The Relationship of the Lingual Nerve to the 3rd Molar Region: A Three Dimensional Analysis

by

Justin W.J. Garbedian

A thesis submitted in conformity with the requirements for the degree of Master of Science
Graduate Department of Dentistry
University of Toronto

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Abstract

The objective of this study was to: (1) model the course of the lingual nerve (LN) in the third molar region using digitized data and (2) investigate landmarks to aid in predicting the position of LN. A MicroScribe 3-DX digitizer and Autodesk® Maya® 8.5 were used to create 3-D in-situ models of LN for seven human cadaveric specimens. Regression analysis demonstrated that an anteriorly positioned lingula is directly proportional to the vertical distance of the LN relative to the alveolar crest (p < 0.05). A superiorly positioned mylohyoid ridge was also directly proportional to the vertical distance of the LN relative to the alveolar crest (p < 0.05). The LN is positioned closer to the alveolar crest in specimens where the mylohyoid ridge is positioned superiorly (p = 0.001). This study demonstrated a novel way of quantifying the relative position of the LN using 3-D computer modeling.
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CN</td>
<td>Cranial Nerve</td>
</tr>
<tr>
<td>CN V$_3$</td>
<td>Mandibular division of the Trigeminal Nerve</td>
</tr>
<tr>
<td>HR</td>
<td>High Resolution</td>
</tr>
<tr>
<td>IAN</td>
<td>Inferior Alveolar Nerve</td>
</tr>
<tr>
<td>LN</td>
<td>Lingual Nerve</td>
</tr>
<tr>
<td>LP</td>
<td>Lateral Pterygoid Muscle</td>
</tr>
<tr>
<td>M1</td>
<td>Mandibular First Molar</td>
</tr>
<tr>
<td>M2</td>
<td>Mandibular Second Molar</td>
</tr>
<tr>
<td>M3</td>
<td>Mandibular Third Molar</td>
</tr>
<tr>
<td>Md</td>
<td>Mandible</td>
</tr>
<tr>
<td>MH</td>
<td>Mylohyoid muscle</td>
</tr>
<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>Mu</td>
<td>Mucosa</td>
</tr>
<tr>
<td>PETRA</td>
<td>Phase Encode Time Reduction Acquisition</td>
</tr>
<tr>
<td>Ref</td>
<td>Reference point</td>
</tr>
<tr>
<td>Sd</td>
<td>Submandibular Duct</td>
</tr>
<tr>
<td>SMd</td>
<td>Submandibular Gland</td>
</tr>
<tr>
<td>S/N</td>
<td>Signal to noise ratio</td>
</tr>
<tr>
<td>TG</td>
<td>Tongue</td>
</tr>
<tr>
<td>3-D</td>
<td>Three Dimensional</td>
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</tbody>
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Chapter 1
Introduction

Knowledge of the position of the lingual nerve (LN) is invaluable to the surgeon operating in the mandibular third molar region. Iatrogenic injury to the nerve can result in significant morbidity to the patient and potential medical-legal repercussions for the surgeon. Previous studies using cadaveric dissections, clinical observation during third molar surgery and high-resolution magnetic resonance imaging have yielded inconsistent data in documenting the position of the LN (Kiesselbach and Chamberlain, 1984; Pogrel et al., 1995; Miloro et al., 1997; Behnia et al., 2000; Hölzle and Wolff 2001). These studies show large variations in the vertical and horizontal location of the LN with respect to the mandibular alveolar crest. Attempts to explain this variability has largely been attributed to several confounding variables in study design. For example Miloro et al. (1997) ascribe such inconsistency to lack of standardized measurements and fixation of specimens. However, in their recent study Hölzle and Wolff (2001) did find a positive correlate between vertical LN positioning and mandibular crest atrophy.

The lack of consensus amongst previous studies warrants further investigation. An in-situ 3-D computer model of the LN and related structures may aid in clarifying the position of the LN in the third molar region. The relationship of the LN with other anatomical structures could also be explored with this data set. Such correlations could be utilized in surgical treatment planning to predict the location of the LN and minimize iatrogenic injury.
1.1 Contents of the Thesis

The present thesis consists of eight chapters presented in the following sequence:

Chapter 1 provides a brief discussion on the ramifications of lingual nerve (LN) damage and the rationale for further investigation into its precise position.

Chapter 2 presents the literature describing the anatomical variations of the LN as it courses from its origin from the mandibular branch of the trigeminal nerve (CN V₃) to the tongue. The relationship of the LN to bony features in the mandibular third molar region will be reviewed in detail followed by an introduction to the factors involved in LN damage and the classifications for peripheral, along with management strategies for LN injuries.

Chapter 3 outlines the hypotheses, objectives and significance of the study.

Chapter 4 describes the dissection approach, digitization and computer modeling of the oral mucosa, medial pterygoid muscle, LN, mylohyoid muscle, medial surface of the mandible and the mandibular second molar.

Chapter 5 is a summary of the results. Qualitative findings such as the shape of the LN and presence of accessory branches are first described. Quantitative data describing the position of the LN with respect to the oral mucosa and mandible was then presented. The final section report describes the quantitative data with a regression analyses between the LN and the mylohyoid ridge and the LN and the lingula.

Chapter 6 is a discussion of the results of this thesis and how it compares with previous studies. The clinical relevance of these findings is also presented.

Chapter 7 and 8 list the conclusions of this thesis and suggest possible future directions.
Chapter 2
Review of the Literature

2.1 Anatomy of the Lingual Nerve

2.1.1 Gross Anatomy and Innervation

The tongue is a complex organ that is involved in speech, mastication, swallowing, taste, respiration and sensation (Zur et al., 2004; McGuire, 2005). The following cranial nerves innervate the tongue:

- The hypoglossal nerve (CN XII) provides the motor supply to the muscles of the tongue except for the palatoglossus muscle, which is innervated by the accessory nerve (CN XI) via the vagus nerve (CN X) (Liegbott, 1986).

- The glossopharyngeal nerve (CN IX) supplies general and special sensory sensation to the posterior one-third of the mucosa of the tongue.

- The LN, a branch of the mandibular division of the trigeminal nerve (CN V₃) provides sensory innervation to the ipsilateral two-thirds of the mucous membranes of the tongue, floor of mouth and the mandibular lingual gingiva (Liegbott, 1986; Zur et al., 2004).

- The chorda tympani, a branch of the facial nerve (CN VII) “hitchhikes” along the course of the LN to transmit special visceral afferent fibres (preganglionic parasympathetic) to the submandibular and sublingual salivary glands and special sensory afferents (taste) to the anterior two-thirds of the tongue (Liebgott, 1986; Zur et al., 2004; Fonseca, 2005).

In a recent anatomical study, Saigusa et al. (2006), suggested that a portion of the superior and inferior longitudinal muscles of the human tongue may be innervated by motor fibres originating from the CN V motor root.
The origin of the LN begins as a branch from the posterior division of CN V3 in the infratemporal fossa. While in the infratemporal fossa, the chorda tympani joins the LN at an acute angle as it exits through the pterygotympanic fissure of the glenoid fossa (Girod et al., 1989). The LN, along with the chorda tympani, then descends medially to the lateral pterygoid muscle and inferior alveolar nerve.

The nerve continues to descend, in an anterior direction, to enter the pterygomandibular space. While in this space, the LN travels between the medial aspect of the mandibular ramus and the lateral aspect of the medial pterygoid muscle. The LN then enters the oral cavity after passing the anterior edge of the medial pterygoid muscle.

The LN courses from a more lateral to medial position as it approaches the mandibular third molar due to the oblique flare in the mandible in this region. As the LN approaches the third molar, its position with respect to the alveolar bone, is variable. Several studies have tried to clarify this complex 3-D relationship with little consistency (Kiesselbach and Chamberlain, 1984; Pogrel et al., 1995; Miloro et al., 1997; Behnia et al., 2000; Hölzle and Wolff, 2001; Karakas et al., 2007). The results of these studies are compared in table 2.1.

As the LN courses along the floor of the mouth, the mylohyoid muscle bounds it inferiorly. In the region of the mandibular second molar, the submandibular ganglion can be found suspended inferiorly from the LN by autonomic secretory fibres. The LN then begins to course anteromedially, looping itself under the submandibular (Wharton’s) duct. The nerve then passes upward onto the genioglossus muscle to enter the ventral mucosa of the tongue anterior to the circumvallate papillae (Zur et al., 2004).

As the LN enters the tongue, it gives off two main branches: a medial and a lateral. The medial branch sends 2-4 small branches to the medial part of the
ventrolateral tongue, while the lateral branch travels along the lateral border of the tongue to send 2-5 large branches to the anterior tip of tongue (Zur et al., 2004). Both medial and lateral branches are generally restricted to the ventrolateral portions of the tongue leaving few, surgically significant, LN fibres in the mid-body of the tongue. Furthermore, the LN has consistent anastomotic connections with the hypoglossal nerve in the body of the tongue (Fitzgerald and Law, 1958; Zur et al., 2004). This neural organization is consistent with the lingua-hypoglossal reflex and is important in the reflex control of tongue movement (Zur et al., 2004).

2.1.2 Anatomical Variations

2.1.2.1 Infratemporal and Pterygomandibular Regions

The branching of the LN from the posterior division of CN V₃ has classically been described at the level of the otic ganglion (Leibgott, 1986). A cadaveric study by Kim et al. (2004) clarified this division by illustrating multiple branching patterns of the LN from the inferior alveolar nerve (IAN). In 65.6% specimens (21 out of 32) the bifurcation of the LN and IAN was located between the sigmoid notch and the otic ganglion. Eight cases (25.0%; 8 out of 32), demonstrated branching patterns in the upper half of the ramus, while only one case (3.1%; 1 out of 32) bifurcated just superior to the lingula. The remaining specimens (6.2%; 2 out of 32) had a plexiform branching pattern from CN V₃. Racz and Maros (1981) reported similar plexiform bifurcations in 8.3% (4 out of 48) of the specimens. A recent cadaveric study by Erdogmus et al. (2008) supports the multiple branching patterns of the LN and IAN. The majority of specimens (66.7%; 14 out of 21) bifurcated above the level of the sigmoid notch. The remaining cases bifurcated between the sigmoid notch and the mandibular lingula (33.3%; 7 out
of 21). Some interconnections between the LN and IAN were observed, 1-3 branches in 47.61% (10 out of 21) of the specimens; however, no plexiform branching pattern was noted.

Kim et al. (2004) also measured the distance of the bifurcation to stable anatomic landmarks. The bifurcation was noted to occur approximately 14.3 mm (range: 7.8 - 24.1 mm) inferior to the foramen ovale and 16.5 mm (range: 4.9 - 24.3 mm) superior to the tip of the hamulus. This reported variation in LN and IAN bifurcation patterns has contributed to the failure rate (13-29%) of mandibular nerve block anesthesia in dentistry (Blanton and Jeske, 2003).

The chorda tympani, a branch of the facial nerve (CN VII) unites with the LN as it descends in the infratemporal fossa. Nerve fibers from the chorda tympani hitchhike along the LN as special sensory fibers to provide taste sensation from the anterior two-thirds of the tongue and presynaptic parasympathetic fibers to the submandibular ganglion. In a cadaveric study by Erdogmus et al. (2008), the junction of the LN and chorda tympani was frequently (80.95%; 34 out of 42) found to be located at the depth of the lateral pterygoid and superior to the upper edge of the medial pterygoid muscles. The remaining cases (19.04%; 8 out of 42) demonstrated a junction in the upper half of the medial pterygoid muscle. The average distance of the junction of the LN and the chorda tympani from the foramen ovale was 15.1 ± 5.8 mm (Erdogmus et al., 2008).

As the LN travels anteroinferiorly in the pterygomandibular region, it generally courses between the lateral surface of the pterygoid muscle and the mandible. Occasionally, the LN has been reported to give off branches to the posterolateral part of the medial pterygoid muscle from the lateral surface (Sakamoto and Akita, 2004). Sakamoto and Akita (2004) reported an atypical spatial relationship of the LN through
the medial pterygoid muscle. This alternative course had the LN penetrating the medial pterygoid muscle and separating the anterolateral muscle bundle into an accessory bundle. This accessory bundle inserted into an area superior to the mylohyoid line in the retromolar region and was innervated by a small branch from the lingual nerve on its medial surface.

2.1.2.2 Retromolar Region

Several studies have reported collateral nerve twigs from the LN innervating the retromolar region (Kiesselbach and Chamberlain, 1984; Girod et al, 1989; Kim et al, 2004; Erdogmus et al., 2008). Erdogmus et al. (2008) noted that the LN provided several small nerve branches to the paralingual area but failed to quantify these “variational nerve innervations”. Kim et al (2004) claimed that 81.2% (26 out of 32) of their specimens had collateral nerve twigs to the retromolar area. These collateral branches were distributed on the lingual gingival in proximity to the mandibular third molar and retromolar mucosa. An average of one nerve twig was reported with a range of zero to three branches. Kim et al. (2004) suggested that this branching pattern should not be considered a variation but a normal innervation pattern of the LN. Furthermore, this anatomic collateral innervation may help to explain the incomplete anaesthesia that is occasionally noted following the administration of local anaesthetic during a mandibular block and long buccal blocks.

As the LN approaches the floor of mouth, communicating branches between the LN and the mylohyoid nerve have been reported (Racz and Maros, 1981; Kim et al., 2004; Sakamoto and Akita, 2004; Erdogmus et al., 2008). Erdogmus et al. (2008) reported an incidence of 11.9% (5 out of 42). Kim et al. (2004) reported a similar
incidence of 12.5% (4 out of 32) in Korean specimens. The LN innervated the superomedial surface of the mylohyoid muscle and communicated with the mylohyoid nerve within the muscle (Sakamoto and Akita, 2004). This communication has been called the “mylohyoid or sublingual curl” and provides an alternative route for collateral sensory transmission.

2.1.2.3 Position of LN in Third Molar Region

As the LN courses anteriorly to the retromolar region, it follows the contours of the medial aspect of the mandible. For many years, the scientific literature was lacking qualitative and quantitative data for the position of the LN in the region of the third molar. It was this lack of knowledge that prompted Kiesselbach and Chamberlain (1984) to evaluate the position and shape of the LN in the third molar region. This study evaluated 34 adult cadaver heads and 256 in-vivo observations of the LN during mandibular third molar extractions. The horizontal distance varied amongst specimens with an average distance of 0.58 ± 0.9 mm from the lingual plate. In 62% (21 out of 34) of the specimens, the nerve was in contact with the lingual plate. Vertical distance of the LN below the alveolar crest was 2.28 ± 1.96 mm. A surprising finding of this study was that in 17.6% (6 out of 34) of the cadaveric specimens and 4.5% (12 out of 256) of the in-vivo cases the LN was positioned at the level of the alveolar crest or higher.

Pogrel et al. (1995) attempted to verify the findings by Kiesselbach and Chamberlain by dissecting 20 cadavers (40 sides) and measuring the location of LN with respect to osseous points. This study used reproducible osseous landmarks for measuring the distance to the LN and accounted for the presence or absence of posterior mandibular teeth. The findings confirmed the variability of the nerve in the sagittal and coronal
planes. The closest distance of the nerve to the mandible was a mean of 3.45 ± 1.48 mm (range: 1 - 7mm), which differs from the findings by Kiesselbach and Chamberlain. The LN showed a close proximity to the lingual cortex of the mandible for a mean distance of 27.7 mm. The mean vertical distance of the superior aspect of the LN to the alveolar crest was 8.32 ± 5.69 mm. In 3 cases (out of 40), the LN was at the level (one case) or superior (two cases) to the alveolar crest, which is in agreement with the findings presented by Kiesselbach and Chamberlain (1984). No statistical relationship was found with regards to the presence or absence of the mandibular third molar and LN position. Furthermore, the position of the LN nerve on one side was not correlated to its position on the contralateral side.

A potential limitation in cadaveric studies is the iatrogenic displacement of the LN during the dissection process. To circumvent this, Behnia et al. (2000) used two clips on the lingual aspect of the posterior gingiva to stabilize the location of the LN. Although this technique may limit LN displacement during dissection, it introduces compression distortion. However, the study was novel, in that the dissections were performed on fresh cadavers within 24 hours of death. Furthermore, this study exceeded previous sample sizes with the evaluation of 669 LNs. The mean horizontal and vertical distances of the LN in the third molar region are summarized in Table 2.1. An unexpected finding in this study was that in one case the LN was located in the retromolar pad (Behnia et al, 2000).

In 2001, Hölzle et al., examined the position of the LN in the third molar region with respect to atrophy of the alveolar crest. The investigators also found that the distance from the LN decreases as the degree of mandibular atrophy increases. Vertical
and horizontal distances of the LN to the alveolar crest were variable to previous anatomical studies (Table 2.1).

All cadaveric studies discussed above utilized calipers for measuring the vertical and horizontal distances of the LN. Karakas et al. (2007) in contrast, used radiographs to quantify in the horizontal and vertical measurements of LN with respect to the mandible. A 3 mm wire was placed along the undisturbed position of LN in 21 sagittally sectioned cadaveric heads. Radiographs were then taken in the superior and lateral planes and vertical and horizontal distances of the LN to mandible were then measured from the radiographs using digital calipers. The mean vertical and horizontal distances were 9.5 ± 5.2 mm and 4.1 ± 1.9 mm respectively (Table 2.1). The horizontal measurements are markedly greater to those presented by Kiesselbach and Chamberlain (1984) and Hölzle and Wolff (2001). Karakas et al. (2007) postulated that this difference might be due to a superiorly positioned mylohyoid muscle and/or greater mylohyoid muscle volume.

**Table 2.1:** Literature Summary of LN position in 3rd molar region

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of Study</th>
<th>N</th>
<th>Measurement (mm)</th>
<th>Percentage (%) of Specimens</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Vertical</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Kiesselbach &amp; Chamberlain</td>
<td>Cad IV</td>
<td>34</td>
<td>2.28 +/- 1.96</td>
<td>0.58 +/- 0.9</td>
</tr>
<tr>
<td>Pogrel et al.</td>
<td>Cad</td>
<td>40</td>
<td>8.32 +/- 4.05</td>
<td>3.45 +/- 1.48</td>
</tr>
<tr>
<td>Behnia et al.</td>
<td>Cad</td>
<td>669</td>
<td>3.01 +/- 0.42</td>
<td>2.06 +/- 1.10</td>
</tr>
<tr>
<td>Hölzle and Wolff</td>
<td>Cad</td>
<td>68</td>
<td>7.83 +/- 1.65</td>
<td>0.86 +/- 1.00</td>
</tr>
<tr>
<td>Karakas et al.</td>
<td>Cad</td>
<td>21</td>
<td>9.56 +/- 5.28</td>
<td>4.19 +/- 1.99</td>
</tr>
</tbody>
</table>

N = Sample Size; Cad = cadaveric study; IV = in-vivo study; RMP = retromolar pad
2.1.3 Cross-section Morphology

The cross-sectional morphology of the LN is variable along its course in the oral cavity, e.g. circular or oval to flat or ribbon-like (Kiesselbach and Chamberlain, 1984; Miloro et al., 1997; Kim et al., 2004). The reported cross sectional morphologies are summarized in Table 2.2. Kiesselbach and Chamberlin (1985) found the LN to be round (61.7%; 21 out of 34), oval (17.6%; 6 out of 34) or flat/ribbon-like (20.5%; 7 out of 34) in the third molar region with no correlation to the distance from the medial surface of the mandible. Miloro at al. (1997) noted that of the 20 LNs examined, 9 (45%) were round, 6 (30%) were elliptical, and 5 (25%) were kidney-bean shaped. Kim et al. (2004) studied the shape of the LN in the retromolar, third molar and second molar region. A circular (40.6%; 13 out of 32) or oval (40.6%; 13 out of 32) morphology of the LN predominated in the retromolar region whereas an oval (59.4%; 19 out of 32) or ribbon-shape (62.5%; 20 out of 32) was most common in the third and second molar region respectively. The ribbon-like shape was not observed in the retromolar or third molar region by Kim et al. (2004).

Table 2.2: Literature Summary of Cross - Sectional Morphology of LN

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Location</th>
<th>Cross Sectional Morphology</th>
<th>Circular</th>
<th>Oval</th>
<th>Flat</th>
<th>Ribbon-like</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiesselbach &amp; Chamberlain</td>
<td>34</td>
<td>M3</td>
<td></td>
<td>31.7%</td>
<td>17.6%</td>
<td>20.5%</td>
<td></td>
</tr>
<tr>
<td>Kim et al.</td>
<td>32</td>
<td>RM</td>
<td></td>
<td>40.6%</td>
<td>40.6%</td>
<td>18.8%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M3</td>
<td></td>
<td>25%</td>
<td>59.4%</td>
<td>15.6%</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M2</td>
<td></td>
<td>3.1%</td>
<td>18.8%</td>
<td>15.6%</td>
<td>62.5%</td>
</tr>
<tr>
<td>Miloro et al.</td>
<td>20</td>
<td>M3</td>
<td></td>
<td>45%</td>
<td>30%</td>
<td>25%</td>
<td>(kidney bean)</td>
</tr>
</tbody>
</table>

N = Sample Size; M3 = Third molar; M2 = Second Molar; RM = Retromolar
2.1.4 Microanatomy

The microanatomy of the LN is similar to other peripheral nerves. The LN has a polyfascicular pattern, which consists of many fascicles of varying sizes but without fascicular grouping (Svane et al., 1986; Abby et al., 1987). The mean number of fascicles for the LN at the third molar region is 8.5 to 10 +/- 4.0 (Girod et al., 1989). Abby et al. (1987) reported 15-18 fascicles in this region, which decreased to 9 fascicles as the nerve entered the tongue. The mean total cross-sectional area of the LN fascicle is 1.87 mm +/- 0.38 mm² (Girod et al., 1989). The number and size of fascicles is critical to the microsurgeon as repair of a nerve requires correlation between the donor and host nerve.

2.2 Imaging Studies of the LN

2.2.1 Introduction

There are limited imaging studies in the literature evaluating the position of the LN (Miloro et al., 1997; Karakas et al., 2007 and Olson et al., 2007). As previously discussed, plain film radiography was utilized by Karakas et al. (2007) to aid in measuring the position of the LN in cadaveric specimens. This technique provides no diagnostic merit, as it requires the placement of a metal wire along the LN. Only one study in the literature has evaluated the position of the human LN using magnetic resonance imaging (MRI) (Miloro et al., 1997). This study represents the first and only documentation of in-vivo measurements of the position of LN in the third molar region. The use of ultrasonography has recently shown promise in locating the LN in cadaveric pigs (Olsen and Troulis, 2007).
2.2.2 Magnetic Resonance Imaging (MRI)

MRI was previously unable to identify the course of nerves due to distortion (signal to noise ratio (S/N)) (Miloro et al., 1997). Advancements made through high resolution (HR-MRI) and specific imaging protocols such as phase encode time reduction acquisition (PETRA) has been applied to the LN by Miloro et al (1997). Ten healthy volunteers with present mandibular third molars underwent axial and coronal HR-MRI PETRA of the mandible, bilaterally. The mandible was examined from the lingula to the mental foramen as reconstructed 1.5 mm slices. The image closest to the center of the tooth was selected to measure the distance from the lateral edge of the LN to the lingual plate (horizontal dimension) and from the superior edge of the LN to the lingual crest (vertical dimension). The LN was only noted to be superior to the lingual alveolar crest in two cases and there was no bilateral correlation. Results are summarized in Table 2.3. Miloro also studied the position of the tongue with respect to LN position and found no correlation.

Table 2.3: Summary of LN Position using MRI

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Mean Nerve Diameter (mm)</th>
<th>Measurement (mm)</th>
<th>Percentage (%) of Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vertical</td>
<td>Horizontal</td>
</tr>
<tr>
<td>20</td>
<td>2.54</td>
<td>2.75 ± 0.97</td>
<td>2.53 ± 0.67</td>
</tr>
</tbody>
</table>

Although Miloro et al. demonstrated that HR-MRI could be utilized to image the LN, its clinical application is limited primarily due to expense and availability. Furthermore, documenting in-situ LN injuries would be limited to complete transections, as subtle injuries would be indiscernible (Miloro et al., 1997).
2.2.3 Ultrasonography

A recent study by Olson et al. (2007) demonstrated the use of ultrasonography in visualizing the LN in cadaver pigs. After sufficient training, all three evaluators could correctly identify the LN. The average distance of the LN to the lingual cortex was 1 mm. This application of ultrasonography proves promising in humans, as the pig’s LN is approximately ¼ of the size. Furthermore, the evaluators could accurately identify an intact, partially transected or fully transected nerve injury 63% of the time.

2.3 Lingual Nerve Injury

2.3.1 Introduction

The LN allows for complex sensory-discriminative-secretomotor function. Damage to it can result in temporary or permanent general sensory changes to the anterior two-thirds of the tongue and floor of mouth. This loss of sensory function can result in changeable degrees of anesthesia, paraesthesia, dyesthesia or hypoesthesia, which can be permanent or transitional. This damage can cause drooling, tongue biting, a burning sensation, pain and speech changes (Fielding et al., 1997; Pichler and Beirne, 2001; Renton and McGurk, 2001; Graff-Radford and Evans, 2003). Damage to the LN can also result in loss of taste to the anterior two-thirds of the tongue and altered salivary secretion on the involved side.

2.3.2 Incidence of LN Injury

While some iatrogenic damage to the LN is unavoidable, such as with the removal of malignant masses, unfortunately the majority of injuries are the result of elective and iatrogenic procedures (Holmes and Lam, 2002; Robinson et al., 2004). The cause of LN injuries include, for example, the surgical insertion of dental implants
(Berberi et al., 1993), inadvertent instrumentation during mandibular osteotomies (Zuniga and Phillips, 1997; Jacks et al., 1998; Becelli et al., 2004), administration of local anesthetic (Hillerup and Jensen, 2005) and removal of mandibular third molars.

Holmes and Lam (2002) suggest that approximately 75% of LN injuries are a result of third molar removal. This is not surprising since removal of impacted third molars is one of the most commonly performed procedures within an oral and maxillofacial surgeon’s office. In 2001, Britain reported impacted third molars to be the eighth most commonly performed surgery with approximately 150,000 procedures per year (Renton and McGurk, 2001). The incidence of LN damage during mandibular third molar surgery is inconsistent within the literature. The majority of studies report an incidence of 0.6% to 2.0% (Pogrel and Renault, 1995; Brann et al., 1999; Behnia et al., 2000, Bataineh, 2001; Hölzle and Wolff, 2001; Renton and McGurk, 2001; Chossegros et al., 2002; Karakas et al., 2007); however, the prevalence has been reported as high as 23% (Middlehurst et al., 1988). Fortunately, the majority of LN injuries result in temporary LN disturbances, with only approximately 0.5 – 1.0 % reporting permanent LN sensory dysfunction (Blackburn and Bramley, 1989; Jerjes et al., 2006).

2.3.3 Factors Influencing LN Injuries

Several factors contribute to the variability of LN paresthesia following third molar surgery. Variations in surgical technique, in particular the use of a lingual retractor, are well documented in the literature (Rood, 1983; Wofford and Miller, 1987; Mason, 1988; Obiechina, 1990; Rood, 1992; Schultz-Mosgau and Reich, 1993; Robinson and Smith, 1996; Brann et al., 1999). Although a topic of debate, many studies agree that avoidance of lingual retraction reduces the incidence of temporary lingual nerve
disturbance and does not increase the incidence of permanent damage (Robinson and Smith, 1996; Batanineh, 2001; Chossegros et al., 2002). A meta-analysis in 2001 corroborates this finding by showing no difference in permanent LN injury rates whether a lingual retractor was used or not (Pichler and Beirne, 2001). Greenwood et al. (1994) argued in support of a broad retractor to protect the LN rather than a Howarth periosteal elevator since it produces less paresthesia at one month. On the other hand, Appiah-Anane and Appiah-Anane (1997) demonstrated a 0.2% incidence of LN damage by avoiding the use of a lingual flap and by preserving the lingual plate of the mandible. Ultimately, the decision to use a lingual flap or retractor is at the discretion of the surgeon.

The classification of impacted mandibular third molars can also affect the incidence of LN injuries. Mesioangular impacted third molars account for 43% of LN paresthesia cases, while distoangular impactions account for only 6% (Peterson, 1993). In contrast, Bataineh (2001) failed to find an association between angulation of the tooth and LN paresthesia.

The relationship between age and LN paresthesia following third molar surgery is inconclusive. Bruce et al. (1980) and Chiapasco et al. (1995) found a positive correlation between older patients and risk of LN damage. In the study by Bruce et al. (1980), the incidence of LN damage was 1.8% for patients with a mean age of 46.5 years, compared to 0.6% for those with a mean age of 20 years. In contrast, many studies have failed to show a correlation of LN damage to the age of the patient (Brann et al., 1999; Bataineh, 2001; Jerjes et al., 2006;).

Studies have shown a greater incidence of LN paresthesia following surgery performed under general anesthetic versus local anesthetic (Bruce et al., 1980; Brann et
al, 1999). Brann et al (1999) reported a 5-fold increase in the incidence of LN paresthesia under general anesthesia compared to local anesthetic alone. This finding could not be explained by age, preoperative pathology or surgical difficulty. Brann et al. (1999) rationalized that this higher incidence rate may be complicated by the positioning of the patient in the supine position, extent of flap exposure / bone removal or greater amount of surgical force generated while a patient is under a general anesthetic. The surgeon’s experience plays a role in the incidence of LN damage (Sisk et al., 1986; Gülicher and Gerlach, 2001; Bataineh, 2001; Jerjes et al., 2006). A prospective study evaluating several predictors of tongue paresthesia, concluded that the seniority of the surgeon to be the only significant predictor (P = 0.022) in determining permanent LN paresthesia (Jerjes et al., 2006). The prevalence of permanent LN paresthesia was 4 times more likely to occur in a group of trainees. This discrepancy is likely to due inexperience, improper use of force and mishandling of surgical instrumentation.
2.3.4 **Classification of LN Injuries**

Several classification schemes exist for describing sensory disturbances secondary to peripheral nerve damage: physiologic, symptomatic, anatomic, histopathologic, and pathophysiologic (McGuire, 2005). While no single classification scheme is ideal, the Seddon (1943) and/or Sunderland (1951) classification is widely used as they correlate severity with prognosis.

2.3.4.1 **Seddon’s Classification**

In 1943, Seddon developed a peripheral nerve classification based on the severity of injury affecting the endoneurium, perineurium, epineurium and supporting tissues. Mild insult to the nerve was termed neuropraxia. With this type of injury, a conduction block occurs without axonal degeneration. Most injuries to the LN due to the use of a lingual flap retractor are classified as neuropraxia. Resolution of these sensory deficits is within hours to days and is complete. Axonotmesis denotes a more serious injury with preservation of the epineurium but varying degrees of afferent fiber degeneration. Incomplete sensory recovery occurs with the potential of neuroma formation. Neurotmesis describes the most severe injury with poor axonal regeneration due to severe disruption or complete discontinuity of all connective layers of the peripheral nerve. Clinical examination reveals anesthesia in the nerve distribution and no sensory recovery.

2.3.4.2 **Sunderland’s Classification**

In 1951, Sunderland expanded Seddon’s classification to further emphasize the mechanism of injury and offer insight into managing such injuries. Under this classification scheme, Sunderland describes five levels of injuries with the first-degree
injury being sub-classified into three types. All Sunderland first-degree injuries are equivalent to Seddon’s neuropraxia. Within this degree of injury, axonal conduction is temporarily blocked but the continuity of the axon is preserved. First-degree type I injuries are due to mild traction or compression which results in transient ischemia. Recovery of the sensory deficit usually occurs within twenty-four hours. First-degree type II injuries are the result of more severe traction or compression causing intrafascicular edema, decreased blood flow and a conduction blockade (Graff-Radford and Evans, 2003). Normal sensation returns as the edema subsides which takes days to weeks. First-degree type III injuries are the result of further traction and compression causing localized mechanical disruption of myelin sheaths and demyelination. This injury usually requires one to two months for normal sensation to return. Sunderland’s second, third and fourth degree injuries correspond with Seddon’s classification of axonotmesis. A second-degree injury results in Wallerian degeneration of the axon without disruption to the endoneurium, perineurium or epineurium. Sensory recovery is usually complete in 2-4 months but may take up to one year for complete recovery. Third-degree injuries occur due to moderate or severe crush or traction insults. Wallerian degeneration occurs with disruption of the endoneurium. This breach of the endoneurium will not allow for axonal regeneration resulting in some degree of sensory loss. Fourth-degree Sunderland injuries occur when the endoneurium and perineurium have been violated due to severe trauma. Neuronal loss occurs with the possibility of neuroma formation or intraneural fibrosis. Fifth-degree injuries correlate with Seddon’s Neurotmesis classification. This type of injury is the result of transection, avulsion or laceration of the nerve, which causes a disruption of all three connective tissue sheaths. Unfortunately, this injury results in complete anesthesia with the potential for
neuropathic responses such as allodynia, hyperalgesia or hyperpathia (Fonseca, 2005). MacKinnon and Dellon, in 1988, added a sixth degree injury to Sunderland’s classification to describe variable degrees of injury that can co-exist within a single nerve (Mackinnon and Dellon, 1988).

2.4 Management of LN Injuries

Robinson et al. (2004), suggest, “patients who are ultimately left with a minor degree of hypoanaesthesia cope well with the sensory deficit are unlikely to benefit from intervention, and are probably best left untreated. In contrast, patients who have either substantial sensory deficit or the painful sensory disorder of dyseaesthesia may benefit from intervention, and so must be identified and managed in a manner that will optimize the outcome”. In his 2004 article, Robinson provides an algorithm (Figure 2.1) for the management of LN injuries as a result of third molar removal.

In the few patients in which LN laceration is noted at the time of third molar removal the algorithm suggests immediate microsurgical repair. Robinson recommends “the use of an operating microscope and insertion of 6 to 8, 8-0 monofilament polyamide epineural sutures”. Variations of this technique are found in the literature with only minor changes in suture size and number (Dobson, 1997; Fonseca, 2009). This technique is only possible if a “tension free repair” is possible (Dobson, 1997). Unfortunately, most LN injuries go unnoticed at the time of injury and it is not until post-operative follow-up or complaint by the patient that they are recognized.

The timing of surgical intervention in LN injuries is paramount. The observational period of three months recommended by Robinson et al. (2004) is to help distinguish between varying degrees of injury. Stimulus evoked paresthesia suggest
neuropraxia-like injuries and thus require no intervention. Complete anesthesia of the LN distribution implies an axonotmesis or neurotmesis and may warrant surgical intervention. The delay of surgical intervention has been attributed to poorer outcomes (Mozsary and Middleton, 1984; Meyer, 1992; Pogrel and Kaban, 1993; Donoff, 1995). Positive surgical outcomes decrease with the passing of time due a higher incidence of Wallerian degeneration, atrophy and fibrosis of the distal portion of the nerve (Wolford and Stevao, 2003). Hillerup and Jensen (2007) reported the fastest recovery occurred during the initial 6 months after injury. Riediger and Cornelius (1989) suggested that repairs conducted after twelve months of the injury are questionable.
Figure 2.1: Protocol for LN Injuries (Adapted from Robinson et al. (2004))
Microsurgical techniques for nerve repair have been used for many years. According to Hillerup and Jensen (2007), microsurgical repair should only be considered in nerves with persistent, total or near total loss of function beyond 3-6 months and the potential benefit of repair will justify microsurgery. Comparing the literature on microsurgical repair of LN is problematic due to lack of standardized outcome assessments and small sample sizes (Graff-Radford and Evans, 2003; Robinson et al., 2004). Wiethölter et al. (1990) and Wolford and Stevao (2003) report better results for IAN repair with end-to-end anastomosis versus nerve grafting. Robinson and Smith (1996) found similar success with direct repair of the LN, stating that it was the most effective repair procedure. A retrospective study conducted by Rutner et al. in 2005 investigated an external neurolysis procedure in combination with an internal neurolysis, neuroma excision or primary neurorrhaphy for LN injuries. The outcomes of this study demonstrated a 90% improvement in neurosensory function. Robinson and Smith (2000) also demonstrated positive outcomes with direct neurorrhaphy of the LN. Successful outcomes of LN repair may appear to be case specific. Collin and Donoff (1990) reported a higher success rate for LN repair in patients with anesthesia (77%) versus pain-paresthesia (42%). Gregg (1990) and Pogrel and Kaban (1993) on the other hand reported good pain reduction following repair. Zuniga et al. (1997) evaluated chemosensory (taste) regeneration following nerve repair with a 50% improvement in 12 patients. Notably they reported that taste is usually compensated overtime. Recently, a bioabsorbable collagen nerve cuff (NeuraGen) has shown promising results when used in conjunction with direct repair of IAN and LN injuries (Farole, 2008). The NeuraGen cuff is believed to minimize scar ingrowth and concentrate growth factors at the site of injury.
While direct apposition is desirable, this treatment modality is not always possible. The nature of LN damage often precludes the ability to obtain tension free co-adaptation and thus a bridge is required between the proximal and distal ends of the nerve. The sural, greater auricular and medial antebrachial cutaneous nerves have been used as donor nerves for the repair of LN injuries (Fonseca 2009). The major disadvantage of this technique is the creation of paresthesia at the donor site. Wolford and Miller (2003) reports less favourable results with LN grafting. Lower success rates are likely associated with higher technical difficulty, limited access and potential incompatibility in shape, size and fascicle numbers between the grafted nerve and LN. Cable grafting of the LN defect has been advocated to improve the match between donor and host (Wolford, 1992). Dobson and Kaban (1997) criticize this technique by stating; “given the variable results after autogenous nerve grafts to reconstruct IAN or LN, any donor site morbidity [which can be quite significant] calls into question the use of autogenous nerve grafts”. An alternative to nerve grafts has lead to the use of autogenous veins and arteries. The use of vascular entubulation for LN repair has shown mixed results (Miloro, 2001; Pogrel and Maghen, 2002). Poor outcomes are likely due to the vein collapse and impediment of axonal growth (Wolford and Stevao, 2003; Fonseca 2009).

Grafting with alloplastic grafts is an attractive option for LN repair due to graft availability and avoidance of donor site morbidity. Several studies involving animal models have demonstrated the ability of nerves to regenerate across defects via tubes and conduits (Dellon and Mackinnon, 1986). Initial trials with permanent conduits were largely unsuccessful with LN repairs. In 1998, Pogrel and Kaban reported a 28% increase in sensory improvement with LN and IAN defects reconstructed with Gortex.
Unfavourable outcomes were likely the result of localized compression and alterations in the blood-nerve barrier by the permanent conduit. Bioabsorbable polyglycolic acid (PGA) conduits have been developed to circumvent the problems associated with permanent conduits. Mackinnon and Dellon (1990) first reported the use of PGA conduits for reconstructing digital nerve repairs. The results of this study demonstrated nerve regeneration across gaps up to 3 cm in length. The use of PGA conduits for CN V₃ repair is lacking in the literature. In 1992, Crawley and Dellon (1992) reported an isolated case in which the IAN was reconstructed with a PGA conduit. A successful outcome was obtained, with clinical improvements beginning 6 months after surgery. Ways to improve artificial nerve conduits are currently been developed. The incorporation of Schwann cells into nerve conduits is currently being investigated in animal models (Kim et al., 2007). Schwann cells promote axonal extension and neuronal survival and their use may greatly facilitate nerve conduit performance (Ichihara et al., 2008).

Non-surgical therapy is also an option for management of LN injury. The use of oral and topical therapies, neural blockade and behavioral strategies have provided mixed outcomes (Graff-Radford and Evans, 2003). Pharmaceuticals such as tricyclic antidepressants have also been used with varying degrees of success (Gregg, 1978).

While many attempts have been made to correct injuries to the LN, treatment is not a simple foregone conclusion. The affects on the patient can be debilitating and permanent. While surgeons try to minimize iatrogenic events, without a clear visualization of the LN their best efforts will remain insufficient.
2.5  **Conclusion of Literature Review**

Anatomical studies have failed to be succinct in predicting the path of the LN. The lack of standardized measurements for the LN and possible displacement of the nerve due to the use of positional clips has contributed to the variability of the data. Imaging studies of the LN are limited and await improved advances in technology.

A 3-D computer model of the course of the LN in the third molar region has not been described in the literature. Such a model would allow for documentation of the position of the LN in multiple planes. Furthermore, potential factors predicting the course of the LN could be evaluated using this model. Such a diagnostic tool would aid in risk stratification for LN damage during mandibular third molar surgery.
Chapter 3
Objectives and Hypotheses

3.1 Objectives

1. To digitize the LN from the pterygomandibular region to the floor of the mouth, medial surface of mandible, medial pterygoid muscle, mylohyoid muscle, second mandibular molar and if present, the third mandibular molar.

2. To reconstruct a 3-D geometric computer model in Autodesk® Maya® of the digitized data to outline the course of the LN in relation to surrounding tissue.

3. To determine whether a relationship exists between the position of the LN and lingula and/or mylohyoid ridge.

4. To quantify the horizontal and vertical distance of the LN to the mandibular alveolus

3.2 Hypotheses

Hypothesis #1

H₀: The height of the mylohyoid ridge is not associated with the position of the lingual nerve.

H₁: A superiorly positioned mylohyoid ridge is directly proportional to the vertical position of the lingual nerve in the mandibular third molar region.

Hypothesis #2

H₀: The anteroposterior position of the lingula is not associated with the position of the lingual nerve.

H₁: An anteriorly positioned lingula is directly proportional to the vertical position of the lingual nerve in the mandibular third molar region.
3.3 **Significance**

A macroanatomical study with 3-D modeling of cadaveric specimens of the course of lingual nerve will provide insight into the location of the nerve from multiple perspectives. Furthermore, the database will allow investigation of various hard and soft tissue landmarks in determining the predictability of the course of the lingual nerve. Clarification of the location of this nerve will provide clinical guidance to ensure LN protection during third molar surgery.
Chapter 4
Materials and Methods

4.1 Specimens

Seven formalin embalmed cadaveric sagitally sectioned heads (2 males / 2 females) were utilized in this study. The inclusion criteria consisted of no visible craniofacial deformity and the presence of a mandibular 2nd molar.

4.2 Dissection Protocol

The cadaver head was first placed on the dissection table with the midsagittally sectioned surface facing down. The inferior border of the mandible was then palpated to localize the angle of the mandible. A dissecting probe was inserted through the skin until the bony mandible was reached. Using a #15 scalpel blade, a full thickness flap was raised in a subperiosteal fashion to expose the angle of the mandible and a portion of the lateral ramus. To obtain adequate exposure, the inferior lobe of the masseter muscle as well as the inferior lobe of the parotid gland was removed.

Next, a hemi-maxillectomy was performed using a modified Weber Fergusson approach (Figure 4.1A). This approach allowed for an unobstructed view of the medial aspect of the mandible with minimal disturbance to underlying anatomy. The first incision was made along the radix of the nose and carried laterally across the infra-orbital rim. The incision was then extended inferiorly along the nasal crease to the philtrum. Next, an intra-oral incision was made approximately 5 mm superior to the mucogingival junction at the midline of the maxilla, which was then carried laterally to the region of the first molar. The skin flap was dissected off the maxilla in a subperiosteal fashion. As the dissection proceeded laterally, the infra-orbital nerve was encountered and transected.
to allow greater flap mobility and exposure. The subperiosteal envelope was continued until the pterygomaxillary fissure and the junction of the hard and soft palate was identified. Next a mucosal incision was made parallel to the posterior border of the hard palate. This incision was then carried just posterior to the maxillary tuberosity to connect to the previously described subperiosteal dissection in the region of the pterygomaxillary fissure.

Using a series of osteotomes and a fissure bur on a Dremel rotary tool (Dremel, Racine, Wisconsin), maxillary osteotomies were made to free the hemimaxilla. The osteotomy started at the nasofrontal suture and continued along the inferior orbital rim. The lateral osteotomy was made along the zygomaticomaxillary buttress. Next, a curved osteotome was placed along the pterygomaxillary fissure and directed medially. While palpating the hamulus intraorally, the osteotome was advanced until it disjoined the posterior maxilla from the pterygoid plate. This approach allowed minimal disruption to the medial pterygoid muscle and underlying lingual nerve. The hemimaxilla was then infractured medially and remaining bony interferences were relieved with rongeurs.

4.3 Method of Fixation

In order to ensure accurate reconstruction of the digitized LN, the mandible and associated masticatory muscles needed to be stabilized with a 2.4 mm mandibular reconstruction titanium plate. The in-line bend of these plates also minimized interferences while digitizing. A minimum of two plates were used in all specimens to secure the mandible in the closed position (Figure 4.1B). The first plate was positioned on the medial aspect of the sagittally cut mandible and spanned posteriorly to the mastoid process. A second plate was then placed from the medial aspect of the mandible (just superior to the first reconstruction plate) to the calvarial bone just superior to the frontal
sinus. The Dremel rotary tool and the plating system’s drill bits were then used to pre-drill all fixation screws. Pre-drilling was necessary to facilitate screw placement and limit propagation of fractures within the bone. Washers were often required between the plate and bone to ensure the plate was passive and not torquing the mandible medially when fixated.

Figure 4.1: A. Approach utilized for hemimaxillectomy. Red dashed line represents the osteotomy. B. Medial view of cadaveric head illustrating reconstruction plates. C. MicroScribe-3DX digitizer D. Image demonstrating “penning technique” with digitizer.
4.4 Digitization and Serial Dissection

4.4.1 Selection of Reference Points

The digitization process required three fixed points on the mandible to enable a 3-D computer reconstruction of the specimen. The retromolar pad, angle of the mandible and the occlusal surface of the second mandibular molar were selected, as they were easily identified landmarks and accessible from all angles during the digitization process. Accurate triangulation of these data coordinates was accomplished by placing fixation screws in all reference points except the occlusal tooth surface. The screw at the mandibular angle was inserted until its head was flush with the surrounding bone. A similar approach was taken at the retromolar pad, except the screw head was only advanced to the level of the oral mucosa. It was important to avoid over advancement of this screw, as this would cause surrounding tissue distortion. The tooth did not receive a fixation screw due to potential fracture. To circumvent this, a divot was made in the center of the tooth using a fissure bur on the Dremel rotary tool.

To ensure that the specimen did not move during the digitization process, the cadaveric head was placed in a vise that had been fixated to the workstation. A calvarial wedge of bone was removed (lateral to the midsagittal plane) to allow for fixation of the vise to the skull.

The MicroScribe-3DX digitizer was the only device utilized throughout this study (Figure 4.1C & D). The fine digitizing tip was used as it allowed for more accurate plotting of delicate structures with minimal tissue disruption and fit into the center of the reference point Phillip’s screw head. Digitization began with the capturing of the reference points. These points were recorded in the same sequence for all specimens.
4.4.2 **Digitization of the Oral Mucosa**

The retromolar pad was first demarcated and marked for digitization using a fine diameter paint pen. Points were placed approximately 2-3 mm apart and the MicroScribe-3DX digitizer was utilized to digitize the circumference of the retromolar. The data was captured with a computer. The area of the oral mucosa to be digitized was then defined and marked with the paint pen:

- The superoinferior boundaries extended from the lingual gingival sulcus to the depth of the lingual vestibule (floor of mouth).
- The posterior and anterior boundaries included the entire retromolar area to the level of the palatoglossus arch and the mid-sagittal osteotomy of the mandible respectively.

The MicroScribe-3DX digitizer was then used to record data points of the oral mucosa.

4.4.3 **Digitization of the Medial Pterygoid Muscle**

The posterior oral mucosa overlying the medial pterygoid was carefully removed using a #15 blade. Dissection of the oral mucosa continued anteriorly until the LN was identified deep to the anterior margin of the medial pterygoid. Once the entire deep surface of the medial pterygoid muscle was exposed, the paint pen was used to demarcate muscle fiber bundles. Points were placed approximately 2-3 mm apart. Next, the fiber bundles were digitized from origin to insertion and then removed using sharp dissection with a #15 blade and tissue forceps. Underlying muscle fibers within a layer were sequentially digitized and removed until the entire muscle was digitized.
4.4.4 Lingual Nerve

4.4.4.1 Reference Points Used for Studying the Position of the LN

The course of the lingual nerve to be measured extended from the posterior margin of the medial pterygoid to the region the nerve first turned medially towards the tongue. These boundaries were marked with a paint pen. Three reference marks were then placed along the superior border of the LN prior to digitization (Figure 4.2A). The first reference point corresponded to the location at which the LN began to diverge medially into the tongue (defined as #1). The distance from point #1 to the reference screw was labeled I. The second point (identified as #2), was the position of the nerve perpendicular to the reference screw head. The distance between point #2 and the reference screw was labeled II. The last reference point (labeled #3), marked the closest position of LN to the reference screw in the retromolar pad. The distance between point #3 and the reference screw was labeled III and represented the shortest distance from the superior aspect of LN to the oral mucosa. Distances I, II and III were measured using a digital boley gauge and recorded to the hundredth of a millimeter. The same distances were then measured using the Autodesk® Maya ® measuring software. A paired t-test was then conducted to validate the accuracy of these measuring techniques. The statistical null hypothesis that there is no difference between the two measurements was accepted with a p < 0.05.

The course of LN was divided into three sections to evaluate its position relative to the mandibular alveolus (Figure 4.2B). The first section (labeled A) was the area between points 1 and 2, and represented the region of the second molar. The region between points 2 and 3 corresponded to the third molar region and was labeled B.
The area posterior to point 3 was labeled section C and represented the retromolar region.

The superior extent of the area in section C was defined by the height of the mandibular alveolus.

**Figure 4.2:**  
A. Reference points used to study the relationship of the LN in the third molar region. Point 1 represents the point at which the nerve courses medially towards the tongue. Point 2 is the superior aspect of the LN below the reference screw in the retromolar pad. Point 3 is the closest position of the LN to the reference screw. The distances from points 1, 2 and 3 to the reference screw are labeled as I, II and III respectively.  
B. Diagram depicting the regions (A, B & C) used to measure the vertical and horizontal distances from the LN to the mandibular alveolus.
4.4.4.2 Technique to Capture Data Co-ordinates for 3-D Reconstruction of LN

The most superior aspect of the nerve was first marked with points (1-3mm) apart using a fine diameter paint pen. These points were then digitized and transferred to a computer. This line represented the most superior in-situ course of the LN. Penning was then performed on the medial surface of the nerve, with points being separated by approximately 1-3 mm (Figure 4.3A). Digitization was conducted in a superior to inferior direction in a serial manner and represented the in-situ medial perimeter of the LN. To digitize the remaining lateral aspect of the nerve, a coronal approach was used. Using a #15 blade, the nerve was first transected at point 1, in a medial to lateral direction (Figure 4.3B). Approximately 5 minutes was allowed to pass, prior to digitizing the circumference of the sectioned LN. This time lapse allowed for tissue rebound following nerve transection. The circumference of the cross-sectioned LN was then digitized in-situ with the aid of a dissection microscope. This process was repeated in an anterior to posterior direction along the course of the LN. Serial sectioning of the nerve was made to coincide with the penning points along the medial surface of the LN (Figure 4.4). The dissection blade was changed frequently to minimize tissue distortion. At each cross-section of the nerve, the morphology of LN was evaluated. Three clinical descriptors were used to classify the shape of the LN: round, oval and ribbon-shaped. The transection and digitization of LN cross-sections ended at the posterior limit of the medial pterygoid muscle.
Figure 4.3: A. Medial view of specimen displaying the superior and medial penning of the LN (Blue and Green dots respectively). B. Medial view of specimen demonstrating the cross-section of the LN. Second molar (M2); Mandible (Md); Mylohyoid muscle (Mh); Submandibular duct (Sd); Lingual nerve (LN).

Figure 4.4: Schematic diagram of serial sectioning of LN and digitization of cross-sectional perimeter.
4.4.5 Digitization of the Mylohyoid Muscle, Mandible and Mandibular Second Molar

Digitization of the mylohyoid muscle proceeded after removal of the LN. Muscle fiber bundles within the superficial layer of the muscle were marked and digitized in a similar manner as the medial pterygoid. Digitization began at the fiber bundle attachment at the mylohyoid ridge to their termination at the midsagittal plane.

Using a periosteal elevator, the remaining soft tissue and muscle attachments were removed from the medial surface of the mandible. Subperioisteal dissection was limited along the condylar neck to avoid displacement of the mandible from its fixated position. Penning of the medial surface of the mandible with a fine tip paint pen then ensued in a superior to inferior direction (Figure 4.5). The marked points were approximately 2-3 mm apart, with closer markings in areas of greater curvature. The mandible was digitized along these points to replicate the osseous topography. The perimeter of the mylohyoid ridge and lingula were then outlined with points. These points were digitized and combined to the mandible data set.
Figure 4.5: Medial view of mandible displaying “penning technique”. The mylohyoid ridge (MR) and lingula (Li) are outlined in red marker.

The second mandibular molar was the last structure digitized. The perimeter of the tooth was marked with a fine paint pen to capture the cusp and fossa anatomy. These data points were then digitized and lofted using Autodesk® Maya® Software to create a 3-D creation of the tooth.

4.5 Creation of a 3-D Model

The animation software, Autodesk® Maya®, along with custom plug-ins developed in our laboratory were used to transform the digitized points into 3-D models of the specimens. The creation of an in-situ 3-D model was obtained by merging the co-ordinate data of the oral mucosa, medial pterygoid muscle, LN and branches, mylohyoid muscle, second molar tooth and mandible. A program script developed in our laboratory was used to recreate the in-situ 3-D course of the LN. The program script combined these digitized points to correspond with the undisturbed superior and medial
data co-ordinates of the LN. The circumferential data co-ordinates were then lofted with Autodesk® Maya® to create an accurate in-situ reconstruction of the 3-D course of the LN.

4.6 **Vertical and Horizontal Measurements of LN from Mandibular Alveolus**

The 3-D model of the specimen was used to measure the location of the LN. The distance between the lateral edge of the LN and the mandibular alveolus (horizontal distance) was measured using the Autodesk® Maya® distance tool (Figure 4.6). Horizontal measurements were taken in 2-3 mm increments along regions A, B and C as illustrated in Figure 4.4. A similar process was used to measure the vertical distance of the LN. This dimension was between the superior aspect of the LN and the mandibular alveolar crest (Figure 4.6).

![Image of mandible with measurements](image)

**Figure 4.6:** Coronal section of the mandible in the region of the second molar illustrating the vertical (X) and horizontal (Y) measurements to LN (red).
4.7 Data Analysis

Mean vertical and horizontal measurements from the LN to the mandibular alveolus were calculated for each specimen using SPSS 16.0 (SPPSS Inc, Chicago, IL). The mean vertical distance for each region (A, B and C) was then tabulated. A one-way ANOVA with Tukey’s post-hoc test was used to compare the means of vertical distances across regions A, B and C. A similar analysis was carried out for the mean horizontal distance for each region.

A regression analysis using SPSS 16.0 (SPPSS Inc, Chicago, IL) was conducted to test possible associations between the LN position (vertical and horizontal) and the location of the lingula and mylohyoid ridge. The minimum vertical and horizontal distances of the LN to mandible in each region (A, B and C) was used in the regression analysis. This minimum distance was selected as it represents the location of greatest vulnerability of the LN during third molar surgery and thus is clinically significant. Ratios were calculated to determine the position of the lingula (A/B) and mylohyoid ridge (X/Y) relative to the ramus and body of the mandible respectively, as shown in Figure 4.7. The lingual ratio was determined by measuring the distance from the anterior border of the ramus to the anterior lingula relative to the entire width of the ramus (Figure 4.7). The mylohyoid ridge ratio was the distance from the alveolar crest to the superior border of the mylohyoid ridge relative to the distance from the mandibular crest to the inferior border of the mandible (Figure 4.7). The measurements used to determine the position of the mylohyoid ridge were conducted in the retromolar region to account for errors mandibular crest atrophy.
Figure 4.7: Medial view of mandible illustrating the ratios used to describe the position of the mylohyoid ridge (yellow outline) and lingula (green outline). The height from the superior border of the posterior mylohyoid ridge to the alveolar crest (X) over the height of the mandible (Y) represented the mylohyoid ratio. The distance from the anterior extent of the lingula to the anterior border of the ascending ramus (A) divided by the width of the ascending ramus (B) represented the lingula ratio.
Chapter 5
Results

5.1 Specimen Demographics

Seven sagittally sectioned cadaveric heads with a mean age of 60.5 ± 19.9 years (Range: 40 – 79 years) were dissected, digitized and modeled.

5.2 Three Dimensional Modeling

A 3-D in-situ model of the LN in relationship to the surrounding architecture was created for all seven specimens from the digitized data (Figure 5.1 A & B). Using this model, the LN could be viewed / studied from any angle (Figure 5.1 C, D, E, F & G). Superimposing the medial pterygoid and mylohyoid muscle onto the mandible provided insight into the relationship between the LN and surrounding muscles. The surface of the mandible and oral mucosa was lofted to recreate their topography. The medial pterygoid and mylohyoid muscles remained as lines to show the path of the fiber bundles. These structures could be created with some translucency such that the relationship to the LN remained visible (text continues on page 47).
Figure 5.1: 3-D Model of Specimen. A. Medial view of raw data set. B. Medial view of transformed data set into 3-D model. Mandible (Md), grey; medial pterygoid muscle (Mp), red; mucosa (Mu), pink; mylohyoid muscle (Mh), yellow; lingual nerve (LN-arrow), green; mandibular second molar (M2); mandibular third molar (M3). Compass legend: Superior (S), Inferior (I), Medial (M), Lateral (L), Anterior (A), and Posterior (P)
Figure 5.1 (continued): 3-D Model of reconstructed specimen from digitized data (multiple views). C. Medial view of specimen (lofted). D. Superior view of specimen (lofted).
Figure 5.1 (continued): 3-D Model of specimen reconstructed from digitized and lofted data (multiple views). **E.** Inferior view (lofted). **F.** Posterior view (lofted). **G.** Anterior view (lofted).
The cross-sections of the LN were linked to create a solid volume (Figure 5.2). All measurements of the LN to various landmarks were recorded from the 3-D data set.

Figure 5.2: Reconstitution of LN using Autodesk® Maya® Software. A. Data of superior margin of LN. B. Medial data points of LN. C. Cross-sectional slices of LN. D. Transposed position of cross-sectioned slices (red) onto digitized nerve. E. Transposition of lofted cross-sectional slices onto medial data set (blue). F. Reconstitution of in-situ LN (green).
5.3 **Lingual Nerve**

5.3.1 **Gross Morphology**

The LN branched from CN V$_3$ in the infratemporal region for the majority of specimens (85.6%; 6 out of 7). In one specimen the LN originated from the CN V$_3$ in the pterygomandibular region, between the sigmoid notch and the lingula.

Inferior to the origin of LN, the nerve passed lateral to the medial pterygoid muscle without penetrating the muscle belly. In this region, the LN was surrounded by an abundant amount of perineural fat.

After passing anterior to the medial pterygoid muscle, 1-3 small accessory branches from the LN could be seen in the retromolar region (Table 5.1). These accessory branches resided on the surface of the mylohyoid muscle and generally traveled in a superior direction. In this region, the LN was in direct contact with the lingual plate of the mandible in three specimens, whereas the remaining four specimens had variable amount of connective tissue (e.g. perineural fat) between the LN and the mandible. Quantification of the distance between the LN and the mandible are presented in section 5.3.5 of this thesis.

In this study, no communicating LN branches to the mylohyoid nerve were observed.
Table 5.1: Observations of the Course of LN

<table>
<thead>
<tr>
<th>SPECIMEN</th>
<th>PENETRATION OF MP</th>
<th>ORIGIN OF LN</th>
<th>ACCESSORY NERVE BRANCHES</th>
<th>CONTACT WITH BONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NO</td>
<td>PTERYGOMANDIBULAR</td>
<td>2</td>
<td>NO</td>
</tr>
<tr>
<td>2</td>
<td>NO</td>
<td>INFRATEMPORAL</td>
<td>3</td>
<td>NO</td>
</tr>
<tr>
<td>3</td>
<td>NO</td>
<td>INFRATEMPORAL</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td>4</td>
<td>NO</td>
<td>INFRATEMPORAL</td>
<td>3</td>
<td>NO</td>
</tr>
<tr>
<td>5</td>
<td>NO</td>
<td>INFRATEMPORAL</td>
<td>1</td>
<td>YES</td>
</tr>
<tr>
<td>6</td>
<td>NO</td>
<td>INFRATEMPORAL</td>
<td>2</td>
<td>YES</td>
</tr>
<tr>
<td>7</td>
<td>NO</td>
<td>INFRATEMPORAL</td>
<td>1</td>
<td>NO</td>
</tr>
</tbody>
</table>

MP = Medial Pterygoid Muscle; LN = Lingual Nerve

5.3.2 Distance from Mucosa to LN / Validation of Measurement from 3-D Model

The mean shortest distance from the oral mucosa in the retromolar pad to the most superior aspect of the LN (distance III) was 9.0 ± 1.4 mm and 9.2 ± 1.7 mm with digital calipers and Autodesk® Maya® 8.5 respectively (Table 5.2). The vertical distance to point 2 on the LN (distance II) was approximately two times longer than the distance to point 3 (distance III). The measurements for distance II were 17.3 ± 3.5 mm and 18.0 ± 2.9 mm using digital calipers and Autodesk® Maya® 8.5 respectively. The distance at which the LN turned medially towards the tongue was 26.3 ± 4.2 mm and 26.4 ± 4.3 mm using digital calipers and Autodesk® Maya® 8.5 respectively. Distance I measured at the point where the LN turned medially towards the tongue was the longest of the three distances measured.

The measurements (distances I, II and III) made directly from the specimens using digital calipers and from the 3-D model using Autodesk® Maya® 8.5 were compared using paired t-tests (p < 0.05). No statistical significant differences were found between the two measuring techniques (Table 5.2).
Table 5.2: Distances from Retromolar Pad to Reference Points on LN

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Distance I (mm)</th>
<th>Distance II (mm)</th>
<th>Distance III (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Digital caliper</td>
<td>Autodesk® Maya®</td>
<td>Digital caliper</td>
</tr>
<tr>
<td>1</td>
<td>29.4</td>
<td>28.2</td>
<td>22.4</td>
</tr>
<tr>
<td>2</td>
<td>20.3</td>
<td>20.4</td>
<td>14.7</td>
</tr>
<tr>
<td>3</td>
<td>26.5</td>
<td>25.9</td>
<td>15.3</td>
</tr>
<tr>
<td>4</td>
<td>29.6</td>
<td>29.2</td>
<td>14.8</td>
</tr>
<tr>
<td>5</td>
<td>29.2</td>
<td>30.4</td>
<td>13.7</td>
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<td>6</td>
<td>20.3</td>
<td>20.5</td>
<td>19.9</td>
</tr>
<tr>
<td>7</td>
<td>28.5</td>
<td>29.9</td>
<td>20.6</td>
</tr>
<tr>
<td>Mean</td>
<td>26.3</td>
<td>26.4</td>
<td>17.3</td>
</tr>
<tr>
<td>S.D.</td>
<td>4.2</td>
<td>4.3</td>
<td>3.5</td>
</tr>
<tr>
<td>p value</td>
<td>0.96</td>
<td>0.69</td>
<td>0.78</td>
</tr>
</tbody>
</table>

5.3.3 Morphology of LN

Each region of LN (A, B and C as outlined in Figure 5.3) was sectioned in order to evaluate cross sectional morphology. A range of 9-17 cross-sections were taken for region A; 7-12 for region B; and 14-22 for region C. The cross-sectional morphology of the LN differed between regions (Figure 5.3). The largest proportion of oval shaped cross-sections was found in region A (60%) followed by region B (50%). Regions B contained the most round shaped cross-sections (21%). The LN appeared to be compressed by the medial pterygoid muscle in region C. The large percentages of oval
(43%) and ribbon shaped (49%) nerve cross-sections in this region support this observation.

Figure 5.3: Cross-sectional morphology of LN. A. Site of cross-sections. B. Pie graphs of cross-section shapes in regions A, B and C. C. Examples of oval, round, and ribbon cross-sectional shapes.
Table 5.3: Distribution of LN Cross Sectional Morphology

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Region A*</th>
<th>Region B*</th>
<th>Region C*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11/17  2/17  4/17  1/10  9/10  0/10  12/22  1/22  9/22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10/14  4/14  0/14  5/10  5/10  0/10  20/20  0/20  0/20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>13/15  0/15  2/15  6/7  0/7  1/7  2/20  1/20  17/20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4/9  0/9  5/9  8/8  0/8  0/8  3/14  1/14  10/14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>11/17  2/17  4/17  1/10  9/10  0/10  12/21  1/21  8/21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6/17  1/17  10/17  8/12  1/12  3/12  4/19  0/19  15/19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>10/14  4/14  0/14  5/10  5/10  0/10  20/20  0/20  0/20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Data is presented as a fraction: number of sections with oval, round or ribbon cross-sectional shape/total number of sections in region.

5.3.4 Vertical Position of LN

The vertical distances of the LN to the alveolar crest for each specimen are summarized in Table 5.4 and Figure 5.4. A value of zero was given when the LN was at the same vertical height as the alveolar crest. This was noted in Specimen 5. A negative value of -3.9 mm was observed in region C of specimen 4. This denotes a measurement in which the LN was above the alveolar crest.

Figure 5.4: Average Vertical Distance to LN in Regions A, B and C for each Specimen
Table 5.4: Vertical Distances from LN to Alveolar Crest

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>16.5±0.8</td>
<td>15.5-17.8</td>
<td>11.3±3.9</td>
</tr>
<tr>
<td>2</td>
<td>13.3±1.4</td>
<td>11.9-15.8</td>
<td>12.0±4.6</td>
</tr>
<tr>
<td>3</td>
<td>16.0±3.9</td>
<td>8.9-20.2</td>
<td>3.7±1.4</td>
</tr>
<tr>
<td>4</td>
<td>12.6±2.7</td>
<td>5.8-14.9</td>
<td>3.9±1.1</td>
</tr>
<tr>
<td>5</td>
<td>14.8±1.5</td>
<td>12.3-17.4</td>
<td>7.9±3.7</td>
</tr>
<tr>
<td>6</td>
<td>12.1±0.4</td>
<td>11.6-12.9</td>
<td>9.5±2.8</td>
</tr>
<tr>
<td>7</td>
<td>13.9±1.4</td>
<td>11.4-15.5</td>
<td>8.4±2.3</td>
</tr>
<tr>
<td>Mean</td>
<td>14.2±1.7</td>
<td>8.1±3.3</td>
<td>2.8±3.9</td>
</tr>
</tbody>
</table>

If the superscript letters differ, then the result is statistically significant. If the letter is the same, then the result is not statistically different.

As depicted in Figure 5.5, the mean vertical distance to the LN from the alveolar crest is highly variable amongst specimens. Region C was the most variable with a mean vertical distance of 2.8 ± 3.9 mm.

Figure 5.5: Average Vertical Distance to LN by Region
5.3.5 Horizontal Position of LN

The mean horizontal distance between alveolar bone and the LN are summarized by specimen in Table 5.5. If the LN had direct contact with the lingual plate, the horizontal distance was zero. This was noted in three specimens (2, 3 and 7). The mean distances for each specimen are graphically displayed in Figure 5.6 and illustrate a non-uniform distribution.

Table 5.5: Horizontal Distance from LN to Lingual Plate

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Region A Mean</th>
<th>Region A Range</th>
<th>Region B Mean</th>
<th>Region B Range</th>
<th>Region C Mean</th>
<th>Region C Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.2±0.8</td>
<td>7.2-10.3</td>
<td>4.2±2.4</td>
<td>1.3-7.8</td>
<td>6.2±5.7</td>
<td>1.1-19.3</td>
</tr>
<tr>
<td>2</td>
<td>4.5±1.0</td>
<td>3.5-5.9</td>
<td>3.8±3.2</td>
<td>0.0-8.4</td>
<td>1.8±2.7</td>
<td>0.0-9.1</td>
</tr>
<tr>
<td>3</td>
<td>3.1±1.0</td>
<td>1.6-5.2</td>
<td>0.2±0.3</td>
<td>0.0-0.7</td>
<td>7.5±6.1</td>
<td>0.0-20.1</td>
</tr>
<tr>
<td>4</td>
<td>4.6±2.0</td>
<td>010-7.1</td>
<td>0.6±0.4</td>
<td>0.1-1.0</td>
<td>7.4±5.9</td>
<td>1.0-16.4</td>
</tr>
<tr>
<td>5</td>
<td>7.3±1.4</td>
<td>5.0-9.7</td>
<td>1.7±1.2</td>
<td>0.2-4.7</td>
<td>4.1±4.3</td>
<td>0.5-14.8</td>
</tr>
<tr>
<td>6</td>
<td>3.2±0.6</td>
<td>2.3-3.9</td>
<td>2.3±1.1</td>
<td>0.8-3.7</td>
<td>4.2±3.9</td>
<td>0.3-11.4</td>
</tr>
<tr>
<td>7</td>
<td>3.6±1.2</td>
<td>2.0-5.4</td>
<td>1.8±0.8</td>
<td>0.8-3.0</td>
<td>3.5±3.5</td>
<td>0.0-10.6</td>
</tr>
<tr>
<td>Mean</td>
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<td>2.4±2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.9±4.1&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If the superscript letters differ, then the result is statistically significant. If the letter is the same, then the result is not statistically different.

Figure 5.6: Average Horizontal Distance to LN in Regions A, B and C for each Specimen
The average horizontal distance to the LN by region was tabulated and plotted in Figure 5.7. The horizontal distance to LN was 2.4 ± 2.0 mm in region B. The largest variability was found in region C with a mean horizontal distance of 7.9 ± 4.1 mm.

**Figure 5.7:** Average Horizontal Distance to LN by Region

5.4 **Relative Position of Mylohyoid Ridge in Relation to the Position of the LN**

The height of the mylohyoid ridge was calculated as a ratio to the height of the mandible and correlated with the vertical and horizontal distance from the alveolar bone to LN in each region. The data is presented in Table 5.6. The assumption that the position of the mylohyoid ridge affects the location of the LN generated the following hypotheses:

$H_1$: A superiorly positioned mylohyoid ridge is directly proportional to the vertical position of the lingual nerve in the third molar region.
H1: A superiorly positioned mylohyoid ridge is directly proportional to the horizontal position of the lingual nerve in the third molar region.

A scatter plot of the data was plotted with a line of best-fit using Excel version 12.1.7 (Microsoft Inc, Redmond, WA) and a regression analysis preformed with SPSS (SPSS Inc, Chicago, IL). No outliers were identified. When a regression analysis was performed (Table 5.7, Figure 5.8), a statistically significant relationship was found between the vertical distance of the LN in the third molar region (Region B) and the height of the mylohyoid ridge (p = 0.002). There was no statistically significant relationship within regions A (p = 0.324) and C (p = 0.136).

Table 5.6: Regression Analysis Source Data: Mylohyoid Ridge Ratio and Minimum Vertical Distance between LN and Alveolar Crest in Regions A, B and C.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Mylohyoid Ridge Ratio</th>
<th>Minimum Vertical Distance between LN and Alveolar Crest (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Region A</td>
</tr>
<tr>
<td>1</td>
<td>0.805</td>
<td>5.8</td>
</tr>
<tr>
<td>2</td>
<td>0.851</td>
<td>8.9</td>
</tr>
<tr>
<td>3</td>
<td>0.843</td>
<td>12.3</td>
</tr>
<tr>
<td>4</td>
<td>0.724</td>
<td>11.6</td>
</tr>
<tr>
<td>5</td>
<td>0.752</td>
<td>11.3</td>
</tr>
<tr>
<td>6</td>
<td>0.733</td>
<td>15.5</td>
</tr>
<tr>
<td>7</td>
<td>0.818</td>
<td>11.9</td>
</tr>
</tbody>
</table>

Table 5.7: Data from Regression Analysis of Mylohyoid Ridge and Vertical Distance to LN

<table>
<thead>
<tr>
<th>Regression Analysis</th>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.193</td>
<td>0.884</td>
<td>0.387</td>
</tr>
<tr>
<td>F-value</td>
<td>1.198</td>
<td>38.288</td>
<td>3.159</td>
</tr>
<tr>
<td>Slope (m)</td>
<td>-25.360</td>
<td>-24.895</td>
<td>-26.946</td>
</tr>
<tr>
<td>y-intercept (b)</td>
<td>31.063</td>
<td>23.180</td>
<td>23.905</td>
</tr>
<tr>
<td>Significance</td>
<td>0.324</td>
<td><strong>0.002</strong></td>
<td>0.136</td>
</tr>
</tbody>
</table>
A statistically significant relationship ($p = 0.009$) was also present between the horizontal distance in Section B and the height of the mylohyoid ridge (Tables 5.8 and Figure 5.9).

**Table 5.8:** Regression Analysis Source Data: Mylohyoid Ridge Ratio and Minimum Horizontal Distance between LN and Lingual Plate in Regions A, B and C.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Mylohyoid Ridge Ratio</th>
<th>Minimum Horizontal Distance between LN and Lingual Plate (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Region A</td>
</tr>
<tr>
<td>1</td>
<td>0.805</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>0.851</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>0.843</td>
<td>5.0</td>
</tr>
<tr>
<td>4</td>
<td>0.724</td>
<td>2.3</td>
</tr>
<tr>
<td>5</td>
<td>0.752</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>0.733</td>
<td>7.2</td>
</tr>
<tr>
<td>7</td>
<td>0.818</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Table 5.9: Data from Regression Analysis of Mylohyoid Ridge & Horizontal Distance to LN

<table>
<thead>
<tr>
<th>Regression Analysis</th>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.047</td>
<td>0.776</td>
<td>0.079</td>
</tr>
<tr>
<td>F-value</td>
<td>0.246</td>
<td>17.365</td>
<td>0.430</td>
</tr>
<tr>
<td>Slope (m)</td>
<td>-9.063</td>
<td>-8.300</td>
<td>-2.530</td>
</tr>
<tr>
<td>y-intercept (b)</td>
<td>10.376</td>
<td>7.005</td>
<td>2.417</td>
</tr>
<tr>
<td>Significance</td>
<td>0.641</td>
<td><strong>0.009</strong></td>
<td>0.541</td>
</tr>
</tbody>
</table>

Figure 5.9: Regression Analysis of Mylohyoid Ridge Ratio To Horizontal Position of LN.
5.5 Relative Position of Lingula in Relation to LN

To test possible associations between the LN position (vertical and horizontal) and the location of the lingula, a regression analysis using SPSS 16.0 (SPSS Inc, Chicago, IL) was conducted. The regression analysis data is presented in Table 5.10 and Figure 5.11.

A regression analysis was done to test the following hypothesis:

\textit{H}_1: \text{ An anteriorly positioned lingula is directly proportional to the vertical position of the lingual nerve in the third molar region.}

The regression analysis showed a statistically significant relationship between regions A and B with a significance (p value) of 0.038 and 0.044 respectively (Table 5.11). Region C showed no statistically significant relationship (p = 0.106).

A regression analysis was also conducted using the horizontal distance to LN and lingula ratio (Table 5.12). This analysis tested the following hypothesis:

\textit{H}_1: \text{ An anteriorly positioned lingula is directly proportional to the horizontal position of the lingual nerve in the third molar region.}

The regression analysis demonstrated no statistically significant association between horizontal position of LN and location of the lingula (Table 5.13).

\textbf{Table 5.10:} Regression Analysis Source Data: Lingula Ratio and Minimum Vertical Distance between LN and Alveolar Crest in Regions A, B and C.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Lingula Ratio</th>
<th>Minimum Vertical Distance between LN and Alveolar Crest (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Region A</td>
</tr>
<tr>
<td>1</td>
<td>0.714</td>
<td>5.8</td>
</tr>
<tr>
<td>2</td>
<td>0.765</td>
<td>8.9</td>
</tr>
<tr>
<td>3</td>
<td>0.651</td>
<td>12.3</td>
</tr>
<tr>
<td>4</td>
<td>0.581</td>
<td>11.6</td>
</tr>
<tr>
<td>5</td>
<td>0.592</td>
<td>11.3</td>
</tr>
<tr>
<td>6</td>
<td>0.557</td>
<td>15.5</td>
</tr>
<tr>
<td>7</td>
<td>0.594</td>
<td>11.9</td>
</tr>
</tbody>
</table>

59
Table 5.11: Data from Regression Analysis of Lingula Position and Vertical Distance to LN

<table>
<thead>
<tr>
<th>Regression Analysis</th>
<th>Region A</th>
<th>Region B</th>
<th>Region C</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.612</td>
<td>0.589</td>
<td>0.437</td>
</tr>
<tr>
<td>F-value</td>
<td>7.887</td>
<td>7.177</td>
<td>3.874</td>
</tr>
<tr>
<td>Slope (m)</td>
<td>-30.667</td>
<td>-13.810</td>
<td>-19.444</td>
</tr>
<tr>
<td>y-intercept (b)</td>
<td>30.556</td>
<td>12.314</td>
<td>15.005</td>
</tr>
<tr>
<td>Significance</td>
<td>0.038</td>
<td>0.044</td>
<td>0.106</td>
</tr>
</tbody>
</table>

Figure 5.11: Regression Analysis of Lingula Ratio to Vertical Position of LN
Table 5.12: Regression Analysis Source Data: Lingula Ratio and Minimum Horizontal Distance between LN and Alveolar Crest in Regions A, B and C.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Lingula Ratio</th>
<th>Minimum Vertical Distance between LN and Lingual Plate (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Region A</td>
</tr>
<tr>
<td>1</td>
<td>0.714</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>0.765</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>0.651</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>0.581</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>0.592</td>
<td>1.8</td>
</tr>
<tr>
<td>6</td>
<td>0.557</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>0.594</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 5.13: Data for Regression Analysis of Lingula Position and Horizontal Distance to LN

<table>
<thead>
<tr>
<th>Regression Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>R²</td>
</tr>
<tr>
<td>F-value</td>
</tr>
<tr>
<td>Slope (m)</td>
</tr>
<tr>
<td>y-intercept (b)</td>
</tr>
<tr>
<td>Significance</td>
</tr>
</tbody>
</table>

5.6 Results Summary

A medial dissection approach was employed to capture the course of the LN in 7 specimens. This approach minimized the amount of tissue distortion to allow for accurate digitization and 3-D computational reconstitution of the specimen. The modeled specimen could then be rotated in 3-D space to appreciate and quantify the relationship of the LN to various soft and hard tissue structures: oral mucosa, medial pterygoid muscle, mylohyoid muscle, and the medial surface of the mandible.

The LN is a posterior branch of CN V₃. In 6 out of 7 specimens, the LN was found to originate in the infratemporal fossa, however in one specimen, the LN branched from CN V₃ in the pterygomandibular region. The LN did not penetrate the medial pterygoid
muscle and maintained a lateral position to the muscle. Anterior to the medial pterygoid muscle the LN, in all specimens, had 1-3 accessory branches. The shape of the LN changed along its course to the tongue. An oval shape was predominant in regions A and B, however in region C the nerve was mainly ribbon shaped.

The mean shortest distance from the oral mucosa of the retromolar pad to the LN as measured manually (using digital calipers) was $9.0 \pm 1.4$ mm and computationally a mean distance of $9.2 \pm 1.7$ mm was obtained using the Autodesk® Maya® distance tool. There was no significant difference between the two methods of measurements.

The average vertical and horizontal distance to LN from the mandibular alveolus was variable amongst the three regions (A, B and C). The mean vertical distance from the alveolar crest to LN was $14.2 \pm 1.67$ mm, $9.1 \pm 3.3$ mm and $2.8 \pm 3.6$ mm for regions A, B and C respectively. The mean horizontal distances for sections A, B, and C were $4.1 \pm 1.6$ mm, $2.4 \pm 2.0$ mm and $7.85 \pm 4.1$ mm respectively.

Several positive correlations were observed between the distance to LN and relative position of the mylohyoid ridge or lingula. The vertical distance of the LN in region B was positively correlated with the height of the mylohyoid ridge ($p=0.002$). No correlations were found in sections A ($p=0.324$) and C ($p=0.136$). An anteriorly positioned lingula was positively correlated with the vertical positioning of the LN in regions A ($p = 0.038$) and B ($p = 0.044$). Evaluation of the position of the mylohyoid ridge with respect to the horizontal position of the LN yielded a positive correlation ($p=0.009$) only in region B. Regression analysis was also conducted to determine if a relationship between the position of the lingula and horizontal position of the LN was present, but no significant association was noted.
Chapter 6
Discussion

6.1 Introduction

Three-dimensional reconstruction of the in-situ course of the LN along the third molar region has not been described in the literature. The method developed in this study is superior to traditional cadaveric dissections in that a 3-D model of the specimen is created which can be viewed and evaluated from any perspective. Furthermore, Autodesk® Maya® allows for magnification and measurement of delicate anatomical structures in the model without fear of tissue distortion or iatrogenic displacement.

6.2 Origin of the LN

In the current study, the majority (6 out of 7) of specimens demonstrated branching from the posterior division of CN V₃ in the infra-temporal region. Kim et al. (2004) and Erdogmus et al. (2008) also reported a high percentage of LN branching in the infra-temporal region (21 out of 32 and 14 out of 21 respectively). An explanation for higher incidence reported in the current study may be attributed to the small sample size. No plexiform pattern between the LN and IAN was observed in the current study, which is in accordance to the findings presented by Erdogmus et al. (2008).

Only one specimen demonstrated a branching pattern inferior to the sigmoid notch. This is clinically significant as it can contribute to the failure rate of LN anesthesia during IAN blocks. The Gow-Gates and Akinosi techniques have been advocated when traditional IAN and LN anesthetic techniques fail (Meechan, 1999). The success of these techniques relies on inserting the anesthetic needle more superiorly so that local anesthetic is deposited near the branching of the LN and IAN. This clinical
finding supports the anatomical observations that the majority of LNs originate in the infra-temporal region.

6.3 Cross-sectional Shape

The cross-sectional morphology of the LN changes along its course towards the tongue. Observations from this study suggest the shape of the nerve is dependent on overlying structures. For example, the highest percentile of ribbon shaped cross-sections was observed in region C where the LN is often found tightly compressed between the mandible and medial pterygoid muscle. This is in contrast to the findings presented by Kim et al. (2004) in which the highest percentage (62.5%; 20 out of 32) of ribbon-like cross-sections was found in the second molar region. This anatomical difference may be related to racial differences as Kim et al. (2004) dissected Korean cadavers. In the current study, a higher percentage of oval and round shapes (50% and 21% respectively) were found in the third molar region. This proportion is similar to Kim’s (2004) finding of predominately oval or circular morphology (59.4%; 19 out of 32, and 25%; 8 out of 32, respectively) in this region. Knowledge of cross-sectional shape is clinically relevant since autogenous nerve grafts should mimic the morphology of the nerve defect (Wolford and Stevao 2003).

6.4 LN Accessory Branches

Collateral branches (Range: 1-3) from the LN in the retromolar and third molar region were found in all specimens in the current study. This finding supports Kim et al.’s (2004) claim that this is not an anatomical variation, rather the predominant pattern. The presence of the collateral LN branches may explain incomplete anesthesia in this
region and the finding of localized paraesthesia of the lingual mucosa in the third molar region following third molar surgery. Evaluation of the 3-D models suggests these accessory branches are particularly vulnerable to lingual plate perforation during third molar surgery misadventures.

6.5 Digitization and Method of LN Reconstitution

Previous cadaveric studies used to evaluate the position of the LN have been criticized due to potential tissue distortion and manipulation of the LN position (Miloro et al., 1997; Behnia et al. 2000). Specimen distortion due to the fixation process has been shown to be negligible (Cutts, 1988). In the current study, several methods were utilized to minimize iatrogenic displacement of LN during dissection. A hemi-maxillectomy was utilized to provide an unobstructed view and allow for greater flexibility of the digitizing arm within this confined space. During the osteotomies, the pterygoid plates were preserved which minimized disruption to the medial pterygoid muscle and underlying LN. The mesoneurium surrounding the LN was left intact to minimize displacement. Magnification (2.5 X Surgical Loupes, Design for Vision, Inc. Ronkonkoma, NY) was used to carefully expose the superior and medial surface of the LN. Digitization of this undisturbed surface allowed for accurate 3-D reconstitution of digitized co-ordinates in Autodesk® Maya® 8.5. In addition, the dissection and digitization process was conducted by one operator to minimize inter-operator variability.

Creating accurate 3-D models through serial dissection and digitization has been validated by several studies done in our laboratory (Kertesz, 2005; Sansalone, 2006). Mahoney et al. (1999) examined the consistency of this technique with an intra-observer reliability between 0.12 and 0.7 mm, and an inter-observer reliability between 0.15 and
0.32 mm. The current study also validated the accuracy of Autodesk® Maya® 8.5 distance tool software to measure distances to LN from the reference screw in the center of the retromolar pad. These distances were also measured manually with digital calipers. A paired t-test between these two measuring techniques demonstrated no statistically significant difference (p < 0.05).

6.6 Anatomic Position of the LN in the Mandibular Third Molar Region

6.6.1 Distance of LN to Oral Mucosa

The center of the retromolar pad was selected as the reference point for oral mucosa measurements to the LN since the underlying basal bone endures minimal resorption (Zarb, 2003). Furthermore, it lies in close proximity to the distal extent of incisions required for the surgical extraction of impacted mandibular third molars. The retromolar pad was free of pathology in all specimens. This was important since a hyperplastic retromolar pad would exaggerate the distance from the oral mucosa to the LN. The mean shortest distance from the oral mucosa in the retromolar pad to the LN was 9.22 ± 1.72 mm. According to data presented by Hölzle and Wolff (2001), the LN lies considerably closer to the oral mucosa with a mean distance of 4.41 ± 1.44 mm. Comparison of these two distances is not possible since the measuring points utilized on the oral mucosa are dissimilar between the two studies. Hölzle and Wolff (2001) simulated an incision up the ascending ramus for third molar surgery and measured the distance to the LN from the most distal part of the incision. Use of this type of incision is highly unlikely as a more lateral incision is usually used in the clinical setting and thus represents a poor choice for standardized measurements to the LN.
The retromolar pad serves as a surgical landmark for outlining safe incisions during third molar surgery. In the current study, the LN was observed to be medial to the retromolar pad in all specimens. Behnia et al. (2000) reported a rare observation (1 out of 669) of the LN traveling in the retromolar region. In view of these findings, a mucosal incision lateral to the retromolar pad is recommended to minimize iatrogenic damage to the LN during third molar surgery.

6.6.2 Vertical Distance of LN to Alveolar Crest

The results of the current study were compared to the findings of Pogrel (1995). Pogrel’s study was unique in that it used definitive reference points for measuring the vertical distance to LN. In the current study, the vertical LN distances in region B correspond to the vertical distance measured by Pogrel. The mean vertical distance from the alveolar crest to the LN in region B was 8.1 ± 2.9 mm in this study, while Pogrel (1995) reported a distance of 8.3 ± 4.1 mm. The similarity between these distances stresses the importance of comparing standardized measurements. Previous studies lacked standardized methods to measure the position of the LN and should be interpreted with caution.

Variability of results reported in the literature may also be due to anatomical variation and age related changes. Anatomical variations such as the position of the mylohyoid ridge (see section 6.6) and lingula (see section 6.7) may also contribute to variable vertical positions of the LN. The loss of muscle tone and connective tissue tension with advanced age may alter the vertical position of the LN. For example, Hölzle and Wolff (2001) concluded a significant relationship between the degree of mandibular crest atrophy and the distance of the LN to the crest. In addition, Miloro et al. (1997)
reported a vertical distance of 2.53 ± 0.67mm in ten young (mean age 24.7 years) volunteers using MRI. These measurements were made from a single coronal MRI slice in the third molar region.

6.6.3 **Horizontal Distance of LN to Lingual Plate**

Previous literature has used manual or digital calipers to measure the horizontal distance of the LN to the lingual plate. This method introduces potential errors as the calipers can inadvertently move the position of the LN. A novel method of using in-situ 3-D models to measure the horizontal distance to LN was introduced in the current study. The ability to manipulate and magnify the 3-D model allowed for multiple horizontal measurements to be conducted along the course of the LN with no iatrogenic displacement.

In region B (third molar region), the LN was in contact with the alveolar bone in 28.57% (2 out of 7) of the specimens, similar to the findings of Behnia et al. (2000) who reported this relationship in 22.27% (149 out of 669) specimens. In the current study the mean distance to the alveolar bone was 2.4 ± 2.0 mm. This distance is similar to the measurement of 2.1 ± 1.1 mm reported by Behnia et al. (2000). Miloro (2001) reported a comparable distance of 2.5 ± 0.7 mm using MRI imaging.

In region C, the LN had direct contact with the lingual plate in three specimens (42.85%; 3 out of 7). The greatest distance between the LN and the lingual plate was 7.9 ± 4.1 mm in region C. Differences of lateral flaring of the mandible in this region may help account for the large variability.

No specimens demonstrated LN contact with alveolar bone in region A. This is not surprising as the LN begins to course medially towards the tongue in this region. The
average mean distance to the bone in this region was 4.1 ± 1.7 mm. This increased distance to the LN in this region would inherently lower the risk of damage to LN due to lingual plate perforations.

6.7 Association Between the Position of the LN and Location of Mylohyoid Ridge

In 2007, Karakas et al. suggested the position of the mylohyoid muscle and/or the volume of the muscle may account for differences in the position of the LN but did not support this statement with findings. Evidence for this relationship was not found in the literature.

The current study examined the potential relationship between the location of the mylohyoid ridge and the position of the LN. A regression analysis demonstrated a positive association between the location of the mylohyoid ridge and the vertical and horizontal distances between the LN and the alveolus in region B. No association was found in regions A and C. The mylohyoid ridge is the origin for the mylohyoid muscle, which forms the floor of the mouth and thus limits the inferior displacement of the LN. The positive association found in region B, means that a more superiorly positioned mylohyoid ridge results in a LN positioned closer to the alveolar crest. However, as the LN courses anteriorly, this relationship is lost, possibly due to muscle laxity or decrease in muscle volume. In the current study, the presence of more perineural tissue around the LN in sections A and C may account for greater variability and the loss of an association with the mylohyoid ridge. No relationship was found with the position of the LN in section C, as there was minimal mylohyoid muscle in this region.
Regression analysis also found a relationship between the position of the mylohyoid ridge and the horizontal position of the LN suggesting a more superiorly positioned mylohyoid ridge is associated with the LN lying closer to the lingual plate of the mandible in region B. The gingiva may account for this association. The lingual gingiva transitions from unattached mucosa inferiorly, to firm attached gingiva superiorly. Thus, a superiorly positioned mylohyoid ridge causes the LN to course under attached gingiva and as a result be tightly bound to the medial wall of the mandibular alveolus.

Atrophy of the alveolar crest is likely not a factor in the association between the position of the LN and location of the mylohyoid ridge since all specimens had mandibular second molars present with no furcation involvement. Furthermore, the distances used to measure the mylohyoid ridge ratio were at the posterior extent of the ridge anatomy and beyond the tooth-bearing region.

The association between the mylohyoid ridge and the position of the LN has clinical implications. The mylohyoid ridge runs diagonally anteroinferiorly from the region of the third molar to the premolar region and is visible on panorex radiographs (White, 2000). Since the mylohyoid ridge is visible on panorex radiographs, this imaging modality could be used to classify the risk of the LN during oral and maxillofacial procedures. The ratio of the distance from the superior border of the mylohyoid ridge to the height of the mandible developed in the current study could potentially be used to predict the location of the LN from panorex radiographs. Variable magnification amongst panorex machines would not be a factor with the use of a ratio. This ratio may allow for universal method for approximating the relative position of the LN in the third molar region.
6.8 Association Between the Position of the LN and Location of Lingula

In the current study, as well as in previous studies, the LN was found to course anterior to the lingula and IAN (Behnia et al., 2000; Hölzle and Wolff, 2001; Erdogmus et al., 2008). The relationship between the lingula and LN has not been discussed in the literature. In the current study, regression analysis demonstrated a positive correlation between the vertical position of the LN and lingula in regions A and B. Thus, when the lingula is situated more anteriorly, the LN is also translated in this direction to maintain its relationship to the IAN. Anterior translation of the LN would then result in the LN lying closer to the alveolar crest in the region of the third molar.

In 1992, Bell reported that the IAN foramina are located in a more superior and posterior position in children compared to adults. Corroborating this finding, with the relationship observed in this study would suggest that children are at a lower risk of LN damage compared to adults. In a prospective study of 2134 consecutive mandibular third molar surgeries, Renton and McGurk (2001) reported a mean age of 36 years for patients with permanent LN injury versus a mean age of 29 years for all subjects. Chiapasco et al. (1995) reported an increased incidence of LN injury with subjects over 24 years of age. In 1991, Herpy and Goupil reported a 25% incidence of temporary LN injury if the patient was over 40 years of age. Although many studies support this claim between age and risk of LN damage, others provide conflicting evidence (Middlehurst et al., 1988; Lopes et al., 1995; Black, 1997; Fielding et al., 1997; Valmaesed-Catellon et al., 2000). Unfortunately, this study could not evaluate anatomical differences between adults and children, as all specimens were over 40 years of age (range 40 – 79). Regardless, the current study provides a possible novel explanation to the potential risk factor of age and incidence of LN damage. In addition, the findings of the current study, along with Bell’s
observation, suggest that early removal of third molars may limit adverse outcomes associated with LN damage. This paradigm requires further investigation.

Furthermore, the positive relationship between the lingula and LN position may aid in risk stratification of impacted mandibular third molars. Distoangular impactions are considered the most problematic since their removal often requires surgical intervention along the mandibular ramus (Peterson, 2003). In 1997, Fielding reported the highest incidence of LN paresthesia with distoangular impacted teeth. In these situations, an anteriorly positioned lingula would place the LN closer to the anterior border of the ramus and thus at greater risk to LN damage.
Chapter 7
Conclusions

The conclusions of the thesis are as follows:

• A hemi-maxillectomy and a medial dissection allowed for the digitization of the oral mucosa, medial pterygoid muscle, LN, mylohyoid muscle, medial aspect of the mandible and the second mandibular molar. Three-dimensional models and a database of the position of the LN within the mandibular 3rd molar region was constructed from digitized data using Autodesk® Maya®.

• The origin of the LN occurred in the infratemporal region for the majority (85.57%) of specimens.

• Small accessory branches (range: 1-3) of the LN were observed in the retromolar region for all specimens.

• The LN displayed a variety of cross-sectional shapes within the oral cavity. In the current study, an oval-round morphology accounted for 71% of cross-sectional shapes in the third molar region.

• The mean shortest distance from the oral mucosa to the most superior aspect of the LN was 9.0 ± 1.4 mm and 9.2 ± 1.7 mm using digital calipers and Autodesk® Maya® software respectively. Thus computation of length measurements yielded no statistical difference (p < 0.05) between these two methods.

• The horizontal and vertical positioning of the LN is highly variable. The vertical measurement of the LN to the alveolar crest in the third molar region (section B) was 8.1 ± 2.9 mm. The mean horizontal distance of the LN to the medial surface of the mandibular alveolus in this region was 2.1 ± 1.7 mm.
• The vertical distance of the LN to the alveolar crest in the third molar region (region B) was positively correlated with the height of the mylohyoid ridge (p = 0.001). However, no correlation was found in sections A (p = 0.327) and C (p = 0.198). Thus, a superiorly positioned mylohyoid ridge is directly proportional to the vertical position of the LN from the alveolar crest in the third molar region. A superiorly positioned mylohyoid ridge in this region was also correlated (p = 0.009) with the LN lying closer to the alveolar bone.

• An anteriorly positioned lingula was directly proportional to the vertical distance of the LN from the alveolar crest in regions A and B (p < 0.05). There was no association between the position of the lingula and the horizontal distance of the LN and the lingual plate of the mandible.
Chapter 8
Future Directions

The current study has demonstrated a novel way of studying the position of the LN using 3-D modeling. Although a potential relationship of the position of the LN with the mylohyoid ridge and lingula was established, further examination with a larger sample size would be required to produce more significant correlations.

Additional studies could evaluate the clinical relevance of imaging the relationship between the LN and mylohyoid ridge and/or lingula. A suitable and convenient imaging modality would be the use of a panorex as it is routinely used prior to third molar surgery. Furthermore, the lingula and mylohyoid ridge are easily identified on a panorex. A potential study could involve obtaining panorex images of cadaveric mandibles prior to dissection and stratifying the potential risk to the LN based on the location of the mylohyoid ridge and lingula from the panorex image. The cadaver could then be dissected and a 3-D model created. Data from the 3-D model could then be used to measure distances to the LN and test the validity of using panorex images as predictors to the position of the LN. Other imaging modalities such as MRI could also be used in a similar manner. Advancements in MRI technology would allow for 3-D volumetric image reconstruction, which could then be compared to the digitized 3-D model.

Histology may provide additional insight into the cross-sectional microanatomy of the LN. Cross-sectional histological examination of the LN would show the number of nerve fascicles in various positions along its course. This information would be useful in ensuring the number of fascicles of the donor nerve graft corresponds with the number of fascicles in the damaged LN segment.
The future use of ultrasonography in depicting the position of the LN remains exciting. Although human trials are pending, this imaging modality may provide an inexpensive, low risk alternative to the prevention and surgical intervention process of LN injuries (Olsen and Troulis, 2007).
Chapter 9
References


Rood JP. (1983). Degrees of injury to the inferior alveolar nerve sustained during the removal of impacted mandibular third molars by the lingual split technique. British Journal or Oral Surgery. 21(2): 103-16


