Int. J. Morphol.,
41(3):851-857, 2023.

Geniohyoid Muscle: Anatomy and Clinical Implications in Dentistry

Músculo Geniohioideo: Anatomía e Implicaciones Clínicas en Odontología

Soyeon Kim[1†]; Jung Hwan Jo[2†]; Larnani Sri[1]; Muhammad Akria Takashi Dharma[1] & Young-Seok Park[1,3]

KIM, S.; JO, J. H.; SRI, L.; DHARMA, M. A. T. & PARK, Y. S. Geniohyoid muscle: Anatomy and clinical implications in dentistry. *Int. J. Morphol., 41(3)*:851-857, 2023.

SUMMARY: The geniohyoid muscle is one of the suprahyoid muslces, and arises from the inferior mental spine and inserts into the hyoid bone. The muscle is a narrow paired one and its main action is pulling the hyoid upward and forward. Its function is very important in deglutition as well as respiration. Therefore, this muscle has been extensively researched, especially in the context of dysphagia and sleep apnea. This review deals with the general anatomic features, main functions, and abnormal states of the geniohyoid muscle, and the clinical implications of these.

KEY WORDS: Geniohyoid muscle; Anatomy; Suprahyoid muscle; Obstructive sleep apnea.

INTRODUCTION

The "genio-" means the chin. The geniohyoid is a narrow paired muscle and is one of the four suprahyoid muscles: the digastric, the mylohyoid, the stylohyoid, and the geniohyoid. The muscle lies above the mylohyoid on the medial side in contact with its opposite partner. Occasionally it is not separated as a paired muscle but is contiguous as a single muscle. It may also be fused with the genioglossus, an extrinsic muscle of the tongue. The root of the tongue is in contact with the geniohyoid and the mylohyoid (Gervasio *et al*., 2011). Like other jaw-opening muscles, it has an architecture to be designed for velocity and displacement rather than force production (Van Eijden *et al*., 1997). In addition, it is composed predominantly of fibers expressing myosin heavy chain type IIA (Korfage *et al*., 2000; Luo *et al*., 2014). In this review, the anatomic features of the geniohyoid are summarized. Functions and malfunctions of this muscle will be discussed, with a focus on swallowing and respiration. Finally, the clinical implications of dysfunction of this muscle will be covered.

General Anatomy

Origin, insertion, and direction. The origin of the muscle is the inferior mental spine. The mental spine is a small bony projection on the back of the mandible around the midline. Usually four spines exist, two superior and two inferior. They are sometimes referred to collectively as the genial tubercle (Standring, 2016). The superior ones are the origin of the genioglossus. The geniohyoid is generally inserted into the anterior portion of the hyoid bone body, but occasionally slips to the greater horn of the hyoid bone. The attachment type of the geniohyoid to the hyoid bone is known to be very diverse (Sonoda & Tamatsu, 2008). The direction from origin to insertion is slightly downward and backward. Interestingly, the geniohyoid of Neanderthals had a horizontal orientation rather than an inclined orientation (Fig. 1) (Barney *et al*., 2012).

Arterial supply and innervation. The geniohyoid is supplied with arterial blood, mainly by the sublingual branch of the lingual artery. Primary innervation is by first cervical nerve fibers running through the hypoglossal nerve, which are called the ansa cervicalis (Banneheka, 2008).

Embryologic development. At the 7th week of gestation, the neuromuscular spindles of the geniohyoid are laid down. Differentiation starts at the 9th week, and the development of the spindle as a definitive structure is complete at the

[1] Department of Oral Anatomy, School of Dentistry, Seoul National University and Dental Research Institute, Korea.
[2] Department of Oral Medicine and Oral Diagnosis, School of Dentistry, Seoul National University and Dental Research Institute, Korea.
[3] Head, Center for Future Dentistry, Seoul National University, Korea.
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF-2021R1I1A2048516).
† Soyeon Kim and Jung Hwan Jo are the first authors. Contributed equally to this work.

Received: 2023-03-31 Accepted: 2023-04-19

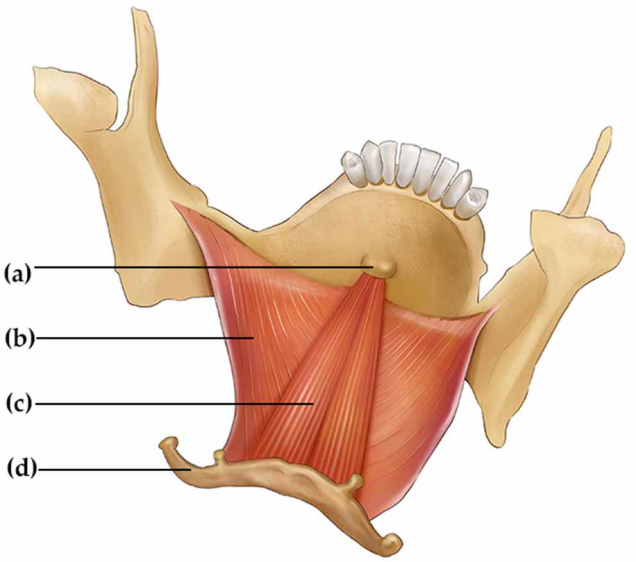

Fig. 1. Geniohyoid muscle and neighboring structures. (a) genial tubercle, (b) mylohyoid muscle, (c) geniohyoid muscle, (d) hyoid bone.

20th week (Mitchenok, 1979). The geniohyoid muscle was reported to be visible on the medial surface of Meckel's cartilage at week 16 of development (Wyganowska-Swiatkowska *et al*., 2012).

The diameter of the muscle fibers of the geniohyoid inserted into the symphysis menti increases from the 24th week (Kurihara & Sato, 2004).

The geniohyoid appears to be associated with mandibular development. During palatal development, geniohyoid activity has been suggested to retract and widen the mandible (Kjaer, 1997). In an animal study, shortening of the geniohyoid resulted in a notable change in the mandible (Davis *et al*., 1981).

Functions. Contraction of the geniohyoid draws the hyoid bone forward and upwards and causes it to act as an antagonist to the stylohyoid in part. In fact, the geniohyoid has the biggest potential to displace the hyoid forward according to a physiological cross-sectional area measurement study.(Pearson Jr. *et al*., 2011) This movement involving the anterior digastric and mylohyoid is important during the first act of swallowing. During swallowing, the mouth floor and the anterior two-thirds of the tongue are elevated by coordinated contraction of the suprahyoid muscle group. The effectiveness of elevation is maximized when the muscles contract against a fixed mandible (Standring, 2016). When the hyoid is fixed by other muscles, such as the infrahyoid muscles, the movements can depress the mandible. In addition, contraction of the muscle causes dilatation of the upper airway, which assists respiration (Brouillette & Thach, 1979; Konrad *et al*., 1984; Takahashi *et al*., 2002). Therefore, the role of the geniohyoid in respiration as well as deglutition has been studied extensively using diverse tools (van de Graaff *et al*., 1984; Guilleminault *et al*., 1997; Pearson Jr. *et al*., 2013). Interestingly, the geniohyoid also appears to be associated with vocalizations (Sapir *et al*., 1981). According to an electromyographic study, there is geniohyoid activity during opening, closing, lateral movement, and protraction of the jaw, as well as swallowing and protraction of the tongue (Vitti & Basmajian, 1977).

Deglutition. Swallowing is a sophisticated movement that requires coordination among muscles. The geniohyoid is a key component of hyoid forward movement according to a computed tomography study (Okada *et al*., 2013). Unsurprisingly, the role of the geniohyoid in deglutition has been studied extensively using diverse methodologies (Palmer *et al*., 1999). The tongue compresses and squeezes the bolus against the palate into the pharynx prior to swallowing. Protraction of the tongue is produced by contraction of the geniohyoid and anterior belly of the digastric. Their synchronous contraction was confirmed in a fine wire EMG study (Inokuchi *et al*., 2014). This usually occurs during the intercuspal and opening phases of the mandible (Palmer *et al*., 1992). However, activation and coordination patterns are known to differ among individuals (Spiro *et al*., 1994). Generally, the geniohyoid shows age-related muscle atrophy (Feng *et al*., 2013; Wakabayashi, 2014). This atrophy is known to entail structural changes at the molecular level (Kaneko *et al*., 2014).

Electromyography has been popularly used in this research field on diverse topics (Palmer *et al*., 2008; Inokuchi *et al*., 2016). In EMG studies, the type and volume of food demonstrated to affect the pattern of geniohyoid activity (Dantas & Dodds, 1990). During the deglutition process, geniohyoid action is not initiated with the genioglossus, but rather lags behind and its working time is short compared to the genioglossus. Both muscles remain active during and after the stage when the food bolus stays in the laryngopharynx (Cunningham & Basmajian, 1969). In patients with a cleft lip and palate, the thyrohyoid muscle appears to compensate for weakness of the geniohyoid and the mylohyoid during swallowing (Nagaoka & Tanne, 2007).

In a high-resolution diffusion tensor imaging study, expansive strain of the geniohyoid was combined with compressive strain of the genioglossus during swallowing (Felton *et al*., 2008). Swallowing function evaluation using a photo sensor was introduced by Kurihara *et al*. (2010) as a noninvasive technology for deglutition studies. Ultrasonography is another widely used tool for deglutition

research. Geniohyoid muscle size is correlated with displacement of the hyoid bone (Feng *et al*., 2015). Ultrasonographic evaluation of the geniohyoid during swallowing demonstrated that average movement of the muscle increased gradually with age in healthy adults (Yabunaka *et al*., 2012).

Dysphagia. There are many types of dysphagia with different etiologies (Wakabayashi, 2014). Aging-related geniohyoid atrophy has been suggested to be a cause of dysphagia (Feng *et al*., 2013) and have an impact on post-stroke swallowing disorder (Sporns *et al*., 2017). Removal of the geniohyoid in patients with oral cancer was significantly related to complications resulting in poor swallowing (Hirano *et al*., 1992). Geniohyoid muscle volumes have also been investigated in head and neck cancer patients (Watkin *et al*., 2001). High radiation dose has been found to be closely related to complications associated with dysfunction of the swallowing muscles, especially the geniohyoid (Kumar *et al*., 2014; Starmer *et al*., 2015). Duchenne muscular atrophy is also associated with dysphagia and limited mandibular motion, including motion of the geniohyoid (van den Engel-Hoek *et al*., 2013; van Bruggen *et al*., 2015).

Shortening of the geniohyoid has been reported to be associated with failed relaxation of the upper esophageal sphincter in patients with neurogenic dysphagia (Williams *et al*., 2002). A sour food bolus was suggested as a stimulatory treatment modality for dysphagia, and resulted in greater EMG activity of the geniohyoid and other swallowing muscles (Palmer *et al*., 2005). Electrical stimulation of the neuromuscular system has also been suggested for dysphagia treatment (Toyama *et al*., 2014). The feasibility of exercise treatment, especially in cancer patients, has also been investigated (Watts, 2013; Hughes & Watts, 2016).

Respiration. Change in breathing mode or body position did not affect the geniohyoid, but did affect the genioglossus in an EMG study. In addition, the geniohyoid showed greater involvement in jaw opening and a shorter latency than the genioglossus (Takahashi *et al*., 2002). Magnetic resonance imaging showed that inspiratory loading activates the geniohyoid (How *et al*., 2007). A recent single motor unit EMG study demonstrated that the geniohyoid has only minimal activity during quiet breathing of a healthy subject (Brown *et al*., 2011).

The geniohyoid is a muscle commonly investigated in anesthesiology in cases of residual paralysis after administration of neuromuscular blocking agents (D'Honneur *et al*., 1995, 1996). The geniohyoid has also been investigated with regard to postoperative obstructive apnea during recovery from general anesthesia (D'Honneur *et al*., 1999).

Neuromuscular changes or adaptations of the geniohyoid are known to be induced by nasal airway obstruction or altered oral sensations (Miller *et al*., 1984, 1985). The neoglottis created after a laryngectomy seems to be opened by the geniohyoid and closed by the inferior constrictor pharyngeus (Nishizawa *et al*., 2001). The neoglottis acts as an airway orifice as well as a digestive tract orifice.

Airway obstruction: obstructive sleep apnea. The obstructive sleep apnea (OSA) is characterized by repetitive symptoms of partial (shallow breathing) or complete apnea during sleep (Yu *et al*., 2017). Since brief arousal breaks the state of hypoxia or hypercarbia, patients usually suffer from fragmented and disturbed sleep (Olaithe *et al*., 2018). Generally, the position of hyoid bone is known to be associated with occurrence of OSA (Riha *et al*., 2005; Sakamoto *et al*., 2016). The dilator muscles of the upper airway have been proposed to be closely associated with obstructive sleep apnea. Reduction of geniohyoid muscle activity during sleep can cause pharyngeal airway collapse, though the relationship is complex and varies from individual to individual (Wiegand *et al*., 1990a,b). The dilatory effect of the geniohyoid and other upper airway muscles has been studied in awake humans by electrical stimulation (Schnall *et al*., 1995). Interestingly, the geniohyoid showed a high fatigue index in severe hypoxia though the muscle maintained its force output in mild hypoxia (Salmone & van Lunteren, 1991).

Magnetic resonance imaging has been used to measure geniohyoid muscle length for OSA diagnosis and research (Cosentini *et al*., 2004). In an MRI study, increased edema and fat content of the muscles has been suggested to be a pathogenetic cause of OSA (Schotland *et al*., 1996). The thickness of the geniohyoid was investigated in a submental ultrasonographic study of patients with OSA (Bilici *et al*., 2017). Mandibular advancement devices have an activating effect on the awake geniohyoid muscle (Johal *et al*., 2007). Modified mortised genioplasty was described for the treatment of OSA to maximize advancement of the geniohyoid (Hendler *et al*., 2001). Electromyostimulation therapy was reported to be effective, suggesting it can be used as a long-term or interval therapy (Ludwig, 2008). Hypoglossal nerve neurostimulation also showed promising results for the treatment of OSA, and a topographical map was suggested (Bassiri Gharb *et al*., 2015).

Voice. Because the geniohyoid is closely associated with respiration, it also plays a role in voice production by lowering or raising the larynx. The muscle assists the cricothyoid muscle in maximum elevation of the fundamental frequency of the voice (Sapir *et al*., 1981). In patients with occupational dysphonia, osteopathic myofascial

techniques have been found to affect the geniohyoid, resulting in lowering of the tonus (Marszalek *et al*., 2012).

Clinical implications

Surgery. When fracture occurs at the anterior region of the mandible, the fragments can be displaced by the elevator muscles, which can be counteracted simultaneously by the geniohyoid and digastric anterior muscle. The chance of including the geniohyoid was found to be relatively small during anterior submandibular subapical osteotomy in a cadaver study, while the genioglossus can be included with a large chance when the osteotomy is extended up to the canine region (Zhang *et al*., 1988). An inferior horizontal bone cut of approximately 5 mm and 11 mm above the menton was suggested for simultaneous advancement of the geniohyoid and genioglossus, and advancement of the genioglossus alone, respectively (Yi *et al*., 2004). A specially designed trephine system for genial bone advancement with a 78 % chance of capturing the geniohyoid was introduced (Hennessee & Miller, 2005). Generally, advancement of the geniohyoid and the anterior belly of the digastric muscle can produce the greatest amount of hyoid bone advancement (Kutzner *et al*., 2017). Several modifications have been reported for more accurate and reliable positioning (Merrick *et al*., 2007).

Meanwhile, paramedian mandibulotomy has been reported to have the advantage over median mandibulotomy that it minimizes osteotomy-related complications of the geniohyoid in oropharyngeal tumor resection and thus is more function-reserving (Dubner & Spiro, 1991; Pan *et al*., 2003; Dai *et al*., 2003; Apinhasmit *et al*., 2007) In fact, the geniohyoid is a frequently resected structure in oral cancer surgery to avoid recurrence (Steinhart & Kleinsasser, 1993).

Along with the digastric and mylohyoid, transection of the geniohyoid is considered for surgical correction of dysmorphic neck (Guyuron, 1992). Intramuscular hemangioma of the geniohyoid was once reported (Harar *et al*., 1997).

Cysts in the floor of the mouth. Dermoid cysts are developmental teratomas of a cystic nature that are believed to develop from epithelial debris enslavement in the midline region. There have been several case reports of midline dermoid cysts in the geniohyoid showing various features (Armstrong *et al*., 2006; Ikeda *et al*., 2007). Sometimes, these cysts contain hair (Jadwani *et al*., 2009). Intraoral surgical approach usually leads to better cosmetic and functional results, whereas an extraoral approach is necessary when the cyst exists under the geniohyoid (Longo *et al*., 2003). Interestingly, epidermoid cysts and thyroglossal duct cysts of the geniohyoid have also been reported, which are different entities to dermoid cysts (Tsirevelou *et al*., 2009; Sarmento *et al*., 2013; Mirza *et al*., 2014; Utumi *et al*., 2016) Interestingly, Kutaya gave the opinion that ultrasonography is more useful for preoperative diagnosis of dermoid cysts than MRI or computed tomography (Kutuya, 2009).

Miscellaneous. Use of botulinum toxin can lead to short-term muscular activity correction and has been suggested as a prophylaxis to prevent relapse after advancement of the mandible (Umstadt, 2002). Lingual cortical fracture followed by posterior displacement was reported as a unique complication after chin bone harvesting. The fragmented bone was pedicled to the geniohyoid with the geinoglosuss (Cordaro *et al*., 2004). Enlarged genial tubercles beyond the alveolar crest due to excessive resorption of the alveolar process was reported in a rare case (Jindal *et al*., 2015).

CONCLUSIONS

The literature on the geniohyoid was extensively reviewed in this narrative paper. The thin and paired geniohyoid muscles elevate and pull forward the hyoid bone when contracted. This action plays an essential role in swallowing and respiratory mechanisms. Thus, any problems during this process can result in great discomfort, and potentially even sudden death in aged or debilitated individuals. An understanding of the anatomic and clinical characteristics of this muscle is therefore critically important. This review should serve as a helpful reference to clinicians from various fields as well as scientists.

KIM, S.; JO, J. H.; SRI, L.; DHARMA, M. A. T. & PARK, Y. S. Músculo geniohioideo: anatomía e implicaciones clínicas en odontología. *Int. J. Morphol., 41(3)*:851-857, 2023.

RESUMEN: El músculo geniohioideo es uno de los músculos suprahioideos que surge de la espina mental inferior y se inserta en el hueso hioides. Son un par de músculo delgados y su acción principal es elevar y estirar el hueso hioides hacia arriba y hacia adelante. Su función es importante tanto en la deglución como en la respiración. Por lo tanto, este músculo ha sido ampliamente investigado, especialmente en el contexto de la disfagia y la apnea del sueño. Esta revisión trata de las características anatómicas generales, funciones principales y estados anormales del músculo geniohioideo, y las implicaciones clínicas de estos.

PALABRAS CLAVE: Músculo geniohioideo; Anatomía; Músculo suprahioideo; Apnea obstructiva del sueño.

REFERENCES

Apinhasmit, W.; Panmekiate, S.; Saengtipbovorn, S. & Ittatirut, S. Dimensions for midline and paramidline andibulotomy: A radiographic study in the dentate thai population. *J. Med. Assoc. Thai., 90(11)*:2377-82, 2007.

Armstrong, J. E.; Darling, M. R.; Bohay, R. N.; Cobb, G.; Lawen, D. & Daley, T. D. Trans-geniohyoid dermoid cyst: Considerations on a combined oral and dermal surgical approach and on histogenesis. *J. Oral Maxillofac. Surg., 64(12)*:1825-30, 2006.

Banneheka, S. Anatomy of the ansa cervicalis: Nerve fiber analysis. *Anat. Sci. Int., 83(2)*:61-7, 2008.

Barney, A.; Martelli, S.; Serrurier, A. & Steele, J. Articulatory capacity of neanderthals, a very recent and human-like fossil hominin. *Philos. Trans. R. Soc. Lond. B Biol. Sci., 367(1585)*:88-102, 2012.

Bassiri Gharb, B.; Tadisina, K. K.; Rampazzo, A.; Hashem, A. M.; Elbey, H.; Kwiecien, G. J.; Doumit, G.; Drake, R. L. & Papay, F. Microsurgical anatomy of the terminal hypoglossal nerve relevant for neurostimulation in obstructive sleep apnea. *Neuromodulation, 18(8)*:721-8, 2015.

Bilici, S.; Engin, A.; Ozgur, Y.; Ozlem Onerci, C.; Ahmet Gorkem, Y. & Aytul Hande, Y. Submental ultrasonographic parameters among patients with obstructive sleep apnea. *Otolaryngol. Head Neck Surg., 156(3)*:559-66, 2017.

Brouillette, R. T. & Thach, B. T. A neuromuscular mechanism maintaining extrathoracic airway patency. *J. Appl. Physiol. Respir. Environ. Exerc. Physiol., 46(4)*:772-9, 1979.

Brown, E. C.; Hudson, A. L.; Butler, J. E.; McKenzie, D. K.; Bilston, L. E. & Gandevia, S. C. Single motor unit recordings in human geniohyoid reveal minimal respiratory activity during quiet breathing. *J. Appl. Physiol. (1985), 110(4)*:1054-9, 2011.

Cordaro, L.; Rossini, C. & Mijiritsky, E. Fracture and displacement of lingual cortical plate of mandibular symphysis following bone harvesting: Case report. *Implant Dent., 13(3)*:202-6, 2004.

Cosentini, T.; Le Donne, R.; Mancini, D. & Colavita, N. Magnetic resonance imaging of the upper airway in obstructive sleep apnea. *Radiol. Med., 108(4)*:404-16, 2004.

Cunningham, D. P. & Basmajian, J. V. Electromyography of genioglossus and geniohyoid muscles during deglutition. *Anat. Rec., 165(3)*:401-9, 1969.

D'Honneur, G.; Combes, X.; Leroux, B. & Duvaldestin, P. Postoperative obstructive apnea. *Anesth. Analg., 89(3)*:762-7, 1999.

D'Honneur, G.; Guignard, B.; Slavov, V.; Ruggier, R. & Duvaldestin, P. Comparison of the neuromuscular blocking effect of atracurium and vecuronium on the adductor pollicis and the geniohyoid muscle in humans. *Anesthesiology, 82(3)*:649-54, 1995.

D'Honneur, G.; Slavov, V.; Merle, J. C.; Kirov, K.; Rimaniol, J. M.; Sperry, L. & Duvaldestin, P. Comparison of the effects of mivacurium on the diaphragm and geniohyoid muscles. *Br. J. Anaesth., 77(6)*:716-9, 1996.

Dai, T. S.; Hao, S. P.; Chang, K. P.; Pan, W. L.; Yeh, H. C. & Tsang, N. M. Complications of mandibulotomy: Midline versus paramidline. *Otolaryngol. Head Neck Surg., 128(1)*:137-41, 2003.

Dantas, R. O. & Dodds, W. J. Effect of bolus volume and consistency on swallow-induced submental and infrahyoid electromyographic activity. *Braz. J. Med. Biol. Res., 23(1)*:37-44, 1990.

Davis, W. H.; Sailer, H. & Poswillo, D. A pilot study on the effect of alteration of the suprahyoid muscles on the growth of the marmoset monkey. *Int. J. Oral Surg., 10(Suppl. 1)*:292-8, 1981.

Dubner, S. & Spiro, R. H. Median mandibulotomy: A critical assessment. *Head Neck, 13(5)*:389-93, 1991.

Felton, S. M.; Gaige, T. A.; Benner, T.; Wang, R.; Reese, T. G.; Wedeen, V. J. & Gilbert, R. J. Associating the mesoscale fiber organization of the tongue with local strain rate during swallowing. *J. Biomech., 41(8)*:1782-9, 2008.

Feng, X.; Cartwright, M. S.; Walker, F. O.; Bargoil, J. H.; Hu, Y. & Butler, S. G. Ultrasonographic evaluation of geniohyoid muscle and hyoid bone during swallowing in young adults. *Laryngoscope, 125(8)*:1886-91, 2015.

Feng, X.; Todd, T.; Lintzenich, C. R.; Ding, J.; Carr, J. J.; Ge, Y.; Browne, J. D.; Kritchevsky, S. B. & Butler, S. G. Aging-related geniohyoid muscle atrophy is related to aspiration status in healthy older adults. *J. Gerontol. A Biol. Sci. Med. Sci., 68(7)*:853-60, 2013.

Gervasio, A.; D'Orta, G.; Mujahed, I. & Biasio, A. Sonographic anatomy of the neck: The suprahyoid region. *J. Ultrasound, 14(3)*:130-5, 2011.

Guilleminault, C.; Hill, M. H.; Simmons, F. B.; Powell, N.; Riley, R. & Stoohs, R. Passive constriction of the upper airway during central apneas: fiberoptic and EMG investigations. *Respir. Physiol., 108(1)*:11-22, 1997.

Guyuron, B. Problem neck, hyoid bone, and submental myotomy. *Plast. Reconstr. Surg., 90(5)*:830-7; discussion 8-40, 1992.

Harar, R. P.; Kalan, A.; Brown, C. L. & Kenyon, G. S. An unique tumour of the geniohyoid muscle: An intramuscular haemangioma. *J. Laryngol. Otol., 111(8)*:769-71, 1997.

Hendler, B.; Silverstein, K.; Giannakopoulos, H. & Costello, B. J. Mortised genioplasty in the treatment of obstructive sleep apnea: An historical perspective and modification of design. *Sleep Breath, 5(4)*:173-80, 2001.

Hennessee, J. & Miller, F. R. Anatomic analysis of the genial bone advancement trephine system's effectiveness at capturing the genial tubercle and its muscular attachments. *Otolaryngol. Head Neck Surg., 133(2)*:229-33, 2005.

Hirano, M.; Kuroiwa, Y.; Tanaka, S.; Matsuoka, H.; Sato, K. & Yoshida, T. Dysphagia following various degrees of surgical resection for oral cancer. *Ann. Otol. Rhinol. Laryngol., 101(2 Pt. 1)*:138-41, 1992.

How, S. C.; McConnell, A. K.; Taylor, B. J. & Romer, L. M. Acute and chronic responses of the upper airway to inspiratory loading in healthy awake humans: An mri study. *Respir. Physiol. Neurobiol., 157(2-3)*:270-80, 2007.

Hughes, T. & Watts, C. R. Effects of 2 resistive exercises on electrophysiological measures of submandibular muscle activity. *Arch. Phys. Med. Rehabil., 97(9)*:1552-7, 2016.

Ikeda, K.; Koseki, T.; Maehara, M.; Ohmura, N.; Kurokawa, H.; Shimizutani, K. & Sawada, S. Hourglass-shaped sublingual dermoid cyst: Mri features. *Radiat. Med., 25(6)*:306-8, 2007.

Inokuchi, H.; Gonzalez-Fernandez, M.; Matsuo, K.; Brodsky, M. B.; Yoda, M.; Taniguchi, H.; Okazaki, H.; Hiraoka, T. & Palmer, J. B. Electromyography of swallowing with fine wire intramuscular electrodes in healthy human: Activation sequence of selected hyoid muscles. *Dysphagia, 29(6)*:713-21, 2014.

Inokuchi, H.; Gonzalez-Fernandez, M.; Matsuo, K.; Brodsky, M. B.; Yoda, M.; Taniguchi, H.; Okazaki, H.; Hiraoka, T. & Palmer, J. B. Electromyography of swallowing with fine wire intramuscular electrodes in healthy human: Amplitude difference of selected hyoid muscles. *Dysphagia 31(1)*:33-40, 2016.

Jadwani, S.; Misra, B.; Kallianpur, S. & Bansod, S. Dermoid cyst of the floor of the mouth with abundant hair: A case report. *J. Maxillofac. Oral Surg., 8(4)*:388-9, 2009.

Jindal, G.; Jindal, S.; Sharma, P. & Singla, A. Rare enlargement of genial tubercles and its management: A case report. *J. Clin. Diagn. Res., 9(11)*:ZD23-4, 2015.

Johal, A.; Gill, G.; Ferman, A. & McLaughlin, K. The effect of mandibular advancement appliances on awake upper airway and masticatory muscle activity in patients with obstructive sleep apnoea. *Clin. Physiol. Funct. Imaging, 27(1)*:47-53, 2007.

Kaneko, S.; Iida, R. H.; Suga, T.; Morito, M. & Yamane, A. Age-related changes in rat genioglossus, geniohyoid and masseter muscles. *Gerodontology, 31(1)*:56-62, 2014.

Kjaer, I. Mandibular movements during elevation and fusion of palatal shelves evaluated from the course of meckel's cartilage. *J. Craniofac. Genet. Dev. Biol., 17(2)*:80-5, 1997.

Konrad, H. R.; Rattenborg, C. C.; Kain, M. L.; Barton, M. D.; Logan, W. J. & Holaday, D. A. Opening and closing mechanisms of the larynx. *Otolaryngol. Head Neck Surg., 92(4)*:402-5, 1984.

Korfage, J. A.; Brugman, P. & Van Eijden, T. M. Intermuscular and intramuscular differences in myosin heavy chain composition of the human masticatory muscles. *J. Neurol. Sci., 178(2)*:95-106, 2000.

Kumar, R.; Madanikia, S.; Starmer, H.; Yang, W.; Murano, E.; Alcorn, S.; McNutt, T.; Le, Y. & Quon, H. Radiation dose to the floor of mouth muscles predicts swallowing complications following chemoradiation in oropharyngeal squamous cell carcinoma. *Oral Oncol., 50(1)*:65-70, 2014.

Kurihara, K. & Sato, I. Distribution of tenascin-c and -x, and soft x-ray analysis of the mandibular symphysis during mandible formation in the human fetus. *Okajimas Folia Anat. Jpn., 81(2-3)*:49-55, 2004.

Kurihara, Y.; Watanabe, K.; Yang, Y. & Tanaka, H. Construction of age model for the evaluation of swallowing function using photo sensors. *IEEE Trans. Neural. Syst. Rehabil. Eng., 18(5)*:515-22, 2010.

Kutuya, N. A case of dermoid cyst of the floor of the mouth: Ultrasonography was more useful than computed tomography and magnetic resonance imaging in the preoperative diagnosis. *J. Med. Ultrason. (2001), 36(1)*:27-31, 2009.

Kutzner, E. A.; Miot, C.; Liu, Y.; Renk, E.; Park, J. S. & Inman, J. C. Effect of genioglossus, geniohyoid, and digastric advancement on tongue base and hyoid position. *Laryngoscope, 127(8)*:1938-42, 2017.

Longo, F.; Maremonti, P.; Mangone, G. M.; De Maria, G. & Califano, L. Midline (dermoid) cysts of the floor of the mouth: Report of 16 cases and review of surgical techniques. *Plast. Reconstr. Surg., 112(6)*:1560-5, 2003.

Ludwig, A. Results of electromyostimulation therapy in obstructive sleep apnea. *Artif. Organs, 32(8)*:655-8, 2008.

Luo, Q.; Douglas, M.; Burkholder, T. & Sokoloff, A. J. Absence of developmental and unconventional myosin heavy chain in human suprahyoid muscles. *Muscle Nerve, 49(4)*:534-44, 2014.

Marszalek, S.; Niebudek-Bogusz, E.; Woznicka, E.; Malinska, J.; Golusinski, W. & Sliwinska-Kowalska, M. Assessment of the influence of osteopathic myofascial techniques on normalization of the vocal tract functions in patients with occupational dysphonia. *Int. J. Occup. Med. Environ. Health, 25(3)*:225-35, 2012.

Merrick, G. D.; Morrison, R. W.; Gallagher, J. R.; Devine, J. C. & Farrow, A. Pedicled genial osteotomy modification of the mandibular release access operation for access to the back of the tongue. *Br. J. Oral Maxillofac. Surg., 45(6*):490-2, 2007.

Miller, A. J.; Vargervik, K. & Chierici, G. Experimentally induced neuromuscular changes during and after nasal airway obstruction. *Am. J. Orthod., 85(5)*:385-92, 1984.

Miller, A. J.; Vargervik, K. & Phillips, D. Neuromuscular adaptation of craniofacial muscles to altered oral sensation. *Am. J. Orthod., 87(4)*:303-10, 1985.

Mirza, S.; Fadl, S.; Napaki, S. & Abualruz, A. Case report of complicated epidermoid cyst of the floor of the mouth: Radiology-histopathology correlation. *Qatar Med. J., 2014(1)*:12-6, 2014.

Mitchenok, V. I. Development of neuromuscular spindles in the muscles of the floor of the human oral cavity during intrauterine development. *Arkh. Anat. Gistol. Embriol., 76(4)*:13-20, 1979.

Nagaoka, K. & Tanne, K. Activities of the muscles involved in swallowing in patients with cleft lip and palate. *Dysphagia, 22(2)*:140-4, 2007.

Nishizawa, N.; Mesuda, Y.; Kobashi, M.; Takahashi, M. & Inuyama, Y. Identification of the opener and closer of the pharyngoesophagus in laryngectomees. *Auris Nasus Larynx, 28 Suppl.*:S63-9, 2001.

Okada, T.; Aoyagi, Y.; Inamoto, Y.; Saitoh, E.; Kagaya, H.; Shibata, S.; Ota, K. & Ueda, K. Dynamic change in hyoid muscle length associated with trajectory of hyoid bone during swallowing: Analysis using 320-row area detector computed tomography. *J. Appl. Physiol. (1985), 115(8)*:1138-45, 2013.

Olaithe, M.; Bucks, R. S.; Hillman, D. R. & Eastwood, P. R. Cognitive deficits in obstructive sleep apnea: Insights from a meta-review and comparison with deficits observed in copd, insomnia, and sleep deprivation. *Sleep Med. Rev., 38*:39-49, 2018.

Palmer, J. B.; Rudin, N. J.; Lara, G. & Crompton, A. W. Coordination of mastication and swallowing. *Dysphagia, 7(4)*:187-200, 1992.

Palmer, P. M.; Jaffe, D. M.; McCulloch, T. M.; Finnegan, E. M.; Van Daele, D. J. & Luschei, E. S. Quantitative contributions of the muscles of the tongue, floor-of-mouth, jaw, and velum to tongue-to-palate pressure generation. *J. Speech Lang Hear. Res., 51(4)*:828-35, 2008.

Palmer, P. M.; Luschei, E. S.; Jaffe, D. & McCulloch, T. M. Contributions of individual muscles to the submental surface electromyogram during swallowing. *J. Speech Lang. Hear. Res., 42(6)*:1378-91, 1999.

Palmer, P. M.; McCulloch, T. M.; Jaffe, D. & Neel, A. T. Effects of a sour bolus on the intramuscular electromyographic (EMG) activity of muscles in the submental region. *Dysphagia, 20(3)*:210-7, 2005.

Pan, W. L.; Hao, S. P.; Lin, Y. S.; Chang, K. P. & Su, J. L. The anatomical basis for mandibulotomy: Midline versus paramidline. *Laryngoscope, 113(2)*:377-80, 2003.

Pearson Jr., W. G.; Hindson, D. F.; Langmore, S. E. & Zumwalt, A. C. Evaluating swallowing muscles essential for hyolaryngeal elevation by using muscle functional magnetic resonance imaging. *Int. J. Radiat. Oncol. Biol. Phys., 85(3)*:735-40, 2013.

Pearson Jr., W. G.; Langmore, S. E. & Zumwalt, A. C. Evaluating the structural properties of suprahyoid muscles and their potential for moving the hyoid. *Dysphagia, 26(4)*:345-51, 2011.

Riha, R. L.; Brander, P.; Vennelle, M. & Douglas, N. J. A cephalometric comparison of patients with the sleep apnea/hypopnea syndrome and their siblings. *Sleep, 28(3)*:315-20, 2005.

Sakamoto, Y.; Yanamoto, S.; Rokutanda, S.; Naruse, T.; Imayama, N.; Hashimoto, M.; Nakamura, A.; Yoshida, N.; Tanoue, N.; Ayuse, T.; *et al*. Predictors of obstructive sleep apnoea-hypopnea severity and oral appliance therapy efficacy by using lateral cephalometric analysis. *J. Oral Rehabil., 43(9)*:649-55, 2016.

Salmone, R. J. & van Lunteren, E. Effects of hypoxia and hypercapnia on geniohyoid contractility and endurance. *J. Appl. Physiol. (1985), 71(2)*:709-15, 1991.

Sapir, S.; Campbell, C. & Larson, C. Effect of geniohyoid, cricothyroid and sternothyroid muscle stimulation on voice fundamental frequency of electrically elicited phonation in rhesus macaque. *Laryngoscope, 91(3)*:457-68, 1981.

Sarmento, D. J.; Araujo, P. P.; da Silveira, E. J. & Germano, A. R. Double thyroglossal duct cyst involving the floor of the mouth and sublingual gland region. *J. Craniofac. Surg., 24(2)*:e116-9, 2013.

Schnall, R. P.; Pillar, G.; Kelsen, S. G. & Oliven, A. Dilatory effects of upper airway muscle contraction induced by electrical stimulation in awake humans. *J. Appl. Physiol. (1985), 78(5)*:1950-6, 1995.

Schotland, H. M.; Insko, E. K.; Panckeri, K. A.; Leigh, J. S.; Pack, A. I. & Hendricks, J. C. Quantitative magnetic resonance imaging of upper airways musculature in an animal model of sleep apnea. *J. Appl. Physiol. (1985), 81(3)*:1339-46, 1996.

Spiro, J.; Rendell, J. K. & Gay, T. Activation and coordination patterns of the suprahyoid muscles during swallowing. *Laryngoscope, 104(11 Pt. 1)*:1376-82, 1994.

Sporns, P. B.; Muhle, P.; Hanning, U.; Suntrup-Krueger, S.; Schwindt, W.; Eversmann, J.; Warnecke, T.; Wirth, R.; Zimmer, S. & Dziewas, R. Atrophy of swallowing muscles is associated with severity of dysphagia and age in patients with acute stroke. *J. Am. Med. Dir. Assoc., 18(7)*:635.e1-635.e7, 2017.

Standring, S. *Gray's Anatomy: The Anatomical Basis of Clinical Practice.* Amsterdam, Elsevier, 2016.

Starmer, H. M.; Quon, H.; Kumar, R.; Alcorn, S.; Murano, E.; Jones, B. & Humbert, I. The effect of radiation dose on swallowing: Evaluation of aspiration and kinematics. *Dysphagia, 30(4)*:430-7, 2015.

Steinhart, H. & Kleinsasser, O. Growth and spread of squamous cell carcinoma of the floor of the mouth. *Eur. Arch. Otorhinolaryngol., 250(6)*:358-61, 1993.

Takahashi, S.; Ono, T.; Ishiwata, Y. & Kuroda, T. Breathing modes, body positions, and suprahyoid muscle activity. *J. Orthod., 29(4)*:307-13; discussion 279, 2002.

Toyama, K.; Matsumoto, S.; Kurasawa, M.; Setoguchi, H.; Noma, T.; Takenaka, K.; Soeda, A.; Shimodozono, M. & Kawahira, K. Novel neuromuscular electrical stimulation system for treatment of dysphagia after brain injury. *Neurol. Med. Chir. (Tokyo), 54(7)*:521-8, 2014.

Tsirevelou, P.; Papamanthos, M.; Chlopsidis, P.; Zourou, I. & Skoulakis, C. Epidermoid cyst of the floor of the mouth: Two case reports. *Cases J., 2*:9360, 2009.

Umstadt, H. E. Botulinum toxin in oromaxillofacial surgery. *Mund. Kiefer Gesichtschir., 6(4)*:249-60, 2002.

Utumi, E. R.; Araujo, J. P.; Pedron, I. G.; Yonezaki, F.; Machado, G. G. & Rocha, A. C. Extensive epidermoid cyst of the submental region. *Autops. Case Rep., 6(2)*:51-4, 2016.

van Bruggen, H. W.; Van Den Engel-Hoek, L.; Steenks, M. H.; Bronkhorst, E. M.; Creugers, N. H.; de Groot, I. J. & Kalaykova, S. I. Reduced mandibular range of motion in duchenne muscular dystrophy: Predictive factors. *J. Oral Rehabil., 42(6)*:430-8, 2015.

van de Graaff, W. B.; Gottfried, S. B.; Mitra, J.; van Lunteren, E.; Cherniack, N. S. & Strohl, K. P. Respiratory function of hyoid muscles and hyoid arch. *J. Appl. Physiol. Respir. Environ. Exerc. Physiol., 57(1)*:197-204, 1984.

van den Engel-Hoek, L.; Erasmus, C. E.; Hendriks, J. C.; Geurts, A. C.; Klein, W. M.; Pillen, S.; Sie, L. T.; de Swart, B. J. & de Groot, I. J. Oral muscles are progressively affected in duchenne muscular dystrophy: Implications for dysphagia treatment. *J. Neurol., 260(5)*:1295-303, 2013.

Van Eijden, T. M.; Korfage, J. A. & Brugman, P. Architecture of the human jaw-closing and jaw-opening muscles. *Anat. Rec., 248(3)*:464-74, 1997.

Vitti, M. & Basmajian, J. V. Integrated actions of masticatory muscles: Simultaneous emg from eight intramuscular electrodes. *Anat. Rec., 187(2)*:173-89, 1977.

Wakabayashi, H. Presbyphagia and sarcopenic dysphagia: Association between aging, sarcopenia, and deglutition disorders. *J. Frailty Aging, 3(2)*:97-103, 2014.

Watkin, K. L.; Diouf, I.; Gallagher, T. M.; Logemann, J. A.; Rademaker, A. W. & Ettema, S. L. Ultrasonic quantification of geniohyoid cross-sectional area and tissue composition: A preliminary study of age and radiation effects. *Head Neck, 23(6)*:467-74, 2001.

Watts, C. R. Measurement of hyolaryngeal muscle activation using surface electromyography for comparison of two rehabilitative dysphagia exercises. *Arch. Phys. Med. Rehabil., 94(12)*:2542-8, 2013.

Wiegand, D. A.; Latz, B.; Zwillich, C. W. & Wiegand, L. Geniohyoid muscle activity in normal men during wakefulness and sleep. *J. Appl. Physiol. (1985), 69(4)*:1262-9, 1990a.

Wiegand, D. A.; Latz, B.; Zwillich, C. W. & Wiegand, L. Upper airway resistance and geniohyoid muscle activity in normal men during wakefulness and sleep. *J. Appl. Physiol. (1985), 69(4)*:1252-61, 1990b.

Williams, R. B.; Wallace, K. L.; Ali, G. N. & Cook, I. J. Biomechanics of failed deglutitive upper esophageal sphincter relaxation in neurogenic dysphagia. *Am. J. Physiol. Gastrointest. Liver Physiol., 283(1)*:G16-26, 2002.

Wyganowska-Swiatkowska, M.; Kawala, B.; Kozanecka, A. & Kurlej, W. Observations on muscular attachments to human developing mandible. *Adv. Clin. Exp. Med., 21(4)*:447-54, 2012.

Yabunaka, K.; Konishi, H.; Nakagami, G.; Sanada, H.; Iizaka, S.; Sanada, S. & Ohue, M. Ultrasonographic evaluation of geniohyoid muscle movement during swallowing: A study on healthy adults of various ages. *Radiol. Phys. Technol., 5(1)*:34-9, 2012.

Yi, H.; Yin, S.; Guan, J.; Lu, W.; Yu, D. & Huang, Y. Applied anatomic study for genioglossus advancement. *Lin Chuang Er Bi Yan Hou Ke Za Zhi 18(12)*:719-22, 2004.

Yu, J.; Zhou, Z.; McEvoy, R. D.; Anderson, C. S.; Rodgers, A.; Perkovic, V. & Neal, B. Association of positive airway pressure with cardiovascular events and death in adults with sleep apnea: A systematic review and meta-analysis. *JAMA, 318(2)*:156-66, 2017.

Zhang, X.; Bell, W. H. & Washko, P. W. Relationship of mandibular anterior tooth apices to genial muscle attachments. *Oral Surg. Oral Med. Oral Pathol., 65(6)*:653-6, 1988.

Corresponding author:
Young-Seok Park, BS, DDS, MSD, PhD
Professor
Department of Oral Anatomy
School of Dentistry
Seoul National University and Dental Research Institute
101 Daehak-ro
Jongno-gu, Seoul
KOREA

E-mail: ayoayo7@snu.ac.kr