JMS 2019;2(2):79-88
UDC: 616.733.5

AN OVERVIEW OF THE THYROHYOID MUSCLE, ITS CLINICAL AND SURGICAL IMPLICATIONS

Sudha Ramalingam, Deepa Somanath

Department of anatomy, Sri Manakula Vinayagar Medical College and Hospital, India

Abstract

The thyrohyoid muscle is one of the infrahyoid muscles located on the deeper layer of the infrahyoid muscles attached to the oblique line of the thyroid cartilage.

The activity of the THM is required in deglutition, phonation and respiration. This article explains the various aspects of the muscle regarding its anatomy, development and clinical correlation.

Key words: infrahyoid muscles, infrahyoid flap, prelaryngeal muscle, strap muscle, thyrohyoid

Introduction

The thyrohyoid muscle (THM) is one of the infrahyoid muscles located deep to sternohyoid and superior belly of omohyoid on the anterolateral aspect of the thyroid lamina in the neck region. It is a key muscle involved in the hyolaryngeal elevation during the second stage of the deglutition process [1].

It plays a role in respiration, phonation and singing [2]. This muscle is involved in diseases like muscle tension dysphonia, dysphagia, dorsal displacement of the soft palate, haemangioma and sleep apnoea. Hence extensive knowledge regarding its development, anatomy and its clinical relevance are indispensable.

Embryology

Branchial arches give rise to the muscles of the head and neck region which are formed during 4 to 7 weeks of gestation. The mesoderm of the arches together with the neural crest cells form the infrahyoid muscles [3]. Conversely, a few neck muscles in the vertebrates do not develop from the somites but they follow a head muscle program and the infrahyoid muscles are derived from somites which can be confirmed by the lack of Myf5 transcription factor coded by Pax3 gene leading to the disturbance in the developing hypohyoid muscles including some tongue muscles [4, 5]. Sato et al stated that the development of most of the myotome occurs in the thoracic region during the fifth week of intrauterine life [6]. Each myotome cleaves into a larger ventral hypomere and a small dorsal epimere. Each spinal nerve divides accordingly and innervates each part. The myoblast of cervical myotomes form the infrahyoid muscles, geniohyoid, scaleni and the prevertebral muscles. Among the muscles well-developed, the infrahyoid muscle belongs to the intermediate grade of development. In contrast, all the infrahyoid muscles including THM pertain to the hypobranchial muscle group which has a close alliance with the tongue musculature phylogenetically and ontogenetically [7].

The cervical region of an early embryo shows condensation of mesenchyme and myoblasts of cervical hypomere called the pre-muscle tissue (lingual-infrahyoid-diaphragmatic band). Further, it differentiates into a recognizable band running inferolateral from the base of the tongue to the tip of the first rib. The separation of this band forms the prelaryngeal muscles of the neck which are innervated by the superior root of ansa cervicalis. In the beginning, the pre-muscle strip divides into superficial and deep layers, the latter forming the thyrohyoid and sternothyroid muscles. The gene which regulates the muscular differentiation is TBX1 which is located on the q arm of chromosome 22 at 11.21 locus and codes for T-box protein [8, 9].

Muller et al studied 8-week-old embryos showing the attachment of thyrohyoid muscle from the lamina of thyroid cartilage in front of the oblique line occupying a large area with a dense attachment and inserted into the body and greater cornu of the hyoid bone continuously while the tendinous portions of the thyrohyoid and sternothyroid are interlaced. The nerve to thyrohyoid arises from the superior root of the ansa cervicalis while it exits off the hypoglossal nerve at the level just above the middle of the superior border of the thyroid lamina and enters the muscle as two twigs near the upper anterior angle of the thyroid lamina. In the embryonic period, the THM extends anteriorly to meet the hyoid bone but in adults, the muscle ascends at a different angle to be located at an utterly different position of the hyoid bone [9].

THM Attachments

The THM is a quadrilateral skeletal muscle that arises from the oblique line of the thyroid cartilage and inserted into the greater corny of extending along the lower border approximately two-third of the entire length and into the adjacent part of the body of the hyoid bone [1]. The THM along with the sternothyroid muscle limits the apex of the lateral lobes as well as the encroachment of the lobes towards the midline of the neck [10]. The posterior border of the muscle acts as a landmark for the piercing point of the internal laryngeal nerve which in the majority of cases was located 0.0 to 1.6 cm behind the margin [11]. Then it travelled deep to the TH muscle along with the superior laryngeal vessels [12].

The average thickness of the left and right THMs in adult male and female were 3.20±0.54 mm and 2.34±0.37 mm, respectively. It had a positive correlation with height, weight, and BMI [1]. The thickness of the muscle was more in case of males and broader on the right side in case both male and female [13, 1]. The thickness of the THM vary according to the neck position. It increases in the flexed and decreases in the extended neck because of the increase and decrease in the muscle belly respectively [1]. Based on the overlapping of sternohyoid and omohyoid muscles, the TH muscle is subdivided into three types, Type I- THM covered by sternohyoid and omohyoid muscles, Type II- THM covered by omohyoid muscle only, Type III- THM not covered by any of these muscles. The frequently observed type is the Type II but Sonoda and Tamatsu showed that the Type I is more prevalent followed by Type II]. He added that the Type I is a mixture of Types I and III and Type II is a mixture of Types I and II [13, 14]. The number of muscle fibers per mm square in the THM, on the right side is1098 and on the left side is 1052, thereby having the greater number of fibers among the other hyoid muscles but lesser than the geniohyoid muscle [6].

Type of muscle fiber and its composition in THM

Hisa et al. reported that among the infrahyoid muscles, the THM has the greatest amount of fiber types which have the slowest contraction times and greatest resistance to fatigue because the Type II A fiber showed the high succinyl dehyrogenase acticity [15].

In a study on cats, THM had the highest percentage of oxidative-fatigue resistant fiber Types I and II A. The mean diameter of the muscle fibers in the THM is the smallest compared to sternohyoid and sternothyroid since it contains more Type I fibers which is smaller than the Type II fibers. This enhances the muscle fiber surface area available for the oxygen diffusion and decreases the distance between the capillaries and mitochondria for the proper exchange of gases [16].

The force -velocity characteristics of muscle fibers are dependent on the myosin heavy chain compositions (MyHC). The muscle fibers expressing MyHC type I are slow-contracting and the fibers expressing MyHC- II A or II X are fast-contracting when compared to the masticatory muscles. In infrahyoid muscles, 40% of muscle fibers showed MyHC-I, 41% MyHC-II A, 4.5 % MyHC-II X and 13% of fibers are hybrid [17].

The THM has both the largest Type I and Type II components. Both of these fibers are associated with frequent recruitment which suggests that most of the total capacity for tension generation in this muscle is often used. The function of the Type I component in the muscle fiber is essential to maintain a constant distance between the thyroid cartilage and the hyoid bone during normal respiration. Inhibition of the same muscle fiber type occurs during hyperpnoea or dyspnoea resulting in distal movement of the thyroid cartilage, an increase in the TH distance and an increase in the width of the rima glottidis Type II B fibers occupy a relatively smaller percentage of the TH muscle possessing a quality of fatigability. This component might be responsible for a short increase in the tension generated by the muscle which would be required for swallowing [15].

Motor neurons of the THM

Miyazaki opined that the cat TH is partly supplied by the hypoglossal nerve which was proved by the injection of horseradish peroxidase into the THM and it was observed that the labeled neurons were located ipsilaterally in the lower lateral part of the hypoglossal nucleus and in the posteromedial part of the anterior horn cells of C1 [18, 19].

On the contrary, Ueyama documented that THM motor neurons were not present in the C1 segment of the spinal cord instead it was localized in the dorsomedial part of the cranial extension of the ventral horn at the caudal medulla. The number of labeled motor neurons was more in the cranial part of the nucleus than in the lower part [7, 20]. Kitamura et al documented that the axons of all the motor neurons of the THM pass through C1 suggesting that there was no contribution from the axons of hypoglossal nuclei. The cranial portion of the motor neuron of THM corresponds to the supraspinal nucleus of Taber instead of the hypoglossal nucleus which are larger and flatter. The motor neurons are scattered from the lower end of the hypoglossal nucleus at the spinomedullary junction to a part of the anterior horn lying postero-lateral to the medial nucleus of caudal C1 [7, 21].

Nerve supply

The nerve to the THM arises from the hypoglossal nerve via C1 before its disappearance under the stylohyoid muscle in close relation to the posterior margin of the hyoglossus muscle adjacent to the tip of the greater cornu of the hyoid bone in the carotid triangle, then it descends on the middle constrictor muscle to supply the THM [22, 23].

Banneheka reported that a considerable amount of C1, C2 and rarely C3 fibers entered and descended in the peripheral aspect of the hypoglossal nerve, then these fibers emerged out of the nerve as three branches namely superior root of ansa cervicalis, nerve to THM and nerve to geniohyoid muscle with no participation of hypoglossal nerve fibers [24]. On its origin, it was found lateral to the lingual artery and superior to the nerve to the geniohyoid muscle [25].

On contrary, Fukushima et al concluded that the pharyngeal branch of vagus nerve supplies the THM and it plays a highly significant role in the elevation of the larynx [26].

Vascular supply

The THM is usually supplied by the superior thyroid artery via its hyoid branch and rarely by the superior laryngeal and lingual arteries. The hyoid artery measured a mean diameter of 0.49 mm, running anteromedially near the hyoid bone to supply the THM. The veins from the muscle accompany the superior thyroid artery draining into the internal jugular vein or its tributaries, the pharyngeal venous plexus or both [27, 28].

Actions

The THM depresses and fixes the hyoid bone by acting synergistically with sternohyoid during the depression of the mandible. It elevates the thyroid cartilage to pull up the pharynx when the hyoid bone is fixed [13]. The extent of contraction of the THM is increased during swallowing after the shaker exercise [1].

The cephalic movement of the larynx is one of the most significant movements during the second stage of deglutition which is chiefly achieved by the THM and geniohyoid muscles [18]. The elevation of the hyolaryngeal complex is accomplished by the suprahyoid muscles, submental muscles and long pharyngeal muscles. These muscles merge with the posterior border of thyroid lamina and lateral pharyngeal walls above the superior oesophageal sphincter to shorten the pharynx while the THM approximate the thyroid cartilage and the hyoid bone, as an intrinsic component of hyolaryngeal complex to open up the sphincter to receive the ingested bolus [29]. The activity of THM was used as a marker for deglutition to investigate the coupling between respiration, mastication and swallowing in the rabbits [30].

Among all infrahyoid muscles, the most active muscle during phonation is the THM with the highest activity during expiration [6, 23]. It is essential for the changes in the pitch and the volume of vocalization in the case of untrained singers [15]. The action of the muscle brings the approximation of the hyoid bone and the larynx and helps in the closure of laryngeal inlet. Any involvement of THM would result in the paralysis of the epiglottis to avoid aspiration [13, 31]. In Dogs, THM plays a vital role in the elevation of the larynx during swallowing and it has a capacity to produce the closure of the larynx along with the support of the suprahyoid muscles even in the absence of recurrent laryngeal nerve and the muscle supplied by it [16].

It prevents the dislocation of the thyroid cartilage during the activity of the cricothyroid muscle thus it is considered an antagonist of the same [2]. It resembles the external laryngeal muscle, the cricothyroid muscle and it is evident that it gives little muscle fibers to it [32]. The main difference between these muscles is that the THM follows the course of the fundamental frequency less precisely than the cricothyroid muscle. The duration of the activity shows a much lower correlation with the call duration and it ends a few milliseconds before the end of the voice. In a peep and chuck which are short high-pitched and short plosive calls respectively, a moderate activity of THM is observed in a squirrel monkey. During cackling, THM showed bursting activity at the beginning of the ascending frequency modulation of the high-pitched component. The low-pitched calls like cawing do not require the activation of THM [2]. In the THM, EMG activity is more in high-pitched activity of larynx [33].

Soft palate stability

In horses, the THM moves the larynx anteriorly and body of the hyoid bone ventrally so that the larynx lies behind the basihyoid bone which is the vital function of the THM in preventing the dorsal displacement of the soft palate. The malfunction of the THM changes the position of the larynx pertaining to the body of the hyoid bone thus displacing the larynx anteriorly and distally in relation to the soft palate thereby the larynx is positioned more ventral to the soft palate. This will lead to an increase in the distance between the lower edge of the soft palate and the anterior surface of the epiglottis resulting in the dorsal displacement of the soft palate. Further caudal displacement of the larynx followed by the advancement of soft palate displacement are enhanced by the alignment of the vector of forces of other infrahyoid muscles and the downward displacement of the larynx associated with tracheal pull. The dysfunction of the THM alone is not sufficient to interfere with the deglutition process [34].

EMG activity

Juch et al reported that the proprioceptive signals from muscles of elevation of the mandible are relayed to the motor centers of the jaw depressors to control the oral movements. He conducted a study where he concluded that the tenotomy of infrahyoid muscles did not affect the EMG activity patterns of the masseter and the digastric muscles and their phase relationships during drinking and chewing. It was evident that the input from the infrahyoid muscles does not control the activity of masseter and digastric muscles since a negligible change in burst durations of the infrahyoid muscles were found [35].

An EMG study observed the activity of infrahyoid muscles depending on the jaw position and in relation to body posture. The activity of the muscles was significantly higher in the intercuspal position than the grinding from the intercuspal position to protruding edge-to-edge contact position and significantly lower than the grinding from the retracted position to intercuspal position and it was more in the lateral positions of the body. This could be of use clinically in the presence of parafunctional habits like clenching or grinding [36].

The EMG activity of THM followed the activity of other hyoidal and masticatory muscles while swallowing in monkeys. Hence it was suggested that the peri-central cortex of the cerebrum has a role in the act of swallowing as well as the duration and other parameters of muscle activity [37].

The amplitudes of the EMG activity in the suprahyoid muscles were greater in suck-swallow cycles particularly in the THM among the other infrahyoid muscles in pigs. The duration of peak THM activity was relatively constant at the onset of such swallow cycles compared to the anterior mylohyoid activity. The THM activity took place in the last stage of the shorter suck-swallow cycles. The study showed that the bursting activity of THM was followed by all the stages of pharyngeal swallow [38]. Its stimulation with electrodes caused elevation and slight twisting of thyroid prominence opposite the side of stimulation. Paired neuromuscular stimulation of THMs and/or mylohyoid muscles produced 50% of elevation of the larynx with maximum velocity during deglutition which can be an option for the treatment of dysphagia in humans [39]. An EMG study in the lambs showed a characteristic contraction of mylohyoid followed by the activity of the THM during swallows of saliva. He added, the THM contractions were found during sucking and swallowing between the short episodes of esophageal contraction [40].

Variations of THM

In a study by Sato et al, in an abnormal THM, the cross-sectional size of the muscle fiber was smallest, measuring 734 µm2 and 765 µm2, on the right and left sides respectively. The unilateral absence of left-sided THM was reported in the dogs. Such an anomaly is rare when compared to the sternohyoid and sternothyroid muscles. The bilateral absence of THM might produce disturbances in the deglutition and the regulation of the airflow [31]. It is a very rare phenomenon that sometimes the THM can insert into the cricoid cartilage and is called the cricohyoid muscle. The

THM often merges with the sternothyroid muscle. If an accessory THM is present, then it is called the muscle of Von Sommering [41].

Comparative anatomy

In the rhesus monkey, the THM is attached to the inferomedial aspect of the greater cornu of hyoid bone whereas, in capuchin and marmoset, it is attached to the lateral most area of the anterior surface of the body of the hyoid bone [42].

In dogs, it reduced the subglottal pressure and voice intensity in contrast to the activity of sternohyoid and sternothyroid muscles by pulling the larynx and hyoid without any tilt. Hence it shortens the vocal folds and widens the cricothyroid distance thereby reduces the pitch of the voice [2, 33].

Clinical aspects

The lateral neck pain with tenderness in the thyrohyoid region aggravated by neck movements and swallowing is called thyrohyoid syndrome. It is due to the calcification of the hyoid bone or ligaments or tendinitis of the related muscles. Local injection of triamcinolone can be preferred as a treatment for this syndrome [43]. In patients with anterior neck pain due to superior laryngeal nerve neuralgia, it can be treated by injecting steroids around the entry point of the internal laryngeal nerve piercing the thyrohyoid membrane behind the THM [12].

Electrical stimulation of the THM during swallowing might improve the dysphagia by enhancing the hyolaryngeal excursion by placing the electrodes on suprahyoid-infrahyoid muscles or on infrahyoid muscles only. This could provoke depression of the hyoid bone at the beginning followed by its anterior movement [44].

Muscle tension dysphonia is one of the functional voice disorders with multifactorial etiology like poor control of breathing, abnormally low-pitched voice, gastroesophageal reflux and increased hard glottal attacks. The palpable THM tension is associated with muscle tension dysphonic patients [45]. The THM is palpated with the thumb and index finger in both thyrohyoid spaces and observed for tension at rest and contraction during the continuous speech as in counting 1 to 5 and with an easy hum [46]. This is a standardized palpation technique for the THM which can be used as a clinical tool to evaluate the muscle tension dysphonia [47]. Voice tremor is a neurological disorder that can be treated by injecting botulinum toxin percutaneously with a monopolar needle into the laryngeal muscles including the THM [48].

The effect of head - lift exercise (Shaker exercise) involving the THM leads to its shortening which would result in the increased anterior movement of the larynx, anteroposterior diameter of the upper esophageal sphincter opening thereby improving the deglutition [49, 50]. Neuromuscular electrical stimulation of THM is employed for the treatment of dysphagia in opercular syndrome [51].

A disease called phagophobia is a condition where the sensation of not being able to swallow without the presence of any anatomical lesion. One of the investigations to rule out psychogenic dysphagia is to record EMG activity of the THM including other infrahyoid muscles [52].

The neuroprosthesis is an electrical- stimulation device used for a variety of applications including dysphagia. In dysphagic patients, one electrode can be placed just proximal to the lesser horns of the hyoid bone and the other placed approximately 4 cm below it. Otherwise, both the electrodes can be kept above the lesser horns of the hyoid bone bilaterally which are intended to stimulate the THM and the anterior belly of the digastric muscle for a successful outcome [53]. The electrical stimulation of the THM might be a choice of treatment for the dorsal displacement of the soft palate in the case of hypoglossal nerve palsy in horses. Such stimulation of the muscle causes the posterior movement of the ossified parts of the thyroid cartilage [54].

The dysfunction of the hyoidal musculature including the THM would fail to maintain the ventral position of the hyoid bone thereby unable to maintain the airway patency causing obstructive apnoea [55].

Galline et al reported a case of pseudotumor of bilateral dystrophic ossification of the thyroid cartilage on the anterolateral aspect with dysphonia. Such a calcified mass may be due to the mechanical forces implicated by the muscles attached to the oblique line of thyroid cartilage like the THM [56].

Haemangioma affecting the head and neck muscles is not common. Giudice et al reported a case of unusual location of intramuscular haemangioma in the THM which was adherent to the medial surface of the right THM involving the thyroid lamina which was removed surgically along with the right lobe of the thyroid gland and a part of the muscle surrounding it to reduce the bleeding from the lesion [57, 58].

The activity of the infrahyoid muscles was greater especially in the THM during swallowing in cleft lip and palate patients suggesting that these patients had a long pharyngeal phase of swallowing to make a bolus [59].To demonstrate fetal swallowing, EMG studies were conducted by using the THM in ovine fetus for the determination of fetal electrocorticogram [60, 61].

Myocutaneous flaps

In pharyngolaryngeal reconstructions and partial reconstruction of the cervical esophagus, the infrahyoid muscles are used as a myocutaneous flap along with the platysma and the overlying skin, measuring about 7x4 cm2. The outcome of the surgery was successful with the majority of the patients showing normal deglutition process. During the procedure, contraindications like previous thyroid surgery, the clue of resection on the side of the flap and radiotherapy on the head and neck region are to be noted. It was finally concluded that the size of the above flap was insufficient to reconstruct the tongue in case of large resection [62]. The infrahyoid muscle flap which is required to close the defect affecting the ventral floor of the oral cavity uses the infrahyoid muscles but the THM is left undisturbed to save superior laryngeal nerve and laryngeal vessels [63, 64]. In a study by Peng et al, it is stated that for medium-sized head and neck defects like oral defects and hypopharyngeal defects, the insertions of sternothyroid and THMs were released from the thyroid cartilage subperichondrially and shifted to the site of the graft [65, 66].

In case of injury to the recurrent laryngeal nerve, the nerve of THM can be taken as a cable graft to join the recurrent laryngeal nerve stump which would result in THM paralysis with loss of adductor property of the vocal folds [23]. The infrahyoid muscles with the overlying skin are used as potential musculocutaneous flaps for the reconstruction of laryngeal defects. If the pedicled hyoid bone is taken along with the muscle, the branches from the superior thyroid artery should not be disturbed [28].

THM with the other infrahyoid musculocutaneous flap can be raised for the soft palate reconstruction. The above-said method would be a reliable and convenient graft even in the case of elderly and weak patients. The motor innervation of the infrahyoid muscles is preserved along with the flap during its new positioning to prevent the atrophy and improving the scarring qualities of the reconstructed soft palate [67].

Other surgical aspects

Upper respiratory tract blockage results in a broad spectrum of clinical diseases ranging from snoring to severe obstructive sleep apnoea syndrome. The treatments available for such conditions are nasal turbinate radiofrequency reduction and soft palate stiffening by radiofrequency, bimaxillary advancement surgery for severe cases [68].

Guzeldir et al employed a surgical procedure in rabbits which involved the total release of the sternohyoid, omohyoid and THM from the hyoid bone thereby pulling the hyoid bone anterosuperiorly by the action of the unopposed suprahyoid muscles leading to the improvement in oropharyngeal air column volume [68].

In case of surgical removal of the thyroid cancer along with the removal of recurrent laryngeal nerve, the lower part of the sternohyoid muscle along with its innervation on the opposite side was used with transfer through the paraglottic space beneath the THMs and the superior horn of the thyroid lamina, if the muscle or the nerve was adhesive to cancer [14]. In the occurrence of a thyroglossal cyst in continuity with the body of the hyoid bone, it is resected after the surgical reflection of sternohyoid and THMs [69].

Conclusion

Developmentally, the THM is derived from either from the cervical myotomes or from the hypobranchial eminence. Based on the innervations, the authors believe that it would have developed from cervical myotomes. The innervation of the muscle by cervical nerves or hypoglossal nerve or both is debatable. The source of blood supply is from the superior thyroid vessels through superior laryngeal vessels and rarely by the lingual vessels. Its anatomical variations may be in the form of agenesis and cricoid attachment which are uncommon. Regarding its thickness and width, they are greater in males, especially on the right side. It is a fast contracting muscle compared to the masticatory muscles and considered to be tonic in relation to the other infrahyoid muscles. The stabilizing activity of the THM upon the hyoid bone and reduction in the hyolaryngeal distance are documented by EMG during the swallowing process. There is a contribution from THM for the production of a high-pitched voice. Its posterior margin acts as a marker for the entry of the internal laryngeal nerve to achieve a nerve block in case of neuralgia. The nerve to THM can be rejoined with the stump of the injured recurrent laryngeal nerve. The THM along with its nerve is taken as a graft usually with the other infrahyoid muscles to restore the medium-sized head and neck defects like pharyngeal, laryngeal and upper esophageal defects. This muscle has to be evaluated and rehabilitated in conditions like muscle tension dysphonia, dysphagia, dorsal displacement of the soft palate, and sleep apnoea.

References:

1. Cheon JH, Nam DH, Kim H, Lee DY, Cho YK, Kang EY, et al. Ultrasonographic measurement of thickness of the thyrohyoid muscle: a pilot study. Ann Rehabil Med 2016; 40(5):878-84.
2. Kirzinger A, Jurgens U. Role of extralaryngeal muscles in phonation of subhuman primates. J Comp Physiol A 1994; 175(2):215-22.
3. Mnatsakanian A, Al Khalili Y. Anatomy, Head and Neck, Thyroid Muscles. StatPearls [Internet] 2019; 1–4.
4. Ericsson R, Knight R, Johanson Z. Evolution and development of the vertebrate neck. J Anat 2013; 222(1):67-78.
5. Theis S, Patel K, Valasek P, Otto A, Pu Q, Harel I, et al. The occipital lateral plate mesoderm is a novel source for vertebrate neck musculature. Development 2010; 137(17): 2961-71.
6. Sato I, Ueno R, Sato T. A consideration of the normal and abnormal human suprahyoid and infrahyoid musculature . Okajimas Folia Anat. Jpn 1987; 64(1):17-38.
7. Kitamura S, Nishiguchi T, Sakai A. Location of cell somata and the peripheral course of axons of the geniohyoid and thyrohyoid motoneurons: a horseradish peroxidase study in the rat. Exp Neurol 1983; 79(1):87–96.
8. Senthil Murugan M, Sudha R, Bhargavan R. Clinical significance of an unusual variation: Anomalous additional belly of the sternothyroid muscle. Sultan Qaboos Univ Med J 2016; 16(4):491-4.
9. Muller F, O'rahilly R, Tucker JA. The human larynx at the end of the embryonic period proper: I. The laryngeal and infrahyoid muscles and their innervation. Acta Otolaryngol 1981; 91(1–6):323-36.
10. Bliss RD, Gauger PG, Delbridge LW. Surgeon's approach to the thyroid gland: Surgical anatomy and the importance of technique. World J Surg 2000; 24(8):891-7.
11. Paraskevas GK, Raikos A, Ioannidis O, Saberi BB. Topographic anatomy of the internal laryngeal nerve: surgical considerations. Head Neck 2012; 24:534-40.
12. Tamaki A, Thuener J, Weidenbecher M. Superior laryngeal nerve neuralgia: case series and review of anterior neck pain syndromes. Ear Nose Throat J. 2019; 98(8):500-3.
13. Sonoda N, Tamatsu Y. Observation on the attachment of muscles onto the hyoid bone in human adults. Okajimas Folia Anat. Jpn 2008; 85(3):79–90.
14. Tanaka S, Asato R, Hiratsuka Y. Nerve-muscle transplantation to the paraglottic space after resection of recurrent laryngeal nerve. Laryngoscope 2004; 114:1118-22.
15. Hisa Y, Malmgren LT, Gacek RR. Actomyosin adenosine triphosphatase activities of the cat infrahyoid muscles. Ann Otol Rhinol Laryngol 1989; 98(3):202-8.
16. Hisa Y, Malmgren LT, Lyon MJ. Quantitative histochemical studies on the cat infrahyoid muscles. Otolaryngol Head Neck Surg 1990; 103(5(Pt1)):723-32.
17. Korfage JAM, Schueler YT, Brugman P, Van Eijden TMGJ. Differences in myosin heavy-chain composition between human jaw-closing muscles and supra - and infrahyoid muscles. Arch Oral Biol 2001; 46(9):821-7.
18. Miyazaki T, Yoshida Y, Hirano M, Shin T, Kanaseki T. Central location of the

motoneurons supplying the thyrohyoid and the geniohyoid muscles as demonstrated by horseradish peroxidase method. Brain Res 1981; 219:423-7.
19. Yoshida Y, Miyazaki T, Shin T, Hirano M, Kanaseki T. Topographic arrangement of motoneurons innervating the suprahyoid and infrahyoid muscles: A horseradish peroxidase study in cats. Ann Otol Rhinol Laryngol 1983; 92:259-66.
20. Ueyama T, Satoda T, Tashiro T, Mizuno N. The distribution of infrahyoid motoneurons in the cat: a retrograde horseradish peroxidase study. Anat Embryol 1988; 177:445-50.
21. Kitamura S, Nishiguchi T, Okubo J, Chen K, Sakai A. An HRP study of the motoneurons supplying the rat hypobranchial muscles: central localization, peripheral axon course and soma size. The anatomical record 1986; 216:73-81.
22. Romanes GJ. Cunningham's text book of anatomy. 11th edition. Oxford university press, London 1972; 707-93.
23. Chhetri DK, Berke GS. Ansa cervicalis nerve: Review of the topographic anatomy and morphology. Laryngoscop 1997;107:1366-72.
24. Banneheka S. Anatomy of the ansa cervicalis: nerve fiber analysis. Anatomical Science International 2008; 83:61-7.
25. Sakamoto Y. Morphological features of the branching pattern of the hypoglossal nerve. Anat Rec (Hoboken). 2019; 302(4):558-67.
26. Fukushima S, Shingai T, Kitagawa J, Takahashi Y, Taguchi Y, Noda T, et al. Role of the pharyngeal branch of the vagus nerve in laryngeal elevation and UES pressure during swallowing in rabbits. Dysphagia 2003; 18(1):58–63.
27. Wang RC, Puig CM, Brown DJ. Strap muscle neurovascular supply. Laryngoscope 1998; 108: 973-6.
28. Eliachar I, Marcovich A, Shai H, Lindenbaum E. Arterial blood supply to the infrahyoid muscles: an anatomical study. Head Neck Surg 1984;7(1):8-14.
29. Pearson WG, Langmore SE, Yu LB, Zumwalt AC. Structural analysis of muscles elevating the hyolaryngeal complex. Dysphagia 2012; 27(4):445-51.
30. McFarland DH, Lund JP. An investigation of the coupling between respiration, mastication, and swallowing in the awake rabbit. J Neurophysiol 1993; 69(1):95-108.
31. Terrado J, Ortega J. Unilateral agenesis of the thyrohyoid muscle in a dog. The Vet J 2002; 164:156-8.
32. Maranillo E, Sanudo J. Laryngeal muscles. Tubbs RS, Shoja MM, Loukas M. Bergman's Comprehensive Encyclopedia of Human Anatomic Variation. 2016; (1):254–261. http://doi.wiley.com/10.1002/9781118430309
33. Hong KH, Ye M, Kim YM, Kevorkian KF, Berke GS. The role of strap muscles in phonation - in vivo canine laryngeal model. J Voice. 1997; 11(1):23–32.
34. Ducharme NG, Hackett RP, Woodie JB, Dykes N, Erb HN, Mitchell LM, et al. Investigations into the role of the thyrohyoid muscles in the pathogenesis of dorsal displacement of the soft palate in horses. Equine Vet J 2010; 35(3):258-63.
35. Juch PJW, Oomen CAM, Van Willigen JD. The effect of infrahyoid-muscle tenotomy on orofacial motor activity in the rat. Arch Oral Biol 1988; 33(7):511–7.
36. Miralles R, Gutierrez C, Zucchini G, Cavada G, Carvajal R, Valenzuela S, Palazzi C. Body position and jaw posture effects on supra- and infrahyoid electromyographic activity in humans. Cranio. 2006; 24(2):98-103.
37. Narita N, Yamamura K, Yao D, Martin RE, Sessle BJ. Effects of functional disruption of lateral pericentral cerebral cortex on primate swallowing. Brain Res 1999; 824:140-5.
37. Thexton AJ, Crompton AW, German RZ. EMG activity in hyoid muscles during pig suckling. J Appl Physiol 2012; 112:1512-9.
38. Burnett TA, Mann EA, Cornell SA, Ludlow CL. Laryngeal elevation achieved by neuromuscular stimulation at rest. J Appl Physiol 2003; 94:128-34.
39. Harding BYR, Titchent DA. Oesophageal and diaphragmatic activity during sucking in lambs 1981; 321:317-29.
40. Lee HY, Yang HJ. Anterior neck muscles. Tubbs RS, Shoja MM, Loukas M. Bergman's Comprehensive Encyclopedia of Human Anatomic Variation 2016; 228–234. http://doi.wiley.com/10.1002/9781118430309.

41. Hilloowala RA. Comparative anatomical study of the hyoid apparatus in selected primates. Am J Anat 1975;142:367-84.
42. Kunjur J, Brennan PA, Ilankovan V. The use of triamcinolone in thyrohyoid syndrome. Br J Oral Maxillofac Surg 2002; 40:450-1.
43. Kim SH, Oh BM, Han TR, Jeong HJ, Sim YJ. Different movement of hyolaryngeal structures by various application of electrical stimulation in normal individuals. Ann Rehabil Med 2015; 39(4):535-44.
44. Altman KW, Atkinson C, Lazarus C. Current and emerging concepts in muscle tension dysphonia: A 30-month review. J Voice. 2005;19(2):261-7.
45. Angsuwarangsee T, Morrison M. Extrinsic laryngeal muscular tension in patients with voice disorders. J Voice. 2002; 16(3):333-43.
46. Khoddami SM, Ansari NN, Jalaie S. Review on laryngeal palpation methods in muscle tension dysphonia: validity and reliability issues. J Voice. 2015; 29(4):459-68.
47. Hertegard S, Granqvist S, Lindestad PA. Botulinum toxin injections for essential voice tremor. Ann Otol Rhinol Laryngol 2000; 109:204-9.
48. Antunes EB, Lunet N. Effects of the head lift exercise on the swallow function: a systematic review. Gerodontology 2012; 29(4):247-57.
49. Mepani R, Antonik S, Massey B, Kern M, Logemann J, Pauloski B, et al. Augmentation of deglutitive thyrohyoid muscle shortening by the shaker exercise. Dysphagia 2009; 24:26-31.
50. Baijens LWJ, Speyer R, Roodenburg N, Manni JJ. The effects of neuromuscular electrical stimulation for dysphagia in opercular syndrome: a case study. Eur Arch Otorhinolaryngol. 2008; 265(7):825-30.
51. Baijens LWJ, Koetsenruijter K, Pilz W. Diagnosis and treatment of phagophobia: a review. Dysphagia 2013; 28:260-70.
52. Steele CM, Thrasher AT, Popovic MR. Electric stimulation approaches to the restoration and rehabilitation of swallowing: a review. Neurol Res 2007; 29:9-15.
53. Zantingh AJ, Ducharme NG, Mitchell LM, Cheetham J. Effects of hypoglossal nerve block and electrical stimulation of the thyrohyoideus muscles on position of the larynx and hyoid apparatus in healthy horses. Am J Vet Res 2013; 74:784-9.
54. Van de Graaff WB, Gottfried SB, Mitra J, van Lunteren E, Cherniack NS, Strohl KP. Respiratory function of hyoid muscles and hyoid arch. J Appl Physiol Respir Environ Exerc Physiol. 1984; 57(1):197-204.
55. Galline J, Marsot-Dupuch K, Bigel P, Lasjaunias P. Bilateral dystrophic ossification of the thyroid cartilage appearing as symmetrical laryngeal masses. AJNR Am J Neuroradiol 2005; 26(6):1339-41.
56. Giudice M, Piazza C, Bolzoni A, Peretti G. Head and neck intramuscular haemangioma: report of two cases with unusual localization. Eur Arch Otorhinolaryngol. 2003; 260(9):498-501.
57. Parajuli R, Thapa S, Maharjan S. Intramuscular hemangioma of thyrohyoid muscle. Case Rep Otolaryngol. 2016; 2016:7158691.
58. Nagaoka K, Tanne K. Activities of the muscles involved in swallowing in patients with cleft lip and palate. Dysphagia 2007; 22:140-4.
59. Roberts TJ, Caston-Balderrama A, Nijland MJ, Ross MG. Central neuropeptide Y stimulates ingestive behavior and increases urine output in the ovine fetus. Am J Physiol Metab 2000; 279:E494-500.
60. Ross MG, Agnew C, Fujino Y, Ervin MG, Day L. Concentration thresholds for fetal swallowing and vasopressin secretion. Am J Physiol. 1992; 262(6 Pt 2):R1057-63.
61. Dolivet G, Gangloff P, Sarini J, Ton Van J, Garron X, Guillemin F, et al. Modification of the infra hyoid musculo-cutaneous flap. Eur J Surg Oncol 2005; 31:294-8.
62. Deganello A, Leemans CR. The infrahyoid flap: A comprehensive review of an

often overlooked reconstructive method. Oral Oncol 2014; 50(8):704-10.

63. Tincani AJ, Del Negro A, Costa Araujo PP, Akashi HK, da Silva Pinto Neves F, Martins AS. Head and neck reconstruction using infrahyoid myocutaneous flaps. Sao Paulo Med J 2006; 124(5):271-4.
64. Peng H, Wang SJ, Yang X, Guo H, Liu M. Infrahyoid myocutaneous flap for medium-sized head and neck defects: surgical outcome and technique modification. Otolaryngol Head Neck Surg. 2013;148(1):47-53.
65. Mirghani H, Meyer G, Hans S, Dolivet G, Périé S, Brasnu D, et al. The musculocutaneous infrahyoid flap: surgical key points. Eur Arch Otorhinolaryngol. 2012; 269(4):1213-7.
66. Gangloff P, Deganello A, Lacave ML, Verhaeghe JL, Lapeyre M, Maire F, et al. Use of the infra hyoid musculo-cutaneous flap in soft palate reconstruction. Eur J Surg Oncol 2006; 32:1165-9.
67. Guzeldir OT, Aydil U, Kizil Y, Akyildiz I, Koybasioglu A. The effect of infrahyoid muscle sectioning on hyoid bone position and oropharyngeal air column volume. Laryngoscope 2015; 125(6):1480-4.
68. Todd NW. Common congenital anomalies of the neck: Embryology and surgical anatomy. Surg Clin North Am 1993;73(4):599-610.