	7.26
	3.45	9.16	3.33	6.34
R. MEAN	**3.345**	**8.625**	**3.83**	**6.8**
L. HALF	2.32	10.24	2.40	5.41
	2.36	11.0	2.5	5.60
L. MEAN	**2.34**	**10.62**	**2.45**	**5.505**

APPENDIX 7: LANDMARK MEAUSREMENTS CONTINUED

No. 13	*TMS*	*EAM*	*PBD*	*TP*
R. HALF	NO	SAMPLE	AVAILABLE	
L. HALF	2.18	11.0	4.20	5.29
	2.45	10.4	4.15	5.15
L. MEAN	**2.315**	**10.7**	**4.175**	**5.22**
No. 14				
R. HALF	3.10	11.35	5.25	7.27
	2.43	11.25	4.44	6.25
R. MEAN	**2.765**	**11.3**	**4.845**	**6.76**
L. HALF	2.45	11.45	4.46	6.19
	2.35	11.05	4.42	7.18
L. MEAN	**2.4**	**11.25**	**4.44**	**6.685**
No. 15				
R. HALF	3.29	11.22	5.45	6.27
	3.46	11.25	5.33	7.26
R. MEAN	**3.375**	**11.235**	**5.39**	**6.765**
L. HALF	2.13	9.04	6.00	4.30
	2.14	9.33	6.21	4.11
L. MEAN	**2.135**	**9.185**	**6.105**	**4.205**
No. 16				
R. HALF	2.21	11.25	11.31	4.33
	2.22	9.46	12.14	4.16
R. MEAN	**2.215**	**10.355**	**11.725**	**4.245**
L. HALF	2.32	9.05	13.01	5.45
	2.45	8.43	13.30	6.41
L. MEAN	**2.385**	**8.74**	**13.155**	**5.93**
No. 17				
R. HALF	3.26	10.1	7.01	7.28
	3.34	11.06	7.06	8.05
R. MEAN	**3.3**	**10.58**	**7.035**	**7.665**

APPENDIX 7: LANDMARK MEASUREMENTS CONTINUED

No. 17	***TMS***	***EAM***	***PBD***	***TP***
L. HALF	2.41	11.35	3.39	5.37
	2.24	12.18	3.20	6.17
L. MEAN	**2.325**	**11.765**	**3.295**	**5.77**
No. 18				
R. HALF	2.46	8.34	6.43	3.41
	2.15	8.40	4.45	3.38
R. MEAN	**2.305**	**8.37**	**5.44**	**3.395**
L. HALF	2.17	9.01	4.2	3.32
	2.13	9.41	4.47	4.04
L. MEAN	**2.15**	**9.21**	**4.335**	**3.68**
No. 19				
R. HALF	2.44	10.32	2.44	5.31
	2.43	10.44	2.45	5.47
R. MEAN	**2.435**	**10.38**	**2.445**	**5.39**
L. HALF	2.36	8.41	3.29	5.44
	2.41	8.28	4.33	6.01
L. MEAN	**2.385**	**8.345**	**3.81**	**5.725**
No. 20				
R. HALF	2.04	9.04	6.33	9.15
	2.41	10.10	6.30	7.22
R. MEAN	**2.225**	**9.57**	**6.315**	**8.185**
L. HALF	2.42	13.36	3.37	9.22
	2.27	12.1	4.25	6.35
L. MEAN	**2.345**	**12.73**	**3.81**	**7.785**
No. 21				
R. HALF	2.37	9.15	7.16	5.13
	2.40	10.35	6.29	5.27
R. MEAN	**2.385**	**9.75**	**6.725**	**5.2**
L. HALF	PAROTID	USED	FOR	HISTOLOGY
No. 22				
R. HALF	2.36	11.21	6.39	8.41

APPENDIX 7: LANDMARK MEASUREMENTS CONTINUED

No. 22	*TMS*	*EAM*	*PBD*	*TP*
	3.20	14.1	5.48	8.29
R. MEAN	**2.78**	**12.655**	**5.935**	**8.35**
L. HALF	2.45	13.03	7.01	8.01
	2.13	13.14	6.22	8.40
L. MEAN	**2.29**	**13.085**	**6.615**	**8.205**
No. 23				
R. HALF	2.41	11.12	6.07	9.18
	2.27	10.44	5.33	7.33
R. MEAN	**2.34**	**10.78**	**5.7**	**8.255**
L. HALF	2.08	9.42	6.04	6.30
	2.35	9.17	4.33	6.40
L. MEAN	**2.215**	**9.295**	**5.185**	**6.35**
No. 24				
R. HALF	2.14	9.42	4.43	5.30
	2.31	8.37	4.38	6.17
R. MEAN	**2.225**	**8.895**	**4.405**	**5.735**
L. HALF	2.07	9.03	5.18	7.12
	2.23	9.00	5.40	6.47
L. MEAN	**2.15**	**9.015**	**5.29**	**6.795**
No. 25				
R. HALF	2.17	11.01	5.34	8.00
	2.15	9.46	5.06	7.34
R. MEAN	**2.16**	**10.235**	**5.2**	**7.67**
L. HALF	2.40	8.27	6.28	5.39
	2.41	8.21	6.23	6.25
L. MEAN	**2.405**	**8.24**	**6.255**	**5.82**
No. 26				
R. HALF	NO	SAMPLE	AVAILABLE	
L. HALF	2.39	9.40	5.46	7.40
	3.17	9.39	5.32	6.29
L. MEAN	**2.78**	**9.395**	**5.39**	**6.845**

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