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An Anatomical Study of the Maxillary Nerve Block Via the Greater Palatine Canal

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AN ANATOMICAL STUDY OF THE MAXILLARY NERVE BLOCK VIA THE GREATER PALATINE CANAL

BY

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DEDICATION

In memory of my grandfather, Ival A. Merchant, D.V.M., M.S., Ph.D., M.P.H. A scientist, teacher, author, and family man, whose charismatic personality and work ethic was not only an inspiration to me, but to so many others.

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I would like to express my sincere gratitude to all of those individuals who helped this thesis become a reality, even during the difficult and emotional times of dealing with the abrupt and controversial closure of our 110 year old dental school by the University's central administration.

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Lastly, I thank my wife Eve and son Robert for their love and support, for without them this work would not have been possible.

VITA

The author was born in Honolulu, Hawaii, in 1958. His pre-doctoral education was completed in California, receiving an Associate of Arts degree from Riverside City College in 1980 and a Bachelor of Science degree in Biology from University of California at Riverside (UCR) in 1982.

After completing a research project in organic chemistry at UCR, he started his dental education at Loyola University School of Dentistry in 1983. He graduated in 1987 to become the second member of his family with a degree of Doctor of Dental Surgery from Loyola.

In June of 1988 he completed a one year general practice residency at the University of California at Los Angeles Medical Center. In August of that same year, he returned to Loyola University School of Dentistry to enter a two year post graduate program leading to a Certificate of Specialty Training in Endodontics.

Starting in July of 1990, he became a full-time faculty member in the Department of Endodontics at Loyola until the School of Dentistry was closed on June 30, 1993. He now continues his academic career at Northwestern University School of Dentistry. Since November of 1990, he also maintains a private practice limited to Endodontics in Oak Brook and Naperville, Illinois.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES - Continued

INTRODUCTION

The nerve block is an effective means of obtaining broad range tissue anesthesia with just a localized and minimal deposition of anesthetic solution. Since the discovery of the nerve block by Halsted and Hall in 1884 using Koller's newly developed cocaine hydrochloride as a local anesthetic,[1,2] there have been vast improvements in both the anesthetic agents and injection techniques. Currently, clinicians in both the dental and medical fields may routinely use various nerve block techniques as a diagnostic test as well as a means of providing comfortable care to their patients during a procedure.

Both spinal and cranial nerves may be anesthetized effectively through a number of regional nerve block techniques. Of interest in this work is the maxillary (second division, V_2) nerve block, which is a method used to anesthetize one of the main branches of the trigeminal or fifth cranial nerve. The maxillary nerve provides sensory innervation to the midface, maxilla, maxillary teeth and sinuses, hard and soft palates, and nasopharynx. Due to the wide distribution of the maxillary nerve (discussed further on pages 11-17), this technique has been found to be an asset in otolaryngologic, plastic, and oral and maxillofacial surgical procedures.[3,4,5] To a lesser degree, the maxillary nerve block may be helpful in dentistry for complete quadrant procedures and for the difficult to anesthetize tooth. In addition, this nerve

block has been found to be useful for: patients prior to non-sedated nasal intubation, differential diagnoses of pain, and for the treatment of neuralgias.[6,7,8]

To achieve a maxillary nerve block, the injection needle is directed to the pterygopalatine fossa where the main trunk of the maxillary nerve resides. This may be accomplished by two general approaches: an extraoral or an intraoral route. The extraoral method is used when the intraoral approach cannot be utilized such as with the presence of trismus, mandibular fractures, or infections of tissues in the area of the intraoral routes.[9] There are five extraoral methods of delivering a maxillary nerve block: the lateral, anterior, orbital, infraorbital, and intranasal routes.

In the lateral approach, the needle is introduced through the skin at a point overlying the mandibular notch just below the zygomatic arch.[10-14] The needle is advanced between the zygomatic arch and the mandibular notch, through the pterygomaxillary fissure to reach the pterygopalatine fossa. With this technique, the needle may have to be redirected in an anterior direction to avoid contacting the lateral plate of the pterygoid process.[14]

The anterior route is similar to the lateral approach in that the needle is introduced along the inferior border of the zygoma, but in this method the needle is anterior to the coronoid process.[14-17] The needle is then advanced in a slightly posterior direction along the posterior surface of the maxilla, through the pterygomaxillary fissure to the pterygopalatine fossa. Matas was the first to attempt the maxillary nerve block by using this technique.[18]

In 1900, Matas reported successfully obtaining a maxillary nerve block by an orbital route in order to perform a maxillectomy for a patient with a recurrent "epithelioma" (squamous cell carcinoma) of the palate.[19] He passed a needle along the inferior lateral aspect of the orbit and through the infraorbital fissure to reach the pterygopalatine fossa and therefore was thus coined the "Matas method."[20]

Hill found he could anesthetize the maxillary nerve by an infraorbital route.[21] He advanced an "ordinary 22 gage hypodermic needle to its full length" through the infraorbital foramen. Using his technique on cadavers, Hill injected methylene blue dye and demonstrated that the dye not only penetrated sufficiently to the posterior to reach the pterygopalatine fossa but also to the trigeminal ganglion.[21]

In the intranasal route, as devised by Sluder,[22] a needle is introduced through the nostril to the posterior end of the middle concha (turbinate) along the lateral wall of the nasal cavity. The needle is then pushed through the lateral wall where it enters the pterygopalatine fossa. The area of the lateral wall transfixed by the needle must be well anesthetized by topical anesthetic to reduce any discomfort.[22] Sluder developed this technique to anesthetize the pterygopalatine ganglion which lies next to the maxillary nerve, but because of this close proximity, the maxillary nerve would also be anesthetized.

There are two intraoral approaches for the maxillary nerve block, the buccal and greater palatine canal routes. The origin of the buccal route can be traced back to 1913 where Smith experimented with a large number of cadavers in developing his injection technique that became popular in 1918.[23,24] The Smith method, or the High

Tuberosity Technique,[25] entails inserting a long needle in the mucobuccal fold in the area of the maxillary second molar and directing it upward, inward, and backwards along the posterior surface of the maxilla to the pterygopalatine fossa. A modification of Smith's method is to introduce the needle posterior to the maxillary third molar and direct it upward and inward along the pterygomaxillary fissure to the pterygopalatine fossa.[26]

The greater palatine canal route is the most widely used approach to anesthetize the maxillary nerve.[27] The pterygopalatine fossa can be directly reached by advancing a needle superiorly through the greater palatine canal (Figure 1). This approach may be useful when other intraoral techniques for maxillary anesthesia, such as supraperiosteal (infiltration) injections or nerve blocks are contraindicated due to the presence of a buccal dento-alveolar ridge abscess (Figure 2).

The first recorded attempt of the maxillary nerve block by way of the greater palatine (pterygopalatine) canal approach was by Nevin in 1917.[28] Trying to anesthetize the infraorbital portion of the maxillary nerve, he passed a 42mm needle through the greater palatine canal to a depth of about 25mm before depositing the anesthetic solution. From his experience he wrote:[28]

> "This method, however, is not successful and is fraught with danger. It is not successful because of the inaccessibility and the difficulty of passing through the pterygopalatine canal, as this canal is frequently constricted in its course and offers resistance to the passage of the needle. The danger arises from the fact that in this narrow space are located the three palatine nerves and ascending palatine artery together with the accompanying veins, offering an opportunity to the needle in its prolonged course to enter the artery and particularly the vein, or perhaps do some injury to the palatine nerves."

Others have also raised concerns of damaging the neurovascular structures by advancing a needle through the greater palatine canal.[29,30,31] But since the first attempt with this approach by Nevin, there have been no reported studies evaluating the effects of the injection needle upon the surrounding soft tissue structures.

It is the purpose of this thesis to conduct a three part anatomical study of the maxillary nerve block via the greater palatine canal using cadavers. The first part of the study documents the effect of the injection needle upon the soft tissues structures within the greater palatine canal. The second part of the study evaluates the neurovascular structures contained within the greater palatine canal. By examining histological specimens, the position of the descending palatine artery and nerve will be examined. The presence of a descending palatine vein through histological sections and gross dissection will also be examined, since this vein has not been observed by the author in previous dissections of the pterygopalatine fossa. The final part of this study calculates the actual depth from the palatal mucosa to the maxillary nerve and the distance of the needle tip to the maxillary nerve using different recommended techniques.

Figure 1: Simulated maxillary nerve block by way of the greater palatine canal (right side). **A,** Long injection needle (35mm) passed through the greater palatine foramen and canal. **B,** Lateral view of the pterygopalatine fossa with the inserted needle from the greater palatine canal. **1,** Lateral pterygoid plate of the sphenoid bone. **2,** Pterygopalatine fossa. **3,** Posterior surface of the maxilla. **4,** Maxillary sinus.

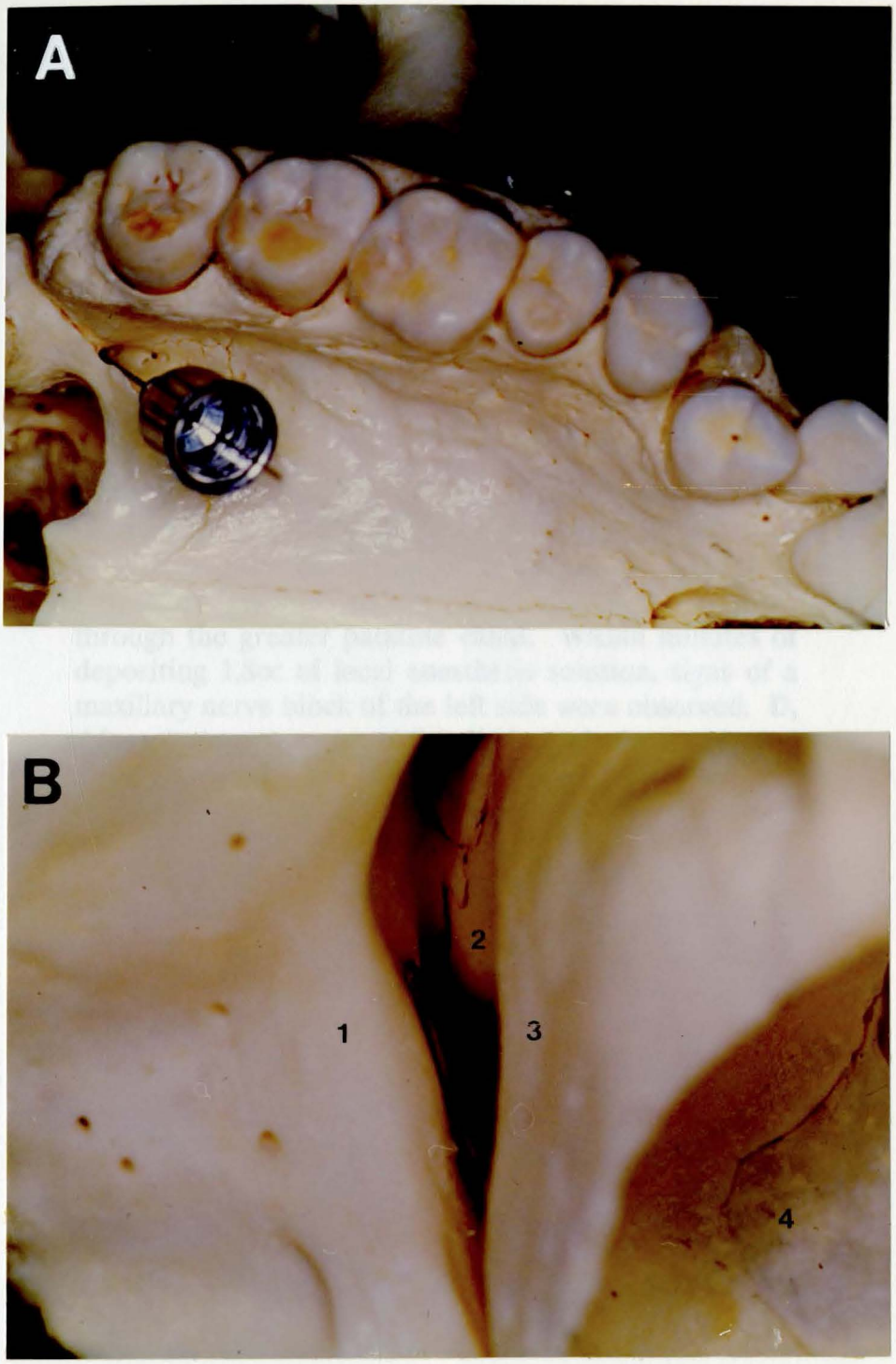

Figure 1

Figure 2: Endodontic indication for the maxillary nerve block by way of the greater palatine canal. **A,** Intraoral view of the left maxillary quadrant of a 14 year old male patient who presented in pain with a dento-alveolar abscess involving the maxillary left first molar (tooth no. 14). Tooth no. 14 was found to be mobile and tender to percussion. In addition, the patient had an infraorbital swelling secondary to the abscess. **B,** Radiograph of tooth no. 14 which reveals existing incomplete endodontic therapy (started by another dentist) of a three year duration and a radiolucency associated with the mesiobuccal root. **C,** Injection needle advanced through the greater palatine canal. Within minutes of depositing 1.8cc of local anesthetic solution, signs of a maxillary nerve block of the left side were observed. **D,** After drainage was established through the tooth and canal preparation completed, an incision and drainage of the intraoral swelling was performed. Both the canal preparation as well as the incision and drainage were completed without discomfort or the need for any additional local anesthetic injection. **E,** Intraoral view 10 days after the incision and draining procedure which shows complete healing. **F,** Six months postoperative radiograph after completed endodontic therapy showing resolution of the periapical radiolucency.

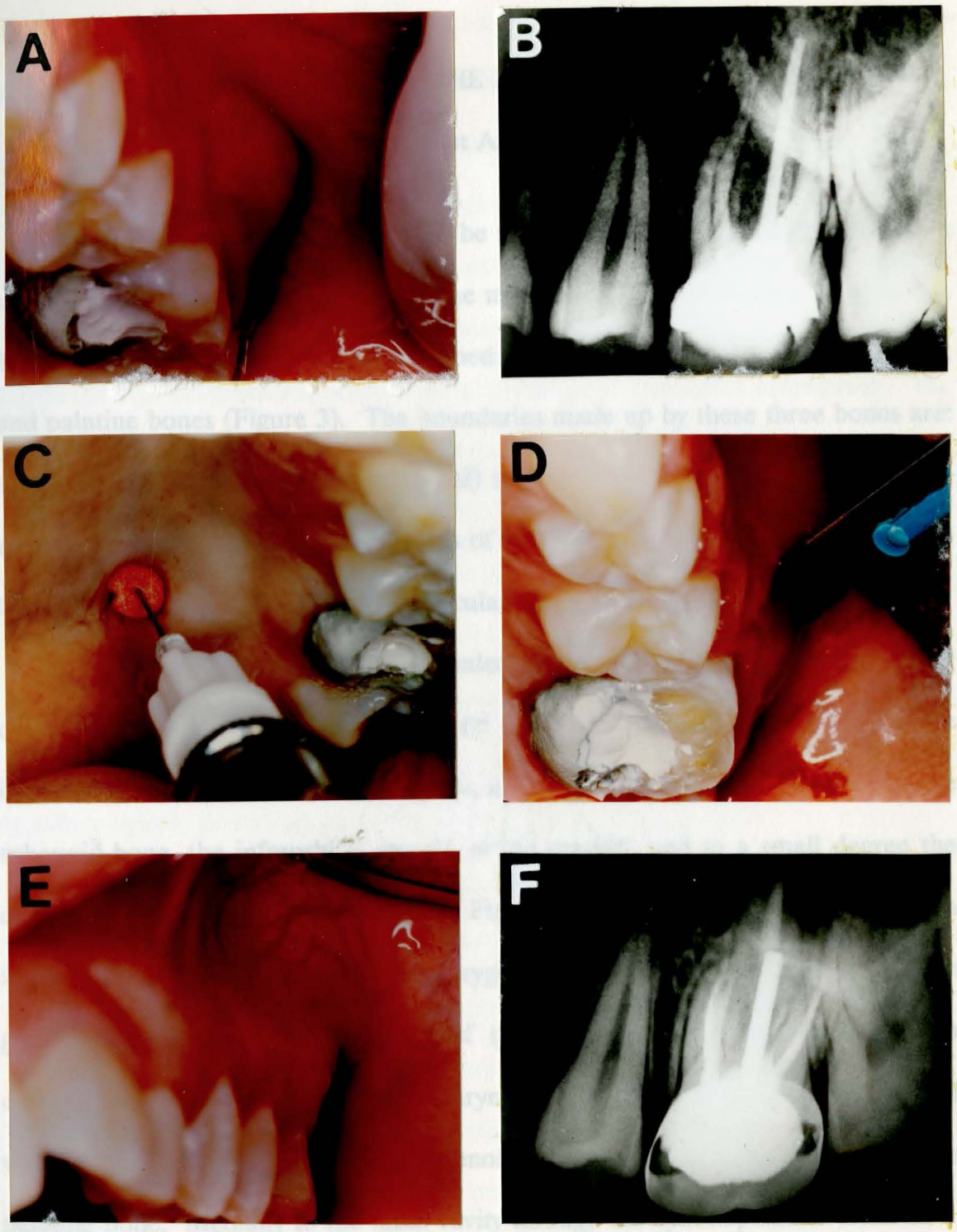

Figure 2

REVIEW OF THE LITERATURE

Pertinent Anatomy

For the maxillary nerve block to be successful, the anesthetic solution must reach the pterygopalatine fossa where the main trunk of the maxillary division lies. The pterygopalatine fossa is a funnel-shaped space[32] formed by the maxilla, sphenoid, and palatine bones (Figure 3). The boundaries made up by these three bones are: anteriorly by the posterior (infratemporal) surface of the maxilla, posteriorly by the anterior surface of the pterygoid process of the sphenoid bone, and medially by the lateral surface of the vertical (perpendicular) plate of the palatine bone.

The pterygopalatine fossa communicates with several cavities or spaces in the cranium, which include: superiorly and anteriorly with the orbit through the infraorbital fissure which is formed by the inferior border of the greater wing of the sphenoid bone, the infraorbital margin of the maxilla, and to a small degree the orbital process of the palatine bone. Posteriorly with the middle cranial fossa through the foramen rotundum and pterygoid canal which are both located in the greater wing and pterygoid process of the sphenoid bone respectively. Also communicating posteriorly with the pharynx by way of the small pharyngeal canal which is formed by the body of the sphenoid bone and the sphenoid process of the palatine bone. Medially to the nasal cavity through the sphenopalatine foramen

which lies just posterior and immediately above the posterior end of the middle concha.[33] The sphenopalatine foramen is formed by the body of the sphenoid bone and the sphenopalatine notch which is created by the sphenoid and orbital processes of the vertical plate of the palatine bone. Laterally to the infratemporal fossa through the pterygomaxillary fissure which is created by the anterior border of the lateral pterygoid plate of the sphenoid bone and the posterior surface of the maxilla. Lastly, the pterygopalatine fossa communicates inferiorly with the hard and soft palate through the greater and lesser palatine canals and foramina respectively. The greater palatine canal and foramen are formed by the greater palatine grooves found in both the posterior medial portion of the maxillary and the lateral surface of the vertical plate of the palatine bones. There are usually two lesser palatine canals and foramina which are found in the pyramidal process of the palatine bones.

The contents of the pterygopalatine fossa include the maxillary nerve and pterygopalatine ganglion along with their branches, the terminal branches of the maxillary artery, as well as fascia and adipose tissue (Figure 4).

The maxillary nerve is a branch of the trigeminal or fifth cranial nerve. The name trigeminal means three twins and refers to its three main divisions: the ophthalmic, maxillary, and mandibular nerves.[34] The three divisions arise from the trigeminal (gasserian, semilunar) ganglion which lies in a depression (trigeminal, Meckle's cave) along the floor of the middle cranial fossa. The maxillary nerve (second division, V_2) emerges as a middle branch from the more superiorly positioned ophthalmic (first division, V_1) branch which is the smallest of the three divisions and

the more inferiorly positioned mandibular (third division,V_3) branch which is the largest of the three divisions (Figure 5A).

The trigeminal nerve is a mixture of both sensory and motor components as was discovered by Sir Charles Bell from his experimental work on animals.[35,36] Its three divisions provide the majority of the sensory innervation (general somatic afferent) to the superficial and deep face (Figure 5B).[37,38,39]

The ophthalmic division carries sensory information from the skin of the upper eyelid and side of the nose, the iris, cornea, and conjunctiva. It also ramifies over portions of the dura matter, scalp, nasal septum, lateral nasal wall, and the anterior and posterior ethmoidal air cells.

The mandibular division delivers sensory innervation to the temporomandibular joint, mandible, mandibular mucosa and gingiva, mandibular teeth, mucosa of the floor of the mouth, buccal mucosa, lower lip, along with the skin from the chin posterior along the mandible to the preauricular area and dura matter. It also provides innervation to portions of the scalp, external auditory meatus, and tympanic membrane. The mandibular division supplies general sensory to the anterior two-thirds of the tongue (general visceral afferent) and a motor root (special visceral efferent) to the muscles of mastication, tensor tympani, tensor (veli) palatine, mylohyoid, and anterior belly of digastric.

The maxillary nerve gives rise to a number of branches along its course (Figure 6). The origins of these branches are in four locations: the middle cranial fossa, pterygopalatine fossa, infraorbital canal, and the face.[40]

Still within the middle cranial fossa, the maxillary nerve gives off a middle meningeal nerve which supplies, in part, the dura matter. The maxillary nerve then exits the middle cranial fossa through the foramen rotundum to enter the pterygopalatine fossa, where it immediately gives rise to two more branches, the zygomatic and pterygopalatine nerves.

The zygomatic nerve exit the pterygopalatine fossa through the infraorbital fissure to enter the orbit where it divides into the zygomaticotemporal and zygomaticofacial nerves. The zygomaticotemporal nerve runs along the lateral wall of the orbit before coursing through the zygomaticoorbital foramen within the zygomatic bone and onto the face to ramify over the anterior temporal region. The zygomaticofacial nerve runs inferior to its counterpart until leaving the orbit through the zygomaticofacial foramen also found within the zygomatic bone to emerge onto the face to provide innervation to the malar region.

The pterygopalatine nerve usually emerges as two distinct branches from the maxillary nerve. These two branches run inferior and medially for a short distance until intersecting the pterygopalatine ganglion. It was originally thought that the pterygopalatine nerves passed through the ganglion as continuous sensory fibers;[41] however, there is evidence that these sensory fibers interact with autonomic fibers within the ganglion resembling an axon reflux mechanism.[42,43] But as the pterygopalatine nerves traverse the ganglion, they break up into four branches: the pharyngeal, orbital, posterior superior nasal, and palatine nerves.

The pharyngeal nerve courses posterior to leave the pterygopalatine fossa

through the pharyngeal canal, where it ramifies over the mucosa of the posterior nasal pharynx. The orbital nerve also leaves the pterygopalatine fossa, where it courses through the infraorbital fissure to provide innervation to the periosteum of the orbit and mucous membranes of the posterior ethmoidal and sphenoid sinuses. A separate orbital branch, called the "orbitociliary nerve," has been reported in monkeys.[44] Unlike the orbital nerve, which is a branch from the pterygopalatine nerve, the orbitociliary was found to project from the main maxillary nerve trunk and has been traced to the retro-orbital plexus of the autonomic nerves.[44]

The posterior superior nasal nerve exits the pterygopalatine fossa and enters the nasal cavity through the sphenopalatine foramen. Within the nasal cavity, this nerve branches extensively to supply portions of the nasal cavity, which include the superior and middle conchae, posterior ethmoidal sinuses, posterior septum, and overlying mucous membranes. Other portions of the nasal cavity receive general sensory innervation from branches of the olfactory, or first cranial nerve, and anterior ethmoidal branches of the ophthalmic division (Figures 7A and B). The nasopalatine nerve emerges as the largest branch of the posterior superior nasal nerve. The nasopalatine nerve courses anterior across the roof of the nasal cavity where it crosses the septum and descends through the incisive canal and foramen of the maxilla to emerge onto the hard palate. Here the terminal branches of the nasopalatine nerve ramify over the anterior one third of the hard palate.

The palatine nerve descends inferiorly through the pterygopalatine fossa where it divides into the greater and lesser palatine nerves. The greater palatine nerve

courses through the greater palatine canal towards the greater palatine foramen. While within the greater palatine canal, it gives rise to the posterior inferior nasal nerve. This branch passes anterior and medial through the vertical plate of the palatine bone at the level of the conchal crest to the nasal cavity to ramify over the middle and inferior meatuses, inferior nasal concha, and overlying mucosa (Figure 7B). As the greater palatine nerve continues to descend through the greater palatine canal, it passes through the greater palatine foramen. Here the nerve turns anteriorly and runs along the palatine process of the maxilla where it divides extensively to supply the posterior two thirds of the hard palate and overlaps with the terminal branches of the nasopalatine nerve (Figure 8). The lesser palatine nerve descends through its own canal posterior to its counterpart until it emerges onto the palate through usually two lesser palatine foramina. The lesser palatine nerves course posterior from the foramina to provide the majority of general sensory innervation to the soft palate. To a minor degree, portions of the soft palate receive ordinary sensory innervation (general somatic afferent) from the glossopharyngeal, or ninth cranial nerve, and innervation of taste buds (special visceral afferent) from the facial, or seventh cranial nerve (Figure 8).[45,46,47]

As the maxillary nerve courses through the superior aspect of the pterygopalatine fossa in an anteriorlateral direction, it enters the infraorbital groove and canal formed by the maxilla. Here as a continuation of the maxillary nerve, it becomes properly termed the infraorbital nerve. The infraorbital nerve runs anterior within its bony canal inferior to the orbit and superior to the maxillary sinus until it

emerges through the infraorbital foramen and onto the face. Exiting through the foramen, the infraorbital nerve divides into three branches: the superior labial nerve which descends towards the upper lip, the external nasal nerve which turns medial towards the nasal process, and the inferior palpebral nerve which takes a superior bend towards the infraorbital rim. These branches provide innervation to the cheek, upper lip, side of the nose, and the lower eye lid.

From the maxillary and infraorbital nerve trunk arise the anterior, middle, and posterior superior alveolar nerves. These three branches not only ramify over the maxillary sinus, along with the nasal branches, but also form the superior gingival nerves and the superior dental plexus. The superior dental plexus is a mass network of nerve branches that supplies innervation to the dental pulps and the surrounding dentin of the maxillary teeth, as well as the alveolar bone, periodontal ligament spaces, and contributes to gingival tissues along with the surrounding facial, buccal, and palatal nerves (Figure 8).[48]

The anterior superior alveolar nerve arises laterally from the infraorbital trunk as one to three branches while it is in the infraorbital canal.[49,50] It may originate along either the anterior, middle, or posterior third of the infraorbital nerve trunk.[49,50] The anterior superior alveolar nerve runs below the orbital floor where it turns inferiorly along the anterior wall of the sinus to supply the anterior portion of the dental plexus that innervates the maxillary anterior teeth.[49,50] Branches of the nasopalatine nerve have been found in close proximity to the apices of the maxillary central incisors and may also contribute to their innervation.[50] The presence of the

middle superior alveolar nerve has been questionable;[49] however, there are several investigators who have reported its presence from 30 to 72% of the time.[50-54] Classically, the middle superior alveolar nerve originates from the infraorbital nerve in the posterior half of the infraorbital canal and is found within either the posterior, lateral, or anterior wall of the maxillary sinuses on its way to the alveolus.[53] When present, the middle superior alveolar nerve contributes to the dental plexus that supplies the maxillary premolar teeth. If absent, the maxillary premolar teeth receive innervation from both the anterior and posterior superior alveolar nerves.[50,53,54] The posterior superior alveolar nerve may emerge as one to four branches from the maxillary nerve before it enters the infraorbital groove.[49,51,54] Its branches travel from the pterygopalatine fossa and through the infratemporal fossa along the posterior surface of the maxilla where its branches enter several alveolar foramina of the maxilla. The posterior superior alveolar nerve contributes to the posterior aspect of the dental plexus which provide innervation to the maxillary second and third molars, approximately 88% of the first molars, and a portion of the first and second premolars.[55] To a lesser degree, the anterior and middle superior alveolar nerves may contribute to the innervation of the maxillary first molar.[55]

The pterygopalatine (sphenopalatine, Meckle's) ganglion is a parasympathetic ganglion for the facial nerve and is usually the largest of three such ganglia located in the head. The other two are the ciliary ganglion for the oculomotor, or third cranial nerve, and the otic or Arnold's ganglion for the glossopharyngeal nerve. These three ganglion are associated with the three divisions of the trigeminal nerve:

the ciliary ganglion with the ophthalmic division, the pterygopalatine ganglion with the maxillary division, and the otic ganglion with the mandibular division.

Because the pterygopalatine ganglion lies in close proximity to the main maxillary nerve trunk, it and its branches also succumb to the effects of the maxillary nerve block. The pterygopalatine ganglion is located in the posterior superior aspect of the pterygopalatine fossa along the pterygoid process of the sphenoid bone. It is suspended between the pterygopalatine nerves and the more medially located nerve of pterygoid canal (Vidian nerve).

The nerve of pterygoid canal enters into the pterygopalatine fossa through the pterygoid canal. This nerve is formed by the junction of the greater and deep petrosal nerves at the posterior entrance of the pterygoid canal (Figure 9). The greater petrosal nerve is made up of preganglionic parasympathetic fibers (general visceral efferent) originating from the facial nerve. The deep petrosal nerve is a branch from the internal carotid plexus which is composed of postganglionic sympathetic fibers. This autonomic plexus originates chiefly from the superior cervical ganglion where the preganglionic sympathetic nerves synapse with postganglionic fibers. The internal carotid plexus is formed by a network of postganglionic sympathetic fibers that intimately follows along with the internal carotid artery in its superior path through the neck and head.

The postganglionic sympathetic fibers traverse the pterygopalatine ganglion dividing into different branches but do not synapse. However, the preganglionic parasympathetic fibers of the facial nerve do synapse in the ganglion with

postganglionic fibers (Figure 9). Thus the composition of nerves emerging from the pterygopalatine ganglion are sensory branches from the maxillary division (already discussed) as well as postganglionic parasympathic and sympathetic fibers.[56]

The postganglionic parasympathetic fibers from the pterygopalatine ganglion accompany selected branches of the maxillary nerve to their destination to provide a secretory and vasodilatory function.[57] These branches extend to the nasal cavity, pharynx, palate, and lacrimal gland.[58,59] The parasympathetic fibers reach the lacrimal gland by way of the zygomatic nerve and a communication branch to the lacrimal nerve which is a branch of the ophthalmic division. In cats, the eye has been shown to receive parasympathetic innervation from both the ciliary and pterygopalatine ganglia.[60,61] The orbital rami from the pterygopalatine ganglion join the internal carotid plexus to form the retro-orbital plexus before entering the eye.[61]

There is evidence that these parasympathetic fibers from the pterygopalatine ganglion also travel with the pterygopalatine, zygomaticotemporal, zygomaticofacial, as well as the anterior, middle, and posterior superior alveolar nerves.[62] Postganglionic parasympathetic fibers from the otic ganglion have been demonstrated along all the ramifications of the mandibular division including the inferior alveolar nerve and the dental pulps of the mandibular teeth.[63,64] Since parasympathetic fibers project along the superior alveolar nerves, it may be reasoned that they also reach to the dental pulps of the maxillary teeth as well, but have yet to be demonstrated.

The postganglionic sympathetic fibers reach similar locations as its parasympathetic counterpart to provide a vasoconstrictive activity to tissues like the

nasal mucosa and lacrimal gland.[65,66,67] Sympathetic innervation also reaches the oral tissues by way of the external carotid plexus.[68] The plexus follows along the branches of the maxillary artery to its destination such as the dental pulp.[68,69,70] The sympathetic fibers that accompany the branches of the maxillary artery through the pterygopalatine fossa, theoretically, would also be effected by the maxillary nerve block.

The maxillary artery arises from the ascending external carotid artery at approximately the level of the condylar notch. The maxillary artery courses through the infratemporal fossa, giving off several branches which include the inferior alveolar artery. The maxillary artery terminates at the pterygopalatine fossa as four branches: the posterior superior alveolar, infraorbital, sphenopalatine, and descending palatine arteries (Figure 10A). Both the posterior superior alveolar and infraorbital arteries accompany the corresponding nerves from the maxillary division to their destination but may not enter the pterygopalatine fossa. However, the sphenopalatine and descending palatine arteries both enter the pterygopalatine fossa (Figure 10A and B). The sphenopalatine artery ascends for a short distance where it joins with the posterior superior nasal nerve through the sphenopalatine foramen to the nasal cavity. The descending palatine artery divides and joins the greater and lesser palatine nerves to the hard and soft palates respectively.

Figure 3: The pterygopalatine fossa (right side). **1,** Maxilla. **2,** Posterior surface of the maxilla. **3,** Lateral pterygoid plate of the sphenoid bone. **4,** Vertical plate of the palatine bone. **5,** Sphenopalatine foramen.

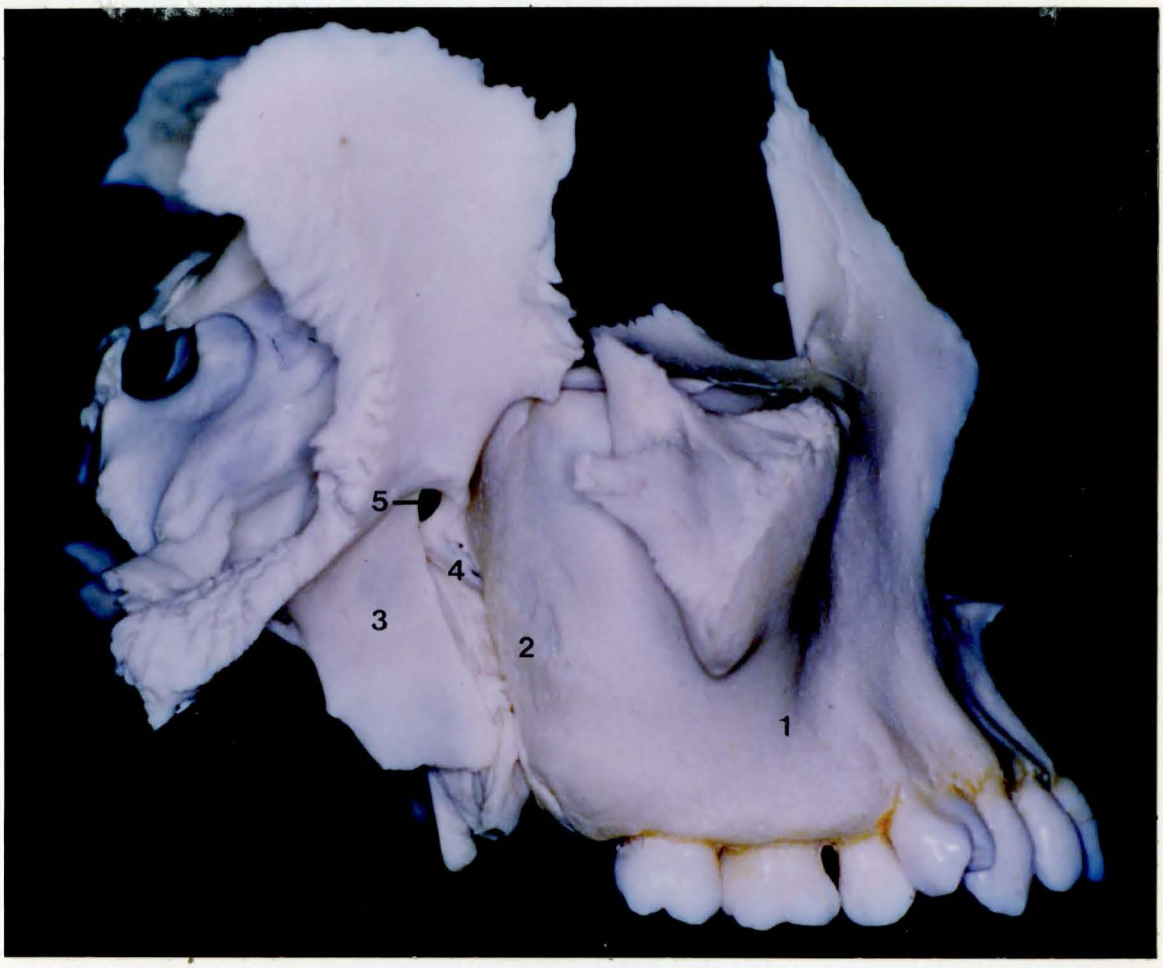

Figure 3

Figure 4: Contents of the pterygopalatine fossa (right side, after removal of the medial and portion of the anterior walls of the pterygopalatine fossa, as well as fascia and adipose tissue). **1,** Maxillary nerve. **2,** Foramen rotundum. **3,** Pterygopalatine nerve. **4,** Pterygopalatine ganglion. **5,** Nerve of the pterygoid canal. **6,** Descending palatine nerve. **7,** Greater palatine nerve. **8,** Lesser palatine nerve. **9,** Greater palatine foramen (portion removed). **10,** Lesser palatine foramen. **11,** Maxillary artery. **12,** Sphenopalatine artery. **13,** Descending palatine artery.

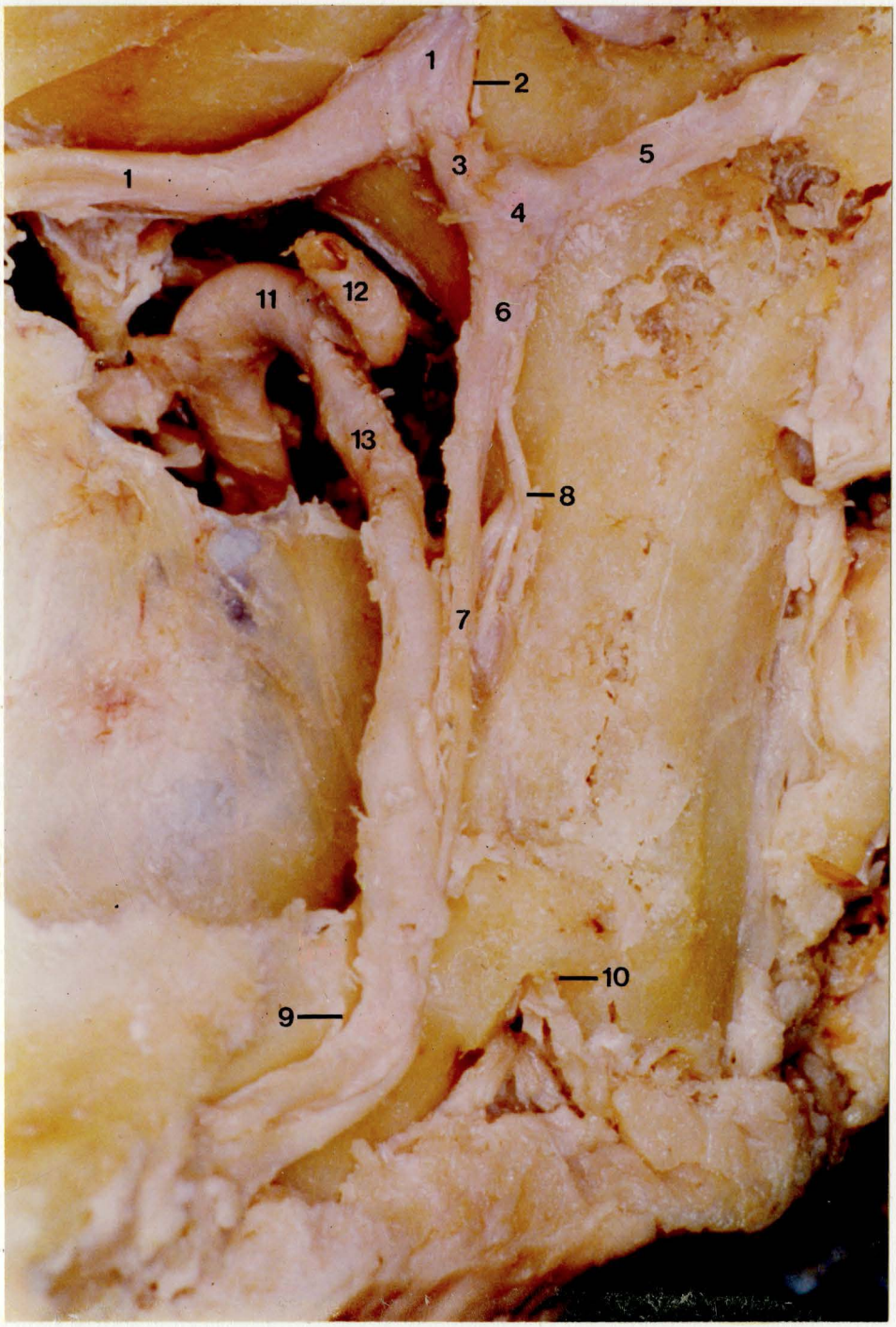

Figure 4

Figure 5: The trigeminal nerve. **A,** The trigeminal ganglion along with the ophthalmic, maxillary, and mandibular divisions. **B,** Approximate distribution of sensory innervation to the head and neck by the ophthalmic, maxillary, and mandibular divisions of the trigeminal nerves and cervical nerves (C-2,C-3).

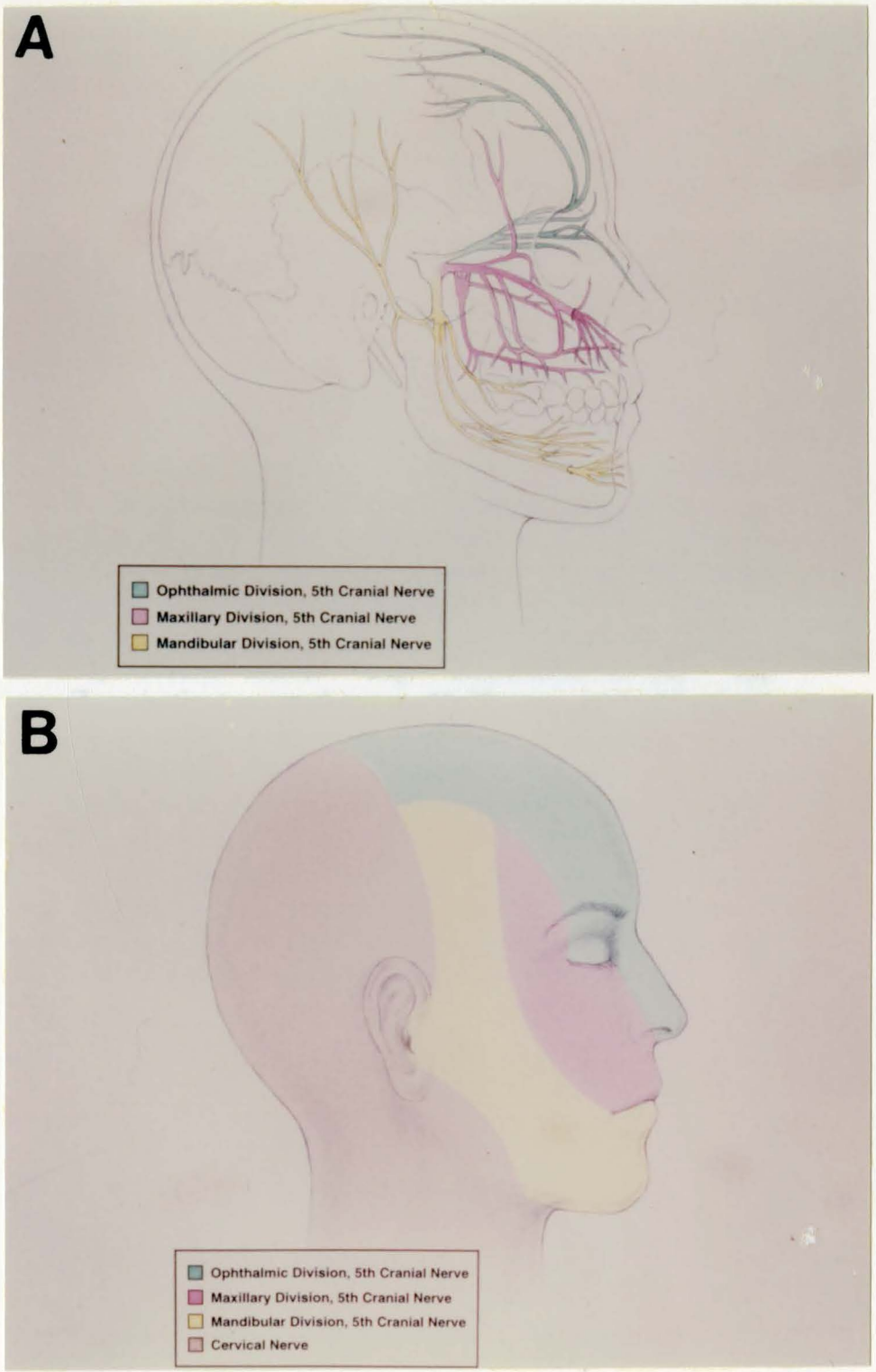
A
Ophthalmic Division, 5th Cranial Nerve
Maxillary Division, 5th Cranial Nerve
Mandibular Division, 5th Cranial Nerve
B
Ophthalmic Division, 5th Cranial Nerve
Maxillary Division, 5th Cranial Nerve
Mandibular Division, 5th Cranial Nerve
Cervical Nerve

Figure 5

Figure 6: Branches of the maxillary nerve. **1,** Trigeminal ganglion. **2,** Ophthalmic division of the trigeminal nerve. **3,** Maxillary division of the trigeminal nerve. **4,** Mandibular division of the trigeminal nerve. **5,** Middle meningeal nerve. **6,** Nerve of pterygoid canal. **7,** Pharyngeal nerve. **8,** Pterygopalatine ganglion. **9,** Pterygopalatine nerves. **10,** Orbital nerve. **11,** Zygomatic nerve. **12,** Zygomaticotemporal nerve. **13,** Zygomaticofacial nerve. **14,** Posterior inferior nasal nerve. **15,** Lesser palatine nerve. **16,** Greater palatine nerve. **17,** Posterior superior alveolar nerve. **18,** Superior gingival nerves. **19,** Middle superior alveolar nerve. **20,** Superior dental plexus. **21,** Nasopalatine nerve. **22,** Infraorbital nerve. **23,** Inferior palpebral nerve. **24,** External nasal nerve. **25,** Superior labial nerve. **26,** Anterior superior alveolar nerve. **27,** Posterior superior nasal nerve.

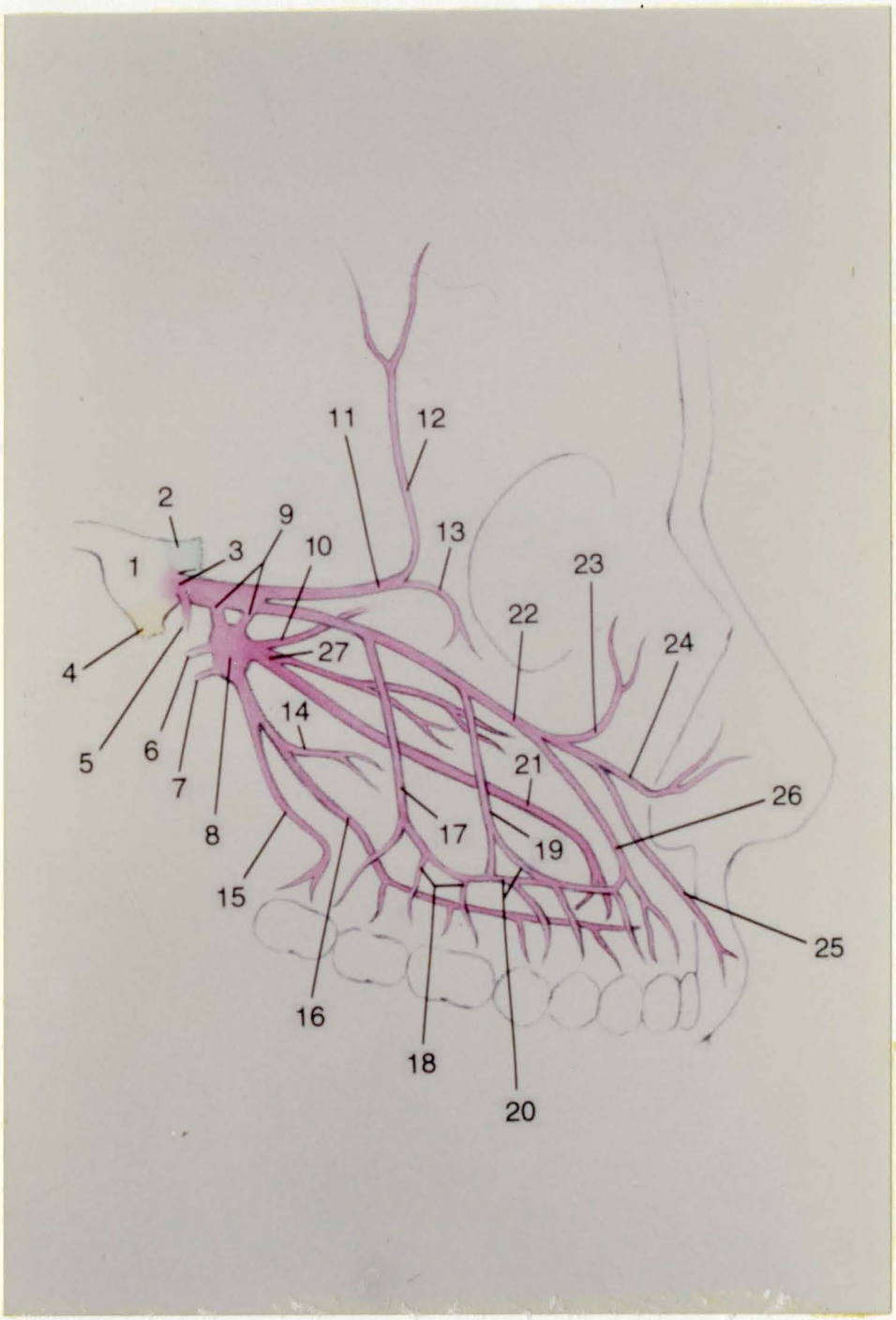

Figure 6

Figure 7: General sensory supply to the nasal cavity. Approximate distribution of sensory innervation to the nasal cavity by branches of the olfactory (I) nerve, anterior ethmoidal branch from the ophthalmic division of the trigeminal (V) nerve, and the posterior superior nasal and posterior inferior nasal branches from the maxillary division of the trigeminal nerve. **A,** The nasal septum. **B,** The lateral wall of the right nasal cavity.

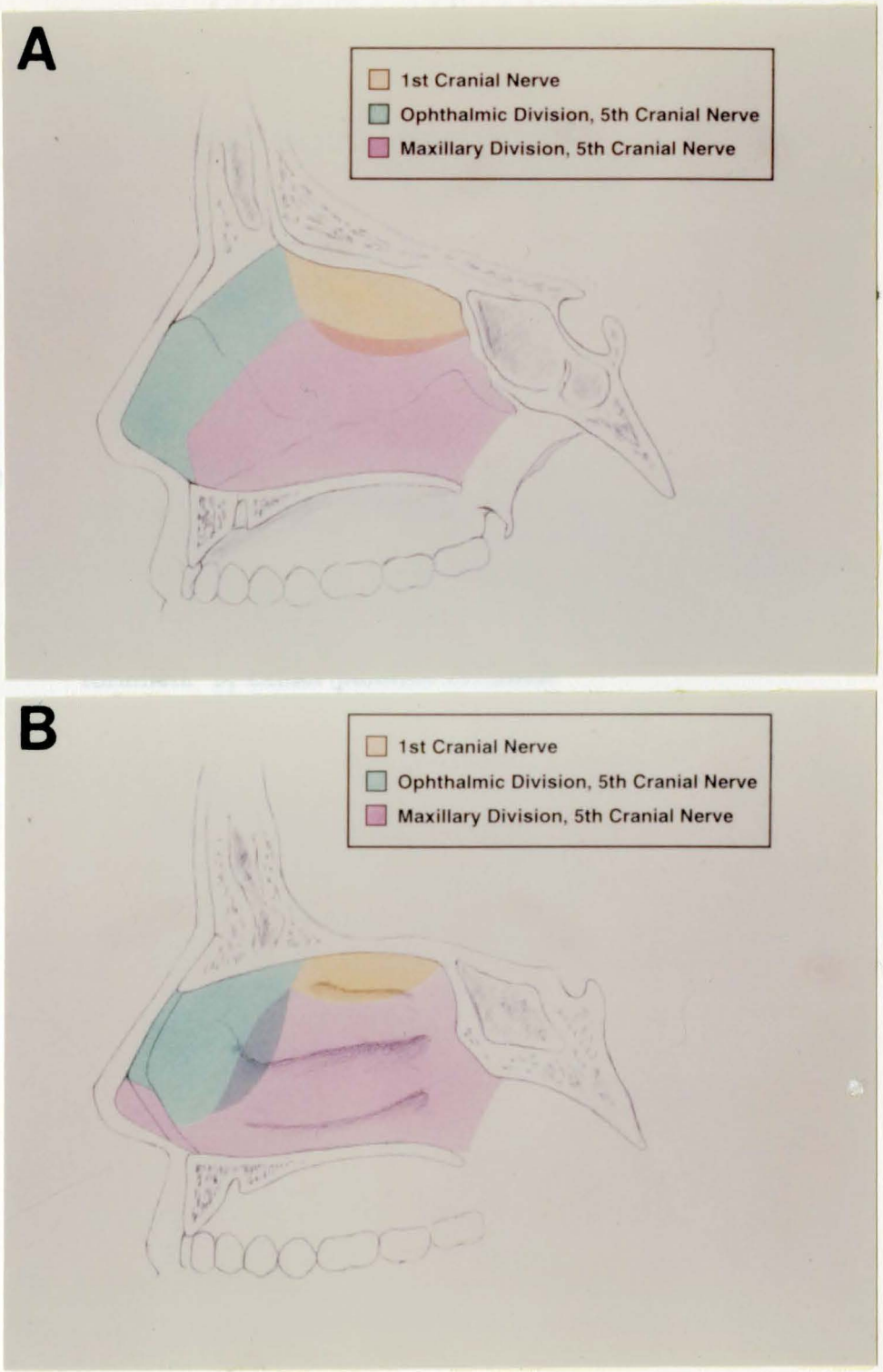
A
1st Cranial Nerve
Ophthalmic Division, 5th Cranial Nerve
Maxillary Division, 5th Cranial Nerve
B
1st Cranial Nerve
Ophthalmic Division, 5th Cranial Nerve
Maxillary Division, 5th Cranial Nerve

Figure 7

Figure 8: General sensory supply to the maxillary portion of the oral cavity. Approximate distribution of sensory innervation to the palate, maxillary teeth and gingival, buccal mucosa, and upper lip by branches of the trigeminal (V), facial (VII), and glossopharyngeal (IX) nerves. **1,** Incisive foramen. **2,** Greater Palatine foramen. **3,** Lesser palatine foramen.

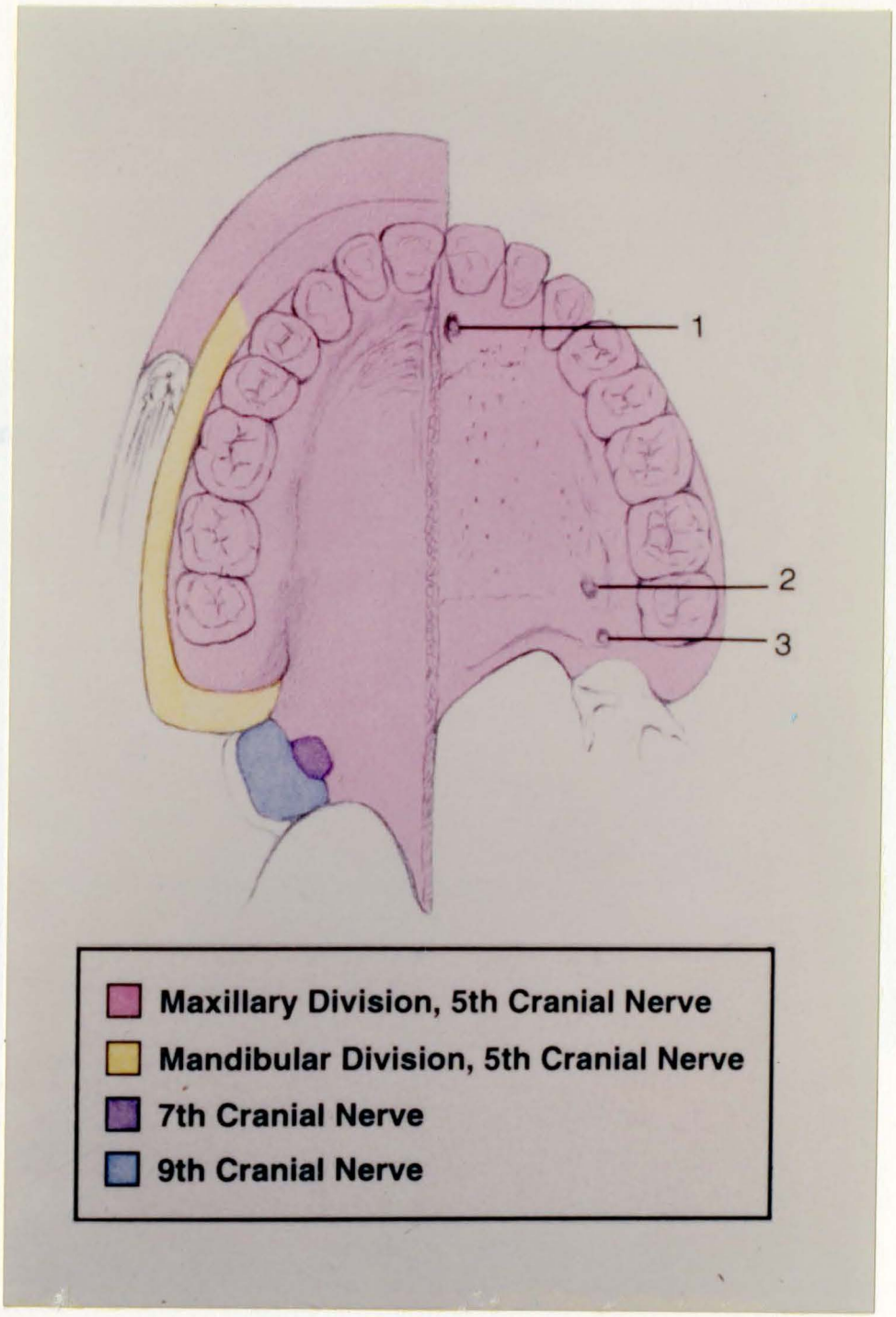
1
2
3
Maxillary Division, 5th Cranial Nerve
Mandibular Division, 5th Cranial Nerve
7th Cranial Nerve
9th Cranial Nerve

Figure 8

Figure 9: The autonomic component of the pterygopalatine ganglion. The nerve of the pterygoid canal is formed by the greater petrosal nerve which carries preganglionic parasympathetic from the seventh cranial nerve, and by the deep petrosal nerve which carries postganglionic sympathetic fibers from the internal carotid plexus. The preganglionic parasympathetic fibers synapse with postganglionic fibers in the pterygopalatine ganglion. From the ganglion, postganglionic sympathetic and parasympathetic fibers distribute along the branches of the maxillary nerve. The postganglionic autonomic fibers reach the lacrimal gland through a communication branch that joins the lacrimal nerve (a branch of the ophthalmic division of the trigenimal nerve).

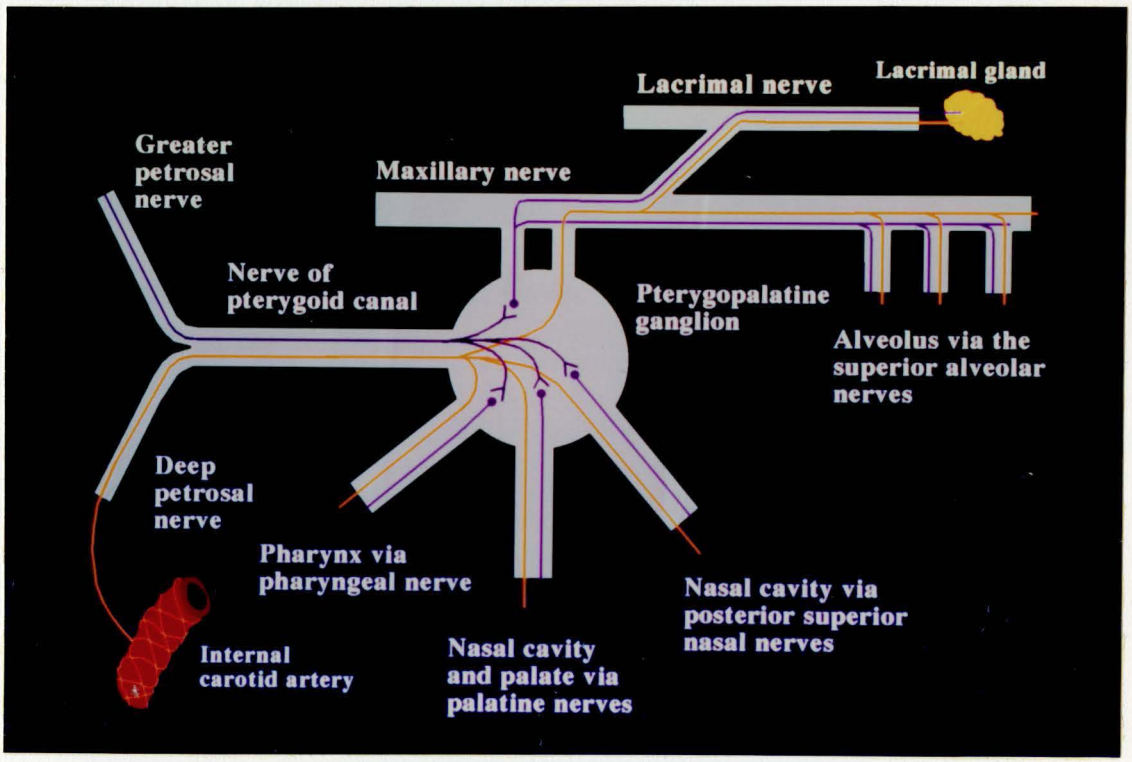
Lacrimal nerve
Lacrimal gland
Greater petrosal nerve
Maxillary nerve
Nerve of pterygoid canal
Pterygopalatine ganglion
Alveolus via the superior alveolar nerves
Deep petrosal nerve
Pharynx via pharyngeal nerve
Nasal cavity via posterior superior nasal nerves
Internal carotid artery
Nasal cavity and palate via palatine nerves

Figure 9

Figure 10: Terminal branches of the maxillary artery. **A,** Branches in the infratemporal and pterygopalatine fossa. **1,** External carotid artery. **2,** Condylar process. **3,** Maxillary artery. **4,** Posterior superior alveolar artery. **5,** Sphenopalatine artery. **6,** Descending palatine artery. **7,** Infraorbital artery. **B,** Branches in the lateral nasal cavity and palate of the right side. **1,** Sphenopalatine foramen. **2,** Sphenopalatine artery. **3,** Lesser palatine artery. **4,** Greater palatine artery. **5,** Lesser palatine foramen. **6,** Greater palatine foramen.

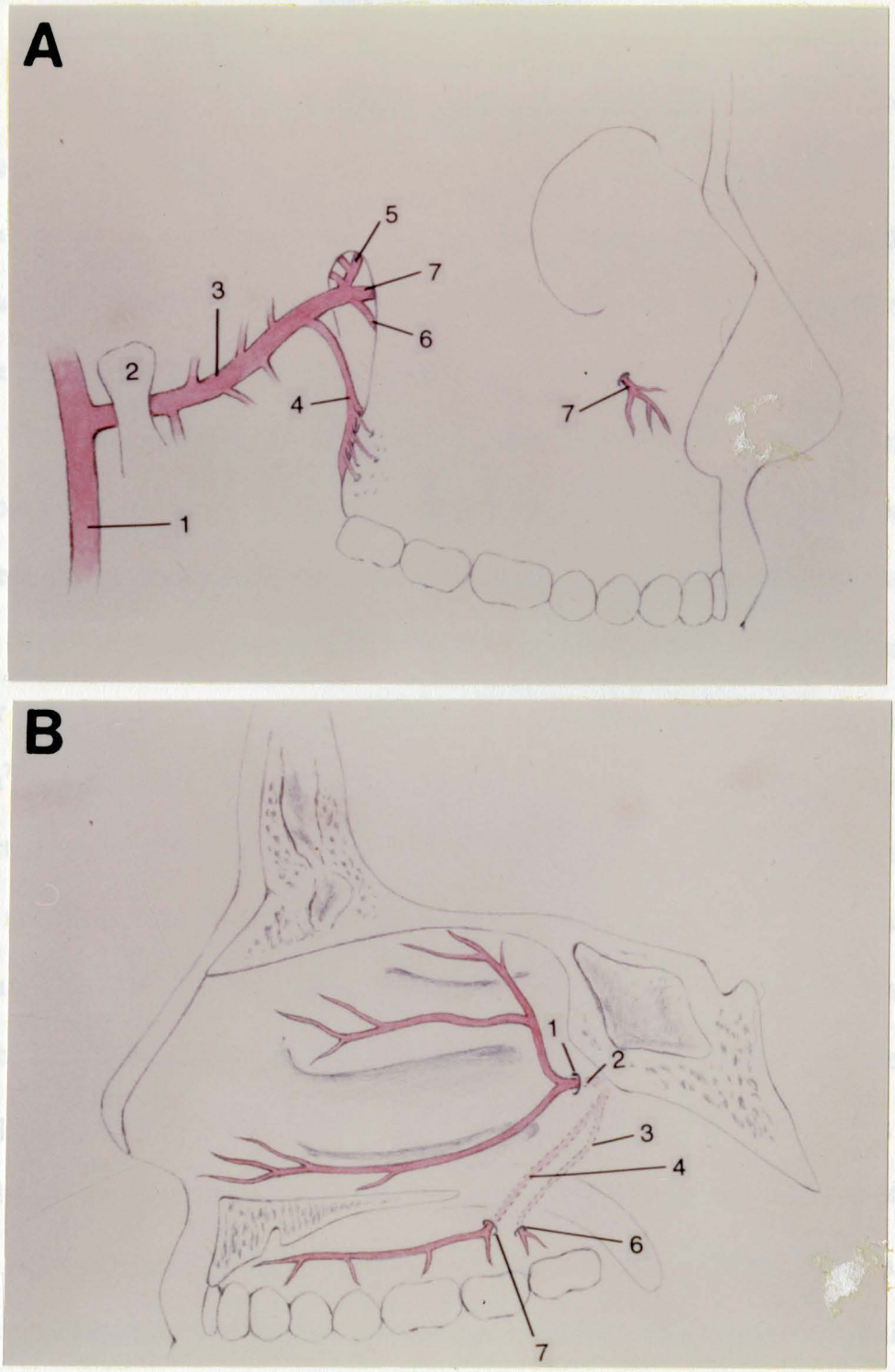

Figure 10

Injection Techniques

A review of the literature reveals a plethora of techniques to achieve profound maxillary nerve anesthesia by way of the greater palatine canal. With all the variations, there are two common themes in methodology: those articles and books that use a standard depth of needle penetration for all patients and those that adjust the needle depth for the individual differences in facial heights.

Using a standard length of needle insertion, Silverman[71,72] in 1923 was the first to report the advantages of the route through the greater palatine canal in order to achieve maxillary nerve anesthesia. His technique required a 22-gauge, 60mm long needle made of nickel. When the needle had reached a depth of 50mm through the greater palatine canal, then 2.0ml of "procain-epinephrin" (sic) solution is injected. Gillam[73] recommended the use of a 25-gauge, $1^{5}/_{8}$ inch (41mm) long needle which is inserted to within $^{3}/_{16}$ of an inch (4mm) of the hub. The remaining $^{3}/_{16}$ of an inch of the needle is used to retrieve the needle in case it should fracture at the hub. Peckham[74] used a $1^{7}/_{8}$ inch (48mm) long 25-gauge needle to deliver a maxillary nerve block. The needle was carried superiorly through the greater palatine canal to a depth of $1^{1}/_{2}$ inches (38mm) where 1.0 to 1.5ml of anesthetic solution was slowly deposited. Lundy[75] recommended carefully advancing a 25-gauge, $1^{5}/_{8}$ inch (41mm) needle "upwards and backwards" through the greater palatine canal. When a depth of about 30mm had been reached, then 2.0ml of anesthetic solution was delivered. Rankow[76,77] inserted a 23-gauge needle similar to Peckham's method of $1^{1}/_{2}$ inches. He suggested using a $1^{5}/_{8}$ or $1^{7}/_{8}$ inch long needle with his technique. Dickson and

Coates[78] advocated a 16-gauge 42mm long stainless steel needle. Once the greater palatine canal was located, the needle was advanced "upwards, backwards, and slightly laterally" to a depth of 39mm, after which 2.0ml of anesthetic solution was slowly injected. Out of 80 cases using their method, they reported 80.0% with complete, 17.5% with partial, and 2.5% with unsuccessful symptoms of maxillary nerve anesthesia. The unsuccessful cases resulted from the failure of the needle to advance through the canal because of bony obstructions. Corbett and Helmore[79] studied a series of skulls and found the approximate distance from the greater palatine foramen to the foramen rotundum was 35mm. Allowing for 4mm of palatal mucosa thickness, "a safe working rule that the needle should be inserted 39mm." They recommended a 42mm 26-gauge needle which was passed gently into the canal, then 2.5 to 3.0ml of 2% procaine with 1:50,000 epinephrine was injected. Using their technique in 95 cases, they found 78.0% with complete, 13.7% with partial, and 2.0% with unsuccessful symptoms of maxillary anesthesia. In 6.3% of the cases, the needle was impeded from advancing through the canal except for a few millimeters. Baddour, et al.[6] used a 27-gauge $1^1/_2$ inch (38mm) needle to deliver a maxillary nerve block prior to nasal intubation. The needle was inserted until its hub contacted the palatal mucosa, then 1.8ml of 2% lidocaine with 1:100,000 epinephrine was injected. Roberts and Sowray[31] recommended a $1^7/_8$ inch (48mm) 25-gauge needle which is fairly rigid but not too thick, otherwise it would not be able to advance superiorly through the greater palatine canal. Once the canal was located, the needle was inserted to a depth of 30mm where 2.0ml of anesthetic solution was slowly deposited.

Arens, et al.[80] employed a $1^5/_8$ inch (41mm) 25-gauge needle to anesthetize the maxillary nerve. After the greater palatine canal was located, the needle was inserted to within 2 to 3mm of the hub, where as much as two cartridges of anesthetic solution was slowly deposited. Sweet and Powell[81] advanced a needle through the canal to a depth not to exceed $1^1/_2$ inches (38mm) where 2.0ml of solution was injected. Allen[82] advised using a 25-gauge long needle gently inserted to a depth of 25mm, where 1.8ml anesthetic solution was injected. He warned that the needle should never be advanced more than 30mm through the greater palatine canal. Bennett's[25] technique paralleled Peckham's by using a 25-gauge $1^5/_8$ inch (41mm) needle which was passed very slowly into the canal at a marked depth not to exceed $1^1/_2$ inches (38mm). Once the needle was at the desired length, then 2.0ml of solution was slowly injected. Cohn[83] preferred to use a 27-gauge long needle with his technique. He stated that if a 37mm length needle was used, it should be inserted to the hub. However, if the needle measured 40 to 41mm, then it was advanced through the greater palatine canal to within 3 to 4mm of the hub. Once the needle had reached its correct length, then 1.8ml of anesthetic solution was deposited. Malamed's[84] technique is similar to Lundy's in which he recommended a 25-gauge long needle for his technique. After the needle had been slowly advanced to a depth of 30mm, 1.8ml of solution was slowly deposited. Finally, Wong and Sved[85] advocated the use of a 27-gauge, 41mm length needle for their technique. The needle was inserted to within 2mm of the hub, then 4.4ml of anesthetic solution was gently introduced into the pterygopalatine fossa.

The recommended standard needle penetration depths for the maxillary nerve block approach through the greater palatine canal are summarized in Table 1. There is a 25mm variation in recommended depths of needle insertion ranging from Silverman[78] at 50mm to Allen[82] at 25mm and a mode length of 38mm.

West[29] was the first to recognize the need for different insertion depths for different facial heights. He advocated the use of a short beveled, 25-gauge needle. The needle was inserted to a depth of $1^1/_2$ inches (38mm) where 2.5 ml of anesthetic solution was injected. But for the larger head, a depth of $1^3/_4$ inches (44mm) was used. Jorgensen[86] felt that even with standard lengths for needle insertion, the maxillary nerve block had fallen into disfavor because of "the inability of the operator to determine the depth of injection essential for optimum anesthesia." Therefore he recorded measurements from 200 adult skulls comparing the distance from the infraorbital margin to the dentin-enamel junction of the bicuspids, labeled the "facial measurement", and the distance from the infraorbital fissure to the dentin-enamel junction of the second molar, referred to as the "needle distance". Jorgensen assumed that the "needle distance" was the ideal needle penetration depth. His results found the facial measurements ranged from 6mm longer to 4mm shorter than the needle distance with the majority of the facial measurements greater than the needle distance. Jorgensen found that by subtracting 1.5mm from the facial measurement, he could approximate the average needle distance, where subtracting 2.0mm would include 84 percent of all people, and subtracting 3.0mm would include 96 percent. Jorgensen reported excellent results with this method after using it on

a large number of patients.[86] He recommended the use of a heavy needle, not less than 25-gauge, with a short bevel for the greater palatine canal approach.[87] Stebbins and Burch[88], as well as Szerlip[89], advocated Jorgensen's technique in order to anesthetize the maxillary nerve. Szerlip arbitrarily used to insert a 25-gauge needle to a depth of $1^1/_4$ inches (32mm) before switching to Jorgensen's adjustable method. Sicher[90] was concerned about the depth the needle could be inserted with the greater palatine approach. He stated, "The needle should not pass too far into the pterygopalatine fossa and should not reach its upper part, which contains the terminal ramification of the maxillary artery." Sicher recommended that the needle be inserted to a maximum depth equal to the measurement from the infraorbital rim to the free alveolar border of the maxillary premolar or canine area. This measurement method is essentially the same as Jorgensen's "facial measurement," but without subtracting 3mm. Jastak and Yagiela[28] stated the maximum depth the needle should be inserted was normally 25 to 30mm. However, they described Sicher's method as a useful technique for determining the correct depth of needle insertion. Mercuri[91] ordinarily advanced a $1^5/_8$ inch (41mm) 25-gauge needle to within 2 to 3mm of its hub. But when the penetration depth was questionable, such as with children and shorter adults, he recommended measuring the distance from the infraorbital foramen to the crest of the alveolus in the second premolar area. Mercuri felt that this distance was a good estimate of penetration depth needed to reach the maxillary nerve in the superior aspect of the pterygopalatine fossa. Malamed and Trieger[92] recorded the distance from Mercuri's measurement method

from 200 skulls, and found the distance to range from 24 to 41mm with an average of 32.16mm. But they added the distance from the infraorbital foramen to the alveolar crest of the maxillary premolars "does not take into consideration the 3-4mm of palatal soft tissue overlying the bone, nor the 1-2mm of soft tissue overlying the alveolar crest between the bicuspids." Using skulls, Cook[30] tried to find a more precise depth of needle insertion by recording 200 measurements from the greater palatine foramen to the foramen rotundum. He found a wide variation in lengths from 30 to 40mm, with an average distance of 35mm. Cook emphasized that the average measurement may be 35mm, but one must be aware of the palatal mucosa depth, which ranges from between 4 to 7mm and is a factor in estimating the depth of needle insertion. Reis Viegas and Hemphill[93] felt that other studies of needle insertion during the maxillary nerve block through the greater palatine canal had focused only on adults and did not take into account gender, race, and age variables. So, they took two measurements from 203 skulls of children, adults, males, females, and different races and devised the following formula: $y = 2.08 + 1.69x_1 + 0.76x_2$, where y is the predicted depth of inserting the needle for skulls; the numbers 2.08, 1.69, and 0.76 are constants; and both x_1 and x_2 are the two measurement variables taken from the face. The two variables are plugged into the equation as measurement in centimeters, where x_1 equals the facial height which corresponds to the distance from the nasion (point between the frontal and two nasal bones) to the gnathion (middle point of the lower border of the mandible at the symphysis) and x_2 equals the zygomatic width which corresponds to the distance between both

zygions (maximum point anteroposteriorally and vertically of the zygomatic arches). After the y value is calculated, the palatal mucosa depth must be added, where 5.0mm mucosa depth is added for adults, 3.0mm for elderly patients, and 2.0mm of thickness for children. Canter, et al.,[94] also examined the length of the pterygopalatine fossa and greater palatine canal using 279 skulls with documented age, sex, and race. They measured from the inferior border of the foramen rotundum within the pterygopalatine fossa to the lateral extreme of the maxillary palatine suture (palatal entrance to the greater palatine canal). As with the study of Reis Viegas and Hemphill, the palatal mucosa depth was not included in the measurement. Canter, et al., also measured the height of the orbit, which was defined as the distance from the supraorbital to the infraorbital margins. The length from the foramen rotundum to the maxillary palatine suture mark ranged from 31 to 34mm with an average of 33mm. The mean height of the orbit was 33mm, from which they concluded that the orbit could be used as an anatomical guide for needle penetration depth. The same investigators did a similar study recording measurements from the same landmarks from 138 specimens except they only looked at craniums of infants and children.[95] They found a significant correlation between the two recorded lengths from the foramen rotundum to the lateral extreme of the maxillary palatine suture and the orbital height. They proposed that regardless of age, the length of the pterygopalatine fossa through the greater palatine canal could be easily determined clinically by measuring the orbital height.

A summary of the different recommended gauge needles is found in Table 2.

There are six different gauges listed, ranging from 16 to 27. The most common needle gauge listed is 25 followed by 27. The single measurement techniques of Jorgensen,[86] Sicher,[90] Mercuri,[91] and Canter et al.[94] used to predict the correct needle insertion depth are summarized in Figure 11.

TABLE 1

SUMMARY OF RECOMMENDED STANDARD PENETRATION DEPTHS OF THE NEEDLE

Author(s), (year)	Needle depth (mm)
Silverman (1923)	50
Gillam (1937)	37
Peckham (1938)	38
Lundy (1942)	30
Rankow (1943)	38
Dickson, Coates (1945)	39
Corbett, Helmore (1948)	39
Baddour, et al. (1979)	38
Roberts, Sowray (1979)	30
Arens, et al. (1981)	39
Sweet, Powell (1983)	38
Allen (1984)	25
Bennett (1984)	38
Cohn (1986)	37
Malamed (1990)	30
Wong, Sved (1991)	39

TABLE 2

SUMMARY OF RECOMMENDED NEEDLE GAUGE

Author(s), (year)	Needle gauge
Silverman (1923)	22
Gillam (1937)	25
West (1937)	25
Peckham (1938)	25
Lundy (1942)	25
Rankow (1943)	23
Dickson, Coates (1945)	16
Corbett, Helmore (1948)	26
Szerlip (1948)	25
Baddour, et al. (1979)	27
Mercuri (1979)	25
Roberts, Sowray (1979)	25
Jorgensen (1980)	25
Arens, et al. (1981)	25
Allen (1984)	25
Bennett (1984)	25
Cohn (1986)	27
Malamed (1990)	25
Wong, Sved (1991)	27

Figure 11: Measurement techniques to determine the needle penetration depth. **1,** Jorgensen's "facial measurement", also used by Sicher, is taken from the infraorbital margin to the dento-enamel junction or the free alveolar border of the maxillary premolar teeth. Sicher's recommended insertion depth is equal to the facial measurement. Jorgensen recommended subtracting 3mm from the facial measurement to obtain his recommended insertion depth. **2,** Mercuri's method from the infraorbital foramen to crest of the alveolus in the second premolar area. **3,** Canter, et al., method from the supraorbital to the infraorbital margins.

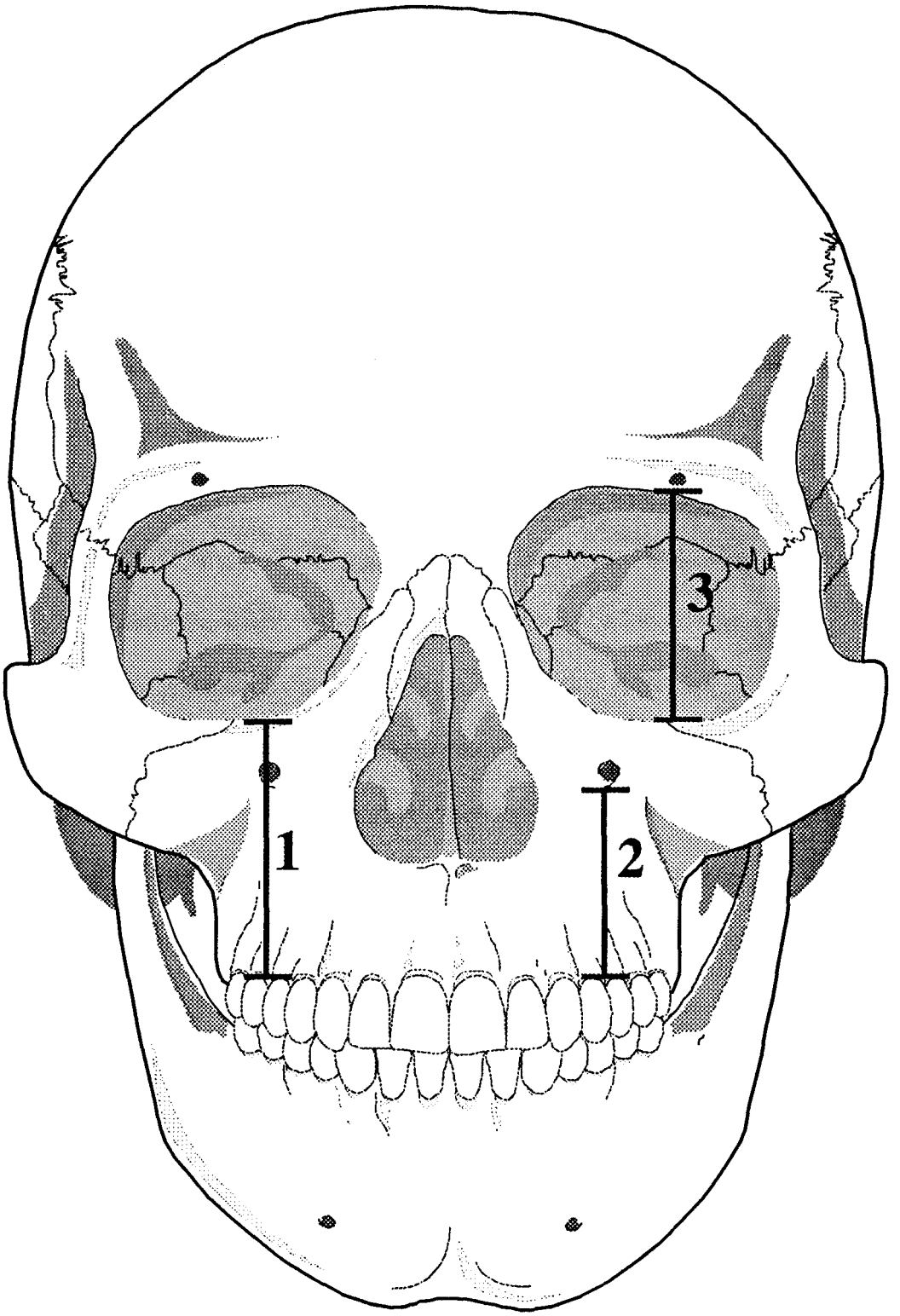

Figure 11

MATERIALS AND METHODS

Forty-four cadaver specimens were obtained for this study from the Loyola University Department of Anatomy. Of the cadavers selected, the average age was 75, with the range being from 51-98 years. There were 21 females, 12 males, and the sex of 11 cadavers was unknown. Each specimen was obtained from a bisected cadaver head, previously dissected by freshmen dental and medical students. The bisection procedure was done along the midsagittal plane following an established protocol.[96] Each specimen used in this study was selected only if the tissues surrounding the injection site, including the walls and the contents of the pterygopalatine fossa, were not previously dissected or damaged, and if the distance from the infraorbital margin to the gingival margin of the maxillary premolar could be measured, henceforth referred to as the *facial measurement*, as coined by Jorgensen,[86] and also used by Sicher[90] (Figure 11). If the specimen was edentulous, then the facial measurement was taken at the alveolar ridge in the area of the missing premolars. If both sides of the bisected head were intact, then the right side was chosen to be in the study. Only 18 of the 45 specimens used in the study had an intact orbit from which to measure the distance recommended by Canter, et al.,[94] which is from the supraorbital to the infraorbital margins, henceforth referred to as the *orbital measurement* (Figure 11).

Forty-three of the specimens were used for the maxillary nerve block study. The remaining specimen was used for histological cross-sections through the greater palatine canal. A block section containing the pterygopalatine fossa and the greater and lesser canals was prepared. The specimen was washed thoroughly and placed into a decalcification solution of equal volumes of 88% formic acid and distilled water.[97] The decalcification process was monitored by radiographic examinations, and when the specimen was determined to be fully decalcified, it was washed, embedded, sectioned, and stained with hematoxylin and eosin. The histological sections of the superior and inferior portions of the greater palatine canal were examined under a light microscope.

For the maxillary nerve block portion of this study, a 27-gauge long needle (35mm)* was attached to an aspirating syringe. A silicone endodontic stop† was then added to the needle to mark off a length of 30mm from the tip. The injection technique was performed as if in a clinical situation following Malamed's recommendations.[84] The initial injection site on the palatal mucosa was lingual to the area of the second or third molars. Upon piercing the palatal mucosa overlying the greater palatine canal, the needle and syringe were angled approximately 45 degrees from the palate. The needle was used to probe the palatine bone until the greater palatine foramen was found, afterwhich the needle was slowly advanced through the greater palatine foramen and canal into the pterygopalatine fossa. If resistance was encountered, the needle was withdrawn a few millimeters, redirected, and then slowly readvanced. Once the needle had been inserted to a depth of

30mm, the syringe was disengaged from the needle, leaving the needle within the specimen (Figure 12A). The injection needle was held in place by a portion of the palatal mucosa while the tissues surrounding the injection needle were dissected out, approaching the pterygopalatine fossa from the lateral wall of the nasal cavity (Figure 12B). The mucoperiosteum covering the vertical portion of the palatine bone, as well as portions of the middle and inferior concha were removed. Next, the anterior and medial walls of the pterygopalatine fossa were cracked by light blows from a chisel. The broken fragments were removed until the contents of the pterygopalatine fossa through to the greater palatine canal were exposed. The connective tissue was then removed from around the needle and surrounding important anatomical structures.

Once the needle was uncovered of its surrounding tissues (Figure 13A), then the following observations were made: the position of the needle in relationship to the pterygopalatine fossa, neurovascular perforations by the needle, the thickness of the palatal mucosa along the path of the needle from the epithelium to the greater palatine foramen, the distance from the needle tip to the descending palatine and sphenopalatine arteries, and the distance from the needle tip to the inferior margin of the maxillary nerve (Figure 13B). From these measurements, the actual distance from the palatal mucosa to the inferior border of the maxillary nerve was derived, henceforth referred to as the *actual measurement*. Using repeated measures statistical analysis, the *actual measurement* was then compared to the different anatomical measuring methods to predict needle insertion depth of Jorgensen, Sicher,

and Canter. Then the distance from the needle tip to the maxillary nerve was then recalculated (from the *actual measurement*) for each specimen as if the needle had been inserted to depths as recommended by Jorgensen, Sicher, and Canter. The needle depths were calculated for Jorgensen's method to be 3mm short of the *facial measurement*,[86] Sicher's were the same as the *facial measurement*,[90] and Canter et al. were equal to the *orbital measurement* of the different specimens.[94] The mean values from the three techniques were then compared to the mean of Malamed's results.

Because there were only 18 specimens with intact orbits from which to take an *orbital measurement*, the data was analyzed in two separate manners. The first analysis group compared the *actual measurement* versus those prepared by Jorgensen and Sicher for all 43 specimens. The second analysis only includes data from the 18 specimens with intact orbits and compares the *actual measurement* against Canter's predicted lengths, as well as, Jorgensen's and Sicher's.

Finally, the data from the different injection techniques of Malamed, Jorgensen, Sicher, and Canter were then adjusted in two different ways. First, the mean values of all four methods were adjusted to best approximate the mean value of the *actual measurement*. Lastly, the measurements from the four were adjusted so that the depth of the needle would not exceed the superior margin of the maxillary nerve.

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† Loyola University, Dept. of Endodontics, Maywood, IL 60153

Figure 12: Dissection approach. **A,** Lateral wall of the nasal cavity of a specimen after a needle has been inserted to a depth of 30mm. **B,** Same specimen after the removal of the anterior and medial wall of the pterygopalatine fossa. The needle has been dissected out along with the important neurovascular structures.

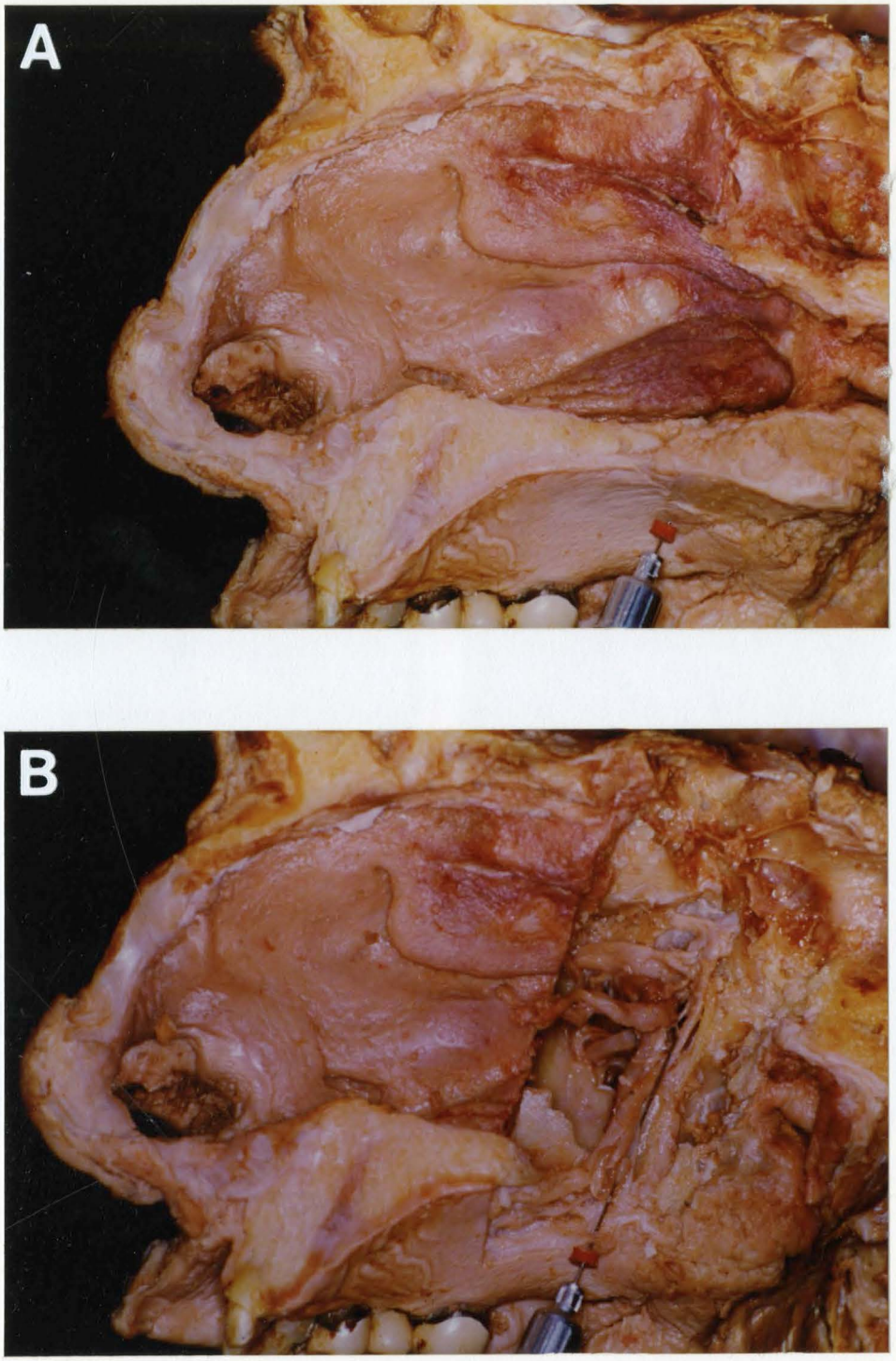


Figure 12

Figure 13: Measurement from the needle to the maxillary nerve. **A,** Completed dissection of the contents of the pterygopalatine fossa. **B,** Measurement from the inferior margin of the maxillary nerve (MN) to the needle tip.

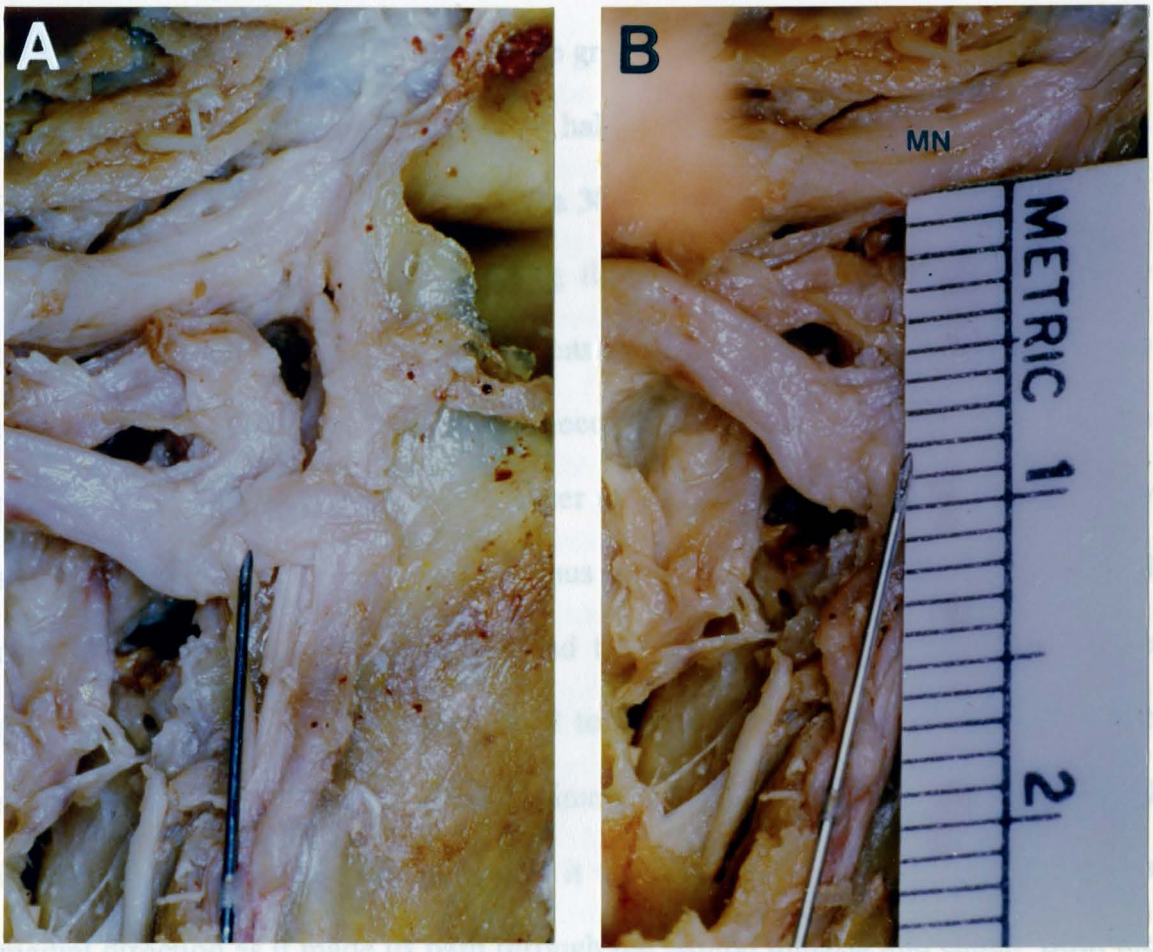


Figure 13

RESULTS

The first part of this study examined the effect of the advancing needle on the tissues of the 43 cadavers. In locating the greater palatine foramen, repositioning of the needle was required in slightly over half of the specimens. Once the foramen was located, the needle was inserted to a 30mm depth.

Significant difficulty in advancing the needle through the greater palatine canal was encountered in three specimens (7.0%). In the specimen in which the most resistance was encountered, the needle was found, after dissection, to have perforated the anterior wall of the greater palatine canal to reside in the maxillary sinus (Figure 14). This specimen was thus dropped from the study. In the second difficult case, the needle perforated and then re-entered the medial wall of the greater palatine canal, which was found to be transparently thin in several of the specimens (Figure 15). In the third specimen with high resistance, the needle stayed in the greater palatine canal, however, it was found to have a gradual bend in a medial direction as it made its path through the palatal mucosa and canal. Both the second and third cases of high resistance were included in the final data.

There was also slight resistance felt in eight additional specimens as the needle was inserted to its full length. After dissection, nothing unusual was found in six of the eight specimens. However, in one specimen, the needle was found to

be slightly curved in an anterior direction as it coursed through the greater palatine canal (Figure 16A). In the second specimen, the needle's path was found to have traveled through the narrower lesser palatine canal to the pterygopalatine fossa and also had a slight bend to it (Figure 16B). All eight of the cases of slight resistance were kept in the final data.

Once the needle was in place, the bony anterior and medial walls of the pterygopalatine fossa were carefully dissected away. In all of the specimens a connective tissue sheath was found to be encapsulating the contents of the fossa (Figure 17). The thickness of the sheath increased in an inferior to superior direction from the greater palatine canal. Once the sheath and the underlying loose connective tissue were removed, the needle and neurovascular components within the pterygopalatine fossa could be fully appreciated.

The maxillary nerve was not violated in any of the specimens, since it was found to lie superior and lateral to the path of the needle in almost every specimen. The pterygopalatine ganglion was also not violated, but it was found to be closer to the needle's path, since it lies medial to the maxillary nerve (Figure 18A).

The descending palatine nerve bundle appeared to be transacted in almost all of the specimens. The needle passed superiorly through the greater palatine foramen, often along the posterior wall of the pterygopalatine fossa, and in most cases without violating any of the vessels (Figures 18B and C). The maxillary artery was not pierced in any of the specimens and was always lateral to the path of the needle. But in 12 of 42 specimens (28.6%) the descending palatine artery was

found to be nicked or pierced which occurred in three general regions along its course: 1) where the artery exits through the greater palatine foramen and onto the palate, in five specimens (Figure 19A); 2) within the greater palatine canal, in three specimens (Figure 19B); and 3) in the pterygopalatine fossa where the artery makes an inferior bend towards the greater palatine canal after branching from the maxillary artery, in four specimens (Figure 19C). In all but two cases (4.8%) of violating the artery, the needle tip passed through and beyond the lumen of the vessel. In the first exception, the needle tip was found within the lumen of the descending palatine artery, as it made its inferior bend toward the greater palatine canal. The other exception involved the only specimen (2.4%) in which the needle pierced the sphenopalatine artery (Figure 19D). This finding occurred in the same specimen where the needle pierced the greater palatine artery as it exited the greater palatine foramen. A summary of the locations where the needle violated the arteries is seen in Figure 20.

Measurements of pertinent soft tissue structures relative to the needle tip were taken on all of the specimens. The distance from the needle tip to the inferior margin of the descending palatine artery ranged from 10.0mm above to 3.0mm below, with a mean distance of the needle tip being 1.3mm above the artery. The distance from the needle tip to the inferior margin of the sphenopalatine artery ranged from 3.0mm above to 8.0mm below the artery, with a mean distance of 2.6mm below the artery. A summary of the distance from the needle top to the descending palatine and sphenopalatine arteries. Lastly, the palatal mucosa thickness ranged from 4.0

to 11.0mm, with a mean of 6.9mm.

The second portion of this study reviewed histological sections of the superior and inferior portions of the greater palatine canal of the undissected 44th specimen. The descending palatine artery was found to be surrounded by several nerve fascicles embedded in connective tissue (Figure 21 and 22). Two lesser palatine canals with the same neurovascular components were also seen (Figure 23). No evidence of a descending palatine vein was observed in the histological section or in the gross dissections of the remaining 42 specimens. Higher power observation of the descending palatine neural bundles found the presence of both myelinated and unmyelinated nerve axons (Figure 23). Cross-section of the descending palatine artery displayed a well-organized and well-defined muscular layer (Figure 24). Branching of the descending palatine artery was observed from the more inferior portion of the greater palatine canal (Figure 25). The branching of this artery was also seen from the gross dissections (Figure 26).

The last part of this study determined the *actual measurement* for each specimen and then compared that value to injection methods of Malamed, Jorgensen, Sicher, and Canter, which are summarized in Table 3.

Using Malamed's injection method, the needle was introduced to a standard depth of 30mm in all 42 specimens. The distance from the needle tip to the inferior margin of the maxillary nerve ranged from 0 to 13mm below the nerve with a mean distance of 7.95mm below the nerve and a standard deviation of 3.32mm. From the data the *actual measurement* was extrapolated, which ranged from 30 to 48mm with

a mean being 38.19mm and a standard deviation of 3.70mm.

Next, the measurement methods of Sicher and Jorgensen were compared to the *actual measurement*. The *facial measurement* recommended by Sicher ranged from 33 to 50mm with a mean depth of 41.60mm and a standard deviation of 4.36mm. Jorgensen's method of subtracting 3mm from the *facial measurement*, ranged from 30 to 47mm, with a mean of 38.60mm and a standard deviation of 4.36mm. Pearson's correlation between the *actual measurement* and the techniques of Sicher and Jorgensen was found to be $r=0.649$ ($p<0.0001$). The top of Figure 27 depicts a graph that compares the mean values of the *actual measurements* against the means of the suggested methods of Sicher and Jorgensen for all 42 specimens.

For a subset of 18 of the 42 specimens, Canter's *orbital measurement* was found to range from 32 to 40mm, with a mean of 35.72mm and a standard deviation of 2.72mm. Looking at just these 18 specimens the *actual measurements* ranged from 33 to 43mm, with a mean of 38.22mm and a standard deviation of 2.70mm. Pearson's correlation between the *actual measurement* and the *orbital measurement* was found to be $r=0.475$ ($p<0.046$). Sicher's technique ranged from 35 to 45mm with a mean of 40.89mm and a standard deviation of 3.22mm. Finally, Jorgensen's suggested penetration depth ranged from 32 to 42mm with a mean of 37.89mm and a standard deviation of 3.22mm. The mean distances using Jorgensen's, Sicher's and Canter's methods are compared against the *actual measurements* of the 18 specimens in the bottom of Figure 27.

The mean distances from the needle tip to the inferior border of the maxillary

nerve were measured for Malamed's method, and extrapolated to the techniques of Sicher, Jorgensen, and Canter, and are summarized in the top of Figure 28. The distance for the Sicher technique (n=42) ranged from 9mm above to 8mm below the nerve, with a mean distance of 3.64mm above and a standard deviation of 3.05mm. Jorgensen's method (n=42) ranged from 6mm above to 11mm below the nerve, with a mean distance of 0.64mm above the nerve and a standard deviation of 3.05mm. Lastly, the distance for Canter's method (n=18) ranged from 3 above to 8mm below the nerve with a mean distance of 2.50mm below the nerve and a standard deviation of 2.69mm.

For the subset of 18 of the 42 specimens, Canter's mean value was compared to the recalculated means of the other three methods as seen in the bottom of Figure 28. The Malamed technique ranged from 3mm to 13mm below the nerve, with a mean of 8.22mm below the nerve and a standard deviation of 2.62mm. Sicher's method ranged from 6mm above to 8mm below the nerve, with a mean of 2.67mm above the nerve and a standard deviation of 3.14mm. Finally, the Jorgensen technique ranged from 3mm above to 11mm below the nerve, with a mean of 0.33mm below the nerve and a standard deviation of 3.14mm.

The basic injection methods of Malamed, Jorgensen, Sicher, and Canter were adjusted from the date in Table 3 to maximize their predictive value to approximate the *actual measurement* through statistical manipulation and is seen in Table 4. By adding 8mm to Malamed's standard 30mm (n=42), the distance would range from 8mm above to 5mm below the nerve, with a mean of 0.05mm above the nerve and

a standard deviation of 3.32mm. For Jorgensen's and Sicher's method (n=42), by subtracting 3.6435mm from the *facial measurement*, the mean distance would be 0.0006mm below the nerve with a standard deviation of 3.0536mm. By rounding up and subtracting 4.0mm from the *facial measurement*, the distance would range from 5.0mm above to 12mm below the nerve with a mean distance of 0.36mm below the nerve and a standard deviation of 3.05mm. Lastly, by adding 2.5mm to the *orbital measurement* (n=18), Canter's technique would have ranged from 5.5mm above to 5.5mm below the nerve with a mean of 0.0mm and a standard deviation of 2.69mm.

Assuming the maxillary nerve is approximately 3mm in diameter, in this the last part of this study, the data was again adjusted for the four injections so that the needle would not exceed the superior margin of the nerve and is seen in Table 4. By adding 3mm to Malamed's standard 30mm (n=42), the distance would range from 3mm above to 10mm below the inferior margin of the nerve, with a mean of 4.95mm below the nerve and a standard deviation of 3.32mm. For Jorgensen's and Sicher's method (n=42), by subtracting 6mm form the *facial measurement*, the mean distance would range from 3mm above to 14mm below the inferior margin of the nerve, with a mean of 2.36mm below the nerve and a standard deviation of 3.05mm. Finally, no adjustment was needed for Canter's *orbital measurement* technique to reach the desired goal.

TABLE 3

MEASUREMENTS FROM THE DIFFERENT INJECTION TECHNIQUES

SPN	Mal (mm)	Act (mm)	Fac (mm)	Sich (mm)	Fac -3 (mm)	Jorg (mm)	Orb (mm)	Cant (mm)
1	- 6	36	42	+ 6	39	+ 3	36	0
2	- 5	35	40	+ 5	37	+ 2	38	+ 3
3	-12	42	45	+ 3	42	0	35	- 7
4	- 8	38	44	+ 6	41	+ 3	32	- 6
5	- 5	35	38	+ 3	35	0	33	- 2
6	- 8	38	43	+ 5	40	+ 2	39	+ 1
7	-10	40	43	+ 3	40	0	37	- 3
8	-11	41	42	+ 1	39	- 2	33	- 8
9	-13	43	35	- 8	32	- 11	40	- 3
10	- 8	38	39	+ 1	36	- 2	36	- 2
11	- 8	38	41	+ 3	38	0	35	- 3
12	- 8	38	38	0	35	- 3	33	- 5
13	-10	40	42	+ 2	39	- 1	39	- 1
14	- 5	35	37	+ 2	34	- 1	32	- 3
15	-11	41	44	+ 3	41	0	40	- 1
16	- 8	38	43	+ 5	40	+ 2	35	- 3
17	- 3	33	35	+ 2	32	- 1	33	0
18	- 9	39	45	+ 6	42	+ 3	37	- 2
19	- 7	37	40	+ 3	37	0		
20	-12	42	49	+ 7	46	+ 4		
21	-10	40	43	+ 3	40	0		
22	-10	40	40	0	37	- 3		
23	- 8	38	35	- 3	32	- 6		
24	-12	42	50	+ 8	47	+ 5		
25	- 8	38	41	+ 3	38	0		
26	- 3	33	38	+ 5	35	+ 2		
27	-12	42	44	+ 2	41	- 1		
28	- 1	31	34	+ 3	31	0		
29	- 3	33	37	+ 4	34	+ 1		
30	-12	42	48	+ 6	45	+ 3		
31	-12	42	48	+ 6	45	+ 3		
32	- 1	31	35	+ 4	32	+ 1		
33	- 7	37	43	+ 6	40	+ 3		
34	-10	40	47	+ 7	44	+ 4		
35	- 5	35	40	+ 5	37	+ 2		
36	- 9	39	47	+ 8	44	+ 5		
37	- 6	36	42	+ 6	39	+ 3		
38	0	30	33	+ 3	30	0		

TABLE 3--Continued

MEASUREMENTS FROM THE DIFFERENT INJECTION TECHNIQUES

SPN	Mal (mm)	Act (mm)	Fac (mm)	Sich (mm)	Fac -3 (mm)	Jorg (mm)	Orb (mm)	Cant (mm)
39	- 8	38	47	+9	44	+6		
40	-11	41	41	+6	38	+3		
41	- 8	38	42	+4	39	+1		
42	-11	41	47	+6	44	+3		
For 42	specimens							
range	6-(-13)	30-43	33-50	+9-(-8)	30-47	+6-(-11)		
mean	-7.95	38.19	41.60	+3.64	38.60	+0.64		
std	3.32	3.70	4.36	3.05	4.36	3.05		
For 18	specimens							
range	-3-(-13)	33-42	35-45	+6-(-8)	32-42	+3-(-11)	32-40	+3-(-8)
mean	-8.22	38.22	40.89	+2.67	37.89	-0.33	35.72	-2.50
std	2.62	2.70	3.22	3.14	3.22	3.14	2.72	2.69

SPN	Specimen number
Mal	Malamed's measurements, from the needle tip to the maxillary nerve
Act	*Actual Measurement*, from the palatal mucosa to the maxillary nerve
Fac	*Facial Measurement*, from the infraorbital rim to the gingival margin of the maxillary premolars, used by Sicher
Sich	Sicher's measurement, from the needle tip to the maxillary nerve
Fac-3	Jorgensen's method of subtracting 3mm from the *facial measurement*
Jorg	Jorgensen's measurement, from the needle tip to the maxillary nerve
Orb	*Orbital Measurement*, from supraorbital to the infraorbital margins
Cant	Canter's measurement, from the needle tip to the maxillary nerve
+/-	Indicates the position of the needle tip to the inferior margin of the maxillary nerve, where (+) means superior and (-) inferior to the nerve
std	Standard deviation

TABLE 4

ADJUSTED MEASUREMENTS FROM THE DIFFERENT INJECTION TECHNIQUES

SPN	Mal +3 (mm)	Mal +8 (mm)	Fac -4 (mm)	Fac -6 (mm)	Fac-3.6435 (mm)	Cant +2.5 (mm)
1	- 3	2	2	0	2.3565	2.5
2	- 2	3	1	- 1	1.3565	5.5
3	- 9	- 4	- 1	- 3	-0.6435	-4.5
4	- 5	0	2	0	2.3565	-3.5
5	- 2	3	- 1	- 3	-0.6435	0.5
6	- 5	0	1	- 1	1.3565	3.5
7	- 7	- 2	- 1	- 3	-0.6435	-0.5
8	- 8	- 3	- 3	- 5	-2.6435	-5.5
9	-10	- 5	-12	-14	-11.6435	-0.5
10	- 5	0	- 3	- 5	-2.6435	0.5
11	- 5	0	- 1	- 3	-0.6435	-0.5
12	- 5	0	- 4	- 6	-3.6435	-2.5
13	- 7	- 2	- 2	- 4	-1.6435	1.5
14	- 2	3	- 2	- 4	-1.6435	-0.5
15	- 8	- 3	- 1	- 3	-0.6435	1.5
16	- 5	0	1	- 1	1.3565	-0.5
17	0	5	- 2	- 4	-1.6435	2.5
18	- 6	- 1	2	0	2.3565	0.5
19	- 4	1	- 1	- 3	-0.6435	
20	- 9	- 4	3	1	3.3565	
21	- 7	- 2	- 1	- 3	-0.6435	
22	- 7	- 2	- 4	- 6	-3.6435	
23	- 5	0	- 7	- 9	-6.6435	
24	- 9	- 4	4	2	4.3565	
25	- 5	0	- 1	- 3	-0.6435	
26	0	5	1	- 1	1.3565	
27	- 9	- 4	- 2	- 4	-1.6435	
28	2	7	- 1	- 3	-0.6435	
29	0	5	0	- 2	0.3565	
30	- 9	- 4	2	0	2.3565	
31	- 9	- 4	2	0	2.3565	
32	2	7	0	- 2	0.3565	
33	- 4	1	2	0	2.3565	
34	- 7	- 2	3	1	3.3565	
35	- 2	3	1	- 1	1.3565	
36	- 6	- 1	4	2	4.3565	

TABLE 4--Continued

ADJUSTED MEASUREMENTS FORM THE DIFFERENT INJECTION TECHNIQUES

SPN	Mal +3 (mm)	Mal +8 (mm)	Fac -4 (mm)	Fac -6 (mm)	Fac -3.6435 (mm)	Cant +2.5 (mm)
37	- 3	2	2	0	2.3565	
38	3	8	- 1	- 3	-0.6435	
39	- 5	0	5	3	5.3565	
40	- 8	- 3	- 4	- 2	-3.6435	
41	- 5	0	0	- 6	0.3565	
42	- 8	- 3	- 2	0	2.3565	
For 42	specimens					
range	+3-(-8)	+8-(-4)	+5-(-12)	+3-(-14)	-0.00064	+5.5-(-5.5)
mean	- 4.95	0.05	-0.36	-2.36	3.053658	0.00
std	3.32	3.32	3.05	3.05		2.69
For 18	specimens					
range	0-(-10)	+5-(-5)	+2-(-12)	0-(-14)		+5.5-(-5.5)
mean	-5.22	-0.22	-1.33	-3.33	-0.9768	0.00
std	2.62	2.62	3.14	3.14	3.1447	2.69

SPN	Specimen number
Mal +3	Adding 3mm to Malamed's standard length of 30mm
Mal +8	Adding 8mm to Malamed's standard length of 30mm
Fac - 3.6435	Subtracting 3.6435 from the *facial measurement*
Fac -4	Subtracting 4mm from the *facial measurement*
Fac -6	Subtracting 6mm from the *facial measurement*
Orb +2.5	Adding 2.5mm to the *orbital measurement*
$^{+}/_{-}$	Indicates the position of the needle tip to the inferior margin of the maxillary nerve, where (+) means superior and (-) inferior to the nerve
std	Standard deviation

Figure 14: Perforation of the maxillary sinus. **A,** Needle within the maxillary sinus after perforating the anterior wall of the greater palatine canal. **B,** Skull specimen demonstrating small foramina (arrow) in the anterior wall of the greater palatine canal which communicate with the maxillary sinus. A needle could be incorrectly advanced with force through one of these foramina to the maxillary sinus.

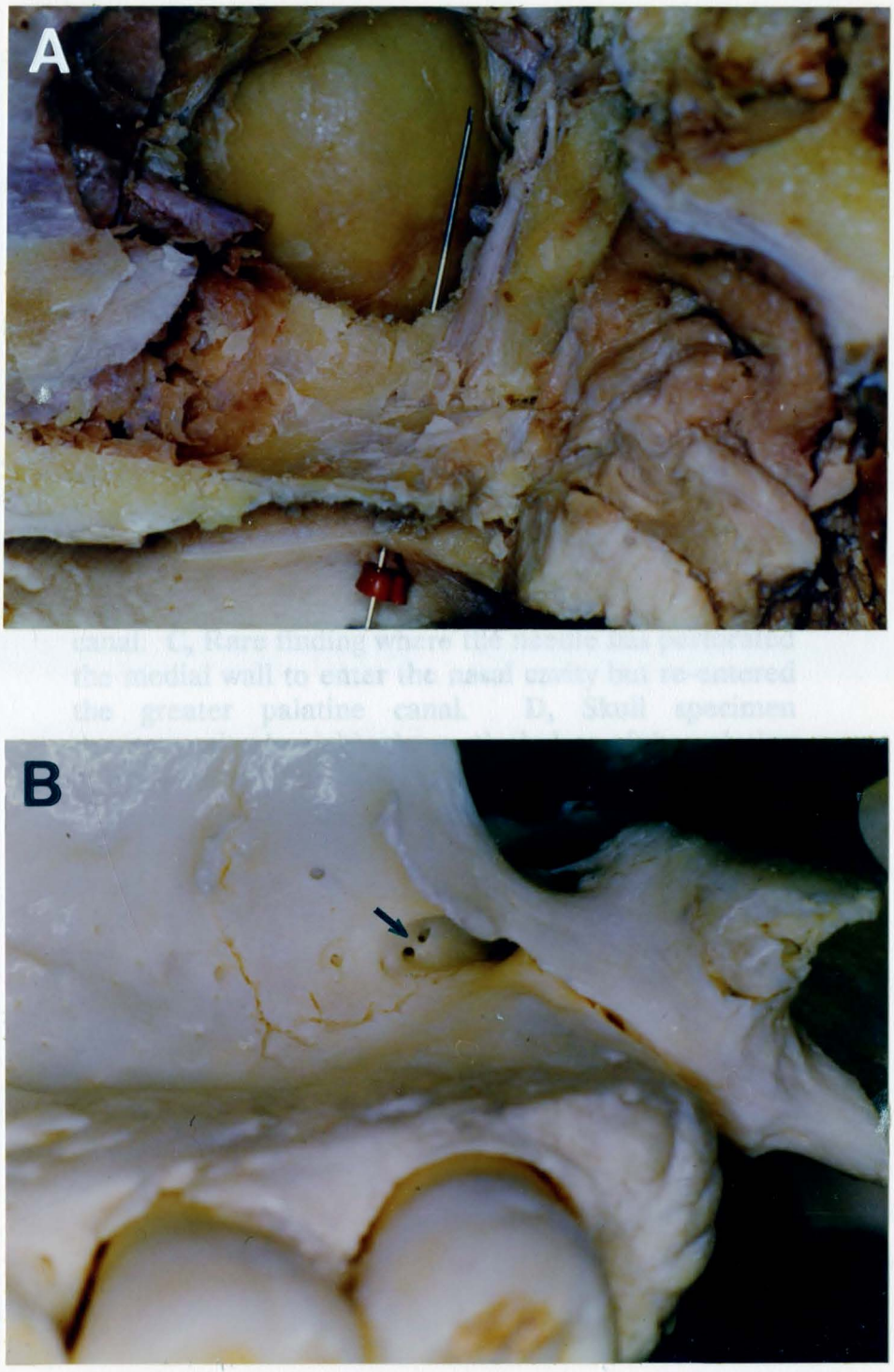


Figure 14

Figure 15: Thickness of the medial wall of the greater palatine canal. **A,** Common finding of the medial wall which appears to have relative thickness. **B,** Occasional finding where the medial wall is transparently thin. The injection needle can be seen within the greater palatine canal. **C,** Rare finding where the needle has perforated the medial wall to enter the nasal cavity but re-entered the greater palatine canal. **D,** Skull specimen demonstrating how thin the vertical plate of the palatine bone can be. This bone makes up the medial wall of the greater palatine canal and the lateral wall of the nasal cavity.

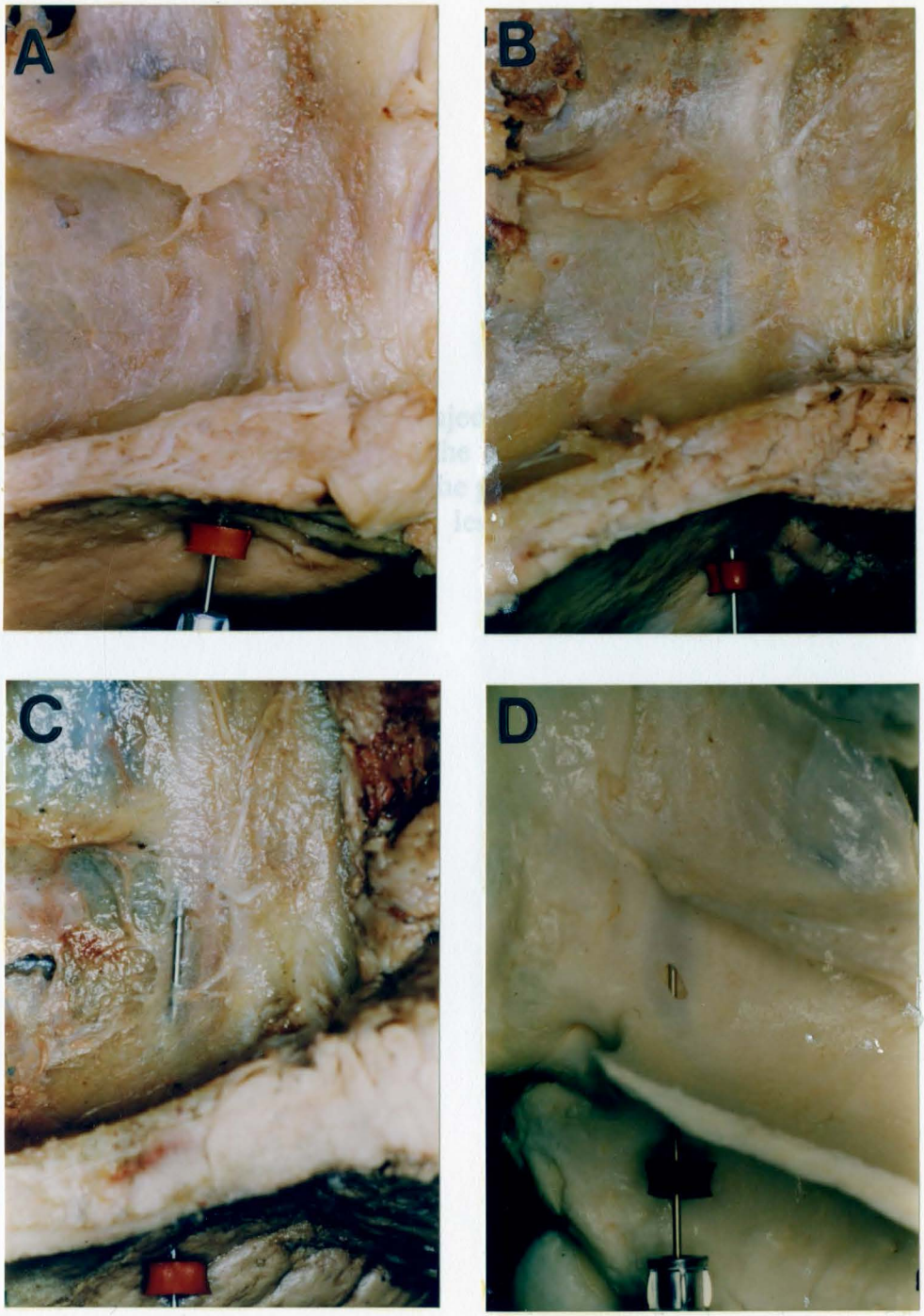


Figure 15

Figure 16: Altered course of the injection needle. **A,** Slight curvature displayed by the needle in an anterior posterior direction within the greater palatine canal. **B,** Needle discovered in the lesser palatine canal after dissection.

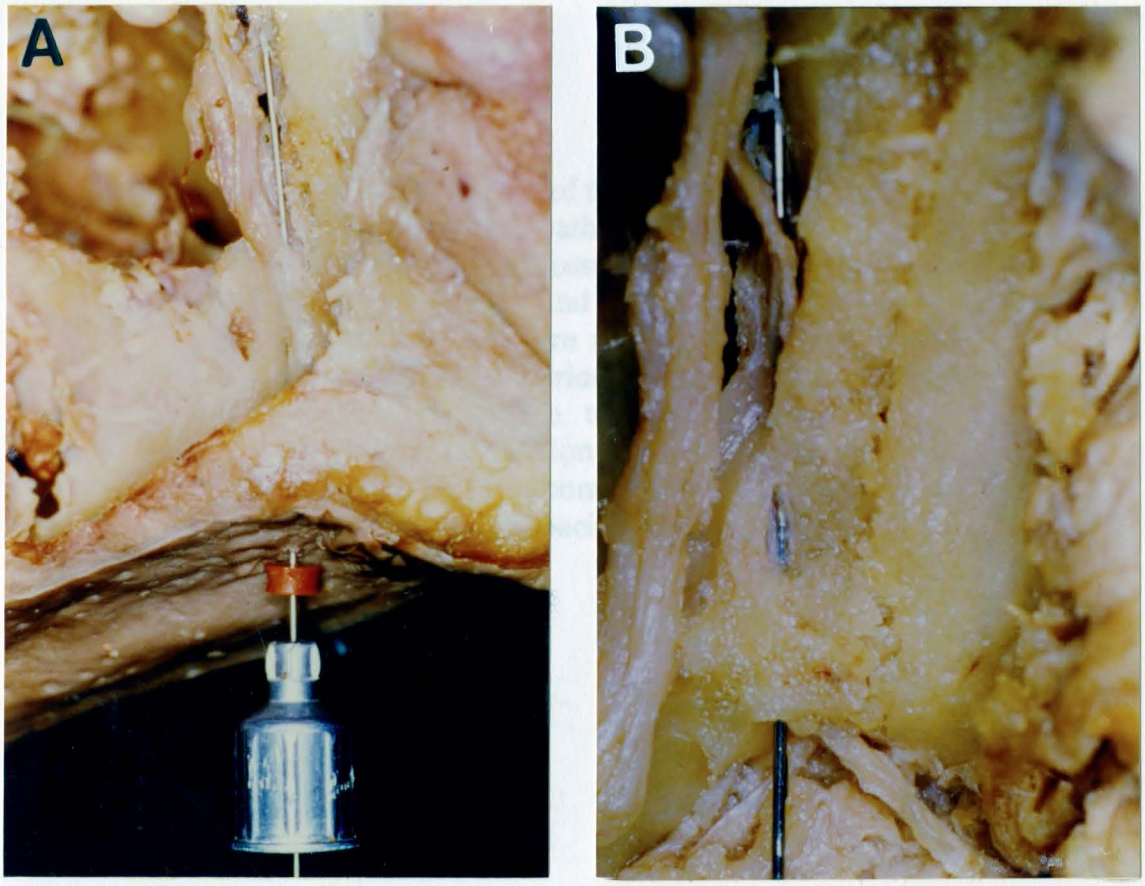


Figure 16

Figure 17: Connective tissue sheath of the pterygopalatine fossa. **A,** The connective tissue sheath, encapsulating the contents of the pterygopalatine fossa. This sheath was found after the anterior and medial walls of the pterygopalatine fossa were removed. The thickness of the sheath increased superiorly from the greater palatine canal (seen here where the needle has perforated through the thinnest portion of the sheath in the greater palatine canal). **B,** The contents of the pterygopalatine fossa from the same specimen after the sheath was removed.

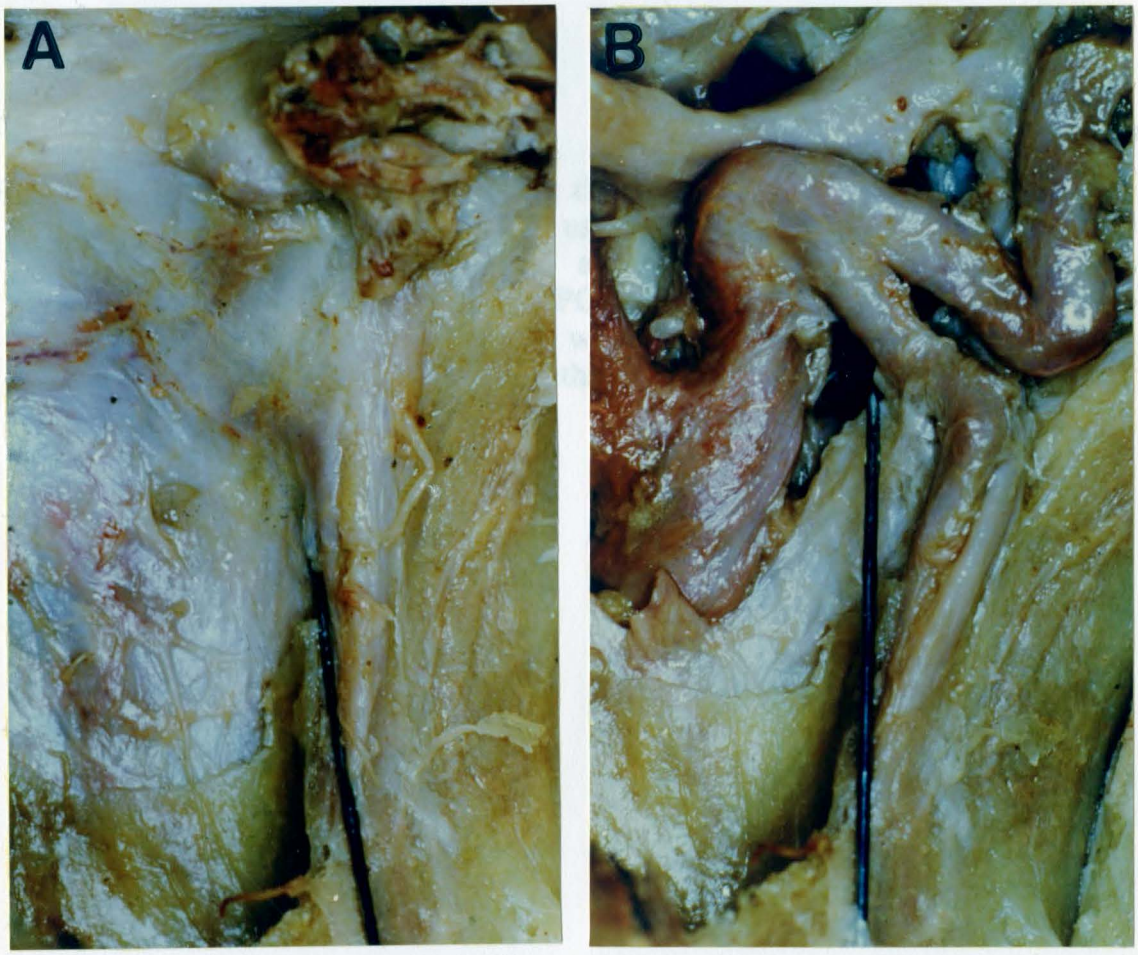


Figure 17

Figure 18: General path of the needle through the pterygopalatine fossa. **A,** The needle was usually found medial to the maxillary nerve (MN) and in line with the pterygopalatine ganglion (PG). **B,** Needle was usually found along the posterior wall of the pterygopalatine fossa. **C,** Needle's course through the greater palatine foramen.

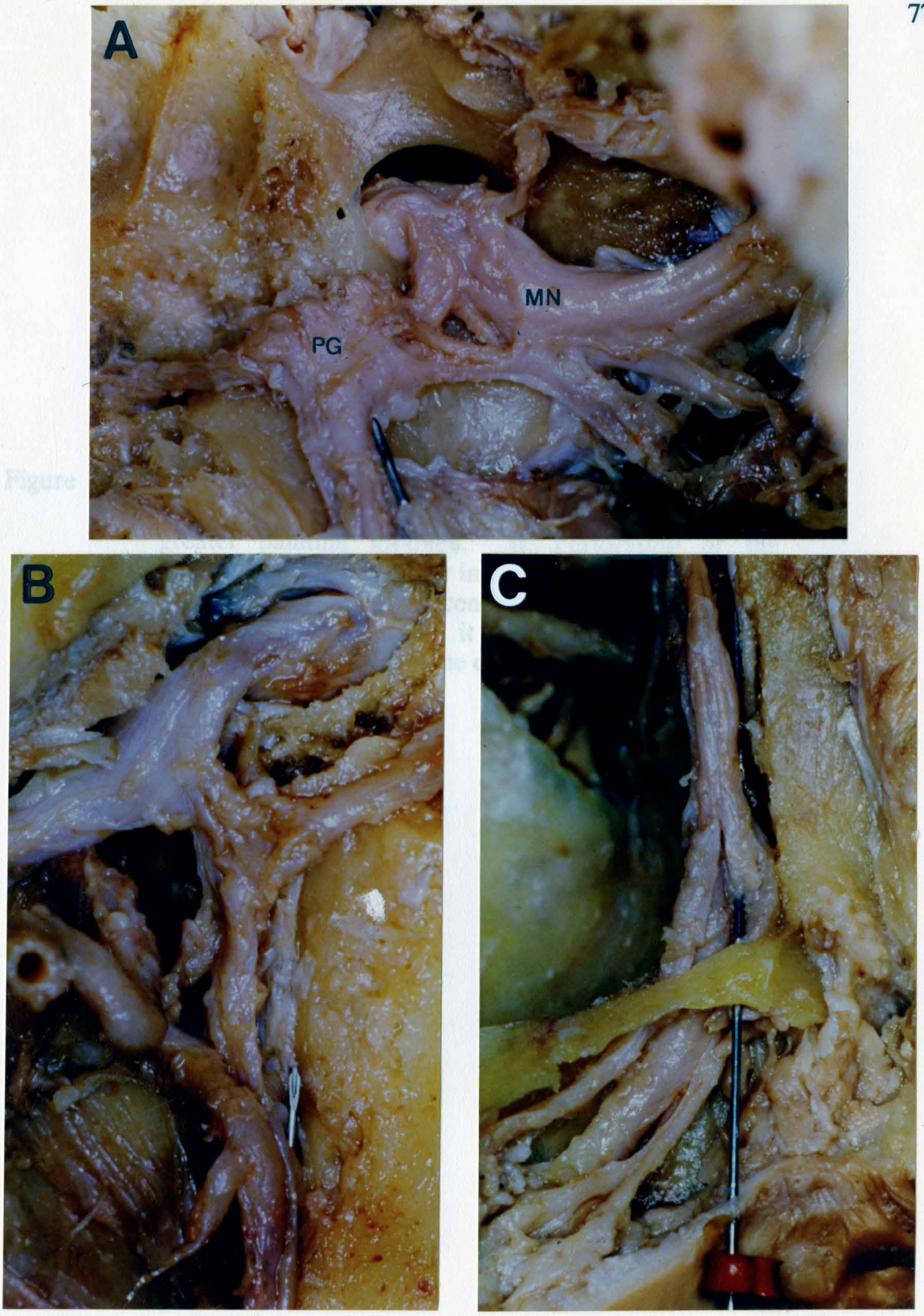


Figure 18

Figure 19: Perforation of vessels by the needle. **A,** Perforation of the descending palatine artery as it emerges from the greater palatine foramen. **B,** Perforation of the descending palatine artery in the greater palatine canal. **C,** Perforation of the descending palatine artery in the pterygopalatine fossa as it makes an inferior bend towards the greater palatine canal. **D,** Perforation of the sphenopalatine artery.

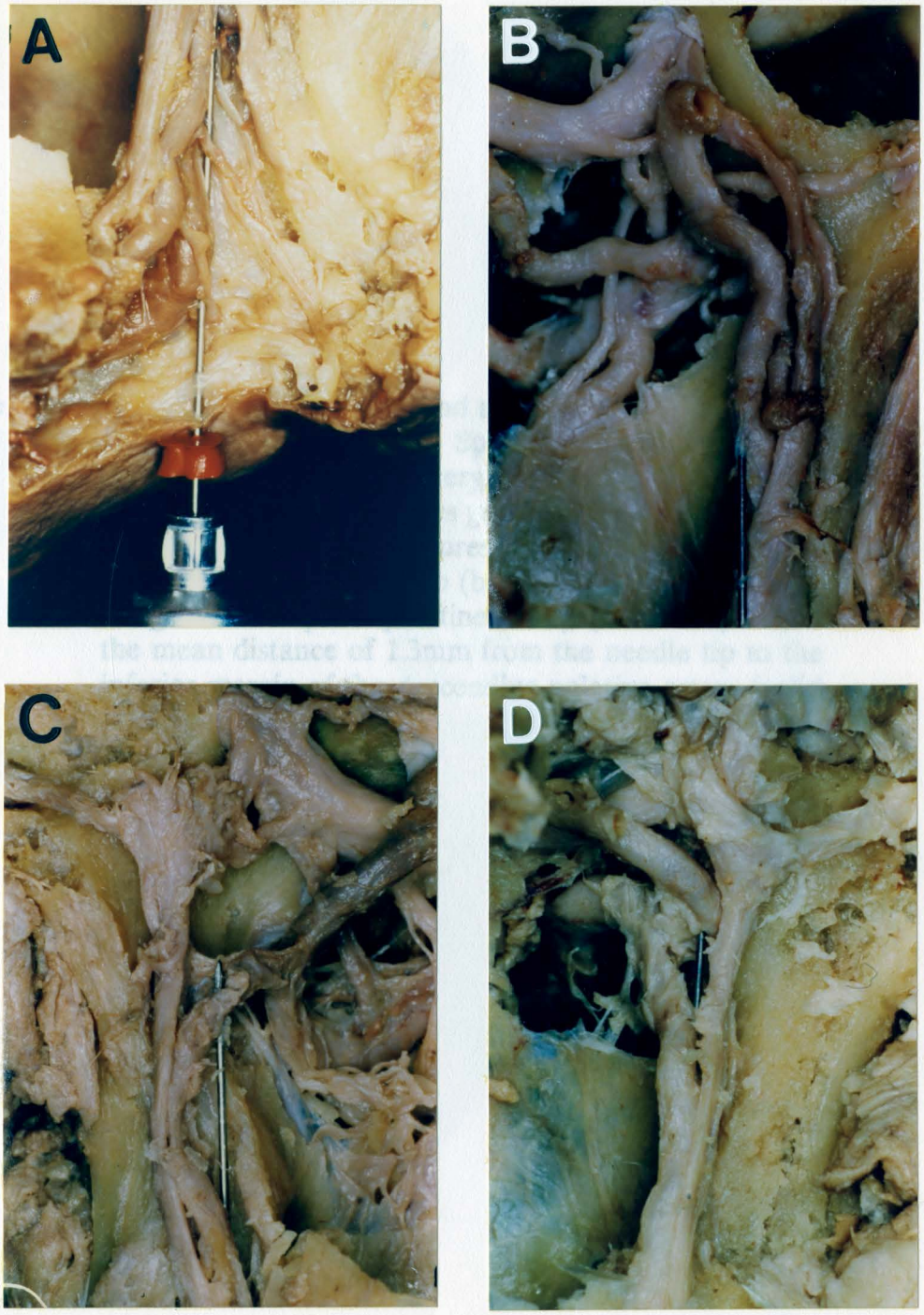


Figure 19

Figure 20: Vessel perforation sites and needle distance to vessels. **1,** Maxillary artery. **2,** Sphenopalatine artery. **3,** Descending palatine artery. **4,** Greater palatine foramen. Asterisk indicates general areas of perforation sites by the needle. **A,** Represents the mean distance of 2.6mm from the needle tip (broken line) to the inferior margin of the sphenopalatine artery (solid line). **B,** Is the mean distance of 1.3mm from the needle tip to the inferior margin of the descending palatine artery (solid line).

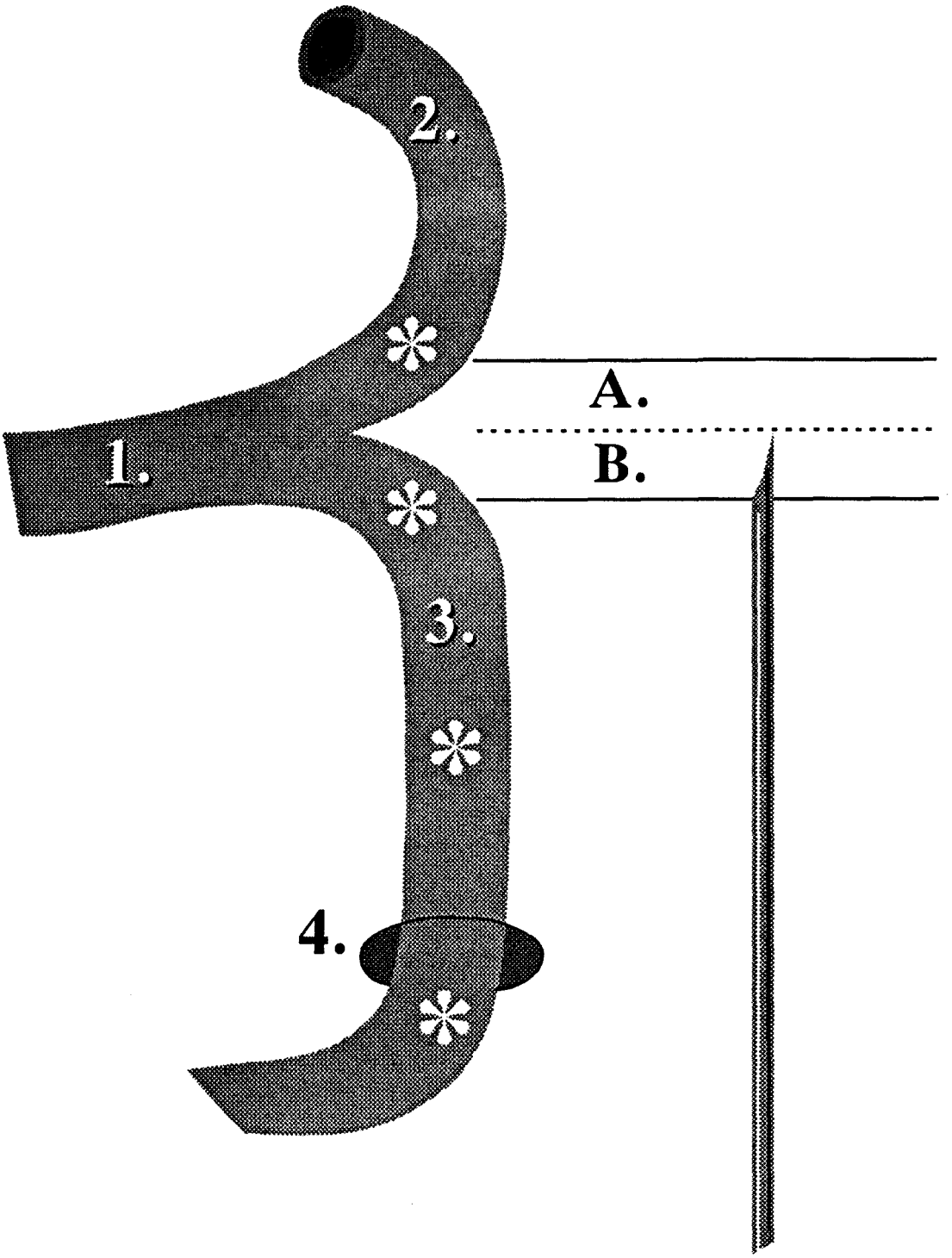


Figure 20

Figure 21: Cross-section of the superior portion of the greater palatine canal. **A,** Photomicrograph illustrating the greater palatine canal containing a muscular artery and nerve fascicles. No evidence of a corresponding vein is noted. H-E Stain, (x40). **B,** Same section. H-E Stain, (x100).

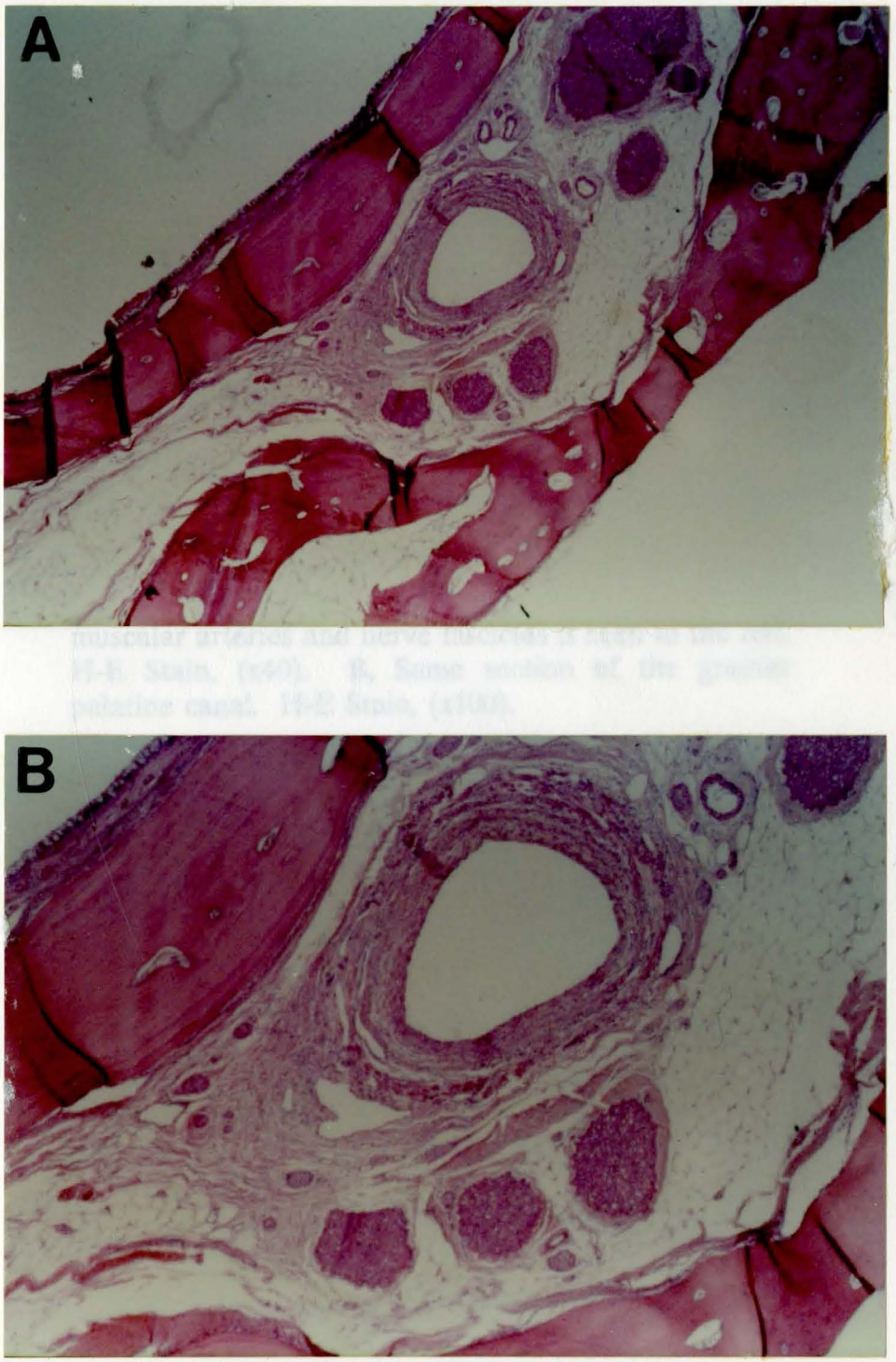


Figure 21

Figure 22: Cross-section of the inferior portion of the greater palatine canal. **A,** Photomicrograph illustrating the greater palatine canal containing muscular arteries and nerve fascicles. No evidence of a corresponding vein is noted. The lesser palatine canal containing smaller muscular arteries and nerve fascicles is seen to the left. H-E Stain, (x40). **B,** Same section of the greater palatine canal. H-E Stain, (x100).

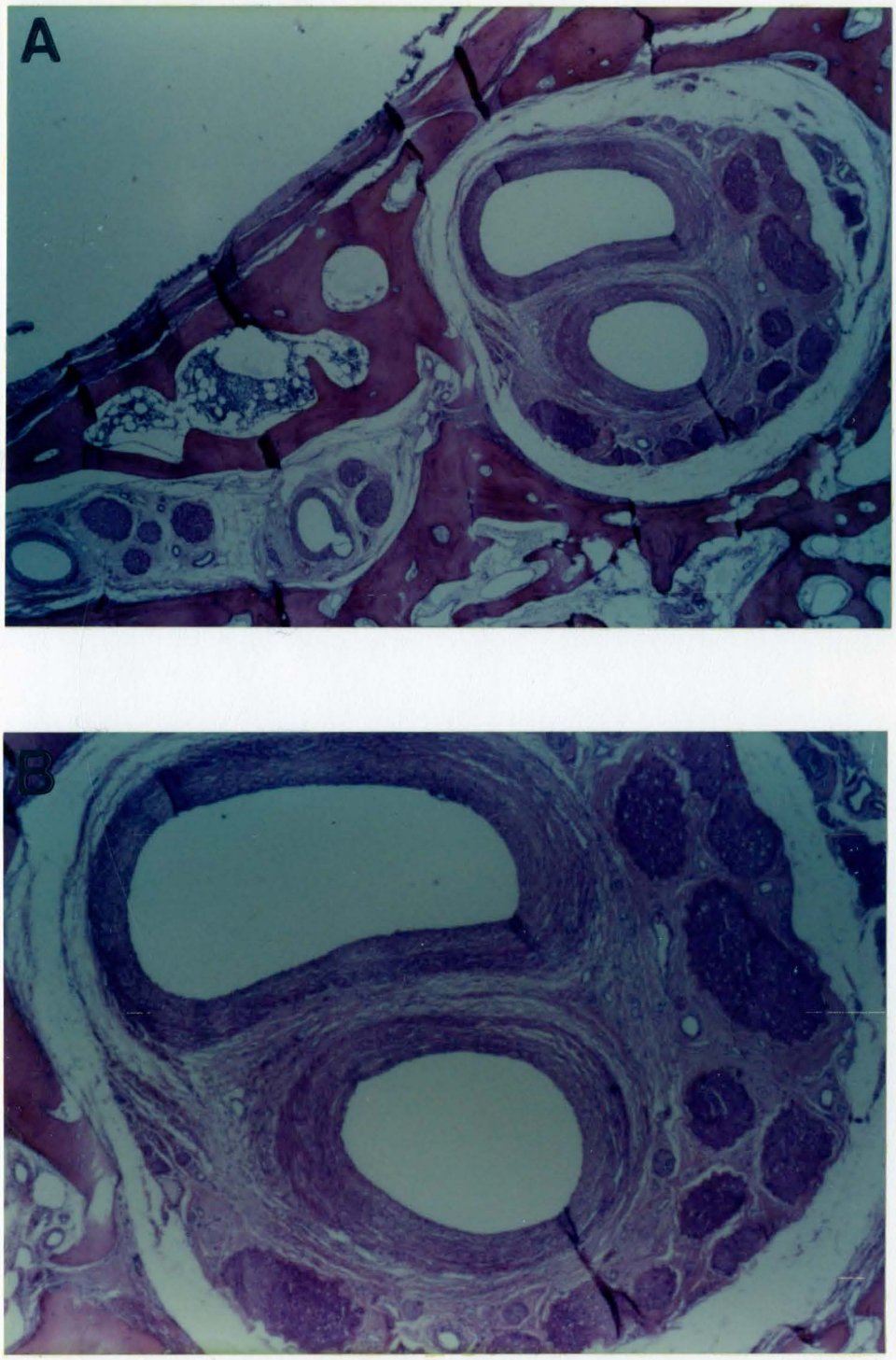


Figure 22

Figure 23: Cross-section of the descending palatine nerve. **A,** Photomicrograph illustrating a nerve fascicle surrounded by perineurium. H-E Stain, (x250). **B,** Nerve fascicle illustrating both myelinated and unmyelinated nerve axons surrounded by perineurium. H-E Stain, (x400).

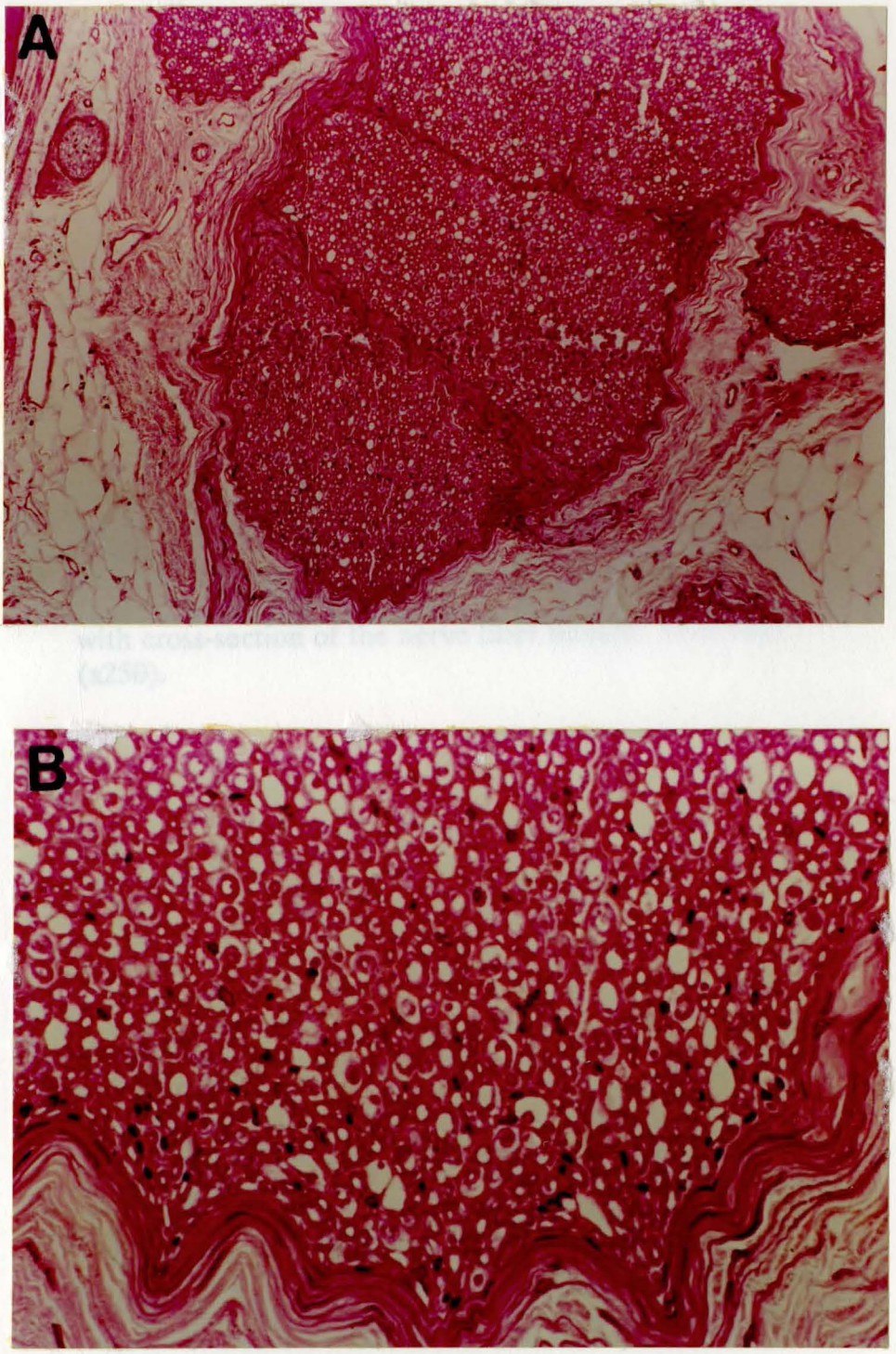


Figure 23

Figure 24: Cross-section of the descending palatine vessel. **A,** Photomicrograph illustrating the muscular layer of the artery. H-E stain, (x250). **B,** Photomicrograph illustrating a fragment of the muscular arterial wall. Note the small size veins and venular structures along with cross-section of the nerve fiber bundle. H-E stain, (x250).

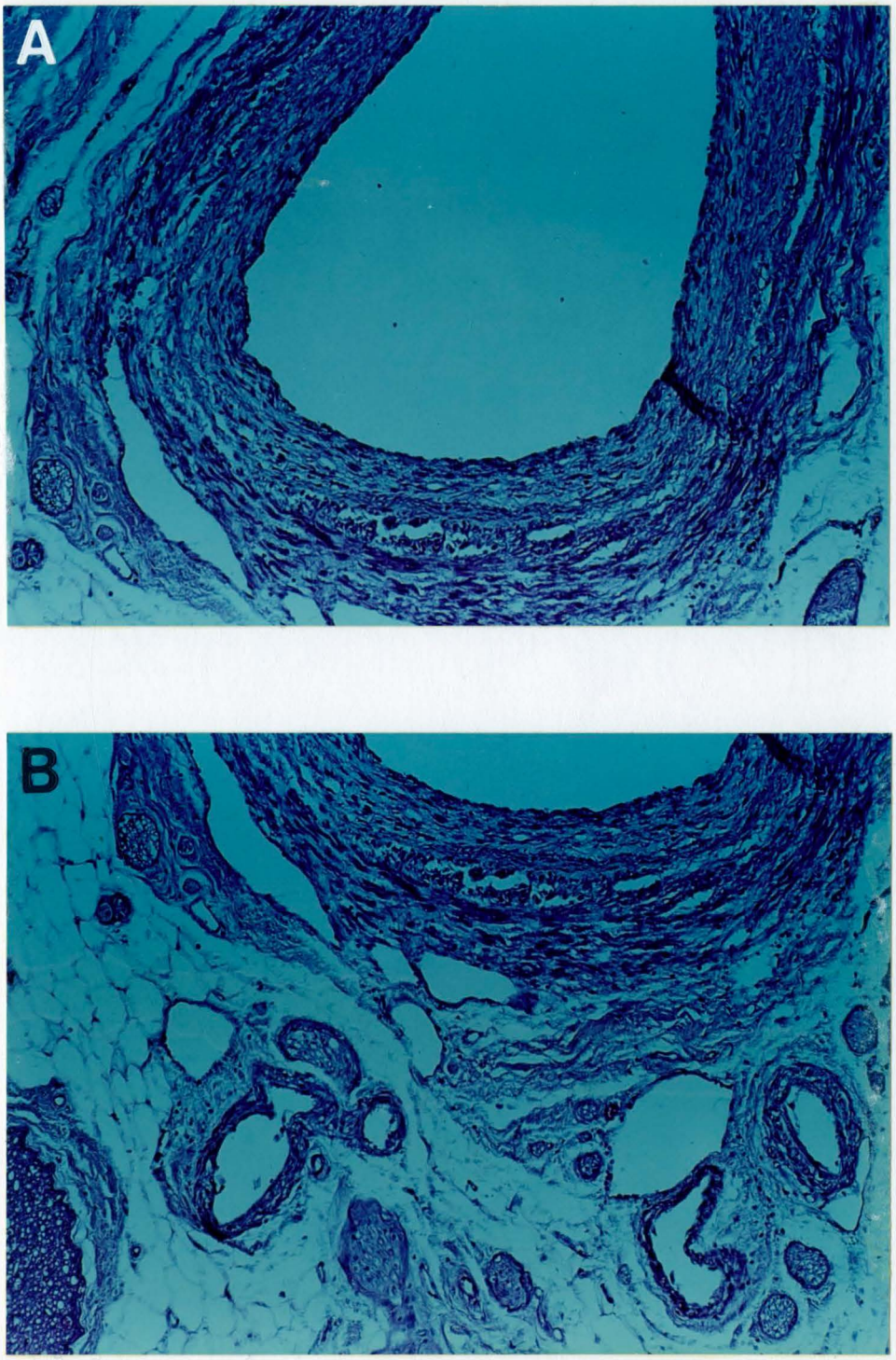


Figure 24

Figure 25: Cross-section of the branching descending palatine artery. **A,** Photomicrograph illustrating infolding of the branching artery (x40). **B,** Photomicrograph illustrating fusion of two separate lumens of the artery by tunica media layer (x40).

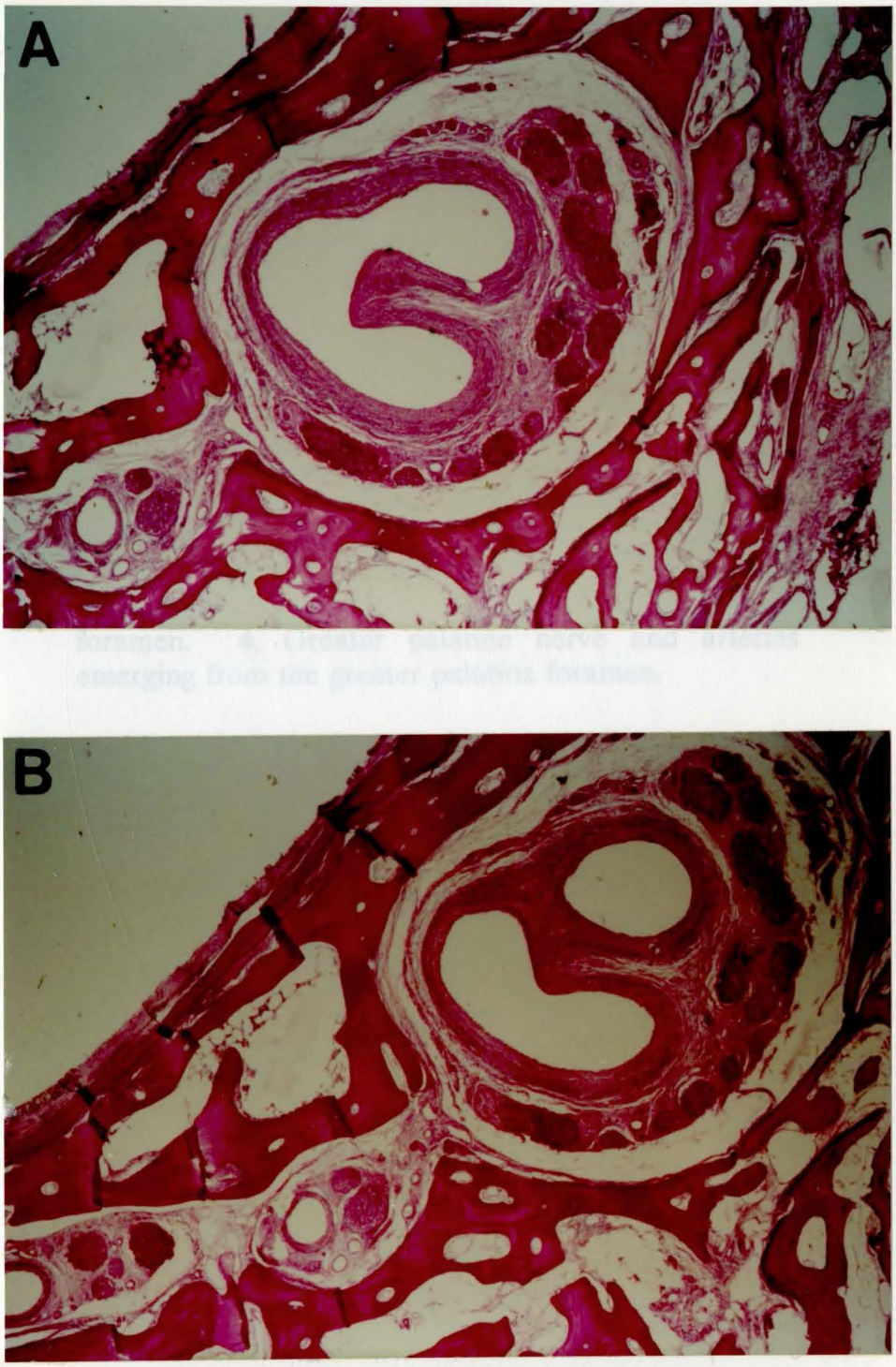


Figure 25

Figure 26: Branching of the descending palatine artery. **1,** Descending palatine nerve. **2,** Descending palatine artery dividing into three separate vessels which were found in the greater palatine canal. **3,** Lesser palatine nerve and artery emerging from the lesser palatine foramen. **4,** Greater palatine nerve and arteries emerging from the greater palatine foramen.

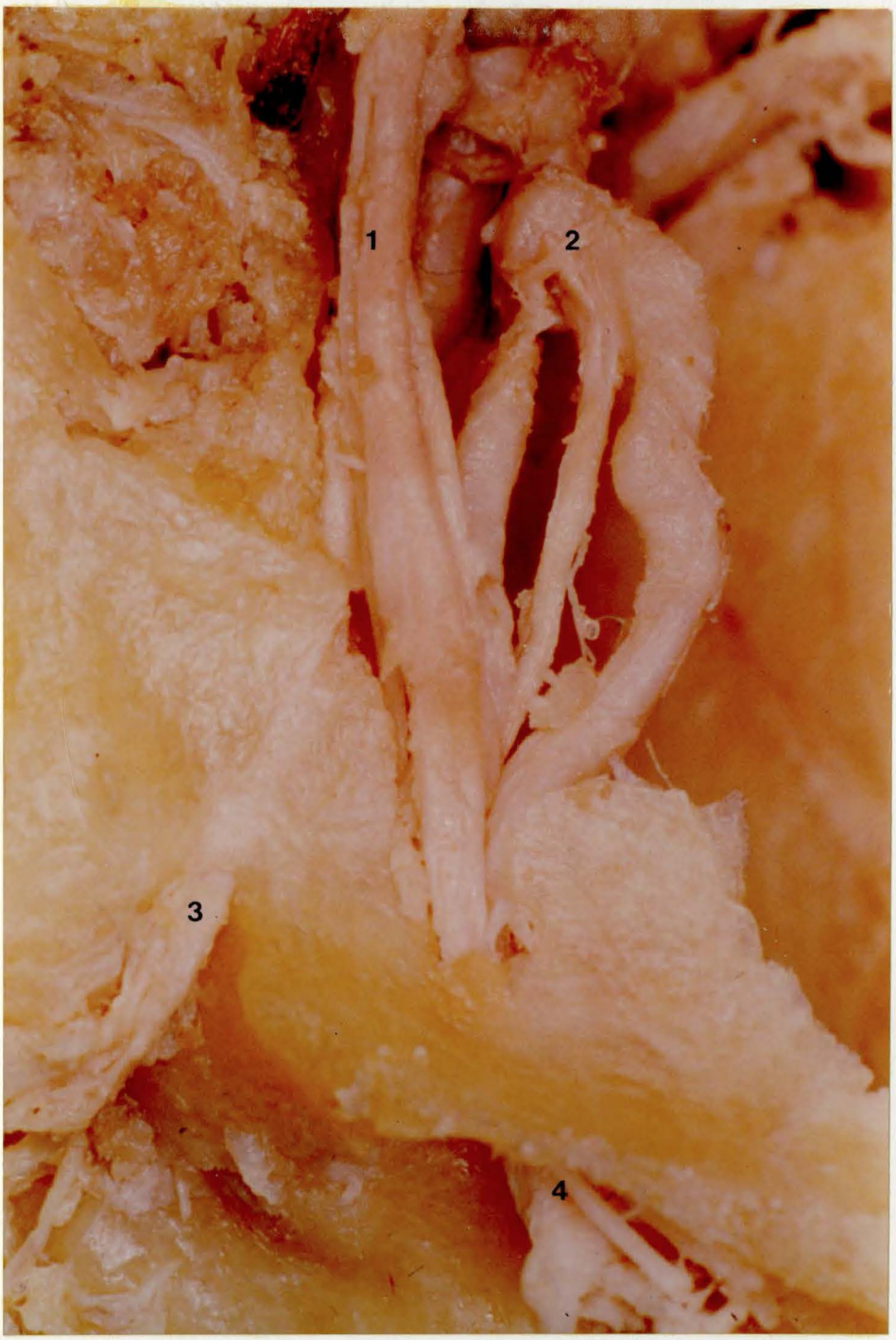


Figure 26

Figure 27: Comparison of the means of actual vs predicted penetration depths. For 42 specimens, the means for Actual, Jorgensen, and Sicher were 38.2, 38.6, and 41.6mm respectively. For 18 specimens, the means for Actual, Jorgensen, Sicher, and Canter were 38.2, 37.9, 40.9, and 35.7mm respectively.

COMPARISON OF THE MEANS OF ACTUAL vs PREDICTED PENETRATION DEPTHS

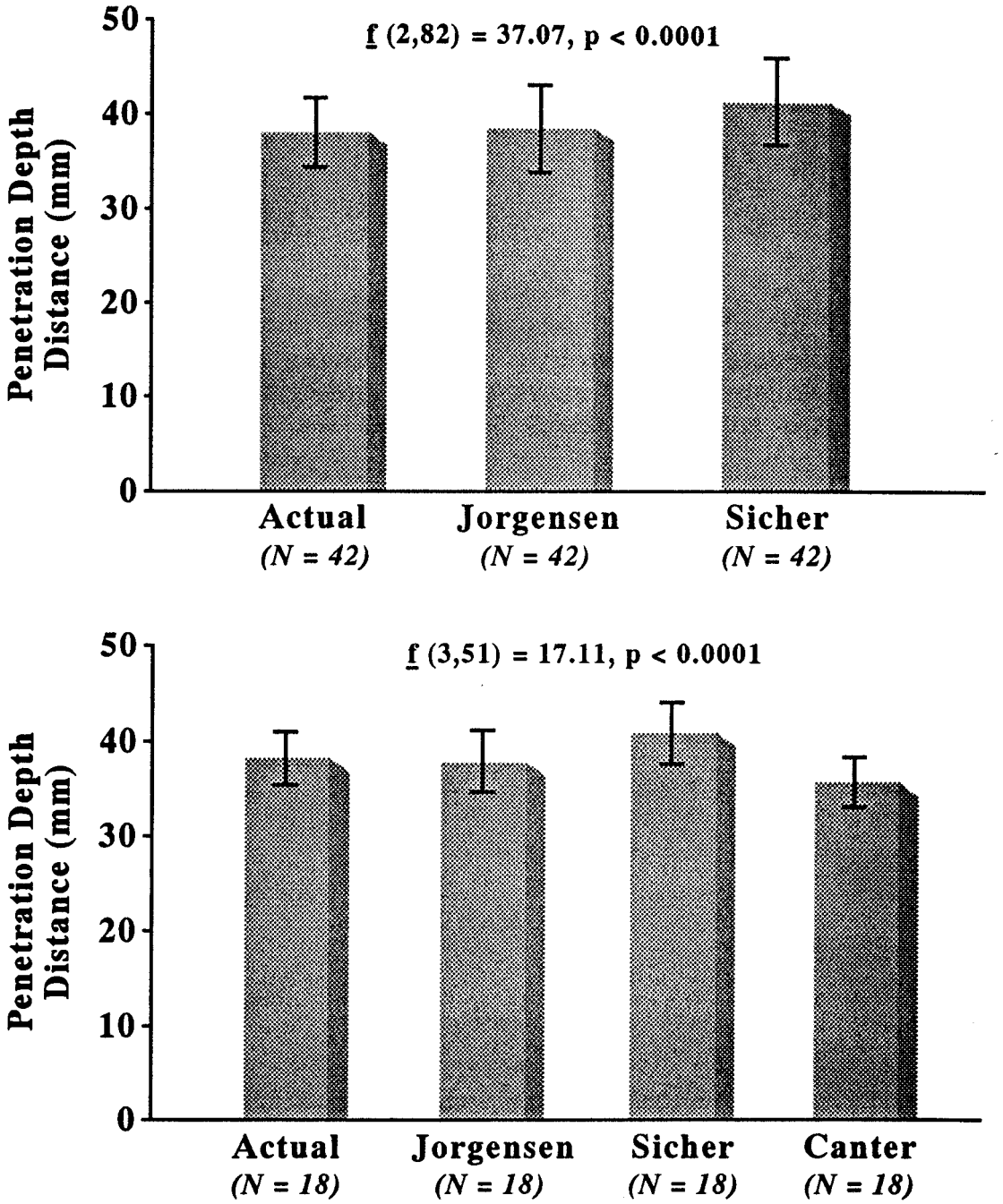
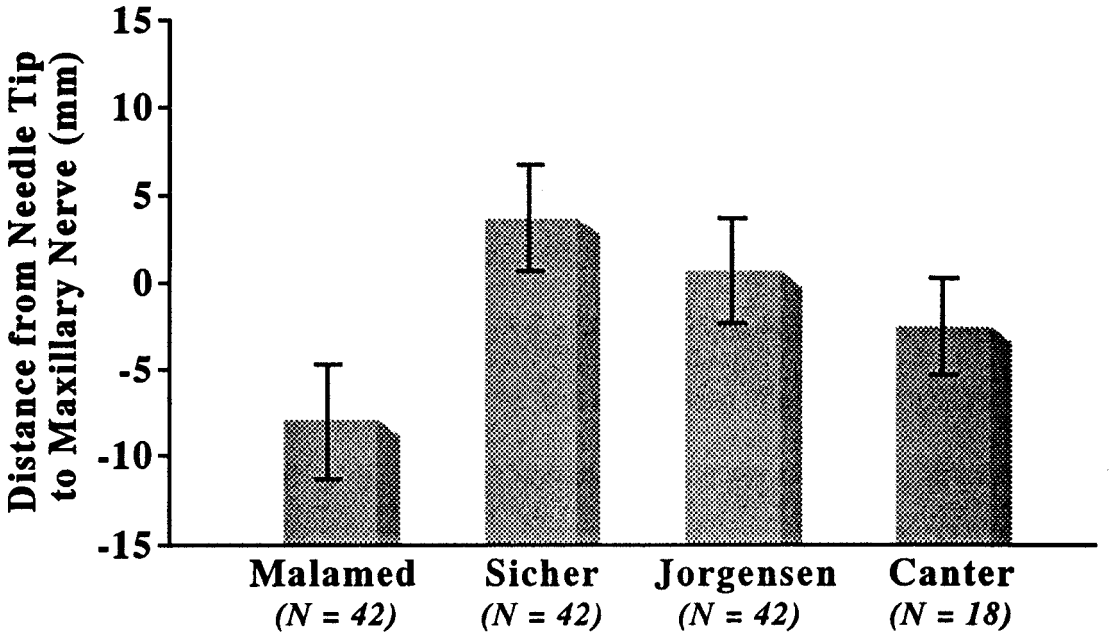


Figure 27

Figure 28: Comparison of mean distances form needle tip to maxillary nerve. The mean distance for Malamed, Sicher, Jorgensen, and Canter were 7.9mm below 3.6mm above, 0.6mm above, and 2.5mm below the nerve respectively.

COMPARISON OF MEAN DISTANCES FROM NEEDLE TIP TO MAXILLARY NERVE



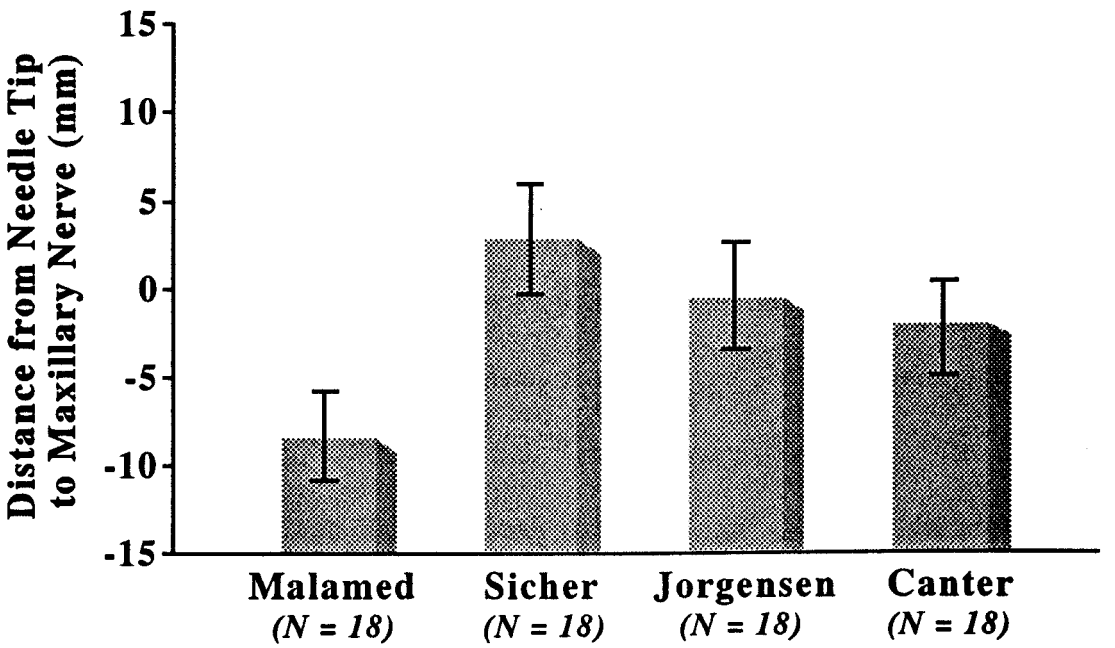


Figure 28

DISCUSSION

In locating the greater palatine foramen, Sicher[90] astutely noted that, "It is the exception rather than the rule, that the needle reaches the foramen at the first attempt." This was also the finding in this study in over half of the specimens. For these specimens, the needle was stepped along the hard palate until the foramen was located; however, care must be taken since stepping the needle off the posterior aspect of the hard palate is the most common error seen with the greater palatine canal route.[92] This error may result from the considerable variation in distance found from the posterior border of the hard palate to the posterior aspect of the greater palatine foramen which has been reported to range from 3 to 12mm.[92] The greater palatine canal is located approximately 15mm from the midline,[71] and is always found anterior to the pterygoid hamulus in the same sagittal plane.[87,92] The foramen is located at the junction of the horizontal portion of the hard palate and the vertical maxillary alveolar process when viewed from a skull.[92] Clinically, this point would be slightly less than halfway from the crest of the alveolar ridge to the midline of the palate.[74] Malamed and Trieger[92] measured 158 skulls to find the greater palatine foramen located along the distal half of the third molar 9.49%, mesial half of the third molar 50.63%, and distal half of the second molar 39.87% of the time. In the developing occlusion of a child, the greater palatine foramen is

located distal to the erupting molar.[95] With the present study, however, the molars of several specimens were missing, which is due in part to the older mean age group among the specimen used in this study. In the case of an edentous patient, the junction of the hard and soft palate may be used as a landmark.[98] Jorgensen[87] states that the location of the greater palatine foramen can easily be palated through the palatal mucosa with a burnisher or cotton swab, where Sicher[98] says the foramen cannot be palated. Locating the greater palatine canal among the specimens used in this study was the most common problem encountered.

In advancing the needle through the greater palatine canal, severe resistance was encountered in three of the 43 specimens (7.0%). Inability to negotiate the needle through the greater palatine canal has been reported in skull studies from 2.4 to 37.0%[87,93,95,99] and clinical experience from 2.5 to 10.0%.[78,79,83,91] The impedance of the needle from ascending through the greater palatine canal appears to increase with age,[81,95] and has been attributed to the canal diameter (varies between $1^1/_2$ to 4mm),[30] being tortuous,[79,89,91] or having bony obstructions.[73,78,87,95] Clinically with such cases, the maxillary nerve block by way of the greater palatine canal would be abandoned. An alternative approach would have to be utilized, since deviation of the needle off the long axis of the greater palatine canal can result in its perforation. From skull studies, the long axis has been found to be parallel to the sagittal plane or an average approximately 6.73° lateral to the sagittal plane;[99,100] the optimal angle of the needle to the hard palated has been reported on average to be from 45.88° to approximately 68.39°.[92,99] However, in the interest of evaluating the needle position

after its insertion to 30mm, the needle was redirected through the path of least resistance. After the dissections were concluded, the location of the needle in these three cases was evaluated. In the first case, which resulted in the most resistance, the needle perforated the anterior wall of the greater palatine canal to reside in the maxillary sinus (Figure 14A). The canal appeared to be tortuous which may, in part, have contributed to the impedance of the needle from advancing superiorly. Significant force was needed to advance the needle in this case after the needle had been redirected to what was thought to be the greater palatine canal. The use of too much force with the needle has been listed as a possible cause of perforating into the sinus.[91] But also contributing to the perforation might be small foramina found in the anterior wall of the greater palatine canal which communicate with the maxillary sinus (Figure 14B). These foramina could act as a pilot hole for the needle and with force the needle might break through to the sinus. Finally, the anterior wall may be paper thin and a needle advanced in the wrong direction could break through.[92] The medial wall of the greater palatine canal was found to be thin in several of the specimens (Figure 15A-C). This is due to the vertical plate of the palatine bone often found to be transparently thin or even fenestrated (Figure 15D). Thus the wall separating the greater palatine canal from the nasal cavity may have no osseous component and may be just the thickness of the nasal mucosa. In the second case of high resistance, the needle perforated and then re-entered the medial wall of the greater palatine canal. This was a result of the specimen having a thin medial wall and medial deviation of the needle.[30,87,92] Such a situation would be evident clinically

upon aspirating air back into the anesthetic cartridge or complaints of the local anesthetic running down the throat if inadvertently injected into the nasal cavity.[84] Epistaxis may result from the needle perforating through the medial wall.[29,85] Deviation of the needle too far in the lateral direction, could result in the local anesthetic passing through the pterygomaxillary fissure and into the infratemporal fossa.[99] In the third specimen with high resistance, the needle was found within the greater palatine canal, but was discovered to have a gradual bend in a medial direction along the sagittal plane. The reason for the difficulty in advancing the needle was not obvious.

Slight resistance in eight additional specimens was encountered. By just repositioning the angle of the needle in the greater palatine canal, as recommended in such cases,[84] the needle was easily advanced to the full 30mm length for all of these eight specimens. Of these eight specimens, only two had unusual findings. In the first case, the needle was found to have a gradual bend in an anterior direction within the greater palatine canal (Figure 16A). In the second case, the needle was discovered in the lesser palatine canal with a slight bend anteriorly towards the pterygopalatine fossa (Figure 16B).

As seen in Table 2, a 25-gauge needle was the most common size recommended for use in the greater palatine canal approach. Malamed[101] advocated the use of a 25-gauge needle over smaller gauges when the potential for aspiration is high and to decrease the likelihood of needle deflection in areas of deeper tissue penetration depths. Such as with the inferior alveolar nerve block, where deflection

of the needle can result in insufficient anesthesia.[102]

It has been reported that conventional 27-gauge long needles have greater deflection than 25-gauge long needles.[103] The flexibility of the 27-gauge needle in this study was demonstrated in the three cases where the needle was found to have a curved course. One of these three was from a case of high resistance and clinically the attempt to advance the needle through the greater palatine canal would have been abandoned. But the flexibility of the 27-gauge needle as used in this study may be helpful in negotiating through the bony confines of the greater palatine canal. This is consistent with the clinical finding of Cohn,[83] who found the 27-gauge needle passed through the canal easier than either the 23- of 25-gauge needles. In regards to aspiration, the 25-gauge needle has been reported to have a greater aspiration rate than the 27-gauge needle,[104] where no significant difference in aspiration rates between the two sizes has also been found.[105]

There is the considerable variance between different manufactures in regards to size and tolerance of the needle lumen and thus creates a problem of trying to compare different gauges.[106] For instance, a 27-gauge needle from one manufacturer may have the same lumen size as a 25-gauge needle from a different manufacturer.[106] Needles are available with regular and thin wall sizes, where the thinner walls increase the lumen size for better aspiration and enhance flexibility.[106] Therefore, it is suggested by the results from this study that the optimum needle to use for the greater palatine canal approach may be a 27-gauge, thin-walled, long needle. A comparison of the efficacy of different needle types and gauges needs to be further

elucidated in a future study.

The needle tip was found on average to be 1.3mm above the inferior margin of the descending palatine artery and 2.6mm below the inferior margin of the sphenopalatine artery (Figure 20). These measurements were meant to give the approximate level of these arteries relative to the needle tip. But since the lateral wall of the nasal cavity was removed during the dissection, the true anatomical position of the sphenopalatine artery in the pterygopalatine fossa may have been altered slightly since its position is dictated by the sphenopalatine foramen located in this lateral wall. Regardless of any slight discrepancies, both the sphenopalatine and descending palatine arteries after branching from the maxillary artery, were found to lie close to the path of the needle. Due to the close proximity of the needle to the sphenopalatine artery, the greater palatine canal approach has been recommended as an aid in the control of prolong posterior epistaxis,[107,108] because the sphenopalatine artery provides the main blood supply to the posterior nasal cavity.[109]

This close proximity of the needle tip to sphenopalatine and descending palatine arteries illustrates the importance of aspiration prior the injection of local anesthetic. Schiano and Strambi[110] reported a positive aspiration occurred in 3 of 21 (14.3%) attempts of the maxillary nerve block by way of the greater palatine canal. This compares with 77 positive aspirations in 702 (11.0%) attempts with the inferior alveolar nerve block. Positive aspiration is a result of tissue trauma caused by the needle rupturing small blood vessels, and actual intravascular aspiration.[111] The needle tip was found in the lumen of the artery in 2 of the 42 (4.8%) specimens, and

would theoretically produce a positive aspiration. The sphenopalatine artery was involved in one specimen and the descending palatine artery in the other.

Vascular injury such as prolonged hemorrhage or hematoma formation resulting from the maxillary nerve block has been noted with the lateral[11,13] and anterior[14] methods, as well as the nasal approach,[22] and the intraoral high tuberosity routes.[79,84] But hematoma as a complication from the greater palatine canal approach has not been reported[112] nor observed clinically.[73,92] Because of the close proximity of the maxillary artery to the pterygopalatine fossa, needle penetration could cause the artery to go into spasm which may result in tissue blanching.[91] However, from this study, vascular violation of the maxillary artery itself was not seen. Rather it was the terminal branches of the maxillary, the sphenopalatine and the descending palatine arteries were found to be perforated in 12 of 42 specimens. The violation was either by the needle tip perforating and then passing beyond the vessel, or remaining within the lumen of the vessel as already discussed. The descending palatine artery was punctured by the needle in all twelve specimens (28.6%), which occurred in three locations along the course of the artery (Figure 20A-C). The sphenopalatine artery was pierced only once (2.4%) which occurred in one of the previous twelve specimens (Figure 20D). From these findings, accidental intra-arterial injection and reflux flow of the vasoconstrictor may also explain the observation of tissue blanching from this approach (Figure 29).[113]

Why the needle pierced these arteries so frequently in this study may be explained partly by the lack of resilience of cadaver tissue in comparison to vital

tissue, where the arteries may be pushed aside as the needle is advanced through the canal.[91] If the incidence of vascular trauma found from this study approximates the true clinical incidence, then hemorrhage or hematoma would theoretically occur. But the fact that vascular complications are not observed with the greater palatine canal approach, may in part be due to the bony housing of the canal for two reasons. First, if hemorrhage did occur in the greater palatine canal, it obviously would not be visible. Second, hematomas are rapidly developing swellings which are dependent on the tissue density surrounding the injured vessel.[114] The greater palatine canal, because of its relatively small size, would quickly limit the amount of bleeding until the extravascular pressure exceeds the injured vessel. Malamed found the incidence of hematomas from the greater palatine nerve block to be quite rare because of the density and adherence of the palatal mucosa and underlying bone.[115] Lastly, the absence of a venous counterpart of the descending palatine artery could also explain the rarity of vascular injury seen with the greater palatine canal approach.[116]

Generally, with anatomical structures, there is a corresponding vein for each artery and different anatomy textbooks refer to a descending palatine vein.[98,117-121] But from examining the histological sections, as well as all of the gross specimens, it was clear that there was an absence of a medium or major size vein compatible with that of the descending palatine artery. Rather, there was just an artery which had a well-organized and well-defined muscular layer (Figure 24). Branching of the descending palatine artery was observed from both the histological sections (Figure 25) and gross dissections (Figure 26). The appearance of more than one vessel may

give the appearance of a descending palatine vein. But careful examination of the histological sections showed the presence of a thick muscular layer in both vessels, and with the dissections, the different vessels could be traced back to a main vessel which originated from the maxillary artery. The findings in this study are consistent with those of Shields,[116] who found through observing gross dissection and histological coronal sections of the hard palate the absence of a greater palatine vein in the region just anterior to the greater palatine canal. The venous drainage of the palate in dogs has been traced to a coarse venous network in the soft palate which is posterior to the greater palatine canal.[122] From the soft palate, venous drainage leads to the pharyngeal plexus which then communicates with the pterygoid plexus.[123]

From the histologic sections of the greater palatine canal, the descending palatine artery was found to be surrounded by several nerve fascicles embedded in connective tissue (Figure 21 and 22). Both myelinated and unmyelinated nerve axons were observed on higher power examinations of the descending palatine nerve (Figure 23). Sensory fibers from the maxillary nerve would be found to be both myelinated and unmyelinated, where the postganglionic sympathetic and parasympathetic fibers traveling along with the sensory fibers would all be unmyelinated.[124] Upon gross dissection, it appeared that the needle had transacted and possibly damaged the descending palatine nerve. However, examining the cross-section of the nerve bundles, the needle apparently traveled through the connective tissue, causing the individual nerve fascicles to separate from the connective tissue to give the appearance that the nerve was shredded and possibly injured. Different

clinical reports have found no symptoms of nerve injury with the greater palatine canal approach.[71,79,92] Unlike the central nervous system, the peripheral nerves are relatively strong and resilient.[124] This resilience in combination with the way the fascicles are embedded and spread out in the connective tissue covering, may explain why there are no reports of injury to the descending palatine nerve.

From the gross dissections, the path of the needle was found to travel along and within the neurovascular bundle through the greater palatine canal. The tip of the needle was often along the posterior wall of the pterygopalatine fossa and was always medial to the foramen rotundum and maxillary nerve (Figure 18). From the foramen rotundum, the maxillary nerve courses laterally towards the infraorbital groove which contributes to the lateral position of the maxillary nerve in relationship to the needle's path. The needle tip was usually found closer to the pterygopalatine ganglion than the maxillary nerve. Because of this close proximity, the greater palatine canal approach has been used to specifically anesthetize the pterygopalatine ganglion.[125,126]

Because of the lateral position of the maxillary nerve to the general path of the needle, the position of the ruler used for the measurements from the needle tip to the nerve, was not parallel but slightly angled off the sagittal plane. From these measurements, the distance from the palatal mucosa to the maxillary nerve, or the *actual measurement* was calculated. This distance from the 42 specimens was found to have a vast range of thirteen millimeters (Table 3). The *actual measurement* is a combination in vertical height of both the cranial component of the pterygopalatine

fossa and the palatal mucosa depth. The palatal mucosa depth in this study was found to range from 4 to 11mm, which differs from the 2 to 7mm estimated depth cited in the literature.[30,73,78,79,92,93,94] This difference in soft tissue thickness could alter the recommended depths of needle insertion by different authors. The extensive range of the *actual measurement* is due to the variation among the specimens and thus validates those injection techniques that account for individual differences.

The methods that account for an individual's facial height, use measurements taken from anatomical landmarks. The method used by Reis Viegas and Hemphill[92] required that two measurements be taken which were then plugged into an equation to predict the correct insertion depth of the needle. However, the calculations involved are time consuming and impractical in a clinical situation. The remaining methods of Jorgensen,[86] Sicher,[90] Mercuri,[91] and Canter, et al.,[94] (Figure 11) require just one measurement. Mercuri's measurement method involves the infraorbital foramen, but clinically this is an approximated landmark, since the foramen is covered by cutaneous tissue. The remaining three techniques use measurements that are taken from easily identifiable anatomical landmarks. Thus the methods of Jorgensen, Sicher, and Canter are more practical in a clinical setting in order to predict the correct length of needle insertion. Through repeated measurement analysis, the Jorgensen technique of subtracting three millimeters from the *facial measurement* was found to be the best method in order to predict the *actual measurement* (Figure 27). Significantly different from the *actual measurement*, were both the *facial* and *orbital* measurements as recommended by Sicher and Canter

respectively.

The closest average distance from the needle tip to the maxillary nerve was from the Jorgensen method (Figure 28). To maximize the mean distance to the nerve for each technique, the data from Table 3 was manipulated, where 38mm became the standard penetration depth for the Malamed method, subtracting 4mm from the *facial measurement* for the Jorgensen and Sicher technique, and adding 2.5mm to *orbital measurement* for the Canter method (Table 4).

The goal with any nerve block is to deposit the local anesthetic solution as close to the nerve trunk as possible.[102] But theoretically, the problem with having the average penetration depth at the level of the maxillary nerve, half of the time the needle tip would be superior to the nerve. Overpenetration of the needle, may in part contribute to diplopia which is the most common complication seen with the maxillary nerve block.[85] The local anesthetic effects the innervation to the muscle of the eye, resulting in the loss of eye coordination.[78] From this study, the Sicher technique resulted in more cases of needle overpenetration. This result would contradict Sicher's recommendation of using the *facial measurement* Technique to decrease the chances of the needle advancing too far within the pterygopalatine fossa.[90]

The safest standard method with the least amount of over penetrations was Malamed's 30mm insertion depth (originally recommended by Lundy[75] and then by Roberts and Sowray,[31] Table 3). Safety was defined as injuring that the needle tip would not go beyond the superior border of the maxillary nerve, and thus decreasing

the opportunity for complications. However, this method resulted with the greatest average penetration depth being 7.95mm below the maxillary nerve. The success of Malamed's method may be explained by the connective tissue sheath (Figure 17) that was found surrounding the contents of the pterygopalatine fossa. This sheath may direct the local anesthetic toward the maxillary nerve and thus allow some latitude for needle insertion depth. Therefore, the success of the maxillary nerve block may not rely so much on the distance from the needle tip to the nerve (as it does with other procedures, like the inferior alveolar nerve block), but for the anesthetic solution to be injected within this connective tissue sheath.

The safest adjustable method (that took into consideration facial height variances) initially seemed to be Canter's method. It resulted in no overpenetrations and the mean distance to the inferior border of the maxillary nerve was 2.5mm. However, this data was based on findings from only 18 specimens.

So keeping in mind the concern of overpenetration of the needle, the data from Table 3 was then re-manipulated so that no needle tip would be inserted beyond the superior margin of the maxillary nerve. The diameter of the maxillary nerve was assumed to be three millimeters. It was hence found that when the penetration depth was equal to the facial measurement minus 6mm, that the mean distance to the maxillary nerve was 2.36mm, thus making this the most accurate method for predicting a safe penetration depth while performing a maxillary block.

This study provides a new dimension to the examination of the maxillary nerve block through the use of cadavers. The utilization of cadavers has been shown to

provide a wealth of knowledge, not only in the review of surgical procedures, but also in the study of injection techniques.[127,128] Unfortunately, the use of cadavers has the inherent problem of tissue desiccation, which can be minimized by diligent specimen preservation. Previous investigators of the maxillary injection technique based their findings on skull studies, with a resultant lack of consistency between recommendations for needle penetration depth. The discrepancies between recommended penetration depths are most likely due to the use of varied landmarks to obtain the measurements, and whether the investigators accounted for the palatal mucosal thickness. Another strong point of this study, is that it accounts for soft tissue variables in measuring the penetration depth to the maxillary nerve proper, and not just to an approximate skeletal location.

Figure 29: Tissue blanching. In delivering a maxillary nerve block (left side) by way of the greater palatine canal, tissue blanching was observed immediately following the administering of local anesthetic (after negative aspiration). The area of the blanching was consistent with the distribution of the terminal branches of the infraorbital artery.

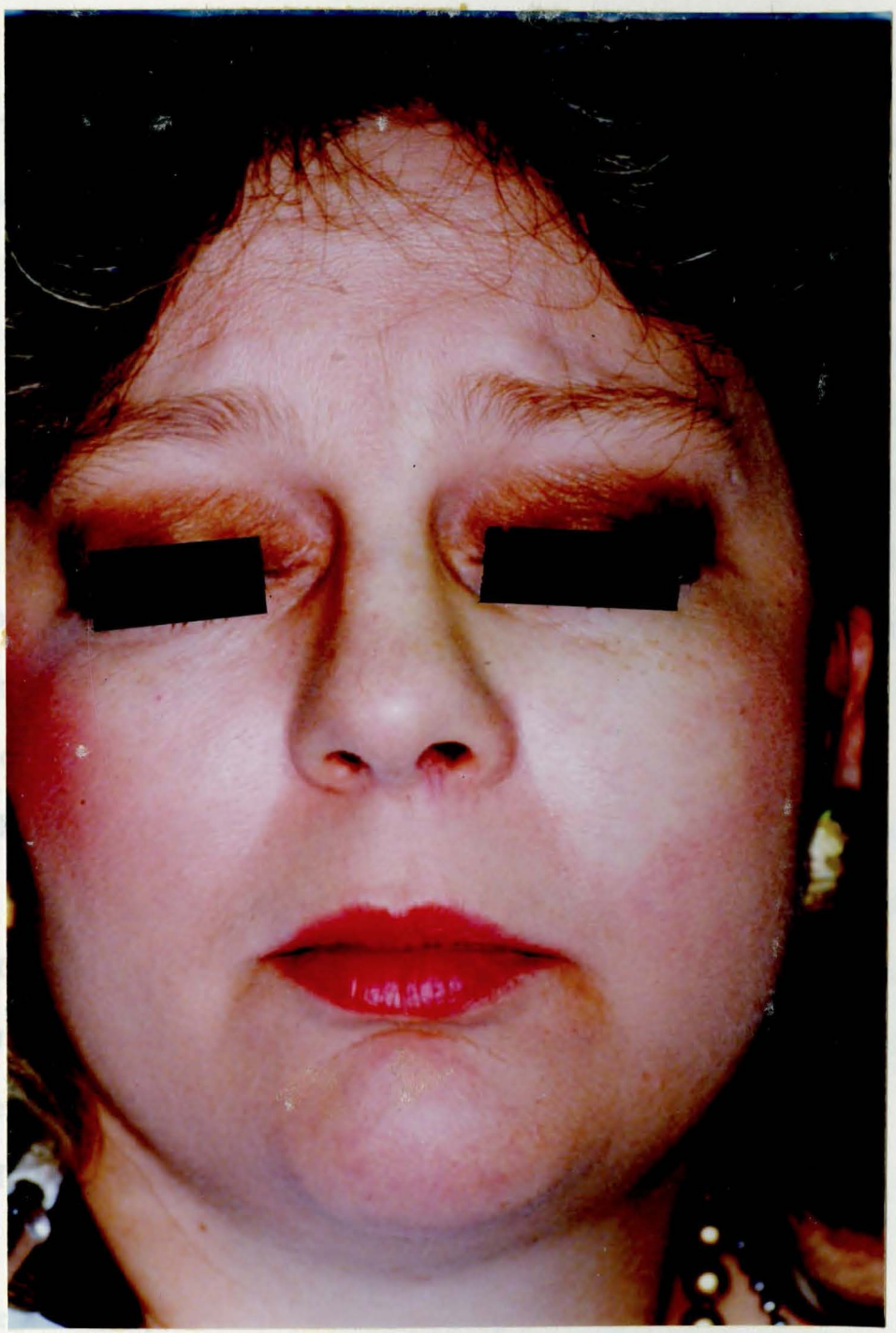


Figure 29

CONCLUSION

This thesis provided a new dimension to the examination of the maxillary nerve block via the greater palatine canal through the use of cadavers.

The effect of the needle on the surrounding tissues was observed in the first part of this thesis. The needle advanced through the canal and along the posterior wall of the pterygopalatine fossa uneventfully in most of the specimens. However, the needle in 12 of 42 specimens had predominantly perforated the descending or greater palatine artery. This re-enforced the necessity for aspiration prior to injection of the anesthetic agent. The 27-gauge needle demonstrated considerable flexibility when maneuvered through the greater palatine canal, and may be the needle of choice for this approach.

The second part of the study examined the neurovascular structures in the greater palatine canal. There was no descending palatine vein found in the canal from either the gross dissections or histological sections. These findings disprove a still common misconception that there is a descending palatine vein that co-exists with the artery in the greater palatine canal.

The third part of this thesis first calculated the actual depth from the palatal mucosa to the maxillary nerve, for each specimen. This measurement was then compared to those predicted by Malamed, Jorgensen, Sicher and Canter. From this

data the best predictive method was determined based on two variables: accuracy and safety.

After statistically manipulating all of the data, it was found that subtracting six millimeters from the facial measurement (the distance from the infraorbital margin to the gingival margin of the maxillary premolars) gave the safest and most accurate method for predicting penetration depth while accounting for patient facial height discrepancies.

In regards to a standard penetration depth, Malamed's 30mm was found to be safe, but not as accurate as the aforementioned technique. However, the high clinical efficacy of this maxillary block technique may be partially due to the presence of a connective tissue sheath in the greater palatine canal, that may funnel the anesthetic toward the nerve.

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