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Ciclo XXXI

ELECTROMYOGRAPHIC EVALUATION OF THE EFFICACY OF MYOFUNCTIONAL THERAPY IN PATIENTS WITH ATYPICAL SWALLOWING

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Anno Accademico 2017 / 2018

A mia madre e mio padre

la mia storia, la mia forza.

ABSTRACT

Objectives:

Swallowing is a complex physiologic function developing mostly in the first years of life. After 6 years old, if a complete maturation is not achieved, swallowing persists as “atypical swallowing” (AS). The therapy provided to re-educate this dysfunction is based on the myofunctional treatment (MFT). The aim of this study was to detect functional (electromyographical) and clinical (orofacial muscular evaluation with score (OMEs) protocol) effects of MFT in a group of patients with AS so to highlight any differences in the muscular activation pattern and muscular orofacial behavior.

Materials and Methods:

20 adolescents and young adults (4 males and 16 females, mean age 17.85 years, SD 4.80) with AS were selected for this study. Standardized surface electromyographic (ssEMG) analysis was performed by the same operator to detect the activity of masseter (MM), temporalis (TA) and submental (SM) muscles before (T1) and after (T2) the logopedic treatment. The MFT was performed by the same speech therapist according to the Garliner method for a period of 10 weeks. The speech therapist completed the OMEs protocol at T1 and T2. A Student-t test for unpaired data was carried out to detect differences between T1 and T2 for both ssEMG and OMEs data. Then, a 3-way ANOVA variance test was performed to detect any differences between the different couples of muscles at T1 and T2. In addition, ssEMG data at T1 and T2 were compared with ssEMG obtained in a control (C) group of 18 adolescents and young adult patients (8 males and 10 females, mean age 17.28 years, SD 2.56) with bimolar class 1 and without AS.

Results:

From the starting group of 20 patients, 15 patients completed the MFT (4 males and 11 females, mean age 17.72 years, SD 5.21). At T2, AS patients showed a significantly shorter duration of activation for each couple of muscles and for the whole duration act of swallowing ($p<.0001$) as well as higher intensity of the SM activity ($p<.01$) than at T1. Within the AS group, at T1 the masticatory muscles (MM and TA) showed lower duration of activation ($p<.05$) and lower intensity of the spike ($p<.0001$) than SM. At T2, masticatory muscles also showed lower values for the activation index (IMPACT) ($p<.0001$) and for the spike position ($p<.01$) than SM. At T2. The OMEs protocol showed a significant increase for the total evaluation ($p<.01$) and specifically for appearance and posture ($p<.01$) and functions ($p<.0001$). If compared to C group, the AS group at T1 showed significantly longer duration of activation for each couple of muscles and for the whole duration act of swallowing ($p<.0001$) as well as lower intensity of the SM activity ($p<.05$) than controls. At T2 all the ssEMG data detected in AS patients showed a general improvement and moved toward the control values. The differences between AS and C groups about the duration of activation of each couple of muscles and the whole duration act of swallowing were lower at T2 than at T1 even if still significantly different from C ones ($p<.0001$).

Conclusion:

MFT confirms itself as an effective method in the treatment of AS dysfunction permitting a shortening of the muscular activation pattern, an increase in SM activity and a general improvement in the orofacial muscular behavior making them closer to the data obtained in controls. ssEMG and OMEs protocol represent valid and useful methods in the analysis of the swallowing function and in establishing the effects of the MFT

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1. INTRODUCTION

1.1 Atypical Swallowing: a common and unclear dysfunction

Swallowing has been defined as a complex physiological act that occurs thousands of times per day and is fundamental for the development of the stomatognathic apparatus[1,2].

A close relation between form and function of the oral environment has been demonstrated in previous studies[3–7]. It has been hypothesized that both alteration in size[8–12], function[13–15] and posture[1,16,17] of the tongue can affect not only the position of the teeth[18,19] but also the oral development, oral functions thus resulting in malocclusion[1].

Swallowing is predominantly regulated by reflex. The central pattern generator (CPG) neurons are located at the telencephalic level. These neurons receive input from the cortex and from oral, pharyngeal and laryngeal sensory afferences and then coordinate the swallowing motor sequence involving around 20 muscles innervated by the V, VII, IX, X and XII couple of cranial nerves[20]. The whole complex swallowing act can be subdivided at least into three phases: oral, pharyngeal and oesophageal[21]. Great interest has always been given in analyzing swallowing and particularly its first stage[22–26]. However, scientific data regarding this complex function are still insufficient. Most of the human neuromuscular circuits involved during swallowing are still unknown[27] such as the regulation of the position of the tongue which is probably connected to the proprioception function of tongues' intrinsic muscles. These muscles seem to be coordinated by sensitive fibers coming from the upper cervical nerve and delivered by the hypoglossal nerve (XII)[28,29].

In the early childhood, swallowing is characterized by a lack of activation of the masticatory muscles and by a major activity of the orbicularis muscle with the interposition of the tongue between the alveolar ridges of the upper and lower incisors. In this way a negative intraoral pressure is provided, and the suction effect and the deglutition are allowed[20]. In continuity with the last fetal period this kind of swallowing is mainly reflex and characterized by peristaltic muscular contractions, similar to the ones observed in the gut[20,30,31]. For this reason, in this period, authors talk about "visceral swallowing", also known as "infantile swallowing".[32,33]

Normally, from six months to six years of age the visceral swallowing pattern changes gradually. At 6 months of age a primitive swallowing-breathing coordination appears[34], then between 6 and 24 months the infant starts to ingest solid and semi-solid foods, the oral phase of swallowing develops and most of the oral reflexes stop[35], finally between 2 and 6 years old mastication function is improved[36,37], and the characteristic tongue thrust of the infantile swallowing is slowly stopped[1,38]. The maturation of a more conscious and voluntary swallowing action is responsible to the change from infantile to adult or somatic swallowing. If this maturation is not achieved, the infantile swallowing persists as "atypical swallowing"(AS), and after the sixth year of life it's considered a dysfunction[1].

The etiopatogeny of AS seems to be multifactorial, in fact environmental and hereditary factors, oral and allergic diseases could be involved in his onset[20,32,39–41].

According to Proffit the incidence of AS is about 50 percent at 5 years old, it decreases significantly in early mixed dentition until 38% at 6 years and still decreases when second dentition is completed at 30% but persists in adults in about 15% of subjects suggesting that functional traits change during growth and benefit from the best occlusal stability achieved at the end of the second dentition[1,40,42].

The treatment modality provided to correct AS can be passive (orthopedic/orthodontic) or active (myofunctional therapy-MFT). According to a recent review the biunique causal relation between AS and malocclusion suggests a multidisciplinary therapeutic approach, orthopedic/orthodontic and myofunctional, to temporarily solve both problems. An early diagnosis and a prompt intervention have a significantly positive influence on the therapy outcome[43], which is even higher considering the conclusion of an another recent study that highlighted the effects of tongue thrust over time on the alveolar and skeletal developments.

Unfortunately, a standardized protocol that can quantitatively detect the efficacy of MFT on muscular behavior is still lacking. But recently a standardized surface electromyographic (ssEMG) protocol has been performed[25] and preliminary data about the activity of the muscles involved during saliva swallowing in normal subjects has been detected.[26]

Analyzing the activity of the masticatory muscles involved during swallowing is a fundamental step in allowing a correct definition of the diagnosis of the atypical swallowing, in establishing a better prognosis and evaluating the effects of a therapy over time.

1.2 Physiology of swallowing

The digestive system transports food internally from the oral environment to a tissue interface for nutrients to reach cellular components of the biological system. The passage of the bolus from the mouth to the esophagus requires the interaction of both the digestive and respiratory tracts, with swallowing providing the propulsion of the food from the oral cavity into the stomach, as well as providing a protective reflex for the upper respiratory tract[44]. Swallowing is a complex sensorimotor behavior involving the coordinated contraction and inhibition of the musculature located around the mouth and at the tongue, larynx, pharynx and esophagus bilaterally[27]. It has been stated that swallowing is subdivided into three phases: oral, pharyngeal, and esophageal. This conventional division of the human swallowing is usually ascribed to Magendie (1825)[45]. Swallowing, however, also been described in two stages i.e. the buccopharyngeal (or oropharyngeal) and esophageal stages[46]. The 3 phases of swallowing are probably related to their innervation pattern: the oral phase is often accepted as voluntary, while the pharyngeal phase is considered a reflex response and the esophageal phase is mainly under dual control of the somatic and autonomic nervous systems[45]. Since the oral and the pharyngeal phases are anatomically and functionally linked, an oropharyngeal phase will be considered. In fact, oral, pharyngeal and laryngeal muscles co-work throughout the whole task.

1.2.1 Oropharyngeal phase of swallowing

The duration of the whole oropharyngeal sequence is found to be in the range of 0.6–1 s and it's remarkably constant in all the mammals studied, including humans[46]. The oral moment of swallowing is mainly voluntary and highly variable in duration depending upon taste, environment, hunger, motivation and consciousness for the human subject. Its primary function is the movement of the tongue, pressing the bolus against the hard palate and initiating the movement of the bolus to the posterior part of the tongue and toward the oropharynx. The submental muscles (floor of the mouth) are particularly important to elevate the tongue, especially for solid bolus. In this stage, the contraction of the lips and cheek muscles (i.e. orbicularis oris and buccinator muscles) are crucial to prevent the escape of solid or liquid from the oral cavity (activation of the VII cranial nerve)[27]. After the mastication of a solid bolus, or the intake of a liquid, the dorsal portion of the tongue forms a spoon-shaped depression in the anterior midline. The anterior half of the tongue is then pressed against the maxillary alveolar ridge and the anterior part of the hard palate in a rapid sequence; moving the bolus posteriorly on the root of the tongue toward the pillars of the fauces[44]. This stage is ended by the triggering of the pharyngeal phase of swallowing. The nature of the triggering of the pharyngeal phase of swallowing is not clearly known. As it will be largely explained the afferent fibers involved in the initiation of swallowing are those running within the trigeminal nerve, the glossopharyngeal nerve and the vagus nerve, especially its superior laryngeal branch. In healthy human subjects, it is evident that there is usually a gradual accumulation of prepared food on the posterior surface of tongue and this solid food reaches the glosso epiglottic vallecula before the initiation of the swallowing. In a small volume swallow (1–2 ml) such as saliva, there is no oral preparation and the oral and pharyngeal stages occur in sequence. In contrast, when taking a large volume liquid bolus, the oral and pharyngeal stages overlap with each other, occurring simultaneously. The size of the bolus does not alter the sequence of events during oropharyngeal swallowing but modulates the timing of each phase of the swallowing. As the bolus size increases (1–20 ml), the pharyngeal transit time increases, as it does laryngeal closure. Although the site, timing and intensity of the oropharyngeal sensory input may vary between different bolus and between healthy subjects and patients with sensory impairment, once swallowing is initiated, the cascade of the sequential muscle activation does not essentially alter from the perioral muscles downward. This is one of the lines of evidence supporting the existence of a central pattern generator (CPG) for human swallowing wich will be discussed later[27]. The oral stage is subjected to marked inter-individual variability, whereas the pharyngeal stage is generally consistent[44]. When the movement of the bolus from the oral cavity to the pharyngeal spaces triggers the swallowing reflex or response, the following physiological events occur in rapid overlapping sequence. These events are as follows[27]:

The nasal, laryngeal and tracheal airways are protected by several "reflex" events including the closure of the velopharyngeal isthmus by the palate, laryngeal elevation and suspension by suprahyoid/submental muscles and closure of the larynx by laryngeal muscles of the vocal folds and epiglottis.

Laryngeal elevation is a vital component of the airway protection as this action does not only facilitate closure of the vestibule but also repositioning of the larynx anterosuperiorly under the tongue base. All swallows take place somewhere between late inspiration and late expiration, and there is always an apneic period during the pharyngeal phase of swallowing.

The tongue thrusts posteriorly to push the bolus throughout the pharynx and into the esophagus (XII cranial nerve). A sequential wave of contraction of the pharyngeal constrictor muscles (X cranial nerve) clears any remaining material into the esophagus. The main propulsive force acting on the bolus is thus, provided by the posterior movement of the tongue. The pharyngeal contraction seems to be minimal in relation to bolus propulsion, although it facilitates subsequent pharyngeal clearance in association with a profound shortening of the pharynx. Simultaneously the larynx rises, and it is pulled under the root of the tongue and the epiglottis folds down over the laryngeal opening. During this phase of pharyngeal constriction, the epiglottis tips inferoposteriorly and the true and false vocal cords protect the laryngeal vestibule by constricting the laryngeal aperture. Thus, the epiglottis facilitates passage of the bolus through the piriform fossae and into the esophagus[44].

The upper esophageal sphincter (UES) relaxes and opens for the bolus transport into the esophagus. The UES consists primarily of the tonically contracting striated cricopharyngeus muscle (CP). During a swallowing, this muscle relaxes and is opened, and the sphincter is pulled upon anteriorly by the contraction of the suprahyoid/ submental muscle groups. Then the pharyngeal phase of swallowing is completed and the UES closes until the next swallowing. The cessation of tonic activity of the CP muscle is likely believed to be due to a neural inhibition, possibly originating from the CPG at the medullary level.

It is believed that the maxillary and mandibular teeth usually make contact during swallowing. This tooth contact is considered to stabilize the mandible while the hyoid and larynx execute superior-anterior movements[44]. Nevertheless, this issue is still controversial because tooth contact, lip and tongue movements, vary considerably between patients.

1.2.2 The esophageal phase of swallowing

In comparison with the extraordinary complexity and rapidity of the oropharyngeal phase, the esophageal phase of swallowing is simpler and slower. It consists of a peristaltic wave of contraction of the striated and smooth muscles, which propagates to the stomach. The peristaltic contraction moves from the proximal to the distal part of the esophagus at a speed that may show a fairly high degree of variability, depending on the species and the nature of the muscles, i.e., on whether an esophagus is composed of striated muscle alone or of both striated and smooth muscle[46] (Figure 1.1). This peristaltic sequence of the esophagus during swallowing, termed primary peristalsis, is distinct from secondary peristalsis, which is initiated by distension as a bolus is placed directly within the esophagus[44]. Secondary peristalsis occurs in response to stimulation of sensory receptors in the esophagus. For example, the transient esophageal distension induced by rapidly inflating an intraluminal balloon can induce peristaltic contractions in the esophagus. This may correspond to the distensions produced when the esophageal content is not completely cleared by the first swallow, or when reflux of the gastric contents occurs into the esophagus. Secondary peristalsis may be initiated at the level of either the striated or the smooth muscle. The wave of contraction usually begins at the level of the distension or just above it[46].

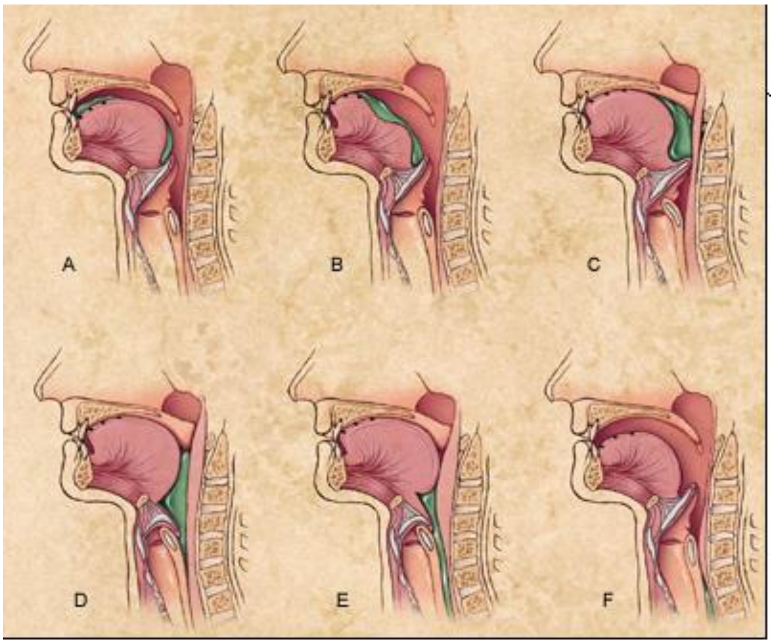


Figure 1.1: Lateral view of the swallowing process in a healthy person, based on videofluorographic recordings. (A) Food (shown in green) is sitting on the dorsum of the tongue. A portion of food is already in the valleculae, having been propelled there during a previous oral propulsive cycle. (B) Moving upward and forward, the tip of the tongue comes into contact with the hard palate anteriorly. (C) The area of tongue-palate contact expands posteriorly, which pushes additional food into the oropharynx. The soft palate and larynx begin to elevate, and the epiglottis begins to tilt. (D) Pushing back into the pharynx, the tongue squeezes the bolus downward through the hypopharynx. The hyoid bone and larynx are pulled upward and forward; as a result, the upper esophageal sphincter opens. (E) The tongue continues pushing backward, and the bolus passes through the upper esophageal sphincter. The posterior pharyngeal wall pushes forward to come into contact with the posterior surface of the tongue. This clears the pharynx of residue. (F) The tongue drops away from the palate, the larynx and nasopharynx open, and the upper esophageal sphincter closes as the bolus passes down the esophagus (Palmer et al 2000)[47].

1.2.3 Evolution of the infantile swallowing

The swallowing function in newborns and children has different characteristics from that of adults and these characteristics are linked to differences in anatomy and phisiology. As other functions like speech articulation, or deambulation, even swallowing follows a specific development through precise stages[48]. Because of the multiple and continuous anatomical, cognitive, social, motor and emotional changes that characterize physiological development from the early childhood to adolescence, we must necessarily divide it into different phases[49].

FETAL PERIOD

The discussion about the swallowing function starts in the fetal period. The first deglutitory acts are observed between the 10th and 11th weeks of gestation. The first suction acts (suckling) are observed between the 18th and the 24th weeks. The oral reflexes appear between the 26th and 29th weeks of gestation. Then the coordination between breathing and swallowing is set between the 32th and 34th weeks of gestation. In this period half of the amniotic liquid is daily swallowed[20]. At the 34th week of gestation the normal ratio of 1:1 between suction and swallowing is reached, with a rhythm of 1 per sec[30]. This kind of suction has been defined as non-nutritive but fundamental as it represent the propaedeutic preparation for the new-born's nutritive sucking.

0-6 MONTHS

In these months feeding takes place mainly at the breast or with a bottle. In this period swallowing is already an efficient function but with significative differences from that of adults. Infants in this period are edentulous, the oral cavity is a virtual space, larynx is high located and high respiratory rate is observed (80 breaths per minute) mainly due to the abdominal movements. Milk is the only element introduced is.

The oral phase is presented as a suckling. During suckling the bolus moves from the outside to the oropharynx thanks to continual anteroposterior movement of the tongue. Facial and labial muscles are hypotonic.

The mandible exerts rhythmic movements of opening and closing allowing the suction effect on the breast. The pharyngeal phase starts thanks to a vallecular trigger and the larynx does not move consistently.

6-24 MONTHS

In this period important changes take place: the child adopts a sitting position, the larynx begins to descend, the first tooth appears, the sense of orientation begins to develop, and the auditory perception improves. In this period there is a staggering evolution of oral functions, the feeding improves and the child is able to take any food[50].

Suction characteristics are modified, and it passes from “suckling” to “sucking”. Even the tongue function changes to an upper-down movement thus creating a negative pressure inside the oral cavity. This change is allowed by the larynx descent, as observed in the animal model[51]. The swallowing- suction ratio is not more than 1:1 but it increases. In this period, the transit time of the bolus through the oral cavity in oral phase becomes faster, thus demonstrating an increased efficiency of the swallowing function. In the pharyngeal phase the hyoid-pharyngeal complex rises to protect the airways during swallowing.

2-6 YEARS

In this period, awareness and compliance increase and the mastication function evolves. The duration, as the number of masticatory cycles decrease significantly[36]. The preparation phase becomes increasingly difficult.

6-12 YEARS

After 6 years old swallowing is a consolidated function. Nevertheless, two important changes take place in this period: the transition to the mature or somatic swallowing with the tongue thrust disappearance and the further improvement of the masticatory function.

The transition to the adult swallowing is mostly linked with the oral phase.

In adults this phase provides the contraction of the masticatory muscles and the elevation of the mandible, at the same time the bolus is pushed by the tongue against the hard palate, thus creating a sort of adhesion, leaving a free central groove for the bolus descent. Labial and mentalis muscles are silent.

In children that have not acquired these automatisms the masticatory muscles are silent; the tongue is hypotonic and moves forward thus not permitting the adhesion on the hard palate. The mentalis muscle is generally hypertonic, whereas the lip muscles can be either hypotonic or hypertonic but generally not silent. During this period a constant reduction in the duration and in number of masticatory cycles is observed demonstrating a general improvement in the masticatory function[35,37]. Recently also the improved capacity in liquid swallowing has been demonstrated: the duration and the number of swallowing acts decrease[24].

1.3 Neuroanatomical basis of swallowing

Swallowing is a well-organized and coordinated task in which the cerebral cortex, motor nuclei of the brain stem and the sensory-motor fibers play a crucial role. Swallowing is usually thought to be the result of local peristaltic mechanisms in the esophagus, combined with reflex involvement of swallowing centers in the brainstem. However, the cerebral cortex appears to play a critical role in the initiation of voluntary swallowing. Indeed, repetitive electrical stimulation of appropriate regions of the cortex in anaesthetized animals or in humans undergoing neurological surgery can induce swallowing[52]. The precentral gyrus of the frontal lobe takes part in the first and voluntary part of swallowing[52]. The central pattern generator (CPG), the premotor circuitry and the motor neurons controlling the phases of swallowing are contained in the brain stem[53]. Corticobulbar fibers connect the cortex with those subcortical centers for the completion and the regulation of the tasks. The knowledge of mechanism and regulation of swallowing has a crucial role both in research and clinics.

1.3.1 Sensory information

The sensory information plays an important role in swallowing regulation, in fact the oro-pharyngeal-laryngeal area shows a high concentration of receptors. Sensory input not only has a major influence on the activity of brainstem swallowing centers but also converges onto cortical sensory and motor areas. Furthermore, it has been shown that the excitability of cortical projections to swallowing muscles can be influenced by the stimulation of afferent fibers in the vagal and trigeminal nerves[52]. The role of sensitivity in swallowing has been the subject of controversy over the years. As an example, during dental anesthetic the oral phase of swallowing can be altered. We also know that salivary flow and that other autonomic events depend on the stimulation of sensory receptors[54]. In addition, olfactory and visual afferences co-work for the anticipatory phase of swallowing. Sensory inputs from peripheral areas play an essential part in inducing the whole swallowing motor sequence or parts of this motor sequence such as esophageal peristalsis. They play the prime role in reflex swallowing and they are also involved in voluntary swallowing. Chemical or mechanical stimuli can activate reflex pharyngeal swallowing, indicating that activation of either chemo- or mechanoreceptors may be effective, but the specific role is still unknown. Studies have found that the most sensitive pharyngeal site for activation of swallowing due to focal pressure is the anterior hypopharynx, but the larynx is more sensitive than the pharynx to either chemical or mechanical stimulation[53]. Moreover, sensory inputs modulate the central network activity to adapt the forthcoming motor sequence to the information arising from peripheral receptors. Although the swallowing motor sequence is centrally organized, it can change as the result of peripheral afferent information[46]. Receptors turn physical or chemical inputs into nervous impulses. The mouth has a special status within the somato-sensory system. Firstly, it is one of the most densely innervated parts of the body, in terms of receptors. This sensory richness is linked to the key role of oral sensorimotor control in eating, drinking and speaking, as well as to the vivid nature of many oral sensations. Secondly, the mouth contains a large range of different tissue types (skin, muscle, teeth) in close proximity and constant interaction. These generate very rich patterns of somato-sensory afferent input. Thirdly, being a cavity, it has some somato-sensory properties typical of the external surfaces of the body, and others more characteristic of the internal milieu. Thus, oral sensations provide an important interface experience, of both the objects in the mouth and of the states and movements of the mouth itself. Nevertheless, oral somato-sensation remains relatively little understood[55]. A study conducted by Longo et al in 2010 showed an interesting model of the oral somato-sensory awareness[56]. The model presents a hierarchy of three stages of sensory processing, reflecting identified levels in the somato-sensory pathway. The first level is proper somato-sensation. This refers to the awareness of individual afferent events, such as touches, noxious stimuli, etc. The second level, which we call somato-perception, refers to the processing of several sensory inputs to form a percept of a specific object or stimulus source. A crucial feature of this level is the integration and combination of information from different receptor types and different regions of the receptor surface. The third and final level of the somato-sensory hierarchy is somato-representation. This refers to the representation of the body as an object in itself. Through continued somato-sensory and other inputs, we gradually build a representation of what our body is like, i.e., a conscious image of the body as a physical object. Importantly, this representation cannot be generated directly by any single somato-sensory afferent signal[56]. The three processing stages of the theoretical model shown in Figure 1.2 can be related to different stages of the oral somato-sensory pathway[55].

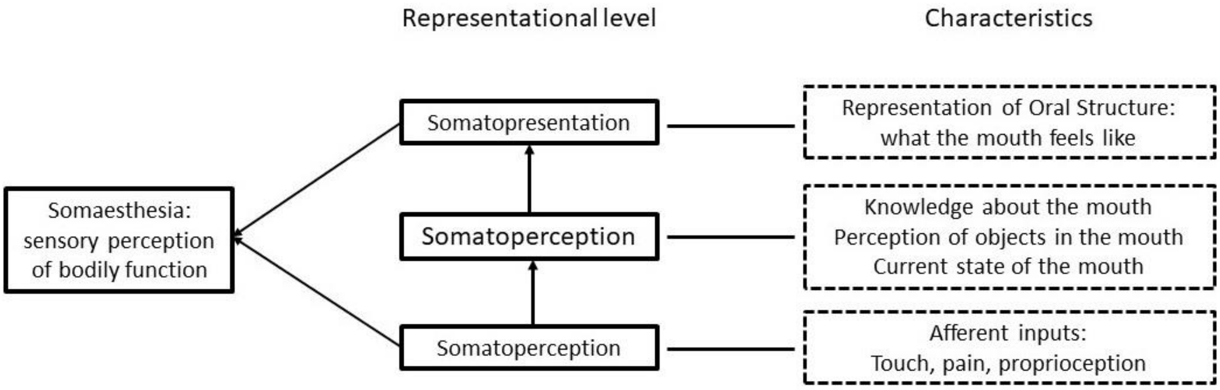


Figure 1.2: different stages of the oral somato-sensory pathway (Haggard and de Boer 2014)[55].

1.3.1.1 Mechanoreceptors

Mechanoreceptors fire when they are mechanically deformed, and their discharged frequencies are related to their deformation and thus to the applied pressure. During swallowing, this may be triggered from mucosal contact with the bolus or by its contact with other oral structures during mastication[54]. Together with chemical receptors, mechanoreceptors are the most represented in the oral cavity and their characteristics change depending on their position. They can be found in the oral mucosa (tongue, gingiva, palatal mucosa, vestibular and malar mucosa), in the temporomandibular joint (capsule and disc) and in the periodontal ligament. The structures that mediate mechanosensitivity in the mouth include Merkel cell complexes, Ruffini type endings, Meissner endings and Pacinian corpuscles. Mechanoreceptors of the anterior region (i.e. tongue tip) have a high discriminative capacity, to properly detect food shape and dimension (oral stereognosis); this capacity becomes less and less important going back to the tongue. Important receptors can be found also in the pharyngeal and laryngeal area and in the periodontal tissues, which give information about the hardness of the food and the muscular strength required for its mastication. Periodontal mechanoreceptors provide important information regarding temporal, spatial and intensive aspects of force acting on the tooth, during the initial tooth food contact[57]. Behavior of receptors depends on their localization. They are mostly located in the apical third of the ligament. The rarest and rapidly adapting receptors are situated below this region but closer to the fulcrum than to the apex[58]. Periodontal mechanoreceptors respond maximally when the area in which they lie is put into tension (i.e. stretch). The receptor types found in the TMJ capsule include free nerve endings, Ruffini endings, Golgi organs and Pacini corpuscles. It has been claimed that the Ruffini endings and the Golgi organs within the capsule function as static mechanoreceptors, the Pacini endings as dynamic mechanoreceptors and the free nerve endings as the pain receptors[58]. Touch and pressure have been used to stimulate pharyngeal swallowing in human subjects and experimental animals. Larger bolus volumes elicit greater tongue propulsive forces and shorter latencies to evoke the swallowing. Another bolus characteristic detected via touch and pressure mechanoreception is viscosity. Higher bolus viscosities elicit increases in oropharyngeal transit times, intrabolus pressures, duration of pharyngeal peristalsis, duration of tongue base contact to the posterior pharyngeal wall, duration and excursion of hyoid movement and duration of upper esophageal sphincter relaxation and opening. Furthermore, the ingestion of solid foods involves transport of the bolus to the occlusal surface of the molars where the bolus is reduced to smaller-size pieces and then transported into the vallecular space before falling into the pharynx. This pattern of ingestion contrasts with that usually observed in single (discrete) sips of liquid, in which the bolus is held in a chamber between the dorsal surface of the tongue and the hard palate and then squeezed in a rostrocaudal direction toward the pharynx by upward and anteriorly directed tongue movements. Discrete boluses of liquid do not usually accumulate in the hypopharynx prior to swallow onset, except in the case of sequential liquid swallowing and during straw drinking[59].

1.3.1.2 Proprioceptors

Kinesthetic receptors are related to swallowing too. Proprioceptors are in the muscular fibers (neuromuscular spindles or MS) and in the endons (Golgi tendon organs). Both are crucial in maintaining muscle tone and facilitating controlled movements.

The spindles in skeletal muscles give information about muscle length and they are part of a complex functional system. They possess multiple roles such as generating antigravity thrust during quiet upright stance, timing of locomotor phases, correcting for muscle nonlinearities, compensating muscle fatigue, determining synergy formation and modulating plasticity. The number of MS in a muscle seems to be related to its function and widely varies from one muscle to the other. Muscles active in gross movements have low spindle density whereas muscles initiating fine movements or maintaining postural stability have a high spindle density[60]. In humans, masticatory muscles (jaw-closing muscles and jaw-opening ones) have different concentration of MS. The adult human masseter muscle contains especially large and complexly arranged muscle spindles. Typical features are a high muscle spindle density, large capsule diameter, a high number of intrafusal fibers per spindle and numerous compound spindles, that is, clusters of spindles located closely together within a common capsule. The largest and most complex spindles are located in the deep masseter and they make the deep portion well adapted for postural mandibular control, possibly of special importance in early learning and improving speech function. In speech, precise jaw movements occur within a three-dimensional space around the mandibular postural position. Interestingly, the number of muscle spindles in the jaw muscles seems to increase in the evolutionary series from lower primates towards man[60]. Masseter muscle spindles do not undergo major changes in morphology and composition from young age to adulthood. This in turn suggests early proprioceptive demands during growth and maturation of jaw motor skills. However, the MS density was three times higher in the young than in the adult masseter[60]. A high density of muscle spindles can be found in the temporal muscle too[58], with a prevalence in the anterior portion of the muscle[61]. This finding reinforces the idea that the jaw-closer spindles should have a strong proprioceptive impact on the control of human function.

Data obtained from suprahyoid muscles confirmed the rareness of these receptors; in fact, the need for MS in jaw opener muscles is reduced by their usual relationship with external forces, such as gravity. Opening of the mouth occurs in gravity favor and can be mainly controlled by the variations of jaw closer muscle tone. Additionally, jaw opener muscles, are almost never subjected to condition of stretching, because of the limit, given to mouth closing, by the teeth contact[62]. Additionally, this suggest that these muscles have either alternative means of proprioceptive control.

Information about muscle length can be processed by the brain to determine the position of body parts and it plays a crucial role in regulating the contraction of muscles, by activating motor neurons via the stretch reflex to resist muscle stretch. Central connections of the periodontal mechanoreceptors are quite unique, because most of these receptors have their cell bodies in the trigeminal mesencephalic nucleus along with the spindle cell bodies. It has been suggested that, in the trigeminal mesencephalic nucleus, an electrical link may exist between the cell bodies of spindles and periodontal receptors. It is also unique that the periodontal receptors and muscle spindles from jaw muscles have direct projections to the cerebellar cortex. It is thought that this direct connection can be used as a reliable signal of tooth contact, and this may be used to zero or recalibrate the spindle afferent discharges. Muscle spindles in the jaw-closing muscles give very finely graded information regarding mandibular movement. However, they cannot give reliable information about jaw position over a long period of time, because the spindle properties and the fusimotor activity change continuously during chewing. For the normal mandibular posture to be maintained, absolute positional information is needed, and that requires calibration of the muscle spindle afferent information with the exact time of tooth contact. This calibration could be done by a comparison of the direct and reliable information received *via* the spindle and periodontal afferents to the cerebellum. This comparison may allow the cerebellum to alter fusimotor activity appropriately and regulate the gain of the spindles in the jaw muscles[58].

Golgi tendon organs are composed by sensory fibers, which lose their myelinic sheaths and which are located in the tendons. These receptors sense changes in muscle tension. The Golgi tendon reflex operates as a protective feedback mechanism to control the tension of an active muscle by causing relaxation before the tendon tension becomes high enough to cause damage, while the spindle stretch reflex operates as a feedback mechanism to control muscle length by causing muscle contraction. Although the tendon reflex is less sensitive than the stretch reflex, it can override the stretch reflex when tension is great, making you drop a very heavy weight, for example. Like the stretch reflex, the tendon reflex is ipsilateral.

There is only limited evidence of the existence of tendon organs in human or animal jaw muscles. The functional connections of these afferents, if they exist, are not known[58].

The proprioception role in the stomatognathic system is a protective role during teeth contact. In general, proprioceptive signals converge on the mesencephalic trigeminal nucleus through the mandibular branch of the trigeminal nerve. In turn, these afferent impulses are transferred to the trigeminal motor neurons to obtain precise control of jaw movements. Takeda and Saitoh (2016)[63] made an electromyographic analysis of swallowing in order to test if swallowing could have been modified by changing the amount of proprioceptive feedback from a number of different receptors while holding a food bolus in the mouth and clenching. Initiation of the swallowing reflex was detected by an anterior shift of the thyroid cartilage using a laser displacement sensor and by submental sEMG signals. To vary the proprioceptive input, the participants were instructed to occlude their teeth at various intensities (weak, intermediate and strong) while holding the 5-ml jelly bolus on the tongue. Contractile forces of the masseter muscles during occlusion tended to correlate negatively with electromechanical delays on suprahyoid muscle contraction.

Afferents from proprioceptors, articular receptors, mucosal and cutaneous mechanoceptors are collected by the Central Nervous System, which coordinates all the information.

1.3.1.3 Other receptors

Chemical receptors are situated along the whole alimentary channel and are particularly represented in the aryepiglottic fold. Gustative receptors take place in the taste buds on the tongue surface as well as on the pharyngeal area and on the palate. The pharyngeal area is sensitive to the four tastes, but less than the oral cavity. Taste sensory input synapses almost exclusively in the nucleus of solitary tract (NTS), but predominantly in regions rostral to the subnuclei that contain interneurons vital to eliciting swallowing. Logemann et al. (1995)[64] measured differences between swallowing a regular barium suspension and a sour barium suspension prepared in a 50% ratio with lemon juice in patients with neurogenic dysphagia. Both oral and pharyngeal transit times were shortened with the sour bolus[59]. A sour bolus elicits more frequent swallowing than a water or a sweet bolus[65]. Nociceptors and thermoceptors are well represented too in the stomatognathic system. Cold stimulation seems to decrease the latency to induce one swallow[59].

1.3.2 Afferent fibers

Signals transmitted by receptors are collected by afferent fibers of cranial nerves and they are converged in the central nervous system (CNS), in order to be processed. Involved nerves are the olfactory nerve (I), the optic nerve (II) (whose pathways are different from the nerves related to the general sensorial information), the trigeminal nerve (V) with its three branches, the facial nerve (VII), the glossopharyngeal nerve (IX) and the vagus nerve (X), especially with its superior laryngeal branch. These nerves bring their information into the brain stem nuclei, the trigeminal nucleus (mesencephalic, pontine and spinal tract) and the solitary nucleus (SN) (VII, IX and X) (Figure 1.3). The trigeminal mesencephalic nucleus (next to the masticatory one) receives signals from the receptors inside of the masticatory muscles and periodontal information, for masticatory regulation. The pontine (main nucleus) receives fine tactile information (from the face, lips, teeth, palate, tongue anterior part), while the spinal nucleus receives less fine tactile information as well as thermal and pain-related information. The IX and X nerves bring information from the posterior region of the tongue, the pharynx and the larynx to the solitary nucleus (SN) in the pontine part of the brain stem. In this context we refer to the VII nerve because it brings the taste sensation of the anterior portion of the tongue, which is then transmitted to the rostral portion of the solitary nucleus (Figure 1.4).

The superior laryngeal nerve innervates the larynx and plays a major role in initiating the swallowing reflex[66]. In fact, the motor sequence can be readily initiated by the internal branch of the superior laryngeal nerve[46]. The SN plays a crucial role in the gustative sensation, but its importance in the swallowing task has been demonstrated as well. Stimulation applied to the solitary tract and its nucleus can induce a very similar swallowing pattern to that obtained in response to the superior laryngeal nerve stimulation[46].

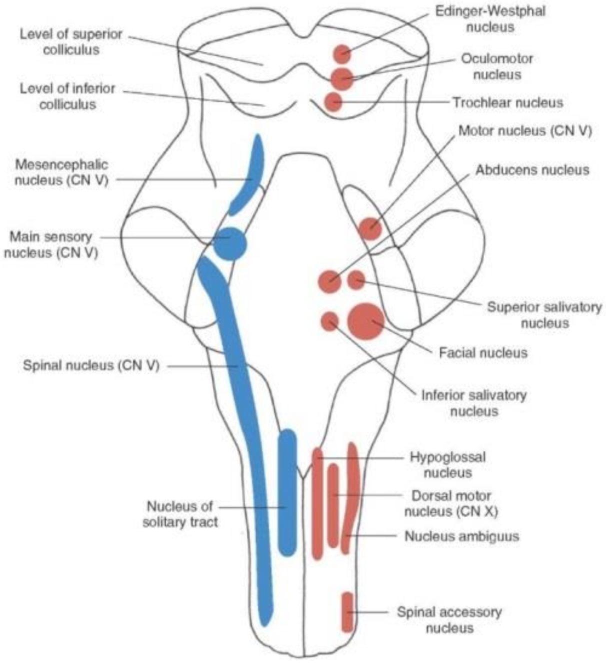


Figure 1.3: brainstem cranial nerves nuclei (Alvarez-Berdugo et al 2016)[67].

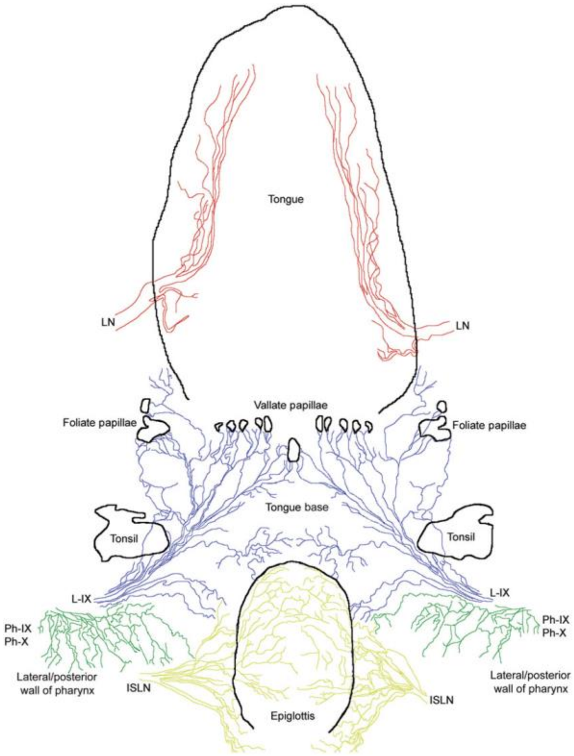


Figure 1.4: distribution of the oropharyngeal sensory innervation. Schematic representation of the distribution of the sensory branches of CN V, VII, IX, and X innervating the oropharyngeal mucosa (Alvarez-Berdugo et al 2016)[67].

1.3.3 Central pattern generator (CPG)

Once the afferent fibers reach the nuclei in the brainstem, the information is led to specific areas which are known as swallowing center and they represent the first central swallowing integration area. Swallowing is a complex but stereotyped motor sequence with a fixed behavioral pattern. It constitutes, however, one of the most elaborated motor functions, even in humans, since it requires the coordination of more than 25 pairs of muscles in the mouth, pharynx, larynx and esophagus. The sequential and rhythmic patterns of swallowing are formed and organized by a central pattern generator (CPG). The CPG can be subdivided into three systems: an afferent system corresponding to the central and peripheral inputs to the center; an efferent system corresponding to the outputs from the center, consisting of the not deal mainly with swallowing. They are most strongly involved in several other orofacial activities such as jaw reflexes, mastication, licking, and sucking. Lesion experiments have shown for example that abolishing the various motoneuron pools involved in swallowing and an organizing system corresponding to the intraneuronal network that programs the motor pattern.

1.3.3.1 Motoneurons

Motoneurons are localized within the trigeminal (V), facial (VII), and hypoglossal (XII) motor nuclei, the nucleus ambiguus (IX, X), the dorsal motor nucleus of the vagus (X) and at the cervical spinal level between C1 and C3. These motor nuclei do not all participate to an equal extent in swallowing, at least during the basic pattern. The V and VII motor nuclei do V motor nuclei does not affect the swallowing sequence. Trigeminal motoneurons mainly involved in swallowing innervate the mylohyoid, anterior digastric, lateral pterygoid, and tensor veli palatini. Within the VII motor nucleus, motoneurons greatly involved in swallowing control the posterior digastric and stylohyoid. Other muscles innervated by these two motor nuclei, such as the medial pterygoid, temporal, and masseter are more facultative swallowing muscles. In fact, the main motor nuclei involved in swallowing are the XII motor nucleus and the nucleus ambiguous[46].

1.3.3.2 Interneurons

The swallowing neurons are in two main brain stem areas: *1*) in the dorsal medulla within the nucleus of the solitary tract (NTS) and in the adjacent reticular formation, where they form the dorsal swallowing group (DSG) and *2*) in the ventrolateral medulla, just above the nucleus ambiguous, where they form the ventral swallowing group (VSG).

A) DSG. Within the NTS, there exist neurons that fire during either the oropharyngeal or the esophageal phase of swallowing. Most of the oropharyngeal neurons are active either just a few milliseconds before or during the oropharyngeal phase of swallowing[46].

B) VSG. In the ventrolateral medulla above the nucleus ambiguus, there also exists a large population of oropharyngeal swallowing neurons. These neurons have been identified as interneurons. The burst firing behavior of the VSG neurons is very similar to that of the DSG neurons in terms of the sequential firing pattern; this population has, however, a lower instantaneous discharge frequency.

Additionally, within the V and XII motor nuclei or in their close vicinity a group of interneurons has been identified as premotor neurons or neurons involved in the bilateral coordination of the motoneuronal pools[46].

1.3.4 Neural network

Within the swallowing network (Figure 1.5), VSG neurons are activated via DSG neurons and motoneurons are driven by neurons of the VSG. Within the swallowing CPG, simple circuits do link the afferent fibers, the DSG neurons, the VSG neurons and the motoneurons together. It has been established in several networks involved in basic motor behavior, such as locomotion, that within a given CPG, not all neurons are equal since some of them play a preeminent role. Concerning swallowing, data suggest that neurons in the DSG are likely candidates to act as generator neurons in the initiation and organization of the sequential or rhythmic motor pattern. The VSG contains the switching neurons, which distribute the swallowing drive to the various pools of the motoneurons involved in swallowing.

The swallowing network in mammals therefore provides a unique example of neurons located within a primary sensory relay, i.e., the NTS, which nevertheless play the role of generator neurons. Several lines of evidence support the idea that NTS neurons play a leading role in swallowing. NTS neurons exhibit a sequential or rhythmic firing pattern that parallels the motor pattern. As this firing remains unaltered after complete motor paralysis, it is a centrally generated pre-motor activity. Moreover, most of the neurons, if not all those which have a preswallowing activity, are located within the NTS[46]. In fact, right before swallowing an activation of premotor neurons in the intermediate (NTSim), ventromedial (NTSvm) and interstitial (NTSis) subnuclei of the NTS can be seen. The primary NTS pre-motor subnuclei that control the pharyngeal phase of swallowing are the NTSis and NTSim[53] (Lang 2009). In addition, in some studies, systematic exploration of the brain stem with concentric bipolar electrodes has been performed in order to determine which central structures responded to stimulation by triggering swallowing. These studies have shown that the active points are situated only in the region of the solitary complex. It may be stated that swallowing results from the stimulation of afferent fibers belonging to the solitary tract.

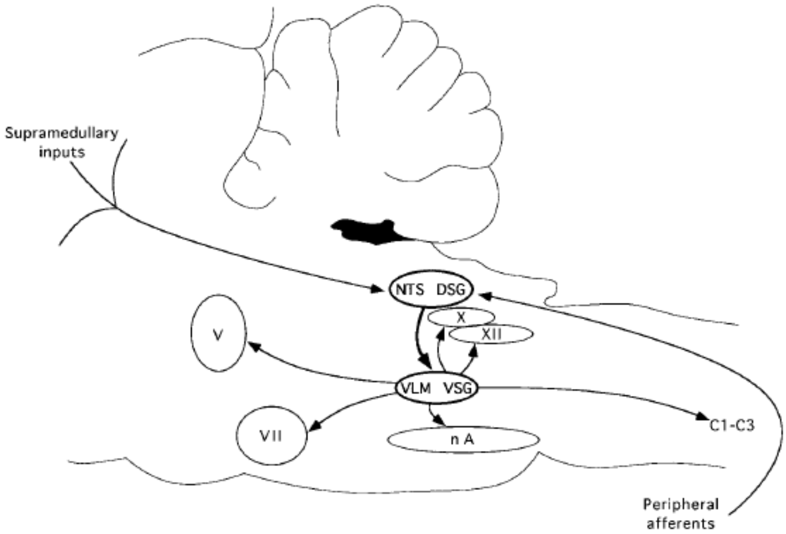


Figure 1.5: diagram of the swallowing central pattern generator (CPG). The CPG includes two main groups of neurons located within the medulla oblongata: a dorsal swallowing group (DSG) located within the nucleus tractus solitarii (NTS) and the adjacent reticular formation and a ventral swallowing group (VSG) located in the ventrolateral medulla (VLM) adjacent to the nucleus ambiguous. The DSG contains the generator neurons involved in triggering, shaping and timing the sequential or rhythmic swallowing pattern. The VSG contains the switching neurons, which distribute the swallowing drive to the various pools of motoneurons involved in swallowing (Jean 2001)[46].

The CPG for swallowing consists of two hemi- CPGs, each located on one side of the medulla. The existence of two hemi-CPGs was established by making longitudinal midline sections of the medulla. After this splitting, stimulation applied to the spinal lemniscus nuclei (SLN) on one side triggered a “unilateral swallowing,” i.e., a swallowing sequence involving only the ipsilateral oropharyngeal muscles, except for the middle and inferior pharyngeal constrictors in some species. These results indicate that under physiological conditions, the two hemi-CPGs are tightly synchronized and organize the coordinated contraction of the bilateral muscles of the oropharyngeal region[46]. The swallowing motor sequence is mainly generated in the ipsilateral hemi-CPG and this CPG transfers the swallowing pre-motoneuron signals to the contralateral CPG[27,46] (Figure 1.6).

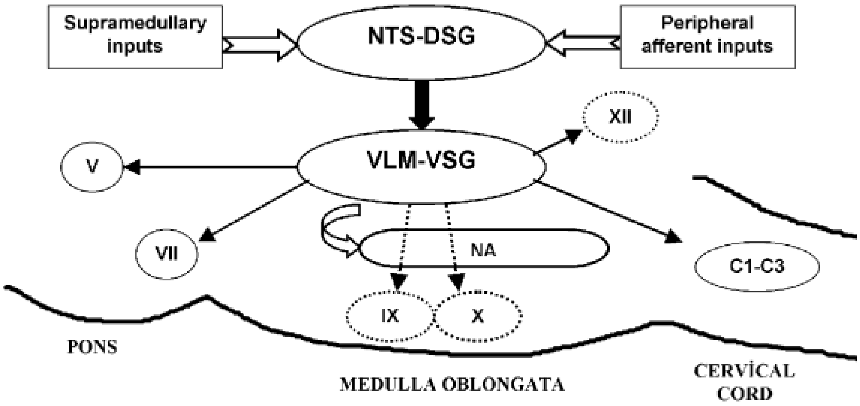


Figure 1.6: schematic representation of the central pattern generator of swallowing. Peripheral and supramedullary inputs reach to and around nucleus tractus solitarius–dorsal swallowing group (NTS-DSG). NTS-DSG activates the ventral swallowing group of premotor neurons in the ventrolateral medulla–ventral swallowing group (VLM-VSG) adjacent to the nucleus ambiguus (NA). VLM-VSG drives the motoneuron pools of the V, VII, IX, X, XII, C1–3 CN bilaterally (Ertekin and Aydogdu 2003)[27].

1.3.5 Superior swallowing control

Experimental data have shown that the basic swallowing pattern can be induced without any supramedullary structures being involved. Under physiological conditions, however, the swallowing network receives inputs from higher centers and several cortical and subcortical structures can also influence the pattern of swallowing. In addition, the descending pathways can initiate or modify the pattern of swallowing through interaction with the peripheral inputs to the brain stem. Thus, although not generally susceptible to central control, the patterned sequence of events associated with swallowing can be modified by learning, for example following surgery for carcinoma of the larynx[44]. It is possible that during repeated swallowing, descending signals from the cortical sites associated with swallowing decrease the threshold to evoke swallowing[27]. The fact that an individual can swallow voluntarily without the existence of any need to ingest food or to protect the upper airways shows that the medullary swallowing network can be activated at least by inputs from the cerebral cortex. In addition, several clinical reports have indicated that cortical dysfunction may result in dysphagia or swallowing impairments or may affect esophageal peristalsis[46]. The triggering of spontaneous swallowing probably does not require cortical drive but could involve communication with the cortex and subcortical regions and can occur between meals and during non-REM sleep and depends on the amount of saliva accumulated in the mouth[27]. These observations point to the involvement of supramedullary influences, although the peripheral afferent pathway and the CPG seem to remain unaltered in these patients. Supramedullary structures may be responsible for various effects on swallowing such as initiating the motor activity, or modulating reflex swallowing. There exist several subcortical sites, including the corticofugal swallowing pathway (which can trigger or modify swallowing), the the internal capsule, the subthalamus, the amygdala, the hypothalamus, the substantia nigra, the mesencephalic reticular formation, and the monoaminergic brain stem nuclei. These influences can be either excitatory or inhibitory. It has been reported that several forebrain regions, including the amygdala and the lateral hypothalamus, may facilitate swallowing by means of dopaminergic mechanisms. Inhibitory effects can be evoked by stimulating brain stem structures such as the periaqueductal gray, the ventrolateral pontine reticular formation, and some monoaminergic cell groups. Results suggest that these inhibitory effects probably involve opiate and monoaminergic mechanisms at the level of the NTS. Whether these influences act directly on the medullary CPG or may involve a more complex central pathway is not known. Few studies have in fact dealt with these central effects on the neurons of the CPG. As far as the supramedullary influences on swallowing and their action at the cellular brain stem level are concerned, all the results available so far have been obtained in studies on the cortical influences on swallowing. However, lesions involving the NTS area involved abolish the swallowing evoked by cortical stimulation, which further indicates that the solitary system is the main central system responsible for swallowing. Results obtained on anesthetized sheep indicate that most of the early neurons in the DSG can be activated by applying cortical stimulation. This agrees with the idea that one of the functions of the cortical area may be to trigger the “voluntary” swallowing motor sequence.

Cortical stimulation induces an initial activity followed by the swallowing burst that accompanies the onset of swallowing. Early neurons in the DSG were cortically activated with a shorter latency than those in the VSG and only 32% of all the neurons in the ventrolateral medulla were cortically activated. Late neurons in the DSG also responded to cortical stimulation, but in small numbers (38%) and with a longer latency. None of the late neurons in the VSG nor the very late neurons either in the DSG or the VSG was activated by cortical stimulation. Based on the finding that during swallowing sensory feedback is conveyed to the cortical area via a first relay in the pons, the swallowing cortical area may have a further function. Neurons in this area may belong to a ponto-cortico-medullary loop so that upon receiving sensory information, they might control the activity of the CPG swallowing neurons as they fire successively, just as peripheral afferent fibers do. It has been shown that cortical neurons in the swallowing cortical area of sheep are activated or inhibited during swallowing. Therefore, the cortical swallowing area may serve mainly to trigger swallowing and control the beginning of the motor sequence, after which the sequence might be carried out without any further cortical control[46]. The swallowing tasks yield activation of the lateral postcentral gyrus localized to Brodmann’s area 3, 2, 1 and/or 43. This finding of swallow-related activation of the postcentral gyrus might reflect various types of oropharyngeal sensory processing and underscore the importance of afferent information in the regulation of swallowing. Cortical activation during both swallowing and swallowing-related motor tasks that can be performed independent of swallowing was also found in the parietooccipital region corresponding to Brodmann’s areas 7, 9 and 31. Somato-sensory and parietal regions have been cited as a region of activity during mechanical and chemical stimulation of the esophagus the somato-sensory cortex and posterior parietal cortex are likely to have a sensory role in the control of swallowing. Also, the temporal lobe has been implicated in a number of functions that are related to swallowing[27]. Speaking about efferent signals, human data show that the locus of the cortical control of swallowing lies within and antero-caudal to the face area of primary motor cortex. Several brain regions with increased activation were detected with positron emission tomography (PET)[52]. The cerebral motor cortex is the portion of the cortex which is responsible for the planning, the regulation and the execution of the voluntary movements. The precentral area is situated in the precentral gyrus and includes the anterior walls of the central sulcus and the posterior part of the frontal gyri. The precentral area may be divided into posterior and anterior regions, the first one, which is referred to as the motor area, primary motor area, or Brodmann area 4, occupied the precentral gyrus. The anterior region is known as the premotor area, secondary motor area, or Brodmann area 6 and parts of areas 8, 44 and 45 (Figure 1.7).

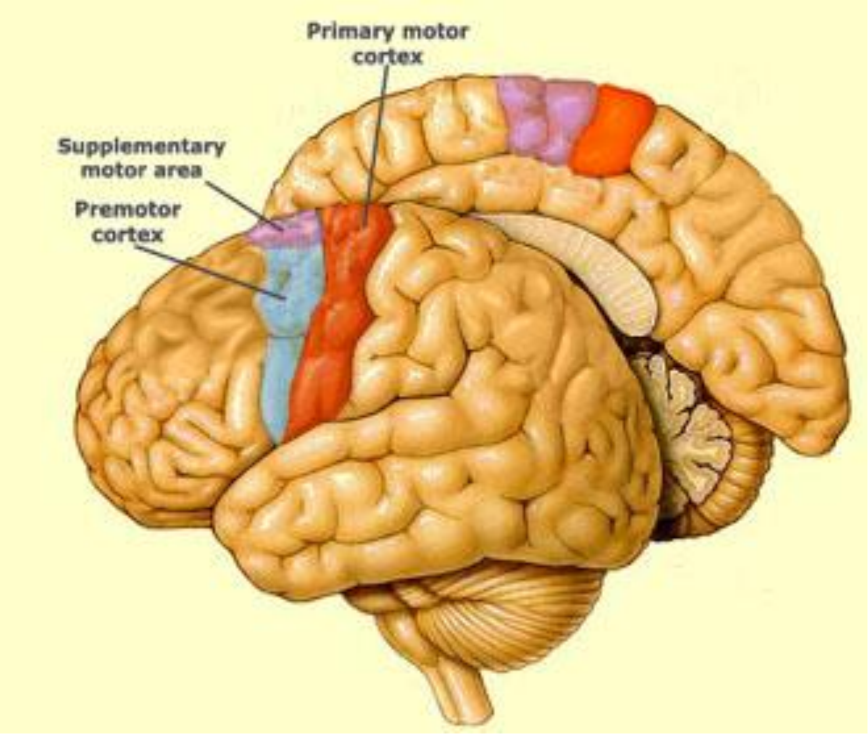


Figure 1.7: representation of the primary motor cortex, premotor cortex and supplementary motor area (Hamdy et al 2000)[52].

The primary motor area receives numerous afferent fibers from the premotor area, the sensory cortex, the thalamus, the cerebellum and the basal ganglia. The primary motor cortex is not responsible for the design of the pattern of movement, but it is the final station for conversion of the design into execution of the movement. The premotor area receives inputs from the sensory cortex, the thalamus and the basal ganglia; its function is to store programs of motor activity assembled as the result of past experience. It can be reported that the premotor area programs the activity of the primary motor area. In terms of human swallowing, there might be two distinct patterns of activity: first, the caudolateral motor cortex, which may be associated with the initiation of the full swallowing sequence at the highest level and second, the premotor regions which may be more modulatory and concerned with "priming" the pharyngoesophageal components of swallowing. The supplementary motor area represented in the superior and middle frontal gyri, is believed to be associated with motor planning and, in particular, with planning of sequential movements as occurs with oropharyngeal swallowing. In addition, the activation of the anterior cingulate cortex during volitional swallowing may reflect the attentional and/or affective component of the swallowing task. Finally, studies have demonstrated how the insula and the frontal operculum are activated during swallowing[27].

Swallowing involves multiple cerebral regions, often in an asymmetrical manner, particularly in the insula, which is predominantly on the right, and in the cerebellum, being mainly on the left. These latter observations are in keeping with the earlier observations that motor cortex representation for swallowing musculature displays degrees of asymmetry[52]. Studies conducted with the technique of transcranial magnetic stimulation showed that in most of the individuals, the projection from one hemisphere tended to be larger than that from the other, i.e. there was an asymmetric representation for swallowing between the two hemispheres, independent of handedness[52,68]. The new technological advances in functional imaging of the human brain have revolutionized our understanding of how the cerebral cortex operates in processing sensory and motor information. Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have become established as useful methods for exploring the spatial localization of changes in neuronal activity during tasks, within both cortical and subcortical structures.

1.3.6 Neural mechanism

Speaking about a swallowing center is quite an oversimplification. A voluntary swallow (VS) can be distinguished from the spontaneous one (SS). In VS, the regions of the cortex and subcortical areas involved with swallowing serve mainly to trigger swallowing and to control the beginning of the motor sequences (i.e., mainly the oral phase of swallowing). After this, sequential muscle activation is carried out without any further cortical control to perform the pharyngeal and esophageal phases. VS occurs with a desire to eat or drink such as during mealtime and while awake and aware. Although saliva swallowing alone cannot precisely distinguish the kind of swallowing, SS is mostly a kind of saliva swallow that occurs without the person being aware, such as between meals and during sleep. The major difference between the VS and SS is the origin of the swallow trigger. Materials in the mouth (food or saliva) and the cortical drive to the tongue and the submental muscles are necessary for initiation of VS. On the other hand, according to the classical view of the initiation of SS, the oral phase is bypassed. Despite this, it has been shown in animals that the perioral, submental and lingual striated muscles can also be activated in SS, probably under the control of the medullary network of the CPG and bypassing the cortical drive. Direct human physiological studies are necessary to investigate those muscles during SS. Although the initiation of the oropharyngeal phase of swallowing is different between VS and SS, the subsequent sequential and stereotyped motor activity of the pharyngeal and esophageal phases are under the control of the brainstem network for both types of swallowing. VS and SS can be differentiated in terms of state of awareness, wakefulness and to what extent the oral phase is involved. In VS, there is clearly a reflexive pharyngeal phase, as in SS. However, there is no strong evidence of a cortical influence on SS in human[69].

It is likely that modulation of the process of swallowing results from activity in cranial nerves other than those directly related to swallowing. For instance, salivary preparation of the bolus cannot occur in the absence of cholinergic activity mediated through the peripheral and autonomic nervous system. Also, the striated muscles mediating swallowing in the pharynx and the upper one-third of the esophagus, are under the control of impulses originating in motor neurons of the corresponding cranial nerve nuclei, whereas the smooth musculature associated with swallowing is innervated by cholinergic vagal preganglionic fibers that synapses with a plexus in the muscle itself, resulting in postganglionic release of acetylcholine[44].

The swallowing center is also said to be linked to the respiratory center, for respiration is transiently suspended in swallowing. Such linkages are certainly likely because all these centers lie very close together, but the exact pathways are not known[46].

Sensory peripheral information is led to the brainstem as well as to the sensory cortex of the brain. In response to a peripheral stimulus, or central command to swallow, the neuronal program of the swallowing center exerts a sequential all-or-none pattern of excitatory and inhibitory effects of the various motoneurons supplying the muscles of swallowing (Figures 1.8-1.9). It is believed that sensory feedback originating from the oropharyngeal mucosae and deeper receptors in the region may modify the CPG of the bulbar swallowing network. However, there has been much debate about the effects of mucosal receptors on oropharyngeal swallowing, because of the discrepancy among the studies of topical anesthesia on the oropharynx. On the other hand, the sensory deficit in the oropharyngeal mucosae has been proven to be one of the most important causes of dysphagia and aspiration in stroke patients. Results obtained during topical anesthesia of the oropharyngeal mucosae in human subjects suggest that adequate sensory inputs are necessary for the perception of the bolus volume and viscosity by the cerebral cortex and the bulbar swallowing network. The insufficiency of the sensory coding would produce an “uncertain evaluation” in the central nervous system. The main role of the oropharyngeal mucosal receptors may be to contribute to the initiation of swallowing, but when swallowing is triggered, the pattern and sequential activity of swallowing is not essentially changed[27]. The efferent portion of the CPG coordinates impulse flow for the Trigeminal, Glossopharyngeal, Vagal and Hypoglossal nerves for soft palate contraction, for pharyngeal constriction, for laryngeal muscles contraction, for tongue muscles contraction and for esophageal muscles contraction. In detail, when the movement of the bolus from the oral cavity to the pharyngeal spaces triggers the swallowing reflex or response, the following physiological events occur in rapid overlapping sequence. All the events until the esophageal phase are mainly controlled by the CPG of the brain stem. The nasal, laryngeal and tracheal airways are protected by several “reflex” events including closure of the velopharyngeal isthmus by the palate, laryngeal elevation and suspension by suprahyoid/submental muscles and closure of the larynx by laryngeal muscles of the vocal folds and epiglottis. Protection of the airway is essentially owing to the CPG.

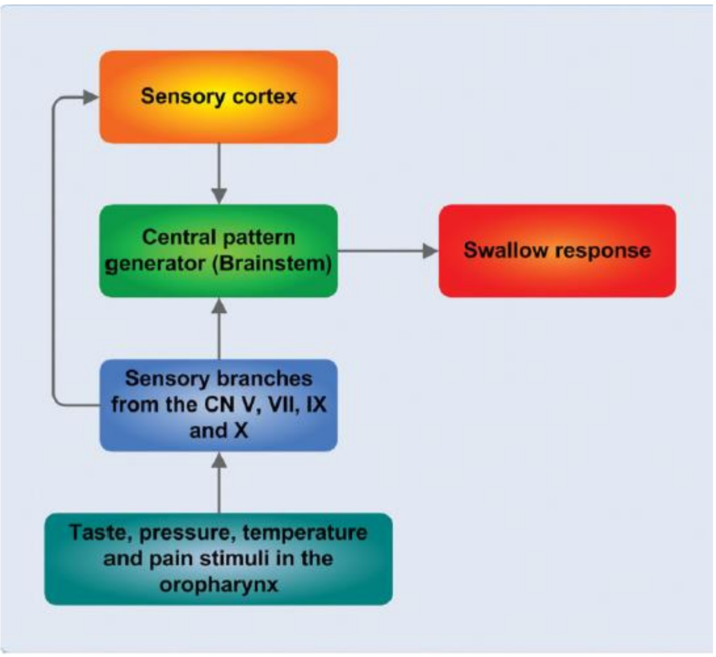


Figure 1.8: sensory pathways and swallow response integration. Schematic representation of the neuronal pathways perceiving stimuli in the oropharynx and larynx that lead to the integration of all the information as the swallow response in the central pattern generator in the brain stem (Alvarez-Berdugo 2016)[67].

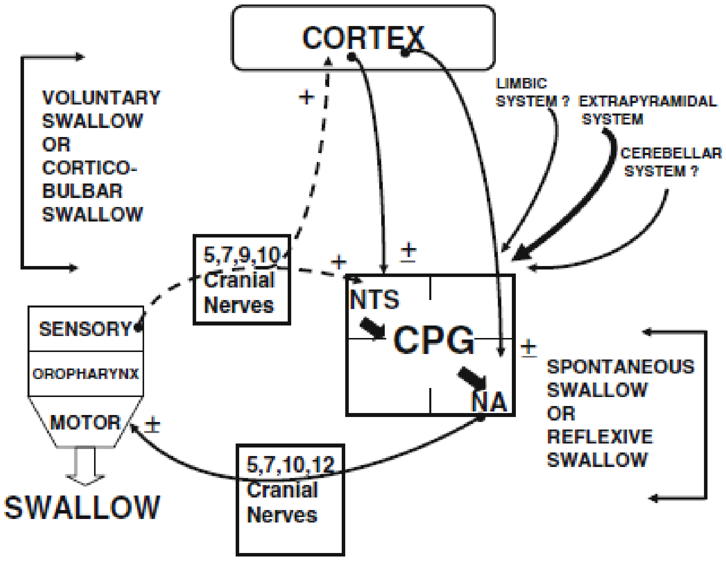


Figure 1.9: schematic of the anatomic physiology in normal swallowing. There are three different locations in the swallowing function: The first location is the peripheral machine of swallowing process known as the oropharynx where all of the peripheral sensory/motor events occur. The second location is the medullary swallowing center in and around the reticular network of nucleus tractus solitarius (NTS) and nucleus ambiguus (NA) at the ponto-bulbar region known as the Central Pattern Generator (CPG). The CPG receives all peripheral inputs and descending motor drives. The third location is the cerebral cortex and some subcortical structures. These are connected to the brainstem CPG especially via corticobulbar pathways (Ertekin 2011)[69].

The CPG must be able to perform a wide range of tasks, such as converting the repetitive messages conveyed by central or peripheral afferent inputs into a bursting activity, transmitting this activity after a variably long delay depending on the nature (oropharyngeal or esophageal) of the neuron in the network, ensuring via a rostrocaudal inhibitory mechanism that the later neurons cannot fire before or during the activity of the earlier neurons, and generating a rhythmic bursting pattern, at least in the case of the oropharyngeal neurons. The bursting pattern of the swallowing neurons may be built up as the result of either re-excitation phenomena or excitatory feedback mechanisms. The centrally generated bursting pattern of swallowing NTS neurons suggests that these mechanisms may well take place within the DSG. Neurons with pre-swallowing activity presumably possess these re-excitation loops so that the neuronal firing will increase until reaching the critical level at which the swallowing burst is generated. In addition to the mechanisms by which the burst firing of the swallowing neurons is generated, the swallowing network can be viewed as a linear-like chain of neurons based on the rostrocaudal anatomy of the swallowing tract (Figure 1.10). There are neurons, within the NTS, which fire sequentially during swallowing. Because of this, each neuron or group of neurons in this chain may control more and more distal regions of the swallowing canal and be responsible for the successive firing behavior. Excitatory connections between neurons may provide the basis for the successive excitation of the cells via increasingly numerous polysynaptic connections. In addition to the central connections, each DSG neuron in the chain may be synaptically activated via peripheral afferent fibers originating in the corresponding part of the tract which is under their control. Whether or not this linear pattern of organization in the form of a chain of neurons exists at the VSG level also has not yet been ascertained. In addition to excitatory connections, there also exist inhibitory connections between the various links in the chain. It has been reported that when the neurons responsible for the beginning of the swallowing sequence fire, the cells controlling the more distal parts of the tract are inhibited, and their activity is delayed. Inhibitory phenomena play an important role in the shaping and timing of the sequence, since the neurons controlling more distal parts of the swallowing canal are subjected to longer periods of inhibition than those controlling rostral parts. Inhibitory mechanisms may not only be responsible for delaying the onset of neuronal firing, but they may also contribute directly to the sequential excitation of the neurons. In fact, via mechanisms such as disinhibition or post-inhibitory rebounds, the inhibitory connections may be at least partly responsible for the progression of the contraction wave. With the assumption that there are only inhibitory connections between swallowing neurons the sequential excitation of neurons may result from post-inhibitory rebounds involving in this case cellular properties of the neurons in addition to network connections.

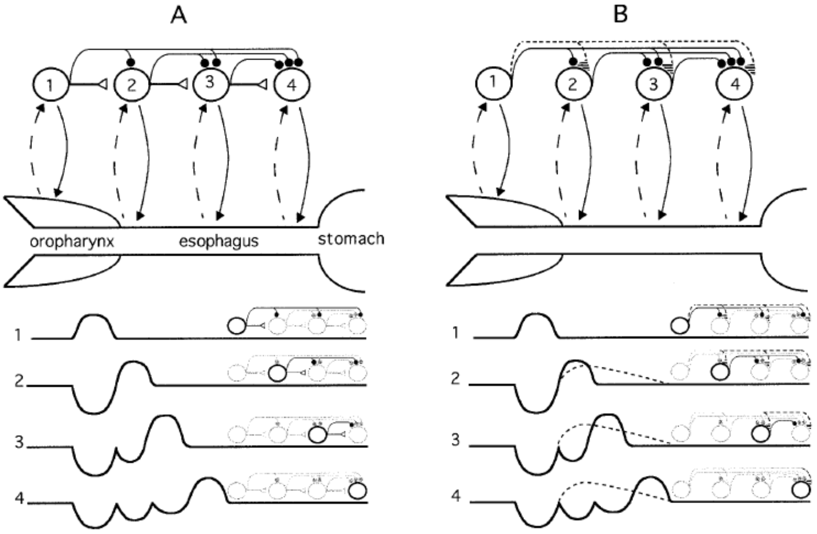


Figure 1.10: possible mechanisms involved in pattern generation. A: the swallowing network can be viewed as a chain of neurons (1-4) that parallels the rostrocaudal anatomy of the swallowing tract. When triggered by peripheral or central inputs, the neurons at the beginning of the chain (1) generate, based on network and/or cellular properties, a burst firing which starts the sequence; they also exert inhibitory effects on the more caudal neurons in the chain (2, 3, and 4) through central inhibitory connections (lines with black dots). The swallowing drive may be transferred by central excitatory connections (white triangles) to the subsequent neuron in the chain (2), which also inhibits the more caudal neurons, etc. The sequential firing behavior therefore results from the successive excitation of the neurons paralleled by a rostrocaudal inhibition, which lasts longer when the neuron is more distal in the chain. This network may function without any sensory feedback, but the peripheral inputs may modulate the sequence (broken lines). Intrinsic properties of the neurons such as pacemaker, post-inhibitory rebound, and delayed excitation properties may intervene in the functioning of the chain. Given this scheme of organization, it can be postulated to account for the differences between primary and secondary peristalsis, that the strength of the central excitatory connections decreases in the caudal direction, while the afferent feedback inputs then become more important. B: the chain may also function mainly on the basis of inhibitory connections. In this case, the sequential firing of the neurons may be produced mainly by mechanisms such as post-inhibitory rebounds. In this case again, these mechanisms will presumably decrease as they occur more caudally. As suggested by field potential recordings, it can be postulated that the neurons generating the oropharyngeal stage can also induce, in addition to the inhibition, a long-lasting excitatory influence on neurons of the esophageal network, indicated here by the dotted line with striped triangles (see text for further information). The sequential firing is therefore dependent on both the inhibitory connections and the properties of the neurons and on a facilitatory influence exerted on the esophageal network in the case of the primary peristalsis. This tentative mechanism of intrinsic modulation may account for the differences between primary and secondary peristalsis. The traces below the diagrams give the membrane potential of oropharyngeal (1) and esophageal neurons (2, 3, and 4). The upward deflection corresponds to a depolarization of the neuron and the downward deflection to a hyperpolarization. The dotted lines in B show a possible long-lasting excitatory or facilitatory influence exerted by the oropharyngeal neurons on the esophageal ones (Jean 2001)[46].

However, there are some differences between the oropharyngeal and esophageal phases of swallowing. In fact, results indicate that unlike the oropharyngeal phase, the esophageal phase may show some lability and suggest that the central program controlling this phase may be less robust than that responsible for the oropharyngeal phase. The size of the neuronal population involved during these two phases is also different. Depending on the number of muscles involved, the number of active neurons during the oropharyngeal phase of swallowing has been found to be far larger than that involved in the esophageal phase. The bursting activity of the oropharyngeal neurons is also very different from that of the esophageal neurons which may reflect differences in the strength of the synaptic connections along the chain of neurons, possibly due to the existence of increasing numbers of synapses, and/or to the properties of the cells. In fact, data obtained in the case of secondary peristalsis have suggested that the swallowing CPG can be subdivided into two subnetworks: an oropharyngeal and an esophageal net of neurons, each of which mediates the patterning of the respective phase of swallowing, but that the esophageal net is likely to have less robust central mechanisms and be more dependent on afferent inputs. The swallowing CPG is not an automatic, continuously functioning CPG and the question arises as to whether the swallowing neurons are completely inactive when no swallowing occurs, or whether these neurons may have other functions. This question is especially interesting, since we have established that swallowing neurons include NTS neurons and it has by now emerged that the NTS is far from being simply a sensory relay. NTS neurons are involved in many activities, such as the autonomic ones, as well as in endocrine processes and in several integrated behaviors such as emotional processes, hunger, thirst, control of pain mechanisms, regulation of the level of consciousness, and probably many other yet non-identified functions.

Are all the NTS neurons in this very small population each devoted to a single fixed function, or are there one or several populations of flexible neurons within the NTS that participate in several functions, depending on the inputs they receive? When a given stimulus is delivered, a pool of appropriate neurons is activated and forms the swallowing CPG, whereas these neurons are involved in other tasks when no swallowing activity is required. It has been established that not only motoneurons, but also interneurons can be involved in at least two different tasks, such as swallowing and respiration, swallowing and mastication, or swallowing and vocalization. Motoneurons presumably receive a drive from separate CPGs, and their activity no doubt depends on synaptic interactions between the two networks. Some recent results have indicated that interneurons localized in the dorsal (DSG) or ventral (VSG) regions of the swallowing network also fire during several motor behaviors such as swallowing, respiration, mastication and vocalization[46].

1.3.7 Muscular coordination

The importance of swallowing in transport and protection is illustrated by the frequencies: 2400 swallows per day increasing to 300/h during eating[44]. Such activity is aided by contraction and coordination of the muscles of different portions of the body. In mammals, all the muscles involved in the oropharyngeal stage are striated and are therefore driven by several pools of motoneurons located in various cranial motor nuclei in the brain stem and the uppermost levels of the cervical spinal cord. The esophageal muscles are composed of both striated fibers and smooth ones, which are controlled by the autonomic nervous system. The oropharyngeal stage of the basic or fundamental swallowing is a complex, stereotyped sequence of excitatory and inhibitory events. It involves a set of muscles that always participate in this fundamental motor pattern and therefore, these muscles have been termed obligate muscles. In addition to the obligate muscles, other muscles, such as extrinsic tongue muscles, facial muscles, lip muscles and elevator mandible muscles, may or may not participate in swallowing, depending on either the species or the swallowing conditions, and therefore constitute facultative swallowing muscles. Muscular events are described below[46].

The oral phase of swallowing recruits the jaw closing muscles (i.e. temporalis, masseter and medial pterygoid) to stabilize the mandible. As a result, the type of bolus affects the recruitment of the jaw closing muscles[27];

The perioral-facial muscles are the first recruited during the oral phase of swallowing to provide an anterior seal of the lips. In healthy human subjects, orbicularis oris and buccinator muscles firmly close the mouth to prevent food from escaping, flatten the cheeks and hold the food in contact with the teeth. It has been observed that the perioral muscle activity is ended just before the pharyngeal phase of swallowing, while the masseter activity can continue or reappear during the pharyngeal phase of swallowing[27](Figure 1.11);

The styloglossus and hyoglossus muscles force the root of the tongue against the soft palate and posterior pharyngeal wall[44];

The tongue movements that initiate swallowing require the concomitant contraction of the mylohyoid, geniohyoid and digastric muscles (submental muscles- SM)[44](Figure 1.12);

SM contraction initiates swallowing, and it continues until the completion of the oropharyngeal swallowing process, since they pull up the hyoid bone into an anterosuperior position, which elevates the larynx and initiates other reflexive changes that constitute the pharyngeal phase. As we will largely describe, when a swallow is initiated voluntarily, the contraction of the SM muscles should be controlled by at least two routes. During the initial part, SM muscles should be activated by the cortical drive either directly or via the brain stem CPG. The latter part of SM muscle activation should, however, be controlled by the CPG of the brain stem network, especially in the period immediately after the onset of laryngeal upward movement, which is an important and early event of the pharyngeal phase in voluntarily induced swallowing. In many of the dysphagic patients, the onset of SM is extremely prolonged, which indicates the difficulties of the cortically induced triggering mechanism due to the involvement of the corticobulbar fibers[27]. SM activity seems to be influenced by the body posture in upright position the electromyographical activity was larger than the one detected in supine position[70].

The elevator and tensor veli palatine muscles elevate the soft palate, with additional shortening and dorsal thickening until approximation against the posterior pharyngeal muscle.

The middle and inferior pharyngeal constrictor muscles narrow the hypopharynx which contributes to the peristaltic wave. The epiglottis tilts dorsally and downward, thanks to muscular elevation of the larynx and the contraction of the floor of the mouth (submental muscles), along with elevation and posterior movement of the hyoid bone[44];

The Cricopharyngeus (CP) muscle is a striated muscle sphincter situated at the pharyngoesophageal junction. It is one of the most important muscles for the evaluation of neurogenic dysphagia The CP sphincter muscle is organized with motoneurons both tonically and physically activated. The muscle is tonically active during rest and this continuous activity ceases during a swallow in human subjects. During a swallow, tonic motoneurons supplying the CP muscle are first inhibited and the CP sphincter is relaxed. Consequently, during the rebound burst, phasic larger motoneurons fire transiently to close the sphincter as fast as possible after passage of the bolus and the tonic motoneurons are re-excited. Although both units are under the control of the CPG, both are also influenced by sensory and cortical inputs[27] (Figure 1.13).

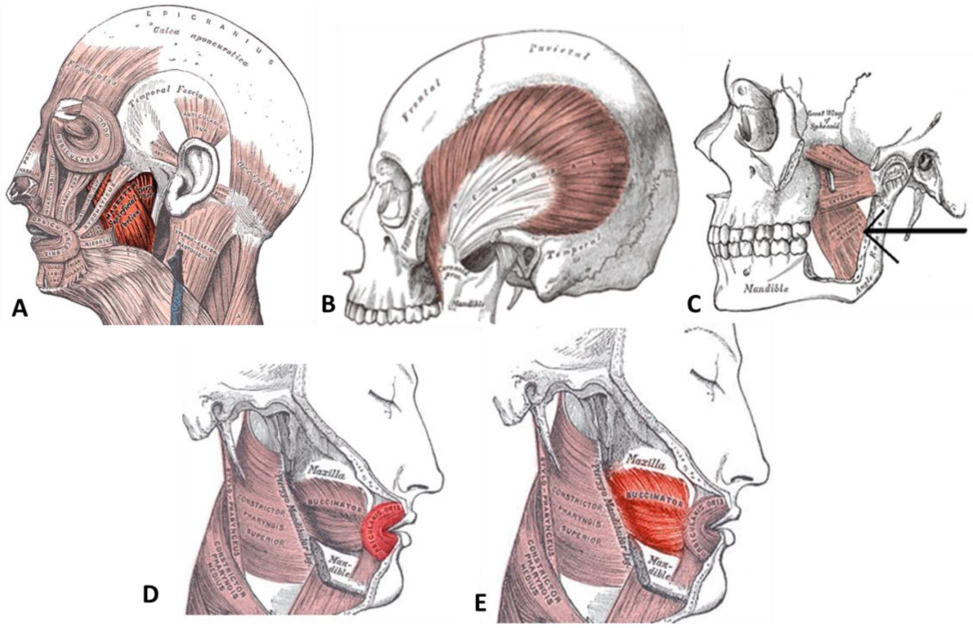


Figure 1.11: Representation of the jaw closing muscles (A-C) and some of the perioral muscles (D-E): A: masseter muscle, B: temporalis muscle, C: medial pterygoid muscle, D: orbicularis oris muscle, E: buccinators muscle (from Gray's anatomy, 2008)[71].

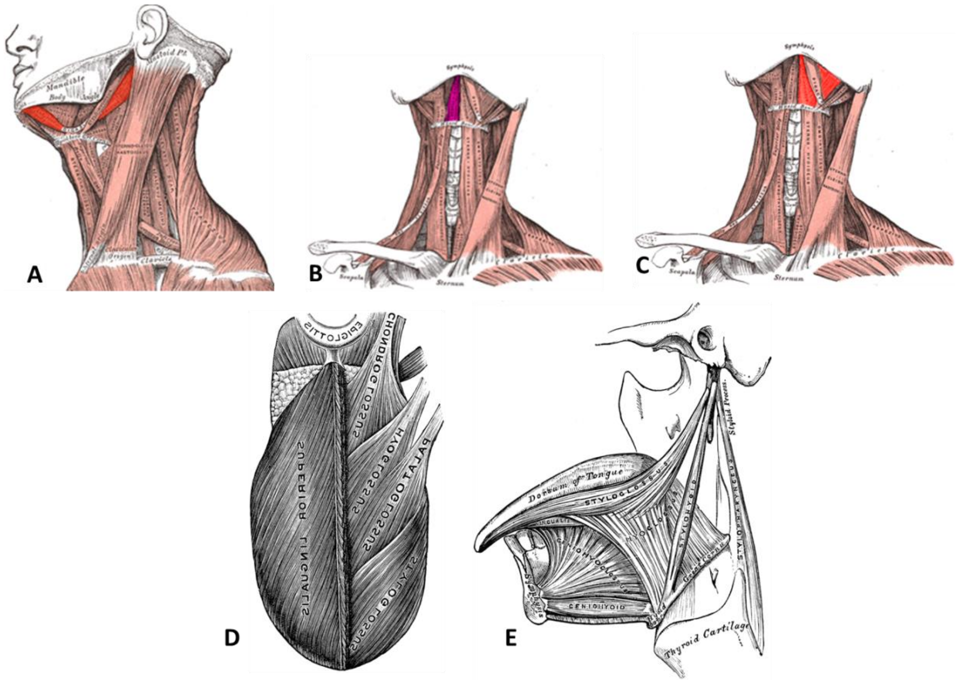


Figure 1.12: Representation of the submental muscles (A-C) and the tongue muscles (D-E): A: digastric muscle, B: genyohyoid muscle, C: mylohyoid muscle, D-E: tongue muscles from different views (from Gray's anatomy, 2008)[71].

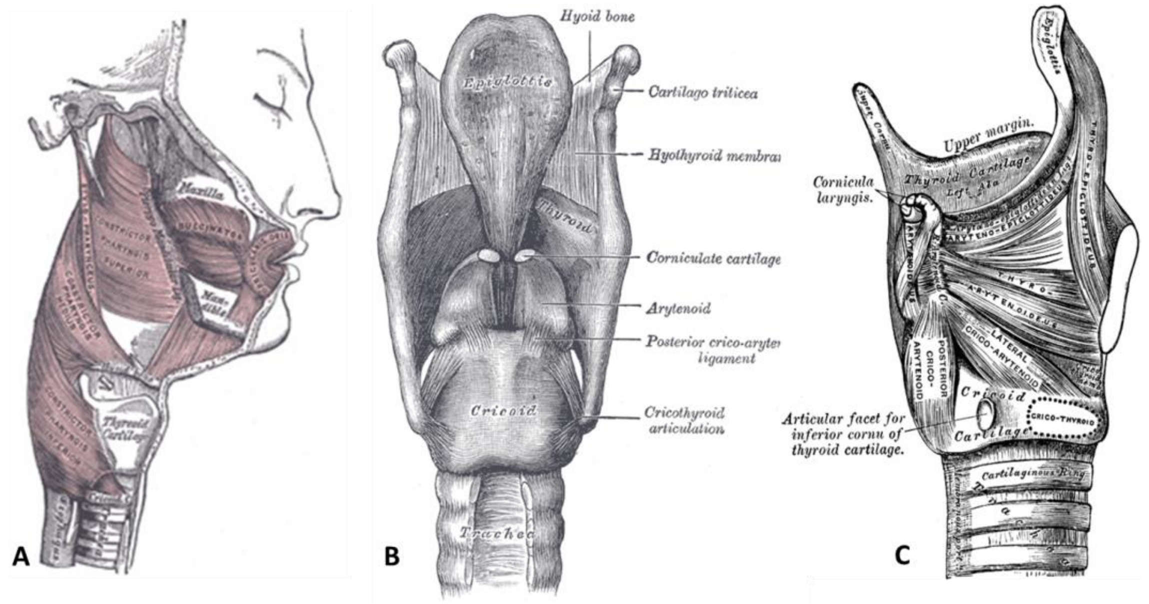


Figure 1.13: representation of the pharyngeal muscles (A) and the larynx structure (B and C) (from Gray's anatomy, 2008)[71].

1.3.8 Infantile neurophysiology

From the fetal period to the adolescence several evolutions take place in human: anatomic, neurologic, motor, cognitive, linguistic, social and emotive and then of course swallowing and breathing. All these changes occur during this period in distinct moments that need to be analyzed separately.

FETAL PERIOD

Unfortunately, knowledge about human nervous regulation in this period is limited. Nevertheless, it seems that the central neural patterns necessary for swallowing appear before the respiratory ones and the gustative fibers, whose receptors are already formed at the 12th week, are able to modify the frequency of the swallowing acts[72].

0-6 MONTHS

This period is characterized by breast- or teat-feeding. From the nervous regulation point of view this is a problematic period for swallowing. In fact, for the first time in this period the new born needs to regulate both breathing and swallowing. In these months a progressive improvement of the neuronal telencephalic connection between the respiratory and deglutitory centers is observed.

Finally, in this period many oral reflexes are clinically found, and they will be lost after the second year of age. In a neurophysiological point of view, the cause of the disappearance of these reflexes after this period is the consequence of an intense process of corticalization, intended as the coordination of the tronco-encephalic reflex centers by the increasing myelination of the cortical circuits, which is maximum during this period. In other words, after the complete maturation and myelination of the cortical circuits these oral reflexes will disappear.

6-24 MONTHS

The neurophysiological modifications of this period are significant: oral and pharyngeal reflexes disappear, oral coordination for the bolus preparation appears and the pharyngeal phase provides a laryngeal excursion. The oral preparation phase, which appears for the first time in this period, involves a primary voluntary action. For this reason, in these months an increase in connections between the neurological structures above and under the mesencephalic roof is observed. In fact, the voluntary action requires the complete involvement of the nervous structures involved in movement: the motor area, the motor programming area, the basal ganglia and the cerebellum.

Finally, the masticatory function slowly starts in this period with a consequent modification in the cortex area involved in swallowing: the masticatory cortex area is indeed more caudal than the suction cortex one[73].

2-6 YEARS

This period is characterized by a significant increase in the masticatory function that is accompanied by a specific change in muscular pattern of the masticatory muscles[74]. In animals, this evolution has been linked to the transition from the suction activity to the masticatory one[75].

Finally, the masticatory cortex area in the frontal lobe is activated for the first time in this period.

6-12 YEARS

This period is characterized by the disappearance of the tongue thrust and by the development of the adult swallowing. This change is accompanied by a specific neural regulation that allows the contraction of the elevator muscles and a modification in tongue behavior.

1.4 The Atypical Swallowing (AS)

In infants, the swallowing function is part of the oral reflexes that we have already treated before (chapter 1.2.3). With growth, these reflexes fade and disappear completely, and a more conscious swallowing pattern slowly matures in the first years of life.

The oral reflexes represent the fundamental feeding motor schemes in infants. These reflexes consist of suction, biting, swallowing, cardinal points etc.

In infants, the swallowing function is considered as part of the complex suction function which begins with the search for the nipple to end with the descent of breast milk into the pharynx and esophagus. During this function the tongue completely fills the oral cavity and interposes itself between the alveolar processes of the maxilla and the mandible, then the lips and cheeks contract to prevent the liquid from escaping from the oral cavity. In this way it is possible to affirm that infants swallow with the lips opened, holding in the mouth the nipple and part of the breast. During suction the mandible elevates pushing the tongue upwards, in this way the tip of the tongue curves and pushes the nipple and the breast against the hard palate, squeezing the milk towards the mouth isthmus. With neurological maturation, the feeding oral components become voluntary and already at the second semester of life the oral mechanisms increase their activity. This maturation is usually linked with the eruption of upper and lower incisors that allow a more defined opening and closing movement of the mandible and reduce the space for tongue position and then starting the mechanism of adult type swallowing.

This mechanism will be completed in the following months thanks to the neuromuscular maturation and the appearance of the erect posture with a consequent change in the gravitational forces of the mandible. The passage to a solid feeding, the starting masticatory desire and the articulatory development complete the transition to a mature swallowing.

The main characteristics of adult swallowing are dental arches in stable occlusion, mandible stabilized by elevator muscles, tongue tip located against the palate, up and back to the upper incisor, and minimum contraction of lips.

If this mechanism is not achieved, swallowing persists as “atypical swallowing” after the fifth year of life, then it’s considered like a dysfunction and can potentially affect the growth of the stomathognatic apparatus resulting in malocclusion[1,5,40].

In adult swallowing, the most active muscles are those with trigeminal innervation (V) as temporal, masseter, internal and external pterygoids, while the styloglossus muscle (XII) contraction allows the formation of the so-called "lingual back" with consequent elevation of the tongue considered as a preliminary moment of the pharyngeal phase. Furthermore, the styloglossus muscle, together with the palatoglossus one, regulates the lingual motility: the tip of the tongue is located against the retroincisal papilla, the back occupies the palatine arch while the root is 45° inclined to the pharyngeal wall. The different coordination of the supra and infra-mandibular muscles allows for the different modalities of mastication (crushing, grinding, etc.).

During adult swallowing, there is no contraction of perioral structures, orbicularis and mentalis muscle[20] and labial closure is passive thus presenting a good orofacial muscle balance.

In atypical swallowing the most active muscles are those with facial innervation (VII.). Specifically, the digastric muscle, which acts to get the mandible downward and backward, and the hyoglossus muscle, which acts to get the tongue backwards, together offer the classic configuration of the "spoon tongue". In this case the oral function is located "forward", with the hyperactivation of the orbicularis and mentalis muscles and the reduced contraction of the masticatory muscles. The tongue tip is in contact with the palatal surface of the anterior teeth or between the dental arches, the lingual back is collapsed unilaterally or bilaterally, the root is in contact with the posterior part of the hard palate and the anterior wall of the pharynx. The set of these functional alterations (Table 1.1) leads to orofacial muscle imbalance[76].

Structures and Functions	**Normal**	**Atypical Swallowing**
Orofacial musculature activity in swallowing	**Tongue**: rises up against the retroincisal papilla **Orbicularis**: active against upper incisors. **Masseters**: they are contracts, active. **Mentalis**: passive, inactive.	**Tongue**: against or between the teeth. **Orbicularis**: inactive or hyperactive against the upper incisors. **Masseters**: inactive or hyperactive. **Mentalis**: contract, active.
Hard palate	**Normal**. The palatal rugae appear smooth and rounded.	**Ogival**. The palatal rugae appear deep, angled, sometimes sharp.
Labial competence at rest	**Lips**: competent, neutral. No contraction of the perioral muscles.	**Lips**: incompetent, open. Contractions of the closing perioral muscles.
Nose-chin space	Unchanged, stable (ensured by the masseter muscles tension).	Increased (mandibular lowering).
Cervical-pelvis-mandibular angle	**Right**: the lingual dorsum "corresponds" to the calciform papillae and it is in contact with the junction between hard and soft palate.	**Obtuse:** the lingual dorsum is absent. The area of the calciform papillae is more backward: the empty space between the tongue and the palate is clearly visible
Breathing Gaudin nasal reflex Rosenthal test	Nasal Nasal wings are dilated Negative	Oral/Mixed Nasal wings are not dilated Positive
Temporo-mandibular-joint	All functions are normalized: • opening • propulsion • lateral movements • symmetrical movements No pain, clicks, roars and rumors are observed.	The opening function can be reduced and asymmetrical. The propulsion function is limited due to the rigidity of the TMJ accompanied by deviations, rumors, roars and click. The lateral movements are insufficient and asymmetric. Painful symptomatology in the TMJ, roars or clik, block or hypomobility in closing, opening and mandible movements. Bruxism. Tension or pains in the larynx, neck and back muscles. Persistent headaches.
Speech and phoniatric articulation	No disorder related to swallowing	Articolatory disorders are correlated: - s /t/ /d/ /n/ /l/

Table 1.1: comparison of the charactristics of normal and atypical swallowing patients (Andretta 2001)[76].

Atypical swallowing is a problem with very high incidence in the population. According to Proffit the incidence of AS is about 50 percent at 5 years old, it decreases significantly in early mixed dentition until 38% at 6 years and still decreases when second dentition is completed at 30% but persists in adults in about 15% of subjects suggesting that functional traits change during growth and benefit from the best occlusal stability achieved at the end of the second dentition[1,40].

According to Ovsenik, the number of children with atypical swallowing decreases from 55% at three years of age to 35% at five years[42]. In another study it was shown that in a group of 8-year-old children the atypical swallowing pattern persisted in 40% of the sample[77].

The etiopathogeny of AS is multifactorial[78]; in fact bad habits[79] environmental and hereditary factors, oral and allergic diseases could be involved in its onset[39,40].

Regarding bad habits, finger sucking, onychophagy, bruxism and prolonged use of the dummy are the most relevant ones. Other causes can be traced to the prolonged artificial feeding and delayed weaning, short lingual frenulum, genetic factors such as the morphology of the palate and the airways and hereditary deformities, hypertrophic adenoids and tonsils with a tendency to oral respiration, allergic rhinitis, postural anomalies of the skull, jaw and tongue, and neurological deficiencies.

The concomitance of the physical factors may give rise to secondary atypical deglutition, which differs from the primary form which, instead, has a psychological origin, due for instance to parental over-attention, and is often associated with a general infantile attitude, sleep, feeding, digestive and behavioral disorders (defense attitude to external stressful situations)[43].

The tongue posture at rest and tongue movements are, in this context, important factors that influence the balance between oral forces. Therefore, it is important to study how the lingual body behaves within the oral cavity during the swallowing act.

1.4.1 AS classification

Clinically, atypical swallowing can be classified as simple or complex[80].

SIMPLE AS is characterized by the contraction of lips, mentalis muscle and the masticatory muscles, the dental arches are in contact but the presence of an anterior open bite (in these cases well circumscribed) forces the tongue in a forward position between the incisors, with the aim of creating an anterior seal[81]. Usually, patients with simple AS are thumb- or dummy-sucking and tongue thrust is maintained as a consequence of an open bite that was created previously created by the bad-habit. The increased overjet (OVJ) is typical in these cases because of the buccal inclination of the upper (and sometimes lower) incisors[82]. In these patients, orthodontic treatment can be decisive in resolving both malocclusion and tongue dysfunction.

COMPLEX AS is characterized by the contraction of labial, facial and mentalis muscles, but there is no contraction of the masticatory muscles[83]. In this case, the jaw stability is guaranteed by mimic muscles, the dental arches are not in contact during swallowing as the tongue interposes between the arches and not in a precise point as in the simple form. In fact, in this form not all the patients show an anterior open bite. Usually complex swallowing patients show oral respiration and present often a history of chronic and allergic respiratory diseases. In these patients, the occlusal stability after orthodontic treatment is always uncertain.

Finally, **RESIDUAL INFANT** AS is characterized by the persistence of the swallowing reflex after the eruption of permanent teeth. There are evident contractions of the labial and facial muscles, the mimic muscles stabilize the mandible during swallowing, the tongue exerts an elevated anterior thrust. Masticatory effort in these patients is high as they are not able to coordinate muscles for biting and chewing and the “mastication” takes place between the palate and the tongue tip. These patients can show both open bite (if the centrifugal force of the tongue prevails) or deep bite (if the centripetal force of the facial musculature prevails) accompanied by proclination of upper and lower incisors as a consequence of the tongue position at rest. Nevertheless, the most common feature in these cases is the second skeletal class, first division, accompanied by an increase in the vertical dimension as a consequence of the clockwise rotation of the mandible.[84] In these cases the combination of myofunctional and orthodontic treatment is necessary.

In literature, most of the authors who deal with the subject of "atypical swallowing" consider as a dysfunction not only the non-physiological lingual movement that occurs during the swallowing act, but also the alteration in the tongue rest position[85]. According to Profitt, in fact, the pressure exerted by the tongue against the incisors during swallowing is too short and it would not be sufficient to explain the incisor proclination[1]. In this sense, it would therefore be more appropriate to speak about "tongue thrust", rather than "atypical swallowing" in the strict sense[43].

1.4.2 Swallowing: form and function

Orthognathic growth is determined by hereditary factors and by the influence of the static and dynamic balance of the orofacial musculature[84]. In this context, the Moss Functional Matrix theory, which highlights the close relationship between form and function, is explicit. It is well known that the development of skeletal structures is influenced by the activity of nerve and muscular components, such as the brain, the tongue, or the masticatory and respiratory muscles, which can positively or negatively model the development of structures around which they perform their function.

Form and function influence each other: the form allows the orofacial muscles to perform various oral functions in a physiological or pathologic way, while muscle activity can influence the direction of growth in a natural or pathological way. Therefore, it is important to take into consideration also the physiological posture of the tongue: it represents the starting point for each functional cycle, so that any neuromuscular anomaly generally develops an altered function[86].

At rest, the tongue is located inside the dento-alveolar arches: the dorsum is in contact with the mucosa of hard and soft palate; the tip, in most cases, is located behind the retroincisal papilla or, in other cases, on the lingual surface of the lower incisors; it only rarely occupies a lower position.

At rest, the mandible dental arch is not in contact with the maxillary one, the space so created is also known as free-way-space (or interocclusal free space) and is about 0.5-2 mm.

The lips are closed without effort or evident contraction. The mandibular position at rest is balanced and regulated by muscle tone and antigravitational myotatic reflexes; it is not constant as it is influenced by various factors such as the waking state, fatigue, stress, and respiratory or mental disorders.

According to multidisciplinary research, the muscles of the tongue, such as the masticatory ones, can be considered as an integrative part of a postural balance that involves also the neck and shoulders muscles, linking each other thanks to the connection to the hyoid bone[87].

The oral cavity can be considered as a muscular corridor: the tongue is contained inside and, outside, there are the perioral muscles. The physiological balance between these two muscular components ensures a harmonious development of the dental arches. The alteration of this balance often causes malocclusions that can be dental, skeletal or mixed[84].

Malocclusions (Figure 1.14) are characterized by the presence of an altered relationship between the teeth of the upper and lower arch and may have dental alveolar or skeletal origin. Types of occlusion can be classified as Class I (normal occlusion), Class II (distal occlusion), or Class III (mesial occlusion) with or without maxillary displacement and contraction[6].

Figure 1.14 Orthodontic skeletal classification: from the left Class I, Class II, Class III.

Atypical swallowing represents one of the most frequent dysfunctions that can potentially influence the development of the oral structures. It is mostly correlated to a series of other factors (hereditary, artificial feeding, non-nutritive suction, macroglossia, ankyloglossia, oral respiration, neurological deficit) that can either support or aggravate the clinical situation.

Finally, a recent research demonstrates a prevalence of myofunctional orofacial disorder in the general population (38%) and particularly in developing children presenting articulation disorders (81%)[88]. In fact, the presence of atypical swallowing, oral respiration, orofacial muscular imbalances and malocclusions represent the most common dysfunctions related to the disorders of speech articulation[89].

According to a recent cephalometric study, patients with AS showed a clockwise rotation of the mandible with an increased OJ and a decreased overbite, which seemed to be compensated by a vertical growth of the alveolar processes and molar extrusion. The proclination of the upper incisors appears to be mainly a consequence of the lingual posture at rest rather than due to the tongue thrust exerted during swallowing. Authors finally recommend interceptive orthodontic treatment in these patients to prevent the compensatory effects related to the maintenance of the atypical swallowing disfunction over time.

1.4.3 AS treatment

As already explained, the indications on the timing, duration or onset of atypical swallowing are not clear yet. Clinical management of concomitant habits, such as non-nutritive suction (NNS) and oral breathing, can lead, directly or indirectly, to a resolution of tongue thrust. The therapy can be implemented through two types of intervention: mechanical or myofunctional therapy (MFT).

Mechanical therapy uses devices that aim to achieve a normalization of the lingual posture, preventing abnormal interpositions and thrusts. These devices can be fixed or removable: lingual shields (lingual grid), lingual stimulators (Tucat's pear) or functional devices (Andresen). However, the forced nature of these intra-oral devices may limit its application[6].

The correction of the malocclusion can then be joined by myofunctional therapy, or a series of exercises designed to restore a correct lingual function. Recent studies, in fact, have shown that orthodontic treatment, in the presence of bad habits and significant functional alterations of the stomatognathic apparatus, is not always sufficient to correct the oral dysfunction[43].

In these cases, the best therapy is represented by a multidisciplinary approach considering more specialists such as the pediatrician, the orthodontist, the speech therapist, the phoniatrist, the otolaryngologist and the pediatric neuropsychiatrist[90].

In literature there’s still no evidence about wether orthodontics or MFT should be prioritized and both these categories of specialists seem to have discordant opinions on this matter[91]. According to Mason if a posterior crossbite is present, orthodontics should be performed before than MFT[92]. According to Proffit the priority should be given in assessing a frontal dental contact[1].

The ideal age to start treatment has also been debated[7]. Some authors recommend MFT treatment before the age of 10 years[6,93,94]. However, there are clinical situations that require the contemporary intervention of the orthodontist and the speech therapist, for example when the therapy of atypical swallowing with myofunctional exercises is associated with the need for expansion of the upper jaw[84]. In addition, others suggest to wait at least until patients are 10 years of age because of the possibility of spontaneous closure of the anterior open bite (AOB)[1].

There are several conditions that contribute to the correction of AS. Most of them are related to patient's age and compliance[95]. According to Condò et al (2012)[96], a logopedic therapy performed during the period of deciduous dentition or primary mixed dentition leads to significantly better results when compared to therapies undertaken later. According to some authors, the incidence of AS is about 50 percent at 5 years old, it decreases significantly in early mixed dentition until 38% at 6 years and still decreases when second dentition is completed at 30% suggesting that functional traits change during growth and benefit from the best occlusal stability achieved at the end of the second dentition[1,40,42].

On the other hand, according to a recent cephalometric study an interceptive treatment in AS patients is reccomended to prevent the compensatory effects related to the maintenance of the atypical swallowing disfunction over time.

1.4.4 AS evaluation procedures

The analysis of the swallowing process is an important phase during the clinical evaluation of the stomatognathic system. It is stated that this physiological task can occur more than 2400 times per day and thus it is important to evaluate its progress step by step. There are many clinical conditions related to a non-physiological swallowing mechanism, such as atypical swallowing or dysphagia. The most important phase of the clinical pathway is the right diagnosis, to ensure the morphology of the different structures involved, the muscular coordination and the neural integrity. A complete examination as well as an anamnestic questionnaire are crucial stages in the diagnostic process.

In addition, also instrumental analysis can be used. Many methods can be listed; among all the techniques, video fluoroscopy (VF), fiberoptic endoscopic evaluation (FEE) and surface electromyography (sEMG) are the most used[97]. Video fluoroscopy is a radiologic exam, in which the passage of the bolus from the oral cavity to the stomach is evaluated. The patient is asked to eat a contrast medium and thus, after x-rays exposition, the passage of the bolus is monitored thanks to a connected monitor (Figure 1.15).

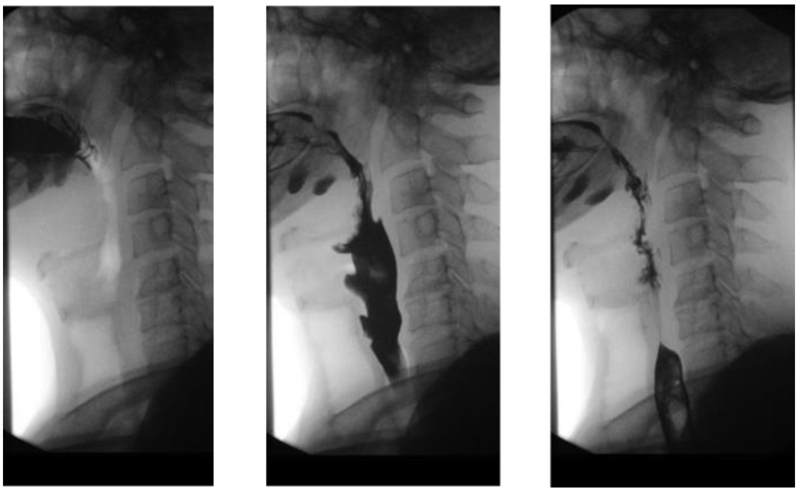


Figure 1.15: an example of videofluoroscopy during swallowing (http://swallowingdisorderfoundation.com/how-aging-affects-our-swallowing-ability/).

The endoscopy was introduced since 1988 as an alternative to the video fluoroscopy. It is composed by a flexible endoscope, which passes trans-nasally to obtain a superior view of the pharynx and larynx. Although FEE does not show swallowing directly, the presence of subglottic residue and oropharyngeal secretion indirectly indicates the wrong progression of the movements[98] (Figure 1.16).

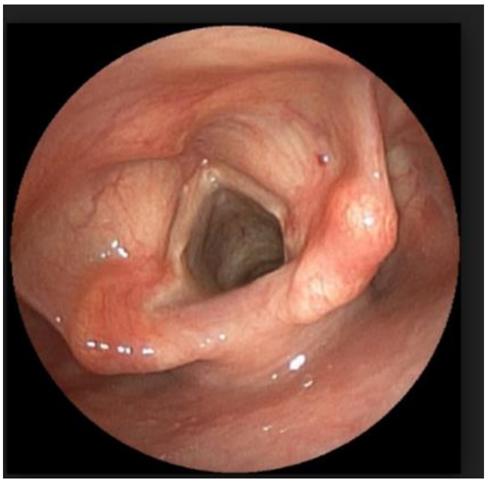


Figure 1.16: an example of endoscopy. Aditus to the larynx can be seen (https://www.medicitalia.it/minforma/gastroenterologia-e-endoscopia-digestiva/1675-la-gastroscopia-transnasale-sempre-piu-gradita-da-pazienti-e-medici.html).

Furthermore, sEMG is another method that provides important information about the muscles involved during swallowing. sEMG is a non-invasive, radiation free and cheap diagnostic technique, which gives information about muscular activity. It registers the myoelectric signal, derived from the electric field generated from muscle fibers depolarization and transmitted to skin thanks to surface electrodes attached to skin. For this reason, it is suitable only for superficial muscles. It was demonstrated how electromyographic potentials in the muscle groups that are effective in swallowing can work reliably[24,98] (Figure 1.17).

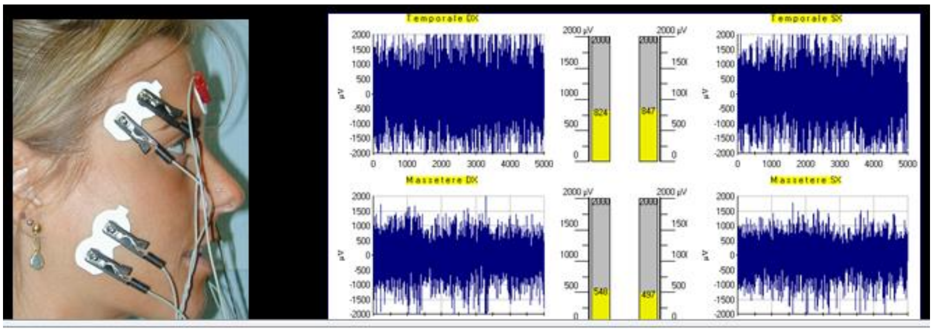


Figure 1.17: an example of surface electromyography of anterior temporalis and masseter muscles.

The main advantages of VF are the integrated observation of all the swallowing phases, that is, observation of the oral preparatory phase and oral transit phase, of the elevation and anterior displacement of the hyoid-larynx complex, of the upper esophageal sphincter opening and of esophageal transit[99]. Nevertheless, VF gives qualitative analysis about the swallowing process and the evaluation of the results is subjective, in addition there are some disadvantages such as the necessity of patient cooperation and transport, failure to directly show the nasopharyngeal, oropharyngeal and laryngeal anatomy, evaluation of only motor ability, risk of aspirating the opaque material and risk of exposure to serious radiation in repeated applications. FEE is reported to be safer, more sensitive and better tolerated than VF. Moreover, the diagnosis and treatment of dysphagia can be ensured without the cooperation and mobilization of the patient[98]. Despite a lack of a consensus, FEE seems to be as an alternative to VF. There have been many controversial opinions on the clinical application of sEMG. The major concern was related to the lack of reliable criteria for comparative and longitudinal evaluations.

In fact, electromyographical signal is influenced by many factors: the type and position of the electrodes, head and back position, muscular cross-talk etc.[100]. Nevertheless, thanks to standardized protocols, the cited factors are limited and are so quantitative comparisons, both comparative (between muscles, between subjects) and longitudinal[100,101]. Considering the muscles related to the stomatognathic system standardized protocols have been developed, for the masseter, temporalis, sternocleidomastoid muscles[102–104].

Recently, a standardized protocol on muscular activity of masseter (MM), anterior temporalis (TA) and submental muscles (SM) during saliva swallowing has been defined[25], the normalized data have been obtained and are available[26]. Further studies about the oral phase of swallowing are then needed to understand the muscular activation pattern to better help the clinicians in their evaluations.

Binge able to evaluate the muscular activity involved in swallowing could help the clinician in establishing diagnosis, setting prognosis, intercepting or investigating the effects of treatment either myofunctional or orthodontic ones.

Another useful tool in detecting tongue strength is the Iowa oral performing instrument (IOPI) (Figure 1.18). It was developed in the early 1990s to measure the pressure generated by contact between the tongue and palate offering speech-language pathologists an objective of assessing tongue strength and endurance.

It has been used primarily in the US over the past two decades. IOPI was originally developed to examine the relationships between tongue strength or endurance and speech motor control; its role has subsequently been extended to examine relationships with swallowing.

Over this time several research studies have been conducted using IOPI on both healthy and clinical populations to provide data that can be used to establish normative IOPI values for tongue strength and endurance and to investigate the possible influences of age, gender, and medical condition on these values[105].

Figure 1.18: the Iowa oral pressure instrument (IOPI) is uded to detect tongue strength and endurance.

IOPI is a portable, handheld device that uses an air-filled pliable plastic tongue bulb (approximately 3.5 cm long and 4.5 cm in diameter with an approximate internal volume of 2.8 ml) connected via a 11.5-cm-long clear plastic tube to measure peak pressure [in kilopascals (kPa)] exerted on the tongue bulb. It contains pressure-sensing circuitry, a peak-hold function, and a timer. Researchers have used this device in many studies to measure tongue strength and endurance with excellent interrater reliability[106,107]. Currently it is one of the most commonly used measurement techniques available to objectively measure tongue strength and endurance[105,108].

1.5 Myofunctional Therapy (MFT)

Myofunctional therapy (MFT) was born at the beginning of 20th century. Rogers and Robin for first defined the etiopathogenetic effort of postural and functional anomalies of the orofacial muscles on the stomatognathic development. In the same years Lischer proposed muscular exercises as the election therapy to treat the altered function of the orofacial muscles and defined it as "myofunctional therapy".[78,109,110]. In the 50's Straub highlighted the link between bad habits and the orofacial muscular imbalance.[4,111]. In the 60's Garliner spread his therapeutic method becoming the first international functional approach to treat the alteration of oral and facial musculature.[39,112]. To do so, this method is based on the education/re-education of all the multi-functions involved in the stomatognathic apparatus: swallowing, breathing, chewing, speech articulation, esthetics and sensory activities. All these specialized functions, even if in different ways, belong to the same system called "oral functions". The speech therapist has to take in consideration all these functions as they are characterized by mutual interactions[20]. The aim of MFT is to treat the orofacial myofunctional disorders (OMD) that include the alteration and dysfunction of the orofacial musculature that interferes with the growth, development, and functions of the stomatognathic apparatus[113]. During MFT the speech therapist must re-establish the correct function by eliminating the deviated pattern, creating new motor images, adopting them and making them automatic.

The acquisition of the body scheme linked to the oral structures, intended as elaboration, fixation and memorization of the motor engrams from which the cortex draws all the reference elements to constitute the different automatisms, allows the execution of the various complex motor sequences in physiological situations.

However, when the parafunctions take over, when the series of motor sequences (or the acquisition of habitual postures) is unsuitable, the body scheme is altered. In these cases, the kind of therapeutic intervention needed to correct these functional alterations is myofunctional therapy.

Andretta (2001)[76] defines MFT as a treatment that uses the muscular force to promote the functional balancing of the orofacial system. This goal is achieved through the re-education of atypical swallowing, oral breathing, alterations of mastication, speech, phoniatric articulation, malocclusion, postural problems and temporo-mandibular disorders. It therefore consists of a series of exercise aimed at erasing atypical motor schemes and re-educating the neuromuscular system with new physiological patterns. Myofunctional therapy is a regular and individualized program based on exercises series that must be repeated in a time interval of at least two / three hours between them. In fact, the muscle fibers need an adequate period known as "functional recovery" to permit an efficient performance. The aim of the treatment is to obtain a functional change, stable over time, preventing the onset of future pathologies linked to muscular imbalances. From a prevention perspective, bad habits such as atypical swallowing, can be eliminated starting from three years of age, as the high correlation between bad habits and malocclusion and consequent muscular imbalance have been demonstrated[76].

The speech therapy can be divided in three phases:

1. Phase of muscle function restoration. This physiotherapeutic phase is characterized by the need to make the muscles involved in swallowing able to perform their function. During this phase, these muscles must be re-educated with a constant increase in the number and difficulty of the proposed exercises, but always considering the abilities of the individual patient. The first aim of the therapy is to eradicate the bad habits, otherwise the treatment would not be effective.
2. Phase of teaching. In these phases, the therapist is aimed at teaching the patient how to properly swallow both solids and liquids. In this period, the physiotherapeutic activity is protracted to maintain the muscle tone and to further improve the functioning of individual muscle groups.
3. Phase of the mental conditioning. In order to permit the maintenance of the changing function, a new brain engram must be created to replace the previous one permanently.

Different methods of myofunctional therapy do exist. Among them the better known are those of Daniel Garliner, Barrett and Hanson, Del Grande and Vernero, Castillo, Fourier, Andretta and Levrini. All the methodologies proposed by these authors have common theoretical principles, but they differ in their clinical application.

1.5.1 The Garliner Method

The international guidelines support the methods of D. Garliner[112]. Daniel Garliner was the first in Europe that spread and applied MFT, discarding the simple concept of tongue thrust, centered on open bite or over-jet exclusively, in favor of a wider and more global vision based on the concepts of form and function[112].

According to the author, in a normal swallowing function, the orofacial muscle strength is comparable to a triangle (Figure 1.19).

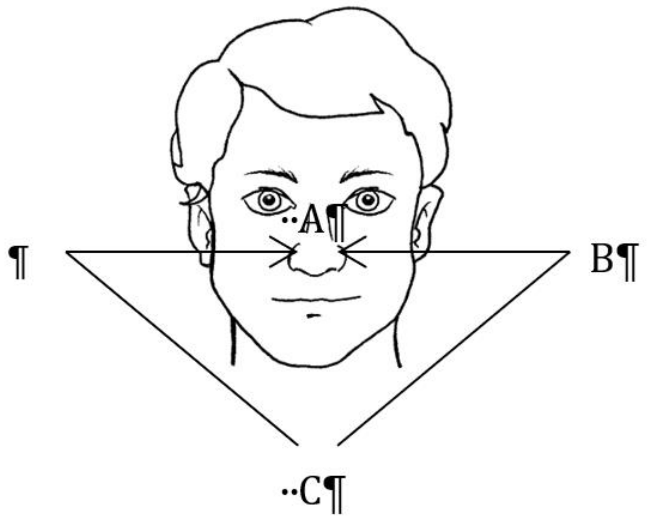


Figure 1.19: the Garliner's triangle of muscular strength (Garliner 1970)[112].

The skeletal and dental development is continuously influenced by the orofacial muscles[76]. If you consider the masseter and buccinator muscles as point A, you notice that they move laterally towards the teeth. The tongue as B point, which is the leading muscle in this force field, is directed against the anterior part of the hard palate which can sustain an enormous amount of pressure. At the same time, the lips exert a backward force against the upper incisors. As point C the mentalis muscle remains inactive. There is no frontal force against the teeth (only lateral and posterior forces). The hard palate is suitable to withstand a constant stress that affect the orofacial muscle balance.

TMF aims to create and establish new motor images by eliminating the deviated patterns and oral habits. It also promotes the normalization of growth and muscle function, supporting the orthodontic therapy, preventing or correcting any speech or TMJ disorders, and improving the aesthetics. Therefore, it offers benefits deriving from a harmonious balance between forms and functions, centrifugal and centripetal thrusts, and between the different muscular forces involved. According to Garliner, patient motivation, the involvement of all muscle areas and consolidation of the new motor behavior are fundamental to carry on a proper MFT.

Garliner proposes a therapeutic method based on 22 sessions within 12 months, considering the time needed to restore the altered oral functions. These sessions provide a period of intensive care (weekly/biweekly sessions) and a follow-up period (spaced sessions).

According to him, the proper age to begin the MFT is between 7 and 10 years.

Specifically, the treatment provides:

- awareness about the location of the retroincisal papilla, as a reference point for the tongue tip;
- re-education of the anterior, middle and posterior part of the tongue, using orthodontic elastics.

These allow the patient to memorize the exact position of the tongue, and to increase its dynamism during the phonatory and swallowing acts;

- strengthening of masticatory muscles
- strengthening of the orbicularis muscle through the use of "button" and "small weights"
- lengthening of the upper lip
- respiratory re-education

Andretta, promoter of MFT in Italy, proposes a therapeutic protocol developed on the basis of the Garliner method. This method involves a cycle of 12-16 sessions, depending on the presence or absence of bad habits, for a period of 6, 9 or 12 months. In the first month and a half the sessions are held weekly. After the first six weeks, the frequency gradually decreases: first every two weeks, then every three weeks, then once a month for two months and finally, once every two months for four months. The patient recruitment is personal, providing an exclusive relationship between the speech therapist and the subject.

Myofunctional training requires the use of specific material (orthodontic elastics, mirror, buttons, cotton rolls).

The main purposes of the therapy are to obtain a proper balance and function of the orofacial muscles and a good aesthetics. To get this, the patients’ motivation and compliance together with a specific and customized treatment are fundamentals[43].

1.5.2 Evaluation of the effects of MFT

1.5.2.1 Clinical evaluation

The evaluation of the efficacy of MFT depends on the possibility to identify and quantify the characteristics of the myofunctional disorder. Also, the evaluation procedure must permit to set a diagnosis. plan a prognosis and analyze the effects of a therapy, considering the functional and anatomical modifications and starting from the etiological factors involved.

Because of the complexity of the orofacial myofunctional disorder (OMD), a complete analysis of all the structures involved is needed. Usually, the oral sensory-motor system is mainly evaluated by Phoniatrists, Dentists and Speech therapists, who deal with the diagnosis and treatment of OMD in subjects with malocclusion[77,114] , oral breathing[115], surgery for tonsillar hypertrophy[116] and temporomandibular disorders[117].

Before proceeding with the evaluation, it is important to collect all the information regarding the oral functions, the disorder’s familiarity, the presence of bad habits and orthodontic or postural problems. During the anamnestic collection it is even necessary to detect the maturity and the compliance of the patient (and, if pediatric, the support of the parents). Then, the observation and evaluation of the morphology, the motility and the functions of the orofacial characteristics are detected through extraoral, intraoral, and functional examination.

Myofunctional orofacial clinical evaluation is necessary for the diagnosis of OMD and can be performed by standardized protocols (in particular the use of quantitative scales, described below) that make it possible to identify the parameters needed to classify the disorder, plan the treatment and obtain outcome measures.

Furthermore, the use of quantitative analyses can be useful not only for clinical purposes but also for research. In the past some authors tryed to express, through a numerical value, the results of myofunctional orofacial clinical evaluation[118].

Among these, the "Interdisciplinary Orofacial Examination Protocol for Children and Adolescents" allows to identify quickly and easily the risk factors that negatively affect the morphological and functional balance of the orofacial region. Also, this test helps to match the different nomenclatures allowing the communication between the different operators[119]. Other protocols have been proposed without having demonstrated any scientific validity. The MBGR Protocol of myofunctional evaluation with scores, proposed for the first time in 2009, has been developed and modified over the years. Although not validated, its effectiveness in identifying subjects with OMD has been demonstrated[115]. Among all the protocols proposed, only two have been validated: the first is the Nordic Orofacial-Test screening (NOT-S), the second is the Orofacial Myofunctional Evaluation with Scores (OMEs). NOT-S is a screening test, provided by using a dichotomous score (from 0 to 1) and is based on an interview and a clinical examination for the screening of orofacial dysfunctions. The OMEs protocol was developed by De Felicio et al in 2008[120], it is a tool for the clinical evaluation of orofacial structures and functions and allows the examiner to express numerically, with a graduated scale, his perception about the characteristics and behaviors observed. This allows different subjects to be differentiated, facilitating treatment planning and providing outcomes measurements.

The OMEs protocol has been initially proposed for subjects between 6 and 12 years with the aim to establish a close relationship between the numerical values proposed by the protocol and the myofunctional orofacial conditions of the patient. Also, the OMEs protocol permits a rapid but exhaustive analysis without needing any particular measuring instruments.

The OMEs protocol represents the evolution of a previous version, the traditional orofacial myofunctional evaluation (TOME) protocol, that has been integrated with the addition of a quantitative scale, through which the clinical characteristics of the subject can be expressed by scores. OMEs does not provide any anamnestic section and is only focused on the clinical examination.

The protocol is divided into four sections:

1. Appearance and posture. The symmetry of the face, the position of the lips at rest, the posture of mandible, cheeks, tongue and hard palate are observed.
2. Mobility. The subject is asked to perform some movements (protrusion, lateralization, elevation, stretching) of lips, tongue, mandible and cheeks.
3. Functions. Respiration (nasal or oral) and swallowing (lips movements, tongue position, presence of dysfunctions and swallowing efficiency) are evaluated.
4. Mastication (laterality and pathological signs).

Finally, the protocol includes a section for the evaluation of the functional occlusion (type of occlusion, mandibular movements, pains, clickings, roars, etc.) without providing any individual scores.

Then, in a second moment, authors proposed a modified version of this protocol in order to obtain more detailed information about the disorders and to better analyze changes after therapy[121].

1.5.2.2 Instrumental evaluation

Many tools do exist for the instrumental evaluation of OMD. A dynamometer permits to measure labial muscular strength, whereas myoscanner allows the strength analysis of the tongue, buccal, mentalis and masseters muscles.

The Payne Technique, invented by E. Payne and Lager, is useful for the evaluation of the lingual posture. This technique permits, through the use of fluorescence, to identify the exact lingual positions during swallowing, mastication, articulation and phonation[20].

During atypical swallowing there are altered non-physiological activities of the masticatory muscles, high levels of mimic muscle activity specially of the buccinator and the labial muscles), and non-physiological movements of the tongue, which is located between (or against) the incisors. The resulting neuromuscular imbalance can influence both the growth direction of the jaws and alveolar processes and the dental eruption[1].

The analysis of the swallowing action can be provided by using other instrumental methods such as pharyngo-esophageal manometry, endoscopy, videofluoroscopy and surface electromyography (sEMG). These methods are useful in the evaluation of the movements of the different anatomical components that are involved during this function[97].

Videofluoroscopy provides qualitative information, however, its interpretation is extremely variable and quantitative data are still lacking. Moreover, videofluoroscopy it implies x-ray exposure. An attempt to quantify data could be applied to the mobility of the hyoid bone during swallowing, which, for example, appears to be different between patients with dysphagia and healthy patients[122].

Regarding the efficacy of MFT in children, two recent electromyographic studies have recorded a significant decrease in masseter and temporal activity in children between 8 and 10 years after MFT[123,124]. In another study, electromyographic analysis of patients with atypical swallowing using ELN (elevator lingual nocturne) showed a significant increase in submental muscle activity, a decrease in the masseter activity and a significant reduction of the duration of swallowing[21].

However, the dynamic phase of growth does not provide a stable system of analysis, because of its characteristic variability and mutability.

2. RESEARCH STUDY

2.1 Introduction and Rationale of the study

Atypical swallowing has been defined as an oral dysfunction that occurs when the correct swallowing maturation does not take place and the typical characteristics of infantile swallowing, such as the tongue thrust, persist even after six years of age.[1,20] The etiopathogenesis of AS is multifactorial[40,78], bad habits, environmental and hereditary factors, oral and allergic diseases could be involved in its onset[1,39,40,79].

According to Proffit, AS prevalence is about 50 percent at 6 years old, it decreases significantly in early mixed dentition until 38% at 6 years and still decreases when second dentition is completed at 30% (14 years old) but persists in adults in about 15% of subjects[1]. Also according to others the percentage of AS at around 12 years old is about 25 -30 percent thus suggesting that functional malocclusion decreases in time[42,125]. The relationship between AS and malocclusion is still controversial and AS can be considered either cause or consequence of dental-maxillary dysmorphisms[1,33,126–128] .

Furthermore, individuals with partial anterior open bite (AOB) and incorrect tongue position exhibit impaired gnostic sensibility of the tongue, which is a symptom of disturbed sensorimotor coordination and is connected with the incorrect position of the tongue resulting in imprecise action and reduced vertical movement of the tongue[129,130]. Cayley reported that children who swallow incorrectly very rarely touch the anterior part of the palate with the tip of the tongue. They perform predominantly horizontal tongue movements and place the tongue between their anterior teeth while speaking and swallowing.[81]

The treatment modality provided to correct AS can be passive (orthodontic) or active (myofunctional therapy-MFT). According to a recent review the biunique causal relation between AS and malocclusion suggests a multidisciplinary therapeutic approach, orthodontic and myofunctional, to solve both problems. An early diagnosis and a prompt intervention have a significantly positive influence on the therapy outcome.[43]

In literature a lot of studies have been published about the use of different orthodontic devices (cribs, palatal spurs, elevator lingual nocturnal appliance-ELN, habit corrector) [21,96,131] with the aim to close the anterior open bite, to reconstitute an anterior contact and stop the dental thrust.[1] However, only a few works have been published about MFT on patients showing atypical swallowing.[5,32,41,132,133]

Considering the growing demand for specialized treatment of orofacial disorders it is necessary to define qualitative and quantitative parameters that allow the involved professionals to establish diagnosis, set prognosis and evaluate the effects of MFT in a standardized manner.

As mentioned before, in the recent years many assessment protocols have been proposed for the detection of OMD, but only a few have been validated: the Nordic Orofacial Test – Screening (NOT-S)[118], the protocol of orofacial myofunctional evaluation with scores (OMEs)[120], OMEs-Expanded[121] and OMEs-Italian version[113] . OMEs is a tool for orofacial structure and function assessment that allows to quantify the clinician's perception by assigning a numerical value to the observed behaviors and functions and it has therefore been recommended for evidence based practice[113].

On the other side, quantitative evaluations about the effects of MFT on tongue strength have been conducted through strain-gauge manometry[134,135], bulb pressure sensors like Iowa Oral Pressure Instrument (IOPI) device[32] , electropalatography[136]and surface electromyographic (sEMG) analysis[21,41,83].

The IOPI device has already been used in literature showing high inter- and intra-judge reliability[32,105,106,137,138]. Potter et al stated that maximum tongue strength can reliably be evaluated in pediatric patients using IOPI[139].

Also, sEMG can be considered as a fast, easy and non-invasive method to assess the muscular activation pattern and duration of activation and it is particularly suitable for the analysis of the first phase of swallowing due to the superficial position of the muscles involved in this function.

Nevertheless, there are two aspects that need to be pointed out:

1. the first is linked to the age of the subjects. In fact, the occlusal contacts provided in the mixed dentition do not allow such a stable proprioceptive response as the adult one, or at least has the one achieved when the second dentition is complete [104];
2. the second remark is linked to the controversial opinions about the clinical application of sEMG. In fact, both technical and biological factors can influence the registered signal and make comparative and longitudinal evaluations difficult to be conducted.[25,26,100,104];

However, the use of standardized sEMG (ssEMG) protocols eliminates such factors and permits a reliable analysis.[101] Repeatability of standardized protocols for the activity of masseter (MM), anterior temporalis (TA) and submental muscles (SM) during maximal voluntary clench and mastication have been conducted previously.[25,104]

Recently a standardized sEMG (ssEMG) protocol has been performed[25] and preliminary data about the activity of MM, TA and SM during saliva swallowing in adult subjects have been made available.[26]

The first aim of this study is to analyze the muscular function during swallowing by means of ssEMG in a group of patients with AS and to assess possible changes compared to patients with normal swallowing patterns.

The second aim is to analyze the qualitative and quantitative effects of MFT by means of ssEMG in the group of patients with AS to detect if any significant variations in the muscular activity of the masticatory muscles or in the functional behavior of the orofacial musculature do exist.

The third aim of this study is to analyze the ssEMG indexes between patients with normal swallowing pattern and AS patients after MFT treatment.

2.2 Materials and Methods

2.2.1 Subjects

Recruitment of the atypical swallowing group (AS group)

25 adolescents and young adults coming to the Department of Biomedical, Surgical and Dental Sciences of the Università degli Studi di Milano were enrolled in this study as experimental group (AS). The diagnosis of AS was performed clinically by a speech pathologist and a final group of 20 AS patients did comply with the inclusion criteria and was included in the study (the other 5 patients did not respect the inclusion criteria). Inclusion criteria for this group were: second dentition complete with at least 28 teeth present, overjet and overbite between 0 and 5 mm, dental crowding inferior to 6 mm and AS.

Recruitment of the control group (C group)

18 adolescents and young adults coming to the Department of Oral Health Sciences – Orthodontics of the University Hospitals Leuven, Belgium were recruited for the control group (C). Diagnosis of normal deglutition was performed clinically by an Orthodontist with 20 years of experience in the field before and after treatment. All patients were previously treated with fixed appliances to resolve crowding and at the time of the electromyographic acquisition, they showed the following characteristics: first molar class, second dentition complete with at least 28 teeth present, no temporo-mandibular disorders (TMD), absence of oral habits or dysfunctions, overjet and overbite between 1 and 4 mm, no vertical or sagittal discrepancies.

Exclusion criteria for both groups were: no periodontal disease, no lateral crossbite, no active medication intake, no active orthodontic therapy, no occlusal overlay, no fixed prosthetic, no active caries, no endodontic treatment and no conservative or oral surgical therapy within the last three months.

2.2.2 Study design

The present work was divided in three phases:

1. In the **FIRST PHASE** an observational case-control study between AS and C groups, analyzed with ssEMG, was performed.
2. In the **SECOND PHASE** a longitudinal prospective study involving AS group was performed analyzing clinical (OMEs protocol and IOPI analysis) and electromyographical (ssEMG) measurements to detect the effects of the MFT. In this phase, the MFT was performed by the same speech therapiest at the Hospital Luigi Sacco of Milan. MFT consisted in 10 weekly appointments of 45 minutes and in carrying out daily exercises at home according to the Garliner method. The therapies were carried on by the same operator, trainee in Logopedy, under supervision of an expert speech therapist.
3. In the **THIRD PHASE** an observational case-control study between AS patients after the MFT and control patients, analyzed with ssEMG, was performed.

The ssEMG analysis used in the first, second (at the beginning (T1) and at the end (T2) of the MFT) and third phase was performed according to a standardized protocol.[26,113]

All patients enrolled in this study were invited to sign an informed consent and the study protocol was approved by the local ethic committees of each University. The study of the University of Milan was registered with the national code DG-EMG-2016 and the study of the University of Leuven was registered with the national code B322201316750.

2.2.3 Electromyographic analysis

Surface EMG activity was recorded using a computerized instrument (Easymyo; 3 Technology S.r.l., Udine, Italy). For more information about the device, the electrode type and procedure of analysis we invite the reader to deepen the previous article[26].

sEMG permits us to analyze the activity of masseter muscles (MM), anterior temporalis muscles (TA) and submental muscles (SM) changes at the end of MFT. The bipolar surface electrodes (21 × 41 mm, 20 mm inter-electrode distance; F3010; Fiab, Firenze, Italy) were positioned on the muscular bellies parallel to muscular fibers as follows:

- MM. The electrodes were fixed parallel to the exocanthion-gonion line and with the upper pole of the electrode under the tragus-labial commissural line.
- TA. The electrodes were fixed vertically along the anterior margin of the muscle (corresponding to the frontal-parietal suture).
- SM. The electrodes were placed in the submental area, paramedian to the midline and lightly diverging, 1 cm posterior to the mental symphysis.

A disposable reference electrode was applied to the forehead or on the earlobe. To reduce skin impedance, the skin was carefully cleaned with alcohol prior to electrode placement, allowing the conductive paste to adequately moisten the skin.

a. sEMG Measurements

At each appointment (T1 and T2) the sEMG analysis was composed of three sets:

1. Masticatory muscles standardization procedures: 2 10-mm-thick cotton rolls were positioned on the mandibular second premolars/first molars of each participant, and a 5-seconds maximum voluntary contraction (MVC) was recorded to standardize TA and MM’s sEMG signal. The mean sEMG potential obtained in the first acquisition was set at 100%, and all further sEMG potentials were expressed as a percentage of this value (μV/ μV × 100).11
2. Submental muscles standardization procedures: participants were asked to push their tongue to the best of their ability (without teeth clenching) against the palate, and a 5-seconds sEMG SM activity was recorded. All further SM sEMG potentials were expressed as a percentage of this value (μV/ μV × 100).[12]
3. Saliva swallowing: after drinking 20 cc of water, the participants were asked to wait 30 seconds, bring their teeth in contact during swallowing of the spontaneously accumulated saliva and keep them in rest position (with no occlusal contacts). At the end; a 5-seconds sEMG activity was recorded. The exercise was repeated twice (A and B) during each appointment. A 90-seconds break period elapsed between the 2 acquisitions.

For each acquisition, the 3- seconds period with the most stable signal was automatically selected by the dedicated software that calculated the Simple Moving Average. During the tests, participants were asked to perform to the best of their ability, to avoid head and neck movements and maintain a relaxed facial expression to reduce cross- talks. During the recordings, participants sat in a comfortable office type chair with a straight posture, feet flat on the floor and arms resting on their legs. For each participant, test order was randomized by a computer random number generator and 90- seconds rest period was allowed. All acquisitions were made by the same operator.

b. sEMG Data Analysis

The sEMG waves (Figure 2.1) were analyzed thanks to the instrumental software tool as follows:

1. POC (%, percentage overlapping coefficient): this index represents the symmetrical activation of each couple of muscles ranging between 0% and 100%. When 2 paired muscles (MM, TA, SM) contract with perfect symmetry, a POC of 100% is obtained.
2. IMPACT (%, standardized activity index): activity index that quantifies the total muscular recruitment (MM, TA, SM) during swallowing relative to the standardization test computing the mean total muscle activities as the integrated areas of the sEMG potentials over time.

From the swallowing wave of each muscles other measurements were taken:

3. Duration of activation of each muscle couple (MM, TA, SM), considered as the interval in which muscle activity was higher than 10% of its standardization test. Values below this threshold were considered muscular basal activity.
4. Duration of the whole swallowing test described as the interval between the beginning of first muscle activation and the end of last muscle activation.
5. Intensity of the spike of activation of each muscle couples.
6. Position of the spike of each muscle couple relatively to its total duration of activity.

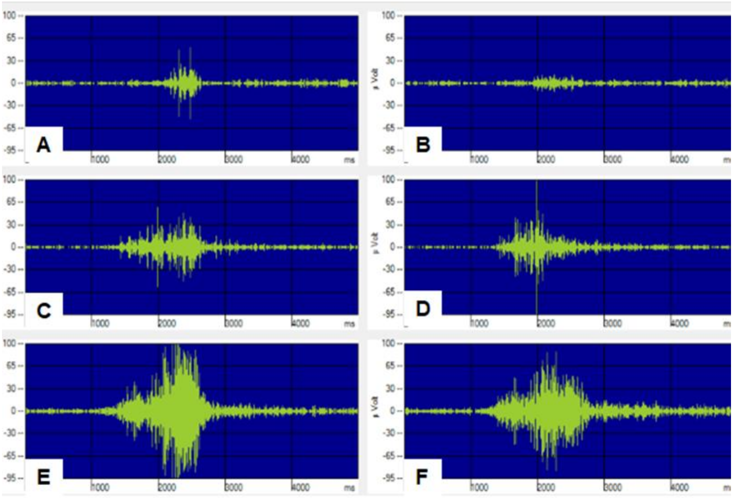


Figure 2.1: A- F, Example of an electromyographical signal of the muscles activated during saliva swallowing. X- axis: time (ms), Y- axis: intensity of activation (µV/µV × 100). A, right anterior temporalis muscle; B, left anterior temporalis muscle; C, right masseter muscle; D, left masseter muscle; E, right submental muscles; F, left submental muscles.

2.2.4 Logopedic Analysis

For the logopedic analysis, performed in the second phase, OMEs and IOPI evaluations were carried out by defining the characteristics during both swallowing and chewing and by detecting tongue strength. Unfortunately, as the IOPI exam was introduced at the final part of our study, we analyzed only 5 patients.

a. OMEs Analysis

Orofacial myofunctional evaluation with scores (OMEs) is a validated test for the clinical evaluation of OMDs that permits the examiner to express numerically, on a graduated scale, his perception about the characteristics and behaviors of the orofacial myofunctional conditions of the patients observed.

This protocol allows to differentiate subjects, facilitating treatment planning and providing results measures. It is divided in 5 sections:

- Appearance and posture: symmetry of the face, the position of the lips at rest, the posture of the jaw, cheeks, tongue. Rating score from 6 to 18 (normal).
- Mobility: the examiner asks the patient to perform some movements (protrusion, lateralization, elevation, stretching) of the lips, tongue, jaw and cheeks. Rating score from 19 to 57 (normal).
- Functions: combination of respiration (nasal or oral) and deglutition (labial behavior, lingual position, presence of dysfunctional behaviors and swallowing efficiency). Rating score from 5 to 18 (normal).
- Mastication: lateral movements of the mandible and pathological signs. Rating score from 3 to 10 (normal).
- Total OMEs: the sum of the previous parameters. Rating score from 27 to 103.

For more information about the OMEs protocol, we invite the reader to deepen the previous articles: Folha GA, *Eur J Oral Sci*. 2015;123(3):165-172[140]; de Felicio CM, *Int J Pediatr Otorhinolaryngol*. 2016;90:5-11[141]; de Felicio CM, *J Oral Rehabil*. 2012;39(10):744-753[142].

b. IOPI Analysis

The IOPI device (IOPI MEDICAL LLC, Redmond, Washington, USA) was used to detect tongue strength by asking the patients to push as hard as they could against a small air-filled bulb that was positioned at first in the anterior region of the hard palate (IOPI-anterior) and then in the posterior part of the hard palate (IOPI-posterior). The IOPI is useful to measure the amount of pressure exerted on the air-filled bulb converting it in a digital data (expressed in kilopascal) displayed on the LCD panel of the instrument.

2.2.5 Statistical evaluation

Descriptive statistics were computed for all sEMG indexes for swallowing.

- In the **FIRST PHASE**, a *Student t-test* for unpaired data was performed to compare data relative to the electromyographic indexes between AS and C groups. In addition, a 1-way ANOVA was performed for all electromyographic indexes to detect any significant differences within the AS and C group.
- In the **SECOND PHASE**, a *Student t-test* for paired samples was performed to compare the changes relative to the electromyographic and logopedic indexes between T1 and T2. In addition, a 1-way ANOVA was performed to detect any differences between the different couples of muscles (MM, TA, SM) at T1 and at T2.
- In the **THIRD PHASE**, a *Student t-test* for unpaired data was performed to compare data relative to the electromyographic indexes between AS at T2 and C groups. In addition, a 1-way ANOVA was performed for all electromyographic indexes to detect any significant differences within the AS and C group.

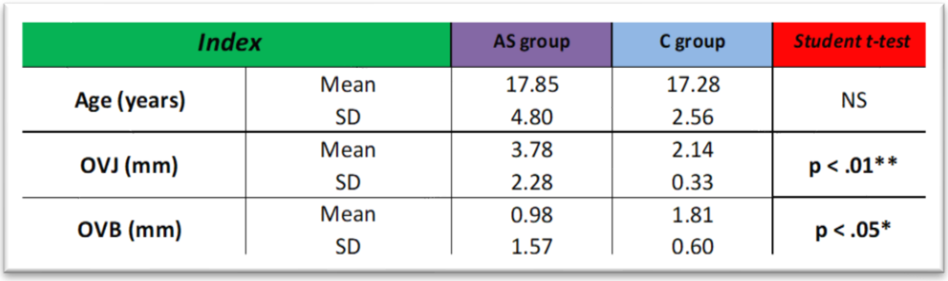
For all statistical tests, significance was set at 5% (p<.05).

2.3 Results

2.3.1 FIRST EXPERIMENTAL PHASE

A total of 20 patients (4 males and 16 females, mean age 17.85 years, SD 4.80) were enrolled for group AS. Between these, 7 were young adults (all females, mean age 23.14 years, SD 3.85) and 13 were adolescents (9 females and 4 males, mean age 15.09 years, SD 1.87). For the C group a total of 18 patients (8 males and 10 females, mean age 17.28 years, SD 2.56) were enrolled. Between these, 7 were young adults (3 males and 4 females, mean age 19.86 years, SD 1.86) and 11 were adolescents (5 males and 6 females, mean age 15.63 years, SD 1.20). No significant age differences were detected between groups.

Data on age, overjet (OVJ) and overbite (OVB) are summarized in Table 2.1.



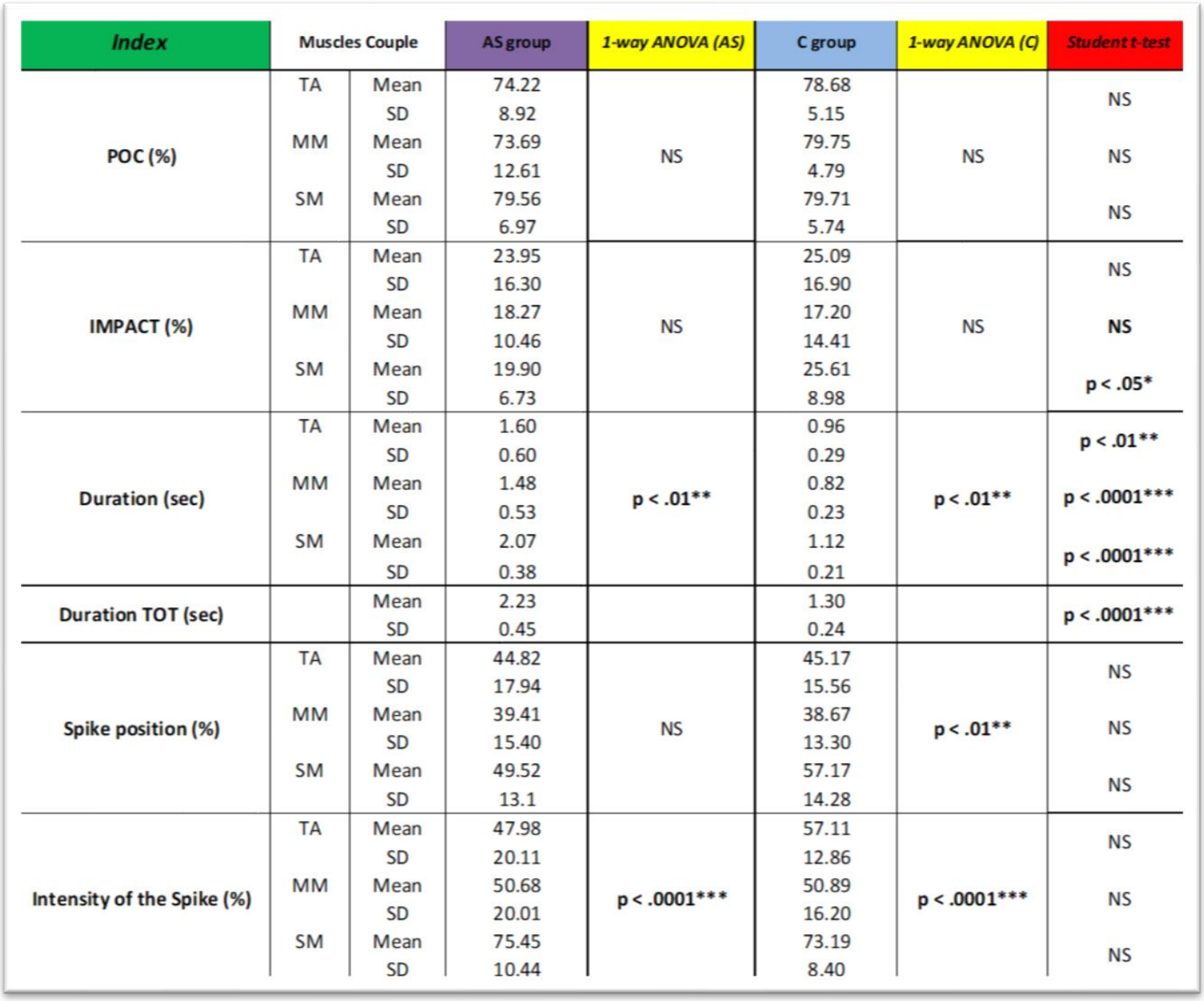
Index		AS group	C group	Student t-test
Age (years)	Mean	17.85	17.28	NS
	SD	4.80	2.56	
OVJ (mm)	Mean	3.78	2.14	**p < .01****
	SD	2.28	0.33	
OVB (mm)	Mean	0.98	1.81	**p < .05***
	SD	1.57	0.60	

Table 2.1: Mean values and standard deviations (SD) of age, overjet (OVJ) and overbite (OVB) in AS and C groups and the differences between values according to the Student-t-test (p<.05, p<.01**, and p<.0001***); NS-not significant.*

At the *Student t-test*, AS patients showed significant (p<.01) higher value of OVJ (3.78 mm, SD 2.28) and significant (p<.05) lower value of OVB (0.98 mm, SD 1.57) compared to C group (2.14 mm, SD 0.33; 1.81 mm, SD 0.60).

Electromyographic result

In Table 2.2, POC, Impact, duration of activation of each couple of muscles, duration of the whole exercise, the position of the spike and the intensity of the spike in AS and C groups are reported with the corresponding significant difference at *Student t-test.*



Index	Muscles Couple		AS group	1-way ANOVA (AS)	C group	1-way ANOVA (C)	Student t-test
POC (%)	TA	Mean	74.22	NS	78.68	NS	NS
		SD	8.92		5.15		
	MM	Mean	73.69		79.75		NS
		SD	12.61		4.79		
	SM	Mean	79.56		79.71		NS
		SD	6.97		5.74		
IMPACT (%)	TA	Mean	23.95	NS	25.09	NS	NS
		SD	16.30		16.90		
	MM	Mean	18.27		17.20		**NS**
		SD	10.46		14.41		
	SM	Mean	19.90		25.61		p < .05*
		SD	6.73		8.98		
Duration (sec)	TA	Mean	1.60	p < .01**	0.96	p < .01**	p < .01**
		SD	0.60		0.29		
	MM	Mean	1.48		0.82		p < .0001***
		SD	0.53		0.23		
	SM	Mean	2.07		1.12		p < .0001***
		SD	0.38		0.21		
Duration TOT (sec)		Mean	2.23		1.30		p < .0001***
		SD	0.45		0.24		
Spike position (%)	TA	Mean	44.82	NS	45.17	p < .01**	NS
		SD	17.94		15.56		
	MM	Mean	39.41		38.67		NS
		SD	15.40		13.30		
	SM	Mean	49.52		57.17		NS
		SD	13.1		14.28		
Intensity of the Spike (%)	TA	Mean	47.98	p < .0001***	57.11	p < .0001***	NS
		SD	20.11		12.86		
	MM	Mean	50.68		50.89		NS
		SD	20.01		16.20		
	SM	Mean	75.45		73.19		NS
		SD	10.44		8.40		

Table 2.2: Standardized ssEMG indexes during saliva swallowing are shown: POC (%), impact (%), duration of activation of each couple of muscles (sec) (masseter muscles MM, temporalis muscles TA and submental muscles SM), duration of the whole exercise (sec), spike position (%) (calculated as a percentage of the duration of activation of each couple of muscles), intensity of the spike (%), mean and standard deviation (SD) for MM, TA and SM. Student t-test for unpaired data was performed between AS and C and significance was set at 5% (p<.05, p<.01**, and p<.0001***, NS-not significant). A 1-way ANOVA was performed between MM, TA and SM muscles within AS and C groups for all electromyographic indexes.*

POC index showed a lower symmetrical activation for TA (74.22 %, SD 8.92) and MM (73.69 %, SD 12.61) in AS group if compared to C group (TA 78.68 %, SD 5.15, MM 79.75 %, SD 4.79) but similar activation of SM in AS (79.56 %, SD 6.97) and C (79.71 %, SD 5.74) groups. No differences between AS and C group were recorded with *Student t-test* and no differences between the muscles couples were recorded within AS and C groups with 1-way ANOVA.

About the IMPACT index, the values recorded in AS group for TA (23.95 %, SD 16.30) and MM (18.27 %, SD 10.46) were similar to the ones obtained in the C group (TA 25.09 %, SD 16.90, MM 17.20 %, SD 14.41), whereas the value of SM was significantly lower (p<.01) in AS (19.90 %, SD 6.73) than in C group (25.61 %, SD 8.98). Even for IMPACT index, no differences were recorded between the different couples of muscles within AS and C group.

The whole duration of the swallowing act was significantly different (p<.0001) between groups recording a mean value of 2.23 sec (SD 0.45) in AS group and a mean value of 1.30 sec (SD 0.24) in C group.

Furthermore, all the mean durations for each couple of muscles were significantly longer in AS group compared to C group for all the couples of muscles observed: TA (p<.01), MM (p<.0001) and SM (p<.0001). In addition, significant differences within group AS and C were recorded at the 1-way ANOVA (p<.01) showing a shorter duration of the masticatory muscles compared to SM.

About the position and intensity of the spike, the Figure 2.2 could be useful in understanding the analysis performed and the differences occurring between the 2 groups.

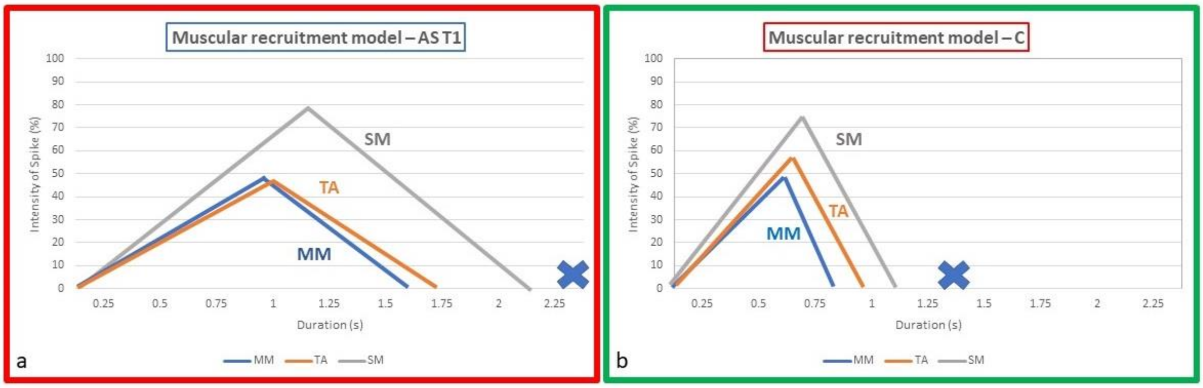


Figure 2.2: Graphic representing the position and the intensity of the spike of activation of each couple of muscles during saliva swallowing in group AS at T1 (fig 2a) and group C (fig 2b), considering mean values. MM, TA and SM are reported with different colors. Duration (s) on the abscissae axis and intensity of activity (%) on the ordinate's axis. MM, masseter; SM, submental muscles; TA, anterior temporalis. "X" is located on the x axis at the time of the end of the swallowing act.

In AS group the muscular recruitment model provides a first activation of masseters that showed an activation time of 1.48 sec (SD 0.53) with a spike position at 39.41 % (SD 15.41) of the whole act and a spike intensity of 50.68 % (SD 20.01); TA activation follows showing an activation time of 1.60 sec (SD 0.60) with a spike position at 44.82 % (SD 17.94) and spike intensity of 47.98 % (SD 20.11). The last couple of muscles that reached the maximum spike activity are SM whose duration was 2.07 sec (SD 0.38), the spike position was at 49.52 % (SD 13.1) with a spike activity of 75.45 % (SD 10.44).

In C group the activity trend for each couple of muscles is similar but the duration time for each couple of muscles is shorter if compared to AS group. Even in this group the muscular recruitment model provides a first activation of masseter that showed an activation time of 0.82 sec (SD 0.23) with a spike position at 38.67 % (SD 13.30) of the whole act and a spike intensity of 50.89 % (SD 16.21). Even in this group TA muscles showed an intermediate duration time (0.96 sec, SD 0.29) with a spike position at 45.17 % (SD 15.56) of the whole act and a spike intensity of 57.11 % (SD 12.86). Also, the last couple of muscles that reached the maximum spike activity was SM whose duration was 1.12 sec (SD 0.21), the spike position was at 57.17 % (SD 14.28) of the whole act and with a spike activity of 73.19 % (SD 8.40).

No statistical differences were recorded between AS and C groups at Student-t-test for both spike position and intensity. At the within groups analysis, statistical differences were recorded at 1-way ANOVA between the different couples of muscles for the intensity of the spike (p<.0001) in both groups and for the spike position (p<.01) in C group, showing an earlier and lower spike in the masticatory muscles compared to SM.

2.3.2 SECOND EXPERIMENTAL PHASE

From the initial sample of 20 patients, 2 gave up the treatment, 1 started orthodontic treatment before the end of the MFT and 2 did not respect the inclusion criteria.

A final group of 15 (4 males and 11 females, mean age 17.72 years, SD 5.21) patients with AS was enrolled for this phase. Of this sample, 10 patients were adolescents (4 males and 6 females, mean age 14.75 years, SD 1.60) and 5 were young adults (3 females, mean age 23.66 years, SD 4.80).

These patients showed an average overjet of 3.83 mm (SD 2.15) and overbite of 0.43 mm (SD 1.55) at T1.

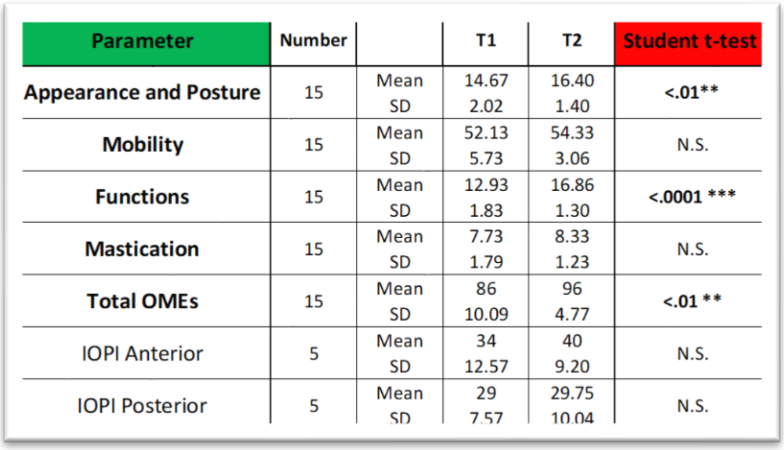
a. Logopedic results

In Table 2.4, *OMEs and IOPI indexes* at T1 and T2 are reported together with the corresponding significant changes.

The OMEs indexes (*n*=15) express a qualitative evaluation of stomatognathic and facial behavior. All these indexes showed an increase in the mean values at T2 with a general reduction of the standard deviations resulting significant for the “Appearance and posture” (P<.01) and “Function” (P<.0001) indexes at T2.

Nevertheless, the total OMEs score showed a significant increase at T2 (P<.01) suggesting that from the MFT a general benefit for the whole orofacial behavior was obtained.

IOPI indexes (*n*=5) were not significant, probably due to the very small sample size. In addition, the dimension of this sample does not permit us to take into account these results.



Parameter	Number		T1	T2	Student t-test
Appearance and Posture	15	Mean	14.67	16.40	**<.01****
		SD	2.02	1.40	
Mobility	15	Mean	52.13	54.33	N.S.
		SD	5.73	3.06	
Functions	15	Mean	12.93	16.86	**<.0001 *****
		SD	1.83	1.30	
Mastication	15	Mean	7.73	8.33	N.S.
		SD	1.79	1.23	
Total OMEs	15	Mean	86	96	**<.01 ****
		SD	10.09	4.77	
IOPI Anterior	5	Mean	34	40	N.S.
		SD	12.57	9.20	
IOPI Posterior	5	Mean	29	29.75	N.S.
		SD	7.57	10.04	

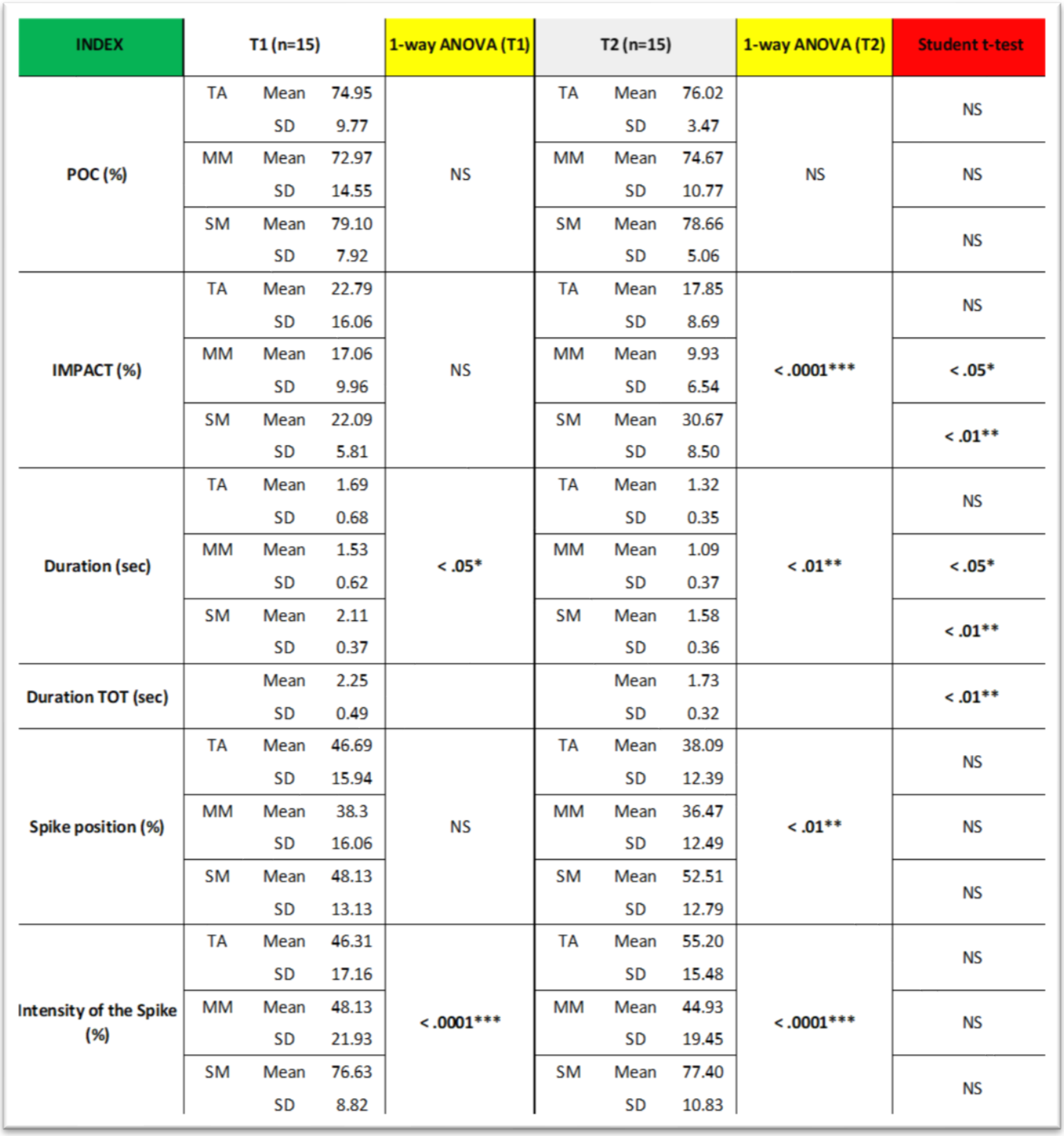
Table 2.4: OMEs, OMEs-I, IOPI indexes before (T1) and after (T2) the MFT Student t-test for paired data was performed between T1 and T2 and significance was set at 5% (p<.05, p<.01**, and p<.0001***); NS-not significant.*

b. Electromyographic result

In Table 2.3, POC, Impact, duration of activation of each couple of muscle, duration of the whole exercise, the position of the spike (reported as a percentage of the duration of the activation of each couple of muscles) and the intensity of the spike at T1 and T2 are reported together with the corresponding significant changes. In addition, the 1-way ANOVA significant values between MM, TA and SM at T1 and T2 are inserted.

At T1 the mean values for POC index showed a lower symmetrical activation for MM (72.97%) and TA (74.94%). At T2 these values increased without significant differences. For SM the mean values at T1 and T2 were similar and closer to normal range (80%). No differences were detected between the different couples of muscles at T1 and T2 with ANOVA test.

About the IMPACT index, at T1 values recorded for TA MM and SM were similar and didn't show any significant differences, suggesting no differences between muscles activity during swallowing. At T2 the mean values of MM decreased (p<.05). Differently, the IMPACT value of SM increased (p<.01). In addition, at T2 a specific swallowing pattern was highlighted characterized by a low activity of MM (9.93%), a moderate activity of TA (17.85%) and high activity of SM (30.67%) showing a meaningful difference between them (1-way ANOVA, p<.0001).



INDEX	T1 (n=15)			1-way ANOVA (T1)	T2 (n=15)			1-way ANOVA (T2)	Student t-test
POC (%)	TA	Mean	74.95	NS	TA	Mean	76.02	NS	NS
		SD	9.77			SD	3.47		
	MM	Mean	72.97		MM	Mean	74.67		NS
		SD	14.55			SD	10.77		
	SM	Mean	79.10		SM	Mean	78.66		NS
		SD	7.92			SD	5.06		
IMPACT (%)	TA	Mean	22.79	NS	TA	Mean	17.85	< .0001***	NS
		SD	16.06			SD	8.69		
	MM	Mean	17.06		MM	Mean	9.93		< .05*
		SD	9.96			SD	6.54		
	SM	Mean	22.09		SM	Mean	30.67		< .01**
		SD	5.81			SD	8.50		
Duration (sec)	TA	Mean	1.69	< .05*	TA	Mean	1.32	< .01**	NS
		SD	0.68			SD	0.35		
	MM	Mean	1.53		MM	Mean	1.09		< .05*
		SD	0.62			SD	0.37		
	SM	Mean	2.11		SM	Mean	1.58		< .01**
		SD	0.37			SD	0.36		
Duration TOT (sec)		Mean	2.25			Mean	1.73		< .01**
		SD	0.49			SD	0.32		
Spike position (%)	TA	Mean	46.69	NS	TA	Mean	38.09	< .01**	NS
		SD	15.94			SD	12.39		
	MM	Mean	38.3		MM	Mean	36.47		NS
		SD	16.06			SD	12.49		
	SM	Mean	48.13		SM	Mean	52.51		NS
		SD	13.13			SD	12.79		
Intensity of the Spike (%)	TA	Mean	46.31	< .0001***	TA	Mean	55.20	< .0001***	NS
		SD	17.16			SD	15.48		
	MM	Mean	48.13		MM	Mean	44.93		NS
		SD	21.93			SD	19.45		
	SM	Mean	76.63		SM	Mean	77.40		NS
		SD	8.82			SD	10.83		

Table 2.3: Standardised sEMG indexes during saliva swallowing are shown: POC (%), impact (%), duration of activation of each couple of muscles (s) (masseter muscles MM, temporalis muscles TA and submental muscles SM), duration of the whole exercise (s), spike position (%) (calculated as a percentage of the duration of activation of each couple of muscles), intensity of the spike (%), mean and standard deviation (SD) for MM, TA and SM. Student t-test for paired data was performed between T1 and T2 and significance was set at 5% (p<.05, p<.01**, and p<.0001***); NS-not significant.*

A common trend affects the mean values of the duration of activation of each couple of muscles involved. In fact, all the couples of muscles analyzed showed a decrease in time of activation and these results were significant for MM (p<.05) and SM (p<.01). Also, the whole duration of the swallowing act decreased significantly (p<.01) from 2.25 to 1.73 seconds. The durations of activation of each couple of muscle were statistically different at both T1 (p.<05) and T2 (p<.0001).

About the position and intensity of the spike the Figure 2.3 could be useful in understanding the analysis performed and the changes that occurred between T1 and T2.

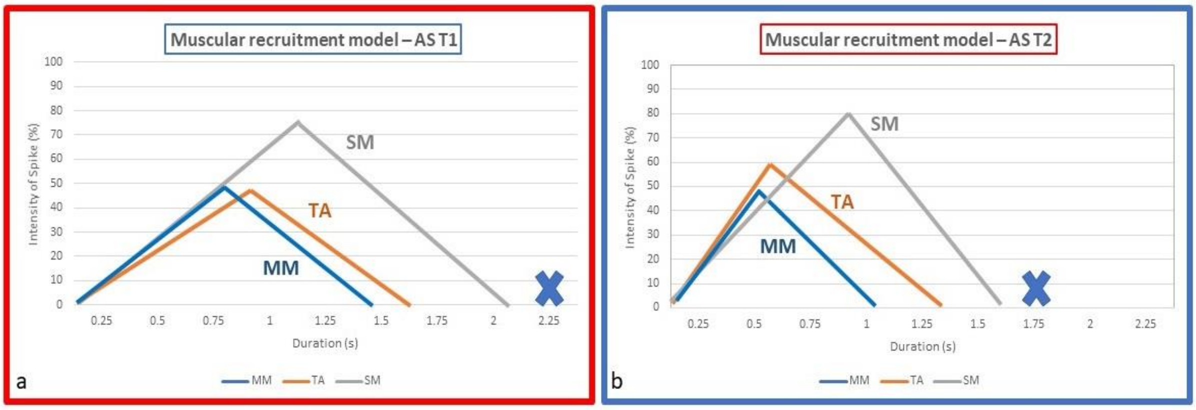


Figure 2.3: Graphic representing the time and the intensity of the spike of activation of each couple of muscles during saliva swallowing in AS group at T1 (fig 3a) and T2 (fig 3b), considering mean values. MM, TA and SM are reported with different colours. Duration (s) on the abscissae axis and intensity of activity (%) on the ordinate's axis. MM, masseter; SM, submental muscles; TA, anterior temporalis. The "X" is located at the end of the whole swallowing act.

At T1 the muscular recruitment model provides a first activation of masseters that showed an activation time of 1.53 sec with a spike position at 38% and a spike intensity of 48%; TA followed showing an activation time of 1.69 sec with a spike position at 46.69% and spike intensity of 46%. The last couple of muscles that reached the maximum spike activity were SM whose duration was about 2.11 sec; the spike position was at 48% with an activity of 76%. At T1 no differences were detected between the spike positions of the different couples of muscles whereas a significant difference was detected between the spike intensity at 1-way ANOVA test (p<.0001).

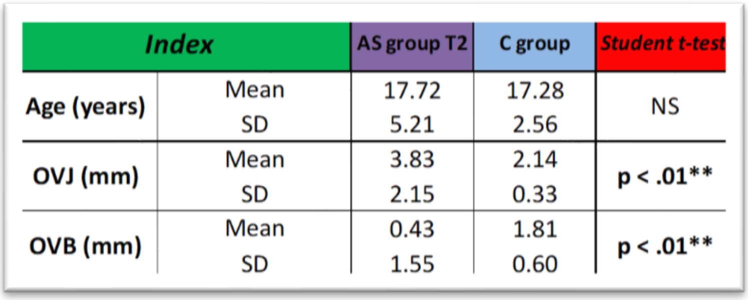
At T2 the duration time for each couple of muscles decreased, the spike position was not altered for MM and SM, while it was decreased for TA passing from 46% to 38%. Also, the spike activity did not alter at T2 for MM and SM, while it was increased for TA passing from 46% to 55%. At T2 significant differences between the different couples of muscles were found at 1-way ANOVA for both the spike position (p<.01) and spike intensity (p<.0001).

The changes in spike position and spike activity were not significant according to the values obtained with the Student t-test.

2.3.1 THIRD EXPERIMENTAL PHASE

In this phase the AS group at T2 consisted in 15 patients, whereas the C group is the same of the first phase consisting in 18 patients. As in the first phase, no significant differences about the age between groups were detected.

Data about the differences between OVJ and OVB in the AS group at T2 and C group are summarized in Table 2.5.



Index		AS group T2	C group	Student t-test
Age (years)	Mean	17.72	17.28	NS
	SD	5.21	2.56	
OVJ (mm)	Mean	3.83	2.14	p < .01**
	SD	2.15	0.33	
OVB (mm)	Mean	0.43	1.81	p < .01**
	SD	1.55	0.60	

*Table 2.5: Mean values and standard deviations (SD) of age, overjet (OVJ) and overbite (OVB) in AS at T2 and C groups and the differences between values according to the Student-t-test (p<.01**); NS-not significant.*

At the *Student t-test*, AS patients showed significant (p<.01) higher value of OVJ (mean 3.83 mm, SD 2.15) and significant (p<.01) lower value of OVB (0.43 mm, SD 1.55) compared to C group (2.14 mm, SD 0.33; 1.81 mm, SD 0.60).

Electromyographic result

In Table 2.6, POC, Impact, duration of activation of each couple of muscles, duration of the whole exercise, the position of the spike and the intensity of the spike in AS at T2 and C groups are reported with the corresponding significant difference at Student t-test.

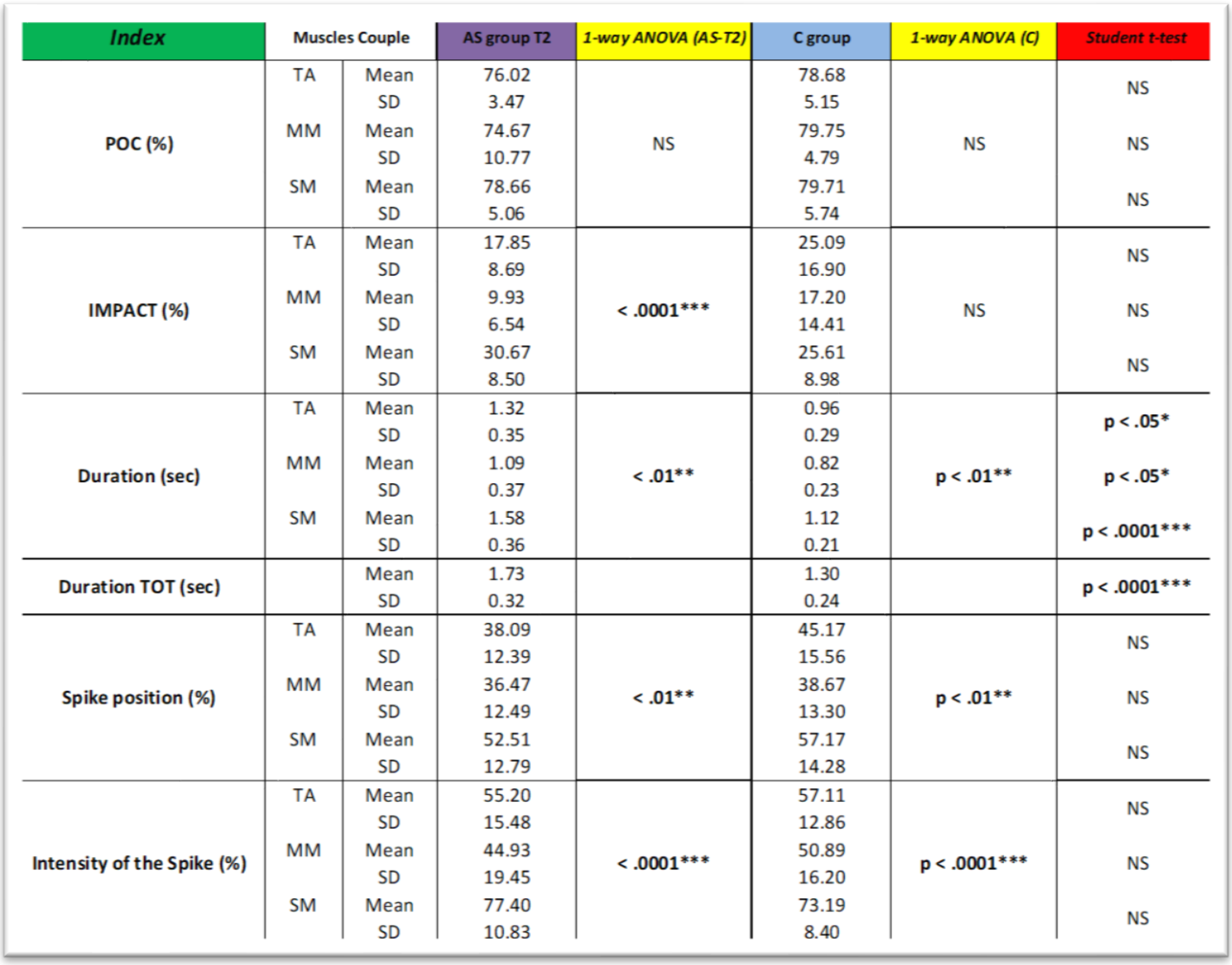
POC index showed a lower symmetrical activation for TA (76.02 %, SD 3.47) and MM (74.67 %, SD 10.77) in AS group if compared to C group (TA 78.68 %, SD 5.15, MM 79.75 %, SD 4.79) but similar activation of SM in AS (78.66 %, SD 5.06) and C (79.71 %, SD 5.74) groups. No differences between AS and C group were recorded with *Student t-test* and no differences between the muscles couple were recorded within AS and C groups with 1-way ANOVA.

Also, for the IMPACT index, the values recorded in AS group for TA (17.85 %, SD 8.69) and MM (9.93 %, SD 6.54) were lower to the ones obtained in the C group (TA 25.09 %, SD 16.90, MM 17.20 %, SD 14.41), whereas the value of SM was lower in C group (25.61 %, SD 8.98) than in AS (30.67 %, SD 8.50). No differences were recorded between the different couple of muscles within C group, whereas a significant difference (p<.001) was detected within the AS group between masticatory muscles and submental muscles.

The whole duration of the swallowing act was significantly different (p<.0001) between groups recording a mean value of 1.73 sec (SD 0.32) in AS group and a mean value of 1.30 sec (SD 0.24) sec in C group.

Furthermore, all the mean durations for each couple of muscles were significantly longer in AS group compared to C group for all the couples of muscles observed: TA (p<.05), MM (p<.05) and SM (p<.0001). In addition, significant differences within group AS and C were recorded at the 1-way ANOVA (p<.01) showing a shorter duration of the masticatory muscles compared to SM.

No statistical differences were recorded between AS and C groups at Student-t-test for both spike position and intensity. At the within groups analysis, statistical differences were recorded at 1-way ANOVA between the different couples of muscles for the intensity of the spike (p<.0001) in both groups and for the spike position (p<.01) in C group, showing an earlier and lower spike in the masticatory muscles compared to SM.



Index	Muscles Couple		AS group T2	1-way ANOVA (AS-T2)	C group	1-way ANOVA (C)	Student t-test
POC (%)	TA	Mean	76.02	NS	78.68	NS	NS
		SD	3.47		5.15		
	MM	Mean	74.67		79.75		NS
		SD	10.77		4.79		
	SM	Mean	78.66		79.71		NS
		SD	5.06		5.74		
IMPACT (%)	TA	Mean	17.85	< .0001***	25.09	NS	NS
		SD	8.69		16.90		
	MM	Mean	9.93		17.20		NS
		SD	6.54		14.41		
	SM	Mean	30.67		25.61		NS
		SD	8.50		8.98		
Duration (sec)	TA	Mean	1.32	< .01**	0.96	p < .01**	p < .05*
		SD	0.35		0.29		
	MM	Mean	1.09		0.82		p < .05*
		SD	0.37		0.23		
	SM	Mean	1.58		1.12		p < .0001***
		SD	0.36		0.21		
Duration TOT (sec)		Mean	1.73		1.30		p < .0001***
		SD	0.32		0.24		
Spike position (%)	TA	Mean	38.09	< .01**	45.17	p < .01**	NS
		SD	12.39		15.56		
	MM	Mean	36.47		38.67		NS
		SD	12.49		13.30		
	SM	Mean	52.51		57.17		NS
		SD	12.79		14.28		
Intensity of the Spike (%)	TA	Mean	55.20	< .0001***	57.11	p < .0001***	NS
		SD	15.48		12.86		
	MM	Mean	44.93		50.89		NS
		SD	19.45		16.20		
	SM	Mean	77.40		73.19		NS
		SD	10.83		8.40		

Table 2.6: Standardized ssEMG indexes during saliva swallowing are shown: POC (%), impact (%), duration of activation of each couple of muscles (sec) (masseter muscles MM, temporalis muscles TA and submental muscles SM), duration of the whole exercise (sec), spike position (%) (calculated as a percentage of the duration of activation of each couple of muscles), intensity of the spike (%), mean and standard deviation (SD) for MM, TA and SM. Student t-test for unpaired data was performed between AS and C and significance was set at 5% (p<.05, p<.01**, and p<.0001***, NS-not significant). A 1-way ANOVA was performed between MM, TA and SM muscles within AS and C groups for all electromyographic indexes.*

About the position and intensity of the spike, the Figure 2.4 could be useful in understanding the analysis performed and the differences occurring between the 2 groups. The muscular recruitment models of both groups have been described in the first and second phases.

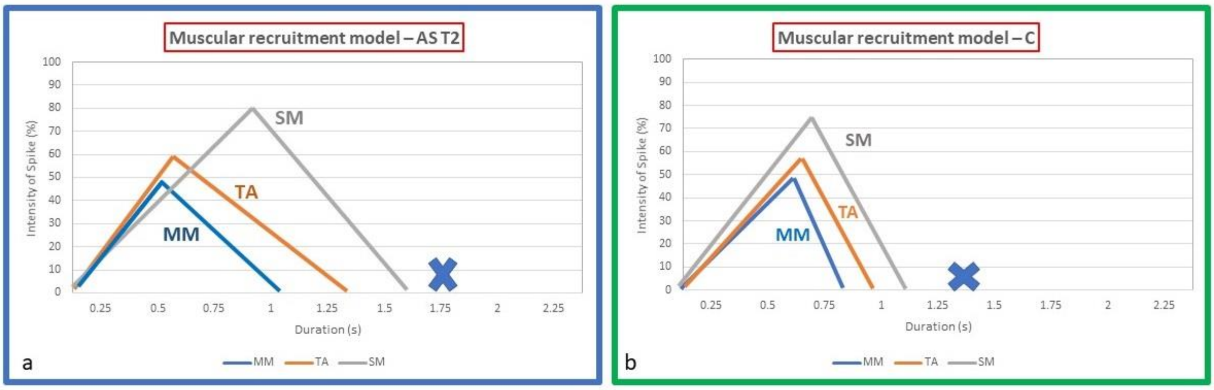


Figure 2.4: Graphic representing the position and the intensity of the spike of activation of each couple of muscles during saliva swallowing in group AS at T2 (fig 4a) and group C (fig 4b), considering mean values. MM, TA and SM are reported with different colors. Duration (s) on the abscissae axis and intensity of activity (%) on the ordinates axis. MM, masseter; SM, submental muscles; TA, anterior temporalis. "X" is located on the x axis at the time of the end of the swallowing act.

2.4 Discussion

ssEMG is considered a helpful tool in the analysis of masticatory muscle function and its use in measuring the activity of MM, TA and SM during clenching has been widely studied.[25,101,104,143,144] In contrast, only a few studies have been performed regarding muscular behavior during swallowing by means of ssEMG[25,26] and the recruitment of masticatory and submental muscles during this function is still unclear.

The main aim of this study was to analyze the effects of MFT on patients with atypical swallowing by using quantitative (ssEMG) and qualitative (OMEs) methods.

The electromyographical test has been performed by asking the patient to keep the teeth in contact while swallowing saliva as it can be considered as the most common physiological activity and it has been demonstrated a reliable test in healthy subjects[25,26].

In this study we have focused on patients with second dentition completed because they show a greater skeletal development, a higher compliance and a better occlusal stability than patients with mixed dentition therefore they better fit with the characteristics required to carry on this study and to help us in obtaining more reliable results.

In the first phase we compared the muscular activation pattern during swallowing in dysfunctional and normal patients. The most relevant outcome of the first phase is related to the duration of muscular activation during swallowing. The duration of the whole act is significantly ($p<.0001$) longer in AS (2.23 sec) than in C (1.30 sec) patients, confirming the values obtained in previous studies[21,128,145,146]. The duration of the activity of all couple of muscles (TA, MM, SM) was also significantly longer in AS than in C patients, but in both groups the same activation pattern was found. Furthermore, a significant difference between the couple of muscles was detected within the groups. MM showed the shortest, SM the longest and TA an intermediate duration confirming the data obtained in our previous work[26], which already suggested that SM works from the earliest stage until the pharyngeal phase of swallowing[26]. Interestingly, the duration of activation in the control group seems to be shorter than that obtained in this previous work, where a group of healthy adult patients not previously treated with orthodontic devices was analyzed[26]. This may be explained considering the differences in study population, since the present control group includes younger subjects previously treated with fixed appliances. This suggests that age and orthodontic therapy may influence the duration of activation of the different couples of muscles.

POC indexes showed low level of symmetry in activation for all the muscles investigated, that result also lower in AS compared to the C group, even if not significantly. In accordance with previous studies[26,147] these data confirm that the swallowing act is an unbalanced activity which makes good muscle symmetry difficult to achieve[147] especially considering the complex system of superior control and the high number of muscles involved[27]. POC data for the control group were similar to that of our previous study[26].

IMPACT values for masticatory muscles were similar between groups while the value for SM resulted significantly higher ($p<.05$) in the C group than in the AS group. In healthy subjects, a lower muscular activity is provided by MM, whereas TA and SM seem to be more involved during swallowing compared to AS patients, a finding also observed by Vaiman et al[148]. Differently, a lower significant activity is provided by SM in AS than in C patients. During swallowing, SM are activated with tongue movement against the palate to stiffen the mouth floor[25].

It should also be added that the activity of all measured muscles was always lower than 30% of their maximal activity. Similar MM, TA and SM activity was detected within the AS group, which was initially surprising as activity for the masticatory muscles has been found to be 30-40% lower than that of SM by other studies[83,148]. The difference may lie in the standardized procedure followed in our research. Before swallowing, patients were asked to keep the teeth in contact to ensure the reproducibility of the method[26]. This guided swallowing may have encouraged AS patients to make a greater effort than they would during spontaneous swallowing.

Regarding spike position, there is a common activation trend characterized by a first activation of MM, an intermediate peak of TA, and a last peak of SM (around 38%, 45% and 50-55% of the whole activity respectively).

A significant difference on spike position ($p<.01$) is observed between masticatory and SM muscles in healthy subjects, whereas no difference is observed in AS patients. This suggests that spike positions in the AS group are almost overlapped and therefore the activation pattern is less defined. In our previous study[26], the spike position of MM, was similar to the one found in this study (36%) while the positions of TA and SM were anticipated (36% and 42% respectively). The intensity of the spike was also similar[26]: MM showed the lowest value, SM the highest and TA recorded intermediate values (around 50%, 72% and 60% respectively). Nevertheless, significant lower ($p<.001$) spike intensity was found in masticatory (MM, TA) than SM both groups.

The main aim of this study has been detected in the second phase, by evaluating the effects of the MFT on the swallowing activity in a group of patients with AS.

We have tried to detect the effects provided in a group of patients showing AS without considering the correct time of treatment. In fact, in literature there's still no evidence about which priority must be given to orthodontics or MFT and both these categories of specialists seem to have discordant opinions on this matter[91]. According to Mason if a posterior crossbite is present, should be performed rather than MFT[92]. However, according to Proffit priority should be given to achieving frontal dental contact[1].

The ideal age to start treatment in this case is always been debated[7]. Some authors recommend MFT treatment before the age of 10 years[6,93,94] However, others suggest to wait at least until patients are 10 years of age because of the possibility of spontaneous closure of the AOB[1].

The most relevant results of this study concern the OMEs protocol and ssEMG protocol as they both consider all the patients recruited. About the IOPI, only 5 patients of the study underwent to this evaluation procedure and therefore, no solid conclusions can be established.

The OMEs qualitative protocol confirms itself as a valid and reliable method in the assessment of patients with OMD such the AS ones. The ability of OMEs protocol to express the effects of MFT in AS patients is demonstrated by the significant differences observed after the therapy for both "Appearance and posture" and "Functions" indexes. Moreover, it is the only instrument with an ordinal level of measurement that has been validated for orofacial myofunctional evaluation of young and adult subjects[149] and its validity has been even provided for clinical applications in pediatric patients with obstructive sleep apnea [141,142].

The "Appearance and posture" index refers to the components of the stomatognathic system, particularly face symmetry, volume and tension of the cheeks, the resting posture and the volume of the lips and tongue are evaluated. "Functions" refers to deglutition and breathing. Breathing was observed and classified as oral or nasal. For deglutition, the pattern was normal when the subject presented the tongue contained in the oral cavity, contraction of elevator muscles and anterior sealing of the oral cavity without effort[142].

Thanks to the OMEs score measurements, the effects of MFT on the increase in the coordination between orofacial muscles, tongue, lips and masticatory muscles during deglutition was provided confirming the theoretical principles underlying the benefits induced by this therapy[4,6,39,112,150,151]. This suggest that after MFT the new functional scheme has been memorized and the patients show greater awareness involving better control and commitment during swallowing.

The IOPI device in the anterior application shows an increase that, even when not-significant, confirms the results obtained by Van Dyck[32] after MFT, with an increase in tongue strength expressed in Kilopascal from 36.3 to 46.1 whereas in our study we record an increase from 34 to 40. The differences are most likely linked to different sample size (in our study only five patients underwent the IOPI exam) but the results suggest that the greater awareness and commitment of the patient during swallowing expressed by the OMEs scores are accompanied by an apparent increase in the muscular activity of the tongue.

In addition, in the study of Van Dyck et al not all MFT children performed correct swallowing just at the end of MFT thus indicating that in some cases longer training or longer time is needed to achieve correct conscious swallowing. The myofunctional protocol has to be adapted to the needs of every individual[32].

In other previous studies no differences in tongue strength were detected between children with and without AS[5,152,153]. The explanation of this is probably linked to the large inter-participant variation in tongue strength [135,154] Also, our data about the posterior IOPI, which record the posterior strength in his dorsum-posterior part, do not show any changes after MFT. This could mean that an effective increase in the tongue strength expressed by IOPI in kilopascal is difficult to be recorded.

The sEMG results show that at first the symmetry in muscular activation for all MM TA and SM muscles during swallowing is unbalanced both at T1 and T2 thus suggesting that this function does not provide a clear activation pattern for the muscles involved as for MVC[104]. This confirms the observations of Eslamian et al in children with AS according to which these patients show systematically more inaccurate tongue movements and poor movement coordination than children without AS[155]

The activation index (IMPACT) shows that the activity of masticatory muscles decreases after MFT whereas the activity of SM significantly increases, with a high standard deviation. This suggest that MFT could provide an increasing activity of SM confirming, in part, the data obtained by the IOPI device. The decreasing in the activation of masticatory muscles suggests that after MFT during oral phase of swallowing, MM ant TA just allow the initial dental contact thus permitting the swallowing reflex to be conducted by the SM. The "spike position" and "spike intensity" indexes at T2 show that MM and TA are activated in the first half of the whole act (38% for TA, 36% for MM) maintaining moderate intensity (55% for TA, 44% for MM) whereas SM muscles are activated for longer period during oral phase of swallowing and reach the spike later (52%) and with more intensity (77%). These data confirmed that obtained in our previous work in normal subjects, suggesting that MFT is able to modify the muscular activation of the muscles involved during swallowing recreating an activation scheme which is similar to the "normal" one[26].

The duration of activation did decrease significantly for all the muscles involved and the whole duration passed from 2.25 to 1.73 reaching the average duration value obtained in our previous study in normal subjects[26]. These results confirm others already seen in similar previous studies[21,22,146,156]

However, in the third phase, the mean values of the whole duration and of the different couple of muscles remain far from the values obtained in the control group. Differently, in the third phase we observed that the mean IMPACT value of the AS group reached the control group one.

Apparently, the longer duration of activation of the muscles involved in the swallowing function remains the most evident characteristic in patients with atypical swallowing even after the myofunctional treatment.

Swallowing is a variable action between subjects, therefore EMG values have been reported to show a high inter individual variability[22,147], which is confirmed also in this study, especially for the Impact index and intensity of the spike of MM and TA. This behavior could be linked to the voluntary action (under cortical control) of jaw elevator muscles, which are recruited for the stabilization of the mandible. Future analysis on larger samples will be necessary to confirm these preliminary data.

In summary, quantitative protocols used in this study show a moderate increase in anterior part of the tongue strength (IOPI anterior), but no modifications in the posterior-dorsum (IOPI posterior), the ssEMG recordings show a low symmetrical activation (POC) for all the muscles at T1 and T2, a significant increase in muscular activation (IMPACT) for SM at T2 and a decrease for MM (significant) and TA (not significant), the spike position changes after MFT and are normalized according to a model which provide an initial and moderate activation of masticatory muscles and a later, longer and strong activation of SM.

The duration of activation of each couple of muscles decreases significantly. The OMEs shows an increase in all the oral functions, and significantly for the appearance and posture, breathing and deglutition.

In literature other authors tried to propose methods to evaluate the swallowing type in a objective way using radio cinematography, electropalatography, and electromagnetic articulography[128,157,158]

But these methods have not been considered appropriate to analyze growing children, especially due to irradiation[33,42]. Ultrasonography has also been used to assess the type of swallowing[33] but the reliability of this method has not been yet verified.

Patients with AS show impaired gnostic sensibility of the tongue[129,130] and it has still to be determined whether oral sensory perception can be improved with MFT[32], we can suppose that the training help to create a new motor scheme involving different muscles coordinated by the cortex and subcortex deglutition centers. As already suggested, the neuro-physiological basis for correction of the AS consists in a neuromuscular adaptation based on a somato-sensitive feedback[159].

Unfortunately, the absence of long-term data in this and other works that have emphasized the positive effects of MFT[5,41,133,155] does not allow us to define with certainty the effectiveness of this therapy over time.

Nevertheless, sEMG, the IOPI device and the use of the OMEs protocol confirm themselves to be fast, valid, reliable method that quantitively and qualitatively permit the clinician to evaluate the effects of MFT on the muscular activity defining a common parameter for the analysis of orofacial disorders.

Further research is needed to understand factors influencing the outcome of MFT, in order to define the best time and modality to improve the patient treatment.

2.5 Conclusion

ssEMG is a valid, non-invasive, rapid and reliable method to detect muscular behavior of masticatory muscles involved in the first phase of swallowing, also in patients with atypical swallowing.

The main differences found between AS and normal patients are linked to the whole swallowing act that has a longer duration in patients with AS than in control subjects. Also, the duration of activity for all the couples of muscles was longer for AS than for control subjects. The spike positions of TA, MM and SM were overlapped in the AS group, being well defined in the C group. In addition, there was a significantly lower activity index (IMPACT) of SM in AS patients than in control subjects.

Atypical swallowing confirms itself as a functional anomaly of the stomatognathic system, that alters the activity of all the muscles involved.

Speech therapy seems to be aid in the improvement of muscle performance specifically in the reduction of muscle activity and total swallowing action allowing a significant energy saving to the muscles involved in this complex physiological act.

3. References

1. Proffit WR, Fields HW, Sarver DM. *Contemporary Orthodontics*. Elsevier/Mosby; 2013.
2. Begnoni G, Serrao G, Musto F, Pellegrini G, Triulzi FM, Dellavia C. Craniofacial structures' development in prenatal period: An MRI study. *Orthod Craniofac Res*. 2018;21(2):96-103.
3. Harvold EP. The role of function in the etiology and treatment of malocclusion. *Am J Orthod*. 1968;54(12):883-898.
4. Straub WJ. Malfunction of the tongue. *Am J Orthod*. 1961;47(8):596-617.
5. Hanson ML, Andrianopoulos M V. Tongue thrust and malocclusion: a longitudinal study. *Int J Orthod*. 1982;20(2):9-18.
6. Saccomanno S, Antonini G, D'Alatri L, D'Angelantonio M, Fiorita A, Deli R. Causal relationship between malocclusion and oral muscles dysfunction: a model of approach. *Eur J Paediatr Dent*. 2012;13(4):321-323.
7. Speidel TM, Isaacson RJ, Worms FW. Tongue-thrust therapy and anterior dental open-bite. *Am J Orthod*. 1972;62(3):287-295.
8. Hotokezaka H, Matsuo T, Nakagawa M, Mizuno A, Kobayashi K. Severe dental open bite malocclusion with tongue reduction after orthodontic treatment. *Angle Orthod*. 2001;71(3):228-236.
9. Liu Z-J, Shcherbatyy V, Gu G, Perkins JA. Effects of tongue volume reduction on craniofacial growth: A longitudinal study on orofacial skeletons and dental arches. *Arch Oral Biol*. 2008;53(10):991-1001.
10. Turner S, Nattrass C, Sandy JR. The role of soft tissues in the aetiology of malocclusion. *Dent Update*. 1997;24(5):209-214.
11. Vig PS, Cohen AM. The size of the tongue and the intermaxillary space. *Angle Orthod*. 1974;44(1):25-28.
12. Lowe AA, Johnston WD. Tongue and jaw muscle activity in response to mandibular rotations in a sample of normal and anterior open-bite subjects. *Am J Orthod*. 1979;76(5):565-576.
13. Alexander S, Sudha P. Genioglossis muscle electrical activity and associated arch dimensional changes in simple tongue thrust swallow pattern. *J Clin Pediatr Dent*. 1997;21(3):213-222.
14. Fuhrmann RA, Diedrich PR. B-mode ultrasound scanning of the tongue during swallowing. *Dentomaxillofac Radiol*. 1994;23(4):211-215.
15. Lowe AA. Correlations between orofacial muscle activity and craniofacial morphology in a sample of control and anterior open-bite subjects. *Am J Orthod*. 1980;78(1):89-98.
16. Karacay S, Akin E, Ortakoglu K, Bengi AO. Dynamic MRI evaluation of tongue posture and deglutitive movements in a surgically corrected open bite. *Angle Orthod*. 2006;76(6):1057-1065.
17. Proffit WR. Equilibrium theory revisited: factors influencing position of the teeth. *Angle Orthod*. 1978;48(3):175-186.
18. Jalaly T, Ahrari F, Amini F. Effect of tongue thrust swallowing on position of anterior teeth. *J Dent Res Dent Clin Dent Prospects*. 2009;3(3):73-77.
19. Dixit UB, Shetty RM. Comparison of soft-tissue, dental, and skeletal characteristics in children with and without tongue thrusting habit. *Contemp Clin Dent*. 2013;4(1):2-6.
20. Schindler O, Ruoppolo G, Schindler A, Omega. *Deglutologia*. Omega; 2011.
21. Ciavarella D, Mastrovincenzo M, Sabatucci A, Parziale V, Chimenti C. Effect of the Enveloppe Linguale Nocturne on atypical swallowing: surface electromyography and computerised postural test evaluation. *Eur J Paediatr Dent*. 2010;11(3):141-145.
22. Vaiman M, Eviatar E, Segal S. Surface electromyographic studies of swallowing in normal subjects: a review of 440 adults. Report 3. Qualitative data. *Otolaryngol Head Neck Surg*. 2004;131(6):977-985.
23. Vaiman M, Eviatar E, Segal S. Surface electromyographic studies of swallowing in normal subjects: a review of 440 adults. Report 2. Quantitative data: amplitude measures. *Otolaryngol Head Neck Surg*. 2004;131(5):773-780.
24. Vaiman M, Eviatar E, Segal S. Surface electromyographic studies of swallowing in normal subjects: a review of 440 adults. Report 1. Quantitative data: timing measures. *Otolaryngol Head Neck Surg*. 2004;131(4):548-555.
25. Musto F, Rosati R, Sforza C, Toma M, Dellavia C. Standardised surface electromyography allows effective submental muscles assessment. *J Electromyogr Kinesiol*. 2017;34:1-5.
26. Dellavia C, Rosati R, Musto F, Pellegrini G, Begnoni G, Ferrario VF. Preliminary approach for the surface electromyographical evaluation of the oral phase of swallowing. *J Oral Rehabil*. 2018;45(7):518-525.
27. Ertekin C, Aydogdu I. Neurophysiology of swallowing. *Clin Neurophysiol*. 2003;114(12):2226-2244.
28. Jean A, Amri M, Calas A. Connections between the ventral medullary swallowing area and the trigeminal motor nucleus of the sheep studied by tracing techniques. *J Auton Nerv Syst*.

1983;7(2):87-96.
29. Schipper J, Arndt S, Maier W, Spetzger U, Ridder GJ. [Paralyzed face. Ansa-cervicalis-nervi-hypoglossi]. *Chirurg*. 2005;76(1):47-53.
30. Gewolb IH, Vice FL, Schwietzer-Kenney EL, Taciak VL, Bosma JF. Developmental patterns of rhythmic suck and swallow in preterm infants. *Dev Med Child Neurol*. 2001;43(1):22-27.
31. Gewolb IH, Vice FL. Maturational changes in the rhythms, patterning, and coordination of respiration and swallow during feeding in preterm and term infants. *Dev Med Child Neurol*. 2006;48(7):589-594.
32. Van Dyck C, Dekeyser A, Vantricht E, et al. The effect of orofacial myofunctional treatment in children with anterior open bite and tongue dysfunction: a pilot study. *Eur J Orthod*. 2016;38(3):227-234.
33. Peng C-L, Jost-Brinkmann P-G, Yoshida N, Miethke R-R, Lin C-T. Differential diagnosis between infantile and mature swallowing with ultrasonography. *Eur J Orthod*. 2003;25(5):451-456.
34. Hall KD. *Pediatric Dysphagia Resource Guide*. Singular/Thomson Learning; 2001.
35. Gisel EG. Effect of food texture on the development of chewing of children between six months and two years of age. *Dev Med Child Neurol*. 1991;33(1):69-79.
36. Schwaab LM, Niman CW, Gisel EG. Comparison of chewing cycles in 2-, 3-, 4-, and 5-year-old normal children. *Am J Occup Ther*. 1986;40(1):40-43.
37. Papargyriou G, Kjellberg H, Kiliaridis S. Changes in masticatory mandibular movements in growing individuals: a six-year follow-up. *Acta Odontol Scand*. 2000;58(3):129-134.
38. Schwaab LM, Niman CW, Gisel EG. Tongue movements in normal 2-, 3-, and 4-year-old children: a continuation study. *Am J Occup Ther*. 1986;40(3):180-185.
39. Garliner D. *Myofunctional Therapy in Dental Practice : Abnormal Swallowing Habits : Diagnosis, Treatment : A Course of Study for the Dental Practitioner and Speech Pathologist*.; 1974.
40. Proffit WR. On the aetiology of malocclusion. The Northcroft lecture, 1985 presented to the British Society for the Study of Orthodontics, Oxford, April 18, 1985. *Br J Orthod*. 1986;13(1):1-11.
41. Saccomanno S, Antonini G, D'Alatri L, D'Angeloantonio M, Fiorita A, Deli R. Case report of patients treated with an orthodontic and myofunctional protocol. *Eur J Paediatr Dent*. 2014;15(2 Suppl):184-186.
42. Ovsenik M, Farcnik FM, Korpar M, Verdenik I. Follow-up study of functional and morphological malocclusion trait changes from 3 to 12 years of age. *Eur J Orthod*. 2007;29(5):523-529.
43. Maspero C, Prevedello C, Giannini L, Galbiati G, Farronato G. Atypical swallowing: a review. *Minerva Stomatol*. 2014;63(6):217-227.
44. Lavelle CLB. *Applied Oral Physiology By Christopher L. B. Lavelle*.
45. Miller AJ. Deglutition. *Physiol Rev*. 1982;62(1):129-184.
46. Jean A. Brain stem control of swallowing: neuronal network and cellular mechanisms. *Physiol Rev*. 2001;81(2):929-969.
47. Palmer JB, Tanaka E, Ensrud E. Motions of the posterior pharyngeal wall in human swallowing: a quantitative videofluorographic study. *Arch Phys Med Rehabil*. 2000;81(11):1520-1526.
48. Arvedson JC, Brodsky L. *Pediatric Swallowing and Feeding : Assessment and Management*. Singular Thomson Learning; 2002.
49. Delaney AL, Arvedson JC. Development of swallowing and feeding: prenatal through first year of life. *Dev Disabil Res Rev*. 2008;14(2):105-117.
50. Carruth BR, Skinner JD. Feeding behaviors and other motor development in healthy children (2-24 months). *J Am Coll Nutr*. 2002;21(2):88-96.
51. Thexton AJ, Crompton AW, German RZ. Transition from suckling to drinking at weaning: a kinematic and electromyographic study in miniature pigs. *J Exp Zool*. 1998;280(5):327-343.
52. Hamdy S, Rothwell JC, Aziz Q, Thompson DG. Organization and reorganization of human swallowing motor cortex: implications for recovery after stroke. *Clin Sci (Lond)*. 2000;99(2):151-157.
53. Lang IM. Brain stem control of the phases of swallowing. *Dysphagia*. 2009;24(3):333-348.
54. Corbin-Lewis KM, Liss JM, Sciortino KF. *Clinical Anatomy & Physiology of the Swallow Mechanism*. Thomson Delmar Learning; 2005.
55. Haggard P, de Boer L. Oral somatosensory awareness. *Neurosci Biobehav Rev*. 2014;47:469-484.
56. Longo MR, Haggard P. An implicit body representation underlying human position sense. *Proc Natl Acad Sci U S A*. 2010;107(26):11727-11732.
57. Kumar A, Castrillon E, Trulsson M, Svensson KG, Svensson P. Fine motor control of the jaw following alteration of orofacial afferent inputs. *Clin Oral Investig*. 2017;21(2):613-626.
58. Turker KS. Reflex control of human jaw muscles. *Crit Rev Oral Biol Med*. 2002;13(1):85-104.
59. Steele CM, Miller AJ. Sensory input pathways and mechanisms in swallowing: a review. *Dysphagia*. 2010;25(4):323-333.
60. Osterlund C, Liu J-X, Thornell L-E, Eriksson P-O. Muscle spindle composition and distribution in human young masseter and biceps brachii muscles reveal early growth and maturation. *Anat Rec*

(Hoboken). 2011;294(4):683-693.

61. Zhang Y-R, Liu J, Huang Y. [Stereology investigation of muscle spindles in human masseter and temporalis muscle]. *Hua xi kou qiang yi xue za zhi = Huaxi kouqiang yixue zazhi = West China J Stomatol*. 2006;24(5):419-422.
62. Saverino D, De Santanna A, Simone R, Cervioni S, Cattrysse E, Testa M. Observational study on the occurrence of muscle spindles in human digastric and mylohyoideus muscles. *Biomed Res Int*. 2014;2014:294263.
63. Takeda H, Saitoh K. Impact of proprioception during the oral phase on initiating the swallowing reflex. *Laryngoscope*. 2016;126(7):1595-1599.
64. Logemann JA, Pauloski BR, Colangelo L, Lazarus C, Fujiu M, Kahrilas PJ. Effects of a sour bolus on oropharyngeal swallowing measures in patients with neurogenic dysphagia. *J Speech Hear Res*. 1995;38(3):556-563.
65. Mulheren RW, Kamarunas E, Ludlow CL. Sour taste increases swallowing and prolongs hemodynamic responses in the cortical swallowing network. *J Neurophysiol*. 2016;116(5):2033-2042.
66. Takahashi K, Shingai T, Saito I, Yamamura K, Yamada Y, Kitagawa J. Facilitation of the swallowing reflex with bilateral afferent input from the superior laryngeal nerve. *Neurosci Lett*. 2014;562:50-53.
67. Alvarez-Berdugo D, Rofes L, Casamitjana JF, Padron A, Quer M, Clave P. Oropharyngeal and laryngeal sensory innervation in the pathophysiology of swallowing disorders and sensory stimulation treatments. *Ann N Y Acad Sci*. 2016;1380(1):104-120.
68. Hamdy S, Aziz Q, Rothwell JC, et al. The cortical topography of human swallowing musculature in health and disease. *Nat Med*. 1996;2(11):1217-1224.
69. Ertekin C. Voluntary versus spontaneous swallowing in man. *Dysphagia*. 2011;26(2):183-192.
70. Shiino Y, Sakai S, Takeishi R, et al. Effect of body posture on involuntary swallow in healthy volunteers. *Physiol Behav*. 2016;155:250-259.
71. Standring S. *Gray's Anatomy : The Anatomical Basis of Clinical Practice.* Elsevier Health Sciences UK; 2008.
72. Ross MG, Nijland MJ. Development of ingestive behavior. *Am J Physiol*. 1998;274(4 Pt 2):R879-93.
73. Iriki A, Nozaki S, Nakamura Y. Feeding behavior in mammals: corticobulbar projection is reorganized during conversion from sucking to chewing. *Brain Res Dev Brain Res*. 1988;44(2):189-196.
74. Green JR, Moore CA, Ruark JL, Rodda PR, Morvee WT, VanWitzenburg MJ. Development of chewing in children from 12 to 48 months: longitudinal study of EMG patterns. *J Neurophysiol*. 1997;77(5):2704-2716.
75. Langenbach GE, Weijs WA, Brugman P, van Eijden TM. A longitudinal electromyographic study of the postnatal maturation of mastication in the rabbit. *Arch Oral Biol*. 2001;46(9):811-820.
76. Pasqualina Andretta. *Riabilitazione Logopedica Della Deglutizione Viziata: Aspetti Metodologici*.; 2001.
77. Gross AM, Kellum GD, Hale ST, et al. Myofunctional and dentofacial relationships in second grade children. *Angle Orthod*. 1990;60(4):247-53; discussion 254.
78. Levrini A. [Atypical deglutition and functional myotherapy]. *Mondo Ortod*. 1977;19(3):24-48.
79. Garattini G, Crozzoli P, Grasso G. [Etiopathogenesis and early treatment of malocclusions related to persistence of atypical deglutition]. *Mondo Ortod*. 1991;16(2):149-156.
80. Lescano de Ferrer A, Varela de Villalba TB. [Effect of the suction-swallowing action on orofacial development and growth]. *Rev Fac Cien Med Univ Nac Cordoba*. 2006;63(2 Suppl):33-37.
81. Sayin MO, Akin E, Karacay S, Bulakbasi N. Initial effects of the tongue crib on tongue movements during deglutition: a Cine-Magnetic resonance imaging study. *Angle Orthod*. 2006;76(3):400-405.
82. Fellus P. [Tongue disfunction and abnormal development]. *Orthod Fr*. 2006;77(1):105-112.
83. Stormer K, Pancherz H. Electromyography of the perioral and masticatory muscles in orthodontic patients with atypical swallowing. *J Orofac Orthop*. 1999;60(1):13-23.
84. POLIMENI A, OTTOLENGHI L, IERARDO G, MANZON L. Aspetti clinici e terapeutici della deglutizione atipica. *Dent CADMOS*. 1999;17:55-78.
85. Fraser C. Tongue thrust and its influence in orthodontics. *Int J Orthod Milwaukee*. 2006;17(1):9-18.
86. Moss ML. The primacy of functional matrices in orofacial growth. *Dent Pract Dent Rec*. 1968;19(2):65-73.
87. Molina M. *Concetti Fondamentali Di Gnatologia Moderna.* [s.n.]; 1996.
88. Hale ST, Kellum GD, Richardson JF, Messer SC, Gross AM, Sisakun S. Oral motor control, posturing, and myofunctional variables in 8-year-olds. *J Speech Hear Res*. 1992;35(6):1203-1208.
89. Barbato E, Manzon L, Fratto G. Disturbi del linguaggio nei quadri di malocclusione. Indagine preliminare. *Dent CADMOS*. 2000;68(4):69-77.
90. Levrini L., Schindler A., Andretta P., Greco L., Farronato G., Polimeni A., Vernero I., Cozza P. LC. Tavolo Tecnico Inter Associativo per L Ortodonzia E La Logopedia - PDF. In: milano; 2015.

91. Umberger FG, Weld GL, Van Rennen JS. Tongue thrust: attitudes and practices of speech pathologists and orthodontists. *Int J Orofacial Myology*. 1985;11(3):5-13.
92. Mason RM, Role EB. Did you know? A question and answer dialogue for the orofacial myologist. *Int J Orofacial Myology*. 2009;35:5-17.
93. Smithpeter J, Covell DJ. Relapse of anterior open bites treated with orthodontic appliances with and without orofacial myofunctional therapy. *Am J Orthod Dentofacial Orthop*. 2010;137(5):605-614.
94. Seemann J, Kundt G, Stahl de Castrillon F. Relationship between occlusal findings and orofacial myofunctional status in primary and mixed dentition: part IV: interrelation between space conditions and orofacial dysfunctions. *J Orofac Orthop*. 2011;72(1):21-32.
95. Silva M, Manton D. Oral habits--part 1: the dental effects and management of nutritive and non-nutritive sucking. *J Dent Child (Chic)*. 2014;81(3):133-139.
96. Condo R, Costacurta M, Perugia C, Docimo R. Atypical deglutition: diagnosis and interceptive treatment. A clinical study. *Eur J Paediatr Dent*. 2012;13(3):209-214.
97. Yu B, Zhu M, Xu L, Li G. *A Pilot Study of High-Density Electromyographic Maps of Muscle Activity in Normal Deglutition*.; 2013.
98. Umay EK, Unlu E, Saylam GK, Cakci A, Korkmaz H. Evaluation of dysphagia in early stroke patients by bedside, endoscopic, and electrophysiological methods. *Dysphagia*. 2013;28(3):395-403.
99. da Silva AP, Lubianca Neto JF, Santoro PP. Comparison between videofluoroscopy and endoscopic evaluation of swallowing for the diagnosis of dysphagia in children. *Otolaryngol Head Neck Surg*. 2010;143(2):204-209.
100. Suvinen TI, Malmberg J, Forster C, Kemppainen P. Postural and dynamic masseter and anterior temporalis muscle EMG repeatability in serial assessments. *J Oral Rehabil*. 2009;36(11):814-820.
101. Sforza C, Rosati R, De Menezes M, Musto F, Toma M. EMG analysis of trapezius and masticatory muscles: experimental protocol and data reproducibility. *J Oral Rehabil*. 2011;38(9):648-654.
102. Botelho AL, Melchior M de O, da Silva AMBR, da Silva MAMR. Electromyographic evaluation of neuromuscular coordination of subject after orthodontic intervention. *Cranio*. 2009;27(3):152-158.
103. Frongia G, Ramieri G, De Biase C, Bracco P, Piancino MG. Changes in electric activity of masseter and anterior temporalis muscles before and after orthognathic surgery in skeletal class III patients. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2013;116(4):398-401.
104. Ferrario VF, Sforza C, Colombo A, Ciusa V. An electromyographic investigation of masticatory muscles symmetry in normo-occlusion subjects. *J Oral Rehabil*. 2000;27(1):33-40.
105. Adams V, Mathisen B, Baines S, Lazarus C, Callister R. A systematic review and meta-analysis of measurements of tongue and hand strength and endurance using the Iowa Oral Performance Instrument (IOPI). *Dysphagia*. 2013;28(3):350-369.
106. Youmans SR, Stierwalt JAG. Measures of tongue function related to normal swallowing. *Dysphagia*. 2006;21(2):102-111.
107. Youmans SR, Youmans GL, Stierwalt JAG. Differences in tongue strength across age and gender: is there a diminished strength reserve? *Dysphagia*. 2009;24(1):57-65.
108. Palmer PM, Neel AT, Sprouls G, Morrison L. Swallow characteristics in patients with oculopharyngeal muscular dystrophy. *J Speech Lang Hear Res*. 2010;53(6):1567-1578.
109. ROGERS AP. A restatement of the myofunctional concept in orthodontics. *Am J Orthod*. 1950;36(11):845-855.
110. Bondi M. *Mioterapia Orofacciale Craniocervicale*. Masson; 1991.
111. STRAUB WJ. The etiology of the perverted swallowing habit. *Am J Orthod*. 1951;37(8):603-610.
112. Garliner D. Myofunctional therapy. *J Maxillofac Orthop*. 1970;3(4):7-12.
113. Scarponi L, de Felicio CM, Sforza C, et al. Reliability and Validity of the Italian Version of the Protocol of Orofacial Myofunctional Evaluation with Scores (I-OMES). *Folia Phoniatr Logop*. 2018;70(1):8-12.
114. Stahl F, Grabowski R, Gaebel M, Kundt G. Relationship between occlusal findings and orofacial myofunctional status in primary and mixed dentition. Part II: Prevalence of orofacial dysfunctions. *J Orofac Orthop*. 2007;68(2):74-90.
115. Marchesan IQ, Berretin-Felix G, Genaro KF. MBGR protocol of orofacial myofunctional evaluation with scores. *Int J Orofacial Myology*. 2012;38:38-77.
116. Valera FCP, Trawitzki LV V, Anselmo-Lima WT. Myofunctional evaluation after surgery for tonsils hypertrophy and its correlation to breathing pattern: a 2-year-follow up. *Int J Pediatr Otorhinolaryngol*. 2006;70(2):221-225.
117. Ferreira CLP, Da Silva MAMR, de Felicio CM. Orofacial myofunctional disorder in subjects with temporomandibular disorder. *Cranio*. 2009;27(4):268-274.
118. Bakke M, Bergendal B, McAllister A, Sjogreen L, Asten P. Development and evaluation of a comprehensive screening for orofacial dysfunction. *Swed Dent J*. 2007;31(2):75-84.
119. Grandi D. The ‘Interdisciplinary Orofacial Examination Protocol for Children and Adolescents’: a resource for the interdisciplinary assessment of the stomatognatic system. *Int J Orofacial Myology*. 2012;38:15-26.

120. Felicio CM de, Ferreira CLP. Protocol of orofacial myofunctional evaluation with scores. *Int J Pediatr Otorhinolaryngol*. 2008;72(3):367-375.
121. de Felicio CM, Folha GA, Ferreira CLP, Medeiros APM. Expanded protocol of orofacial myofunctional evaluation with scores: Validity and reliability. *Int J Pediatr Otorhinolaryngol*. 2010;74(11):1230-1239.
122. Kellen PM, Becker DL, Reinhardt JM, Van Daele DJ. Computer-assisted assessment of hyoid bone motion from videofluoroscopic swallow studies. *Dysphagia*. 2010;25(4):298-306.
123. Uysal T, Yagci A, Kara S, Okkesim S. Influence of pre-orthodontic trainer treatment on the perioral and masticatory muscles in patients with Class II division 1 malocclusion. *Eur J Orthod*. 2012;34(1):96-101.
124. Yagci A, Uysal T, Kara S, Okkesim S. The effects of myofunctional appliance treatment on the perioral and masticatory muscles in Class II, Division 1 patients. *World J Orthod*. 2010;11(2):117-122.
125. Melsen B, Stensgaard K, Pedersen J. Sucking habits and their influence on swallowing pattern and prevalence of malocclusion. *Eur J Orthod*. 1979;1(4):271-280.
126. Giuca MR, Pasini M, Pagano A, Mummolo S, Vanni A. Longitudinal study on a rehabilitative model for correction of atypical swallowing. *Eur J Paediatr Dent*. 2008;9(4):170-174.
127. Cheng C-F, Peng C-L, Chiou H-Y, Tsai C-Y. Dentofacial morphology and tongue function during swallowing. *Am J Orthod Dentofacial Orthop*. 2002;122(5):491-499.
128. Ichida T, Takiguchi R, Yamada K. Relationship between the lingual-palatal contact duration associated with swallowing and maxillofacial morphology with the use of electropalatography. *Am J Orthod Dentofacial Orthop*. 1999;116(2):146-151.
129. Premkumar S, Avathvadi Venkatesan S, Rangachari S. Altered oral sensory perception in tongue thrusters with an anterior open bite. *Eur J Orthod*. 2011;33(2):139-142.
130. Koczorowski M, Gedrange T, Koczorowski R. Changes of oral sensibility in subjects with partial anterior open bite and the incorrect position of the tongue. *Ann Anat*. 2012;194(2):220-223.
131. Insabralde NM, de Almeida RR, Henriques JFC, Fernandes TMF, Flores-Mir C, de Almeida MR. Dentoskeletal effects produced by removable palatal crib, bonded spurs, and chincup therapy in growing children with anterior open bite. *Angle Orthod*. 2016;86(6):969-975.
132. Lowe AA, Takada K, Yamagata Y, Sakuda M. Dentoskeletal and tongue soft-tissue correlates: a cephalometric analysis of rest position. *Am J Orthod*. 1985;88(4):333-341.
133. Takahashi O, Iwasawa T, Takahashi M. Integrating orthodontics and oral myofunctional therapy for patients with oral myofunctional disorders. *Int J Orofacial Myology*. 1995;21:66-72.
134. Proffit WR, Chastain BB, Norton LA. Linguopalatal pressure in children. *Am J Orthod*. 1969;55(2):154-166.
135. Proffit WR, Mason RM. Myofunctional therapy for tongue-thrusting: background and recommendations. *J Am Dent Assoc*. 1975;90(2):403-411.
136. Cayley AS, Tindall AP, Sampson WJ, Butcher AR. Electropalatographic and cephalometric assessment of tongue function in open bite and non-open bite subjects. *Eur J Orthod*. 2000;22(5):463-474.
137. Vanderwegen J, Guns C, Van Nuffelen G, Elen R, De Bodt M. The influence of age, sex, bulb position, visual feedback, and the order of testing on maximum anterior and posterior tongue strength and endurance in healthy belgian adults. *Dysphagia*. 2013;28(2):159-166.
138. Clark HM, Henson PA, Barber WD, Stierwalt JAG, Sherrill M. Relationships among subjective and objective measures of tongue strength and oral phase swallowing impairments. *Am J speech-language Pathol*. 2003;12(1):40-50.
139. Potter NL, Short R. Maximal tongue strength in typically developing children and adolescents. *Dysphagia*. 2009;24(4):391-397.
140. Folha GA, Valera FCP, de Felicio CM. Validity and reliability of a protocol of orofacial myofunctional evaluation for patients with obstructive sleep apnea. *Eur J Oral Sci*. 2015;123(3):165-172.
141. de Felicio CM, da Silva Dias FV, Folha GA, et al. Orofacial motor functions in pediatric obstructive sleep apnea and implications for myofunctional therapy. *Int J Pediatr Otorhinolaryngol*. 2016;90:5-11.
142. de Felicio CM, Medeiros APM, de Oliveira Melchior M. Validity of the ‘protocol of oro-facial myofunctional evaluation with scores’ for young and adult subjects. *J Oral Rehabil*. 2012;39(10):744-753.
143. Ferrario VF, Tartaglia GM, Galletta A, Grassi GP, Sforza C. The influence of occlusion on jaw and neck muscle activity: a surface EMG study in healthy young adults. *J Oral Rehabil*. 2006;33(5):341-348.
144. Dellavia C, Francetti L, Rosati R, Corbella S, Ferrario VF, Sforza C. Electromyographic assessment of jaw muscles in patients with All-on-Four fixed implant-supported prostheses. *J Oral Rehabil*. 2012;39(12):896-904.

145. Sonies BC, Parent LJ, Morrish K, Baum BJ. Durational aspects of the oral-pharyngeal phase of swallow in normal adults. *Dysphagia*. 1988;3(1):1-10.
146. Monaco A, Cattaneo R, Spadaro A, Giannoni M. Surface electromyography pattern of human swallowing. *BMC Oral Health*. 2008;8:6.
147. Pernambuco L de A, Silva HJ da, Lima LM de, et al. Electrical activity of masseter muscle in young adults during swallowing of liquid. *J Soc Bras Fonoaudiol*. 2011;23(3):214-219.
148. Vaiman M. Standardization of surface electromyography utilized to evaluate patients with dysphagia. *Head Face Med*. 2007;3:26.
149. *The International Classification Of Sleep Disorders, Revised Diagnostic and Coding Manual*.; 1990.
150. Homem MA, Vieira-Andrade RG, Falci SGM, Ramos-Jorge ML, Marques LS. Effectiveness of orofacial myofunctional therapy in orthodontic patients: a systematic review. *Dental Press J Orthod*. 2014;19(4):94-99.
151. Christensen M, Hanson M. An investigation of the efficacy of oral myofunctional therapy as a precursor to articulation therapy for pre-first grade children. *J Speech Hear Disord*. 1981;46(2):160-165.
152. Lambrechts H, De Baets E, Fieuws S, Willems G. Lip and tongue pressure in orthodontic patients. *Eur J Orthod*. 2010;32(4):466-471.
153. Dworkin JP, Culatta RA. Tongue Strength. *J Speech Hear Disord*. 1980;45(2):277.
154. Fazio D Di, Lombardo L, Gracco A, D’amico P, Siciliani G. Lip pressure at rest and during function in 2 groups of patients with different occlusions. 2011.
155. Eslamian L, Leilazpour AP. Tongue to palate contact during speech in subjects with and without a tongue thrust. *Eur J Orthod*. 2006;28(5):475-479.
156. Wilson EM, Green JR. Coordinative organization of lingual propulsion during the normal adult swallow. *Dysphagia*. 2006;21(4):226-236.
157. Cayley AS, Tindall AP, Sampson WJ, Butcher AR. Electropalatographic and cephalometric assessment of tongue function in open bite and non-open bite subjects. *Eur J Orthod*. 2000;22(5):463-474.
158. Fujiki T, Takano-Yamamoto T, Noguchi H, Yamashiro T, Guan G, Tanimoto K. A cineradiographic study of deglutitive tongue movement and nasopharyngeal closure in patients with anterior open bite. *Angle Orthod*. 2000;70(4):284-289.
159. Meyer-Marcotty P, Hartmann J, Stellzig-Eisenhauer A. Dentoalveolar Open Bite Treatment with Spur Appliances. *J Orofac Orthop / Fortschritte der Kieferorthopädie*. 2007;68(6):510-521.
160. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361-374.

4. List of Abbraviations

- AOB: anterior open bite
- AS: atypical swallowing
- AS group: atypical swallowing group
- C group: control group
- CNS: central nervous system
- CPG: central pattern generator
- CP: cricopharyngeus muscle
- DSG: dorsal swallowing group
- FEE: fiberoptic endoscopic evaluation
- ELN: elevator lingual nocturne
- IOPI: iowa oral performing instrument
- fMRI: functional magnetic resonance imaging
- MFT: myofunctional therapy
- MM: masseter muscles
- MS: muscular splindles
- NA: nucleus ambiguous
- NNS: non-nutritive suction
- NOT-S: nordic orofacial-test screening
- NTS: nucleus of solitary tract
- NTSim: intermediate subnuclei of the solitary tract
- NTSis: interstitial subnuclei of the solitary tract
- NTSvm: ventro-medial subnuclei of the solitary tract
- OJ: overjet
- OMD: orofacial myofunctional disorders
- OMEs: orofacial myofunctional evaluation with scores
- OVB: overbite
- OVJ: overjet
- PET: positron emission tomography
- POC: percentage of overlapping coefficient
- sEMG: surface electromyography
- ssEMG: standardized surface electromyography
- SLN: spinal lemniscus nuclei
- SM: submental muscles
- SN: solitary nucleus
- SS: spontaneous swallowing
- TA: anterior temporalis muscles
- TMJ: temporo-mandibular Joint
- TOME: traditional orofacial myofunctional evaluation
- UES: upper esophageal sphincter
- VF: video-fluoroscopy
- VLM: ventro-lateral medulla
- VS: voluntary swallowing
- VSG: ventral swallowing group

5. Attached files

Attached file 1

Standardized Surface Electromyographic protocol

Electrode type and positioning

The anterior Temporalis (TA), Masseter (MM) and submental area muscles (SM) of both sides (left and right) were examined. Disposable pre-gelled silver/silver chloride bipolar surface electrodes (rectangular shape, 21 x 41 mm, 20 mm inter-electrode distance) (F3010, Fiab, Firenze, Italy) were positioned according to the recommendations of SENIAM (Surface EMG for Non-Invasive Assessment of Muscles)[160]. On each muscle a bipolar electrode was positioned on the muscular bellies parallel to muscular fibres as follows:

- MM: the operator, standing in front of the seated subject, pal-pated the muscular belly while the subject clenched his/her teeth. The electrodes were fixed parallel to the exocanthion-gonion line and with the upper pole of the electrode under the tragus-labial commissural line.
- TA: the muscular belly was palpated during tooth clenching and the electrodes were fixed vertically along the anterior margin of the muscle (corresponding to the fronto-parietal suture).
- SM: each electrode was placed parallel to the anterior digastric belly, paramedian to the midline and lightly diverging, 1 cm posterior to the mental symphysis.

A disposable reference electrode was applied to the forehead or on the earlobe (Figure 5.1). To reduce skin impedance, the skin was carefully cleaned prior to electrode placement, and recordings were performed 5 min later, allowing the conductive paste to adequately moisten the skin.

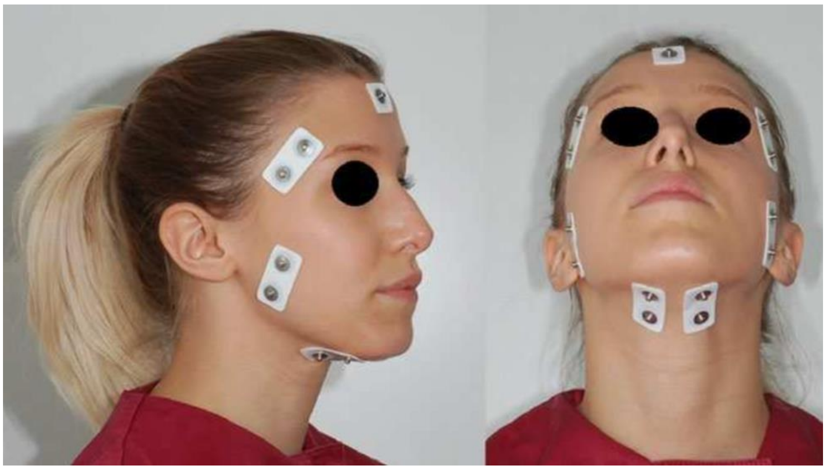


Figure 5.1. Electrodes positioning for Masseter muscles, Temporalis Muscles, Submental area Muscles. Reference electrode was applied on the earlobe.

Instrumentation

Surface EMG activity was recorded using a computerised instrument (Easymyo, 3 Technology S.r.l., Udine, Italy). The analogues EMG signal was amplified (gain 100, bandwidth 0–1000 Hz, peak-to-peak input range from 0 to 3600 mVpp) using a differential amplifier with a high common mode rejection ratio (CMRR100 dB in the range 0–60 Hz, input impedance 100Gohm), digitized (24 bit resolution, 4000 Hz A/D sampling frequency), and digitally filtered (high-pass filter set at 30 Hz, low-pass filter set at 400 Hz,band-stop for common 50–60 Hz noise). The signals were averaged over 25 ms, with muscle activity assessed as the root mean square (RMS) of the amplitude (mV). SEMG signals were recorded for further analysis. Before acquisition session, the subjects were properly trained to elicit true maximal voluntary contraction using a non-time sEMG signal visualization.

Measurements

Each appointment was composed by three acquisition steps:

- Masticatory muscles standardisation procedures: two 10-mm thick cotton rolls were positioned on the mandibular second premolars/first molars of each subject, and a 5-s maximum voluntary contraction (MVC) was recorded to standardise TA and MM sEMG signal. The mean sEMG potential obtained in the first acquisition was set at 100%, and all further sEMG potentials were expressed as a percentage of this value (mV/mV x 100)[104]
- Submental muscles standardisation procedures: the subjects were invited to push their tongue at their best (without teeth clenching) against the palate, and a 5-s sEMG SM activity was recorded. All further SM sEMG potentials were expressed as a percentage of this value (mV/mV x 100). This test was repeated twice (A and B) in each appointment, in order to assess SM muscles standardisation procedures repeatability.
- Saliva swallowing: after drinking 20 cc of water, the participants were asked to wait 30 seconds, bring their teeth in contact during swallowing the saliva spontaneously accumulated and keep them in rest position (with no occlusal contacts) at the end; a 5-seconds sEMG activity was recorded. The exercise was repeated twice (A and B) during each appointment. A 90-seconds break period elapsed between the 2 acquisitions.

For each acquisition, the 3- seconds period with more stable signal was automatically selected by the dedicated software that calculated the Simple Moving Average. During the tests, participants were asked to perform to the best of their ability, to avoid head and neck move-ments and maintain a relaxed facial expression to reduce cross- talks. During the recordings, participants sat in a comfortable office type chair with a straight posture, feet flat on the floor and arms resting on their legs. For each participant, test order was randomised by a computer random number generator and 90- seconds rest period was allowed. All acquisitions were made by the same operator.

Attached file 2

Evaluation protocol for Atypical Swallowing

Cognome______________ Nome_____________

Data di nascita_______________

Età________________

Indirizzo_______________ Telefono_______________

Invio_______________

Scolarità______________ Sport__________________

Professione______________

Anamnesi

Allattamento: naturale – artificiale – eventuali problemi

Svezzamento – difficoltà:

Abitudini alimentari:

Salivazione:

Dentizione:

Masticazione:

Deambulazione:

Crescita e sviluppo motorio:

Vista:	Udito:
Linguaggio:	Ritardo di linguaggio:

Tonsille ed adenoidi:

Allergie respiratorie:

Sonno:

Altre condizioni:

Osservazione generale

Suzione e vizi orali

Bocca da biberon

Uso e durata della tettarella del biberon

- Succhiotto ______ Tipo_________ fino all'età____________

Dito/a________ quale/i?_________ fino all'età____________

Nocca /e del dito /delle dita ____________________________

- Braccio____________ Lingua_________________

Oggetto transazionale___________________________________

Lapisfagia

Morso del labbro

Morso delle guance

Onicofagia

Altre parafunzioni

Respirazione orale

Bruxismo

Digrignamento

Tics orofacciali

Atteggiamenti posturali

Interventi posturali specifici (ortopedia – fisiatria – osteopatia – posturologia – chiropratica – altro)

Ausili (lenti correttive – occhiali – suolette/plantari – protesi uditive)

Precedenti familiari di malocclusione

Difficoltà nel deglutire compresse

Apparecchi ortodontici

Altri dispositivi ortodontici (contenzione, splintaggio, placche, espansore palatale ortopedico, quad-helix...)

Diagnosi ortodontica (tipo di problema occlusale)

Overjet____

Occlusione solo nella zona molare______________________________________

Open bite____

Biprotrusione____

Occlusione di pseudo III Classe____

Occlusione di III Classe____

Closed bite____

Depressione unilaterale zona molare_____________________________________

Depressione bilaterale zona molare______________________________________

Attached file 3

Orofacial Myofunctional Evaluation with Scores (OMEs) - Italian version (de Felicio et al. 2015)

Cognome e Nome:____
Data di nascita______/______/______
Età:___________
sesso: (F) (M)
Indirizzo:____
Logopedista:____
Osservazioni:____________________
Data________/__________/________

ASPETTO E POSTURA

Postura delle labbra		**Punteggi**
Chiusura (sigillo) delle labbra normale	Soddisfano la funzione di chiudere la bocca e sono a contatto senza sforzo	(3)
Chiusura delle labbra con sforzo	Aumento dell'attività delle labbra e del muscolo mentoniero	(2)
Labbra aperte (incompetenza labiale)	Disfunzione lieve	(2)
	Disfunzione severa (grave)	(1)

Postura verticale della mandibola		**Punteggi**
Postura normale	Con spazio libero interocclusale: i denti sono disclusi, non a contatto con gli antagonisti ("freeway space")	(3)
Occlusione dentale	Senza spazio libero interocclusale: i denti sono a contatto con gli antagonisti	(2)
Bocca aperta	Disfunzione lieve	(2)
Bocca molto aperta	Disfunzione severa	(1)

Aspetto delle guance		**Punteggi**
Normale		(3)
Ipertrofiche o Flaccide/cascanti	Disfunzione lieve	(2)
	Disfunzione severa	(1)

Aspetto della faccia		**Punteggi**
Simmetria tra i lati destro e sinistro	Normale	(3)
Asimmetria	Disfunzione lieve	(2)
	Disfunzione severa	(1)

Postura della lingua		**Punteggi**
Contenuta nella cavità orale	Normale	(3)
Interposizione della lingua tra le arcate dentarie	Adattamento alla malocclusione o disfunzione	(2)
	Protrusione eccessiva	(1)

Aspetto del palato		**Punteggio**
	Normale	(3)
Ridotta ampiezza trasversale (Palato stretto)	Lieve	(2)
	Severa	(1)

Totale dei Punteggi per Aspetto e Postura (Somma)	

MOBILITÀ

Disfunzioni o alterazioni sono considerate presenti quando si osservano: mancanza di precisione del movimento, tremore, e/ o movimenti congiunti (associati) di altre componenti (esempio: labbra che accompagnano i movimenti della lingua) e inabilità (impossibilità) nell'eseguire i movimenti richiesti.

Esecuzione	**MOVIMENTI DELLE LABBRA**			
	Protrusione	**Retrusione (sorriso chiuso)**	**Laterale a Destra**	**Laterale a Sinistra**
Precisa	(3)	(3)	(3)	(3)
Imprecisa	(2)	(2)	(2)	(2)
Severa inabilità	(1)	(1)	(1)	(1)
			Risultato (somma)	

Esecuzione	**MOVIMENTI DELLA LINGUA**					
	Protrusione	**Retrusione**	**Laterale a Destra**	**Laterale a Sinistra**	**Sollevare**	**Abbassare**
Precisa	(3)	(3)	(3)	(3)	(3)	(3)
Imprecisa	(2)	(2)	(2)	(2)	(2)	(2)
Severa inabilità	(1)	(1)	(1)	(1)	(1)	(1)
					Risultato (somma)	

Esecuzione	**MOVIMENTI DELLA MANDIBOLA**				
	Apertura	**Chiusura**	**Laterale a Destra**	**Laterale a Sinistra**	**Protrusione**
Precisa	(3)	(3)	(3)	(3)	(3)
Imprecisa	(2)	(2)	(2)	(2)	(2)
Severa inabilità	(1)	(1)	(1)	(1)	(1)
				Risultato (somma)	

Esecuzione	**MOVIMENTI DELLE GUANCE**			
	Gonfiare	**Succhiare**	**Ritrare (sorriso chiuso)**	**Trasferire aria da destra a sinistra**
Precisa	(3)	(3)	(3)	(3)
Imprecisa	(2)	(2)	(2)	(2)
Severa inabilità	(1)	(1)	(1)	(1)
			Risultato (somma)	

Totale dei Punteggi per Mobilità (Somma)	

FUNZIONI

Respirazione		**Punteggi**
Respirazione nasale	Normale	(3)
Respirazione oronasale	Disfunzione lieve	(2)
Respirazione orale	Disfunzione severa	(1)
Risultato		

Deglutizione: Comportamento delle labbra		**Punteggi**
Chiusura (sigillo) labiale normale	Le Labbra sono a contatto senza sforzo	(3)
Chiusura labiale con sforzo	Disfunzione lieve	(2)
	Disfunzione moderata	(1)
Assenza di chiusura labiale	Disfunzione severa	(1)
Risutato		

Deglutizione: Comportamento della lingua		**Punteggi**
Contenuta nella cavità orale	Normale	(3)
Interposizione della lingua tra le arcate dentarie	Adattamento o disfunzione	(2)
	Protrusione eccessiva	(1)
Risultato		

Deglutizione: Altri comportamenti e segni di disfunzione		**Punteggi**
Movimenti della testa	Assenti	(1)
	Presenti	(0)
Tensione dei muscoli facciali	Assenti	(1)
	Presenti	(0)
Fuoriuscita del cibo dalle labbra	Assenti	(1)
	Presenti	(0)
Risultato		

Elementi complementari – Efficienza della Deglutitzione	**Punteggi**
Bolo solido	
Deglutizione singola	(3)
Doppia deglutizione	(2)
Deglutizioni multiple	(1)
Bolo liquido	
Deglutizione singola	(3)
Doppia degutizione	(2)
Deglutizioni multiple	(1)
Risultato	

Totale dei Punteggi per Funzioni (Somma)	

MASTICAZIONE

Masticazione – morso		**Punteggi**
Morde con i denti incisivi e/o canini	Normale	(3)
Morde con i denti posteriori	Disfunzione lieve	(2)
Non morde	Disfunzione severa	(1)

Masticazione		**Punteggi**
Bilaterale	Alternata (40%-65% per ogni lato)	(4)
	Simultanea (verticale)	(3)
Unilaterale (mastica su un lato)	Preferenziale (66% sullo stesso lato)	(2)
	Cronica (95% sullo stesso lato)	(1)
Anteriore	Triturazione con gli incisivi	(1)
Non esegue la funzione		(1)
Risultato		

Masticazione: Altri comportamenti e segni di disfunzione		**Punteggi**
Movimenti della testa	Assenti	(1)
	Presenti	(0)
Postura alterata	Assenti	(1)
	Presenti	(0)
Fuoriuscita di cibo dalle labbra	Assenti	(1)
	Presenti	(0)
Risultato		

Totale dei Punteggi per Masticazione (Somma)	

VALUTAZIONE DELL’OCCLUSIONE FUNZIONALE

Linea Mediana	Normale	Deviazione a destra	Misura (mm)	Deviazione a sinistra	Misura (mm)

Classificazione di Angle

Destra	Normale I Classe	II Classe 1a Divisione	II Classe II 2a Divisione	III Classe
Sinistra	Normale I Classe	II Classe 1a Divisione	II Classe II 2a Divisione	III Classe

MOVIMENTI MANDIBOLARI

	Movimenti					Misure (mm)		
	Normale	Deviazione		Dolore		Ovebite	Distanza massima tra denti incisivi inferiore e superiore	Totale
Apertura		D	S	D	S			
Chiusura		D	S	D	S			

D: destra; S: sinistra

Overbite ovvero la distanza tra margine incisivo superiore e margine incisivo inferiore, sul piano sagittale.

Movimenti Laterali			Piste di Disocclusione (guida occlusale)	Interferenze occlusali (presenti o assenti)		
	Dolore			Lato lavorante	Lato bilanciante (o non di lavoro)	Misura
Destra	D	S				
Sinistra	D	S				

D: destra; S: sinistra

Protrusione	Movimento				Interferenze Posteriori		Misure (mm)		
	Dolore		Deviazione				Overjet	Distanza	Totale
	D	S	D	S	D	S			

D: destra; S: sinistra

Overjet ovvero la distanza tra margine incisivo superiore e margine incisivo inferiore, sul piano orizzontale.

Rumori articolatori (Articolazione temporomandibolare) presente o assente	Apertura	Chiusura	Protrusione	Laterale a destra	Laterale a sinistra
Destra					
Sinistra					

Attached file 4

Speech therapy protocol (10 steps) (based on the Garliner method)

Prima seduta
Correzione dei vizi orali
Esercizio del “risucchia e inghiotti” (1.2.3.4.):

- si posiziona l'elastico sulla punta della lingua;
- si innalza la punta della lingua con l'elastico sulla papilla retroincisiva;
- si chiudono i denti (rilassati) e si “risucchia” o si aspira un po' d'aria;
- si deglutisce (intercuspidazione dentale), mantenendo le labbra aperte.

Questo esercizio base permette di avere una quantità sufficiente di saliva per deglutire più volte senza difficoltà. Deve essere eseguito 6 volte per 1 volta il primo giorno aumentando nei giorni successivi fino a 12-15 volte per 3 volte al giorno. Tutti i movimenti debbono essere eseguiti tre volte al giorno con le labbra aperte e con una distanza tra una serie e l'altro di almeno due ore.

Seconda seduta
L'esercizio dell'1.2.3.4. deve essere completamente appreso e “dominato” prima di proseguire.
Si prosegue con l'elastico delll'1.2.3. con un elastico sull'apice linguale, senza risucchio facendolo eseguire a casa 10 volte per tre volte al giorno.
Esercizio dell'1.2.3.4. con due elastici, uno sull'apice linguale e uno sul dorso della lingua, deglutire correttamente con le labbra aperte 10 volte per tre volte al giorno,
Eseguire 20 schiocchi linguali per tre volte al giorno.
Esercizio della “Gioia della Madre”: si esegue l'esercizio dell'1.2.3. poi si chiudono le labbra e si resta in questa posizione per 5 minuti (non dev'esserci nessuna contrazione periorale). Inizialmente si esegue per 5 minuti, ma gradualmente si aumenta il tempo fino ad arrivare a 10 minuti al giorno per una volta al giorno.
Esercizio dello “spingi-tieni” (hold-pull): consiste nel posizionare la lingua (apice e dorso) sul palato duro creando pressione negativa all'interno del cavo orale, aprendo la mandibola il più possibile, contando per 10 secondi. Questo esercizio si esegue per 3 ripetizioni per 3 volte al giorno.

Terza seduta
Esercizio dell'1.2.3. con 1 elastico, 10 ripetizioni per tre volte al giorno.
Esercizio dell'1.2.3. con due elastici eseguito 10 ripetizioni per tre volte al giorno.
Esercizio dell'1.2.3. con 3 elastici, uno sull'apice linguale, uno sul dorso e l'altro sulla radice linguale: deglutire correttamente con le labbra aperte per 10 volte per tre volte al giorno.
Esercizio dello “spingi-tieni” per tre volte per tre volte al giorno.
Esercizio dello “spingi-tieni” con un sorso d'acqua tenuto sulla parte centrale (dorso) della lingua e si eseguono 5 sorsi per tre volte al giorno con le labbra aperte.
“Gioia della Madre”: 20 minuti per una volta al giorno.
Esercizio del Tiro del bottone: si pone un bottone, collegato ad un filo di cotone morbido, tra le labbra e i denti; si tira opponendo resistenza. Si eseguono 10 tiri per tre volte al giorno.
Lista di parole 1: questa lista contiene parole che servono a posizionare correttamente la parte anteriore della lingua. (Solo in questa lista si utilizza l'elastico sull'apice linguale)
Esercizio dei masseteri: appoggiare le dita delle mani in corrispondenza dei muscoli masseteri chiudendo i denti in modo energico e contare fino al 10 per tre volte per tre volte al giorno.

Quarta seduta
Sempre tutti gli esercizi vengono controllati completamente prima di iniziare quelli nuovi. In questa seduta viene eseguita una verifica dei progressi raggiunti.
Esercizio dell'1.2.3. con l'elastico, otto volte per tre volte al giorno. Esercizio dell'1.2.3. con due elastici, 10 volte per tre volte al giorno. Esercizio dell'1.2.3. con tre elastici: deglutire correttamente con le labbra aperte per 10 volte per tre volte al giorno.
Esercizio dell'1.2.3. con un pezzo di cracker utilizzando l'elastico sull'apice linguale. Si esegue con quattro-cinque “boli” per tre volte al giorno.
Esercizio dello “spingi-tieni” con un sorso d'acqua tenuto sulla parte centrale (dorso) della lingua, 5 sorsi per tre volte al giorno.
Tutti questi esercizi vanno eseguiti mantenendo le labbra aperte.
Esercizio del “Tiro del bottone”: 10 tiri per tre volte al giorno.
“Gioia della madre”: 30 minuti per una volta al giorno.
Esercizio dei masseteri per tre volte al giorno.

Esercizio del “Tiro alla fune”: questo esercizio si esegue in due persone. Entrambe posizionano all'interno della bocca (tra le labbra e le arcate dentali) un bottone collegato all'altro mediante un filo di cotone morbido, chiudere le labbra e tirare in modo energico e deciso. Entrambe le persone debbono fare una specie di “gara” per rafforzare la muscolatura dell'orbicolare. Si eseguono 20 tiri, tre volte al giorno.
Lista di parole 1. Lista di parole 2: questa lista contiene parole che servono a posizionare correttamente l'apice e il dorso della lingua e viene eseguito per tre volte al giorno.
Esercizio del massaggio del labbro: questo esercizio si esegue sollevando il labbro inferiore che va a “coprire” quello superiore stirandolo e massaggiandolo con decisione, 30 volte per tre volte al giorno.
Esercizio del “sollevamento pesi”: si infilano due (o più a seconda delle capacità personali del paziente) dischetti di plastica (pesi-bulloni) alla fune con un nodo finale. Si solleva la fune con lavoro sinergetico di labbra e arcate dentali senza nessuna partecipazione della lingua. Si seguono due sollevamenti per tre volte al giorno.

Quinta seduta
Viene eseguita una verifica dei progressi raggiunti.
Esercizio 1.2.3. con elastico, 6 volte per tre volte al giorno, in questa fase s'invita il soggetto ad eseguirlo con le labbra chiuse prima di deglutire.
Esercizio 1.2.3. con due elastici, 8 volte per tre volte al giorno.
Esercizio 1.2.3. con tre elastici, 10 volte per tre volte al giorno.
“Gioia della Madre”: 45 minuti per una volta al giorno.
Esercizio dei masseteri per tre volte al giorno.
“Tiro del bottone”: 10 tiri per tre volte al giorno.
“Tiro alla fune”: 20 tiri per tre volte al giorno.
Esercizio dei massaggi del labbro: 50 per tre volte al giorno.
Lista parole 1-2 e s'introduce la Lista 3 che contiene parole per esercitare l'apice, il dorso e la radice della lingua durante l'articolazione del linguaggio.
Esercizio del sorso d'acqua per tre volte al giorno.
Esercizio del sollevamento pesi: si aggiungono a seconda delle capacità altri dischi di plastica, 2 sollevamenti per tre volte al giorno.
Esercizio del pasto con 1 elastico (1.2.3.): s'invita il soggetto a mangiare mezzo pasto attraverso la procedura dell'1.2.3. con le labbra aperte, una volta al giorno.

Sesta seduta
Esercizio 1.2.3. con tre elastici a labbra chiuse: 8 volte per tre volte al giorno.
Esercizio 1.2.3. senza elastico, 10 volte per tre volte al giorno con le labbra chiuse
“Gioia della Madre”: 50 minuti per una volta al giorno
Si introduce l'esercitatore labiale: una piastrina di plastica da introdurre tra le labbra chiuse e rilassate per favorire ed aumentare competenza labiale e la respirazione nasale. Tale esercizio non può essere proposto in caso di respirazione orale da patologia ostruttiva delle vie aeree superiori.
L'esercitatore bilabiale va tenuto tra le labbra, contemporaneamente all'esecuzione della Gioia della Madre.
Esercizio dei masseteri per tre volte al giorno
“Tiro del bottone”: 10 tiri per tre volte al giorno.
“Tiro alla fune”: 20 tiri per tre volte al giorno.
Esercizio dei massaggi del labbro: 70 per tre volte al giorno.
Lista parole 1-2 e 3.
Esercizio del sorso d'acqua per tre volte al giorno.
Esercizio del sollevamento pesi: si aggiungono a seconda delle capacità altri dischi di plastica, 2 sollevamenti per tre volte al giorno.
Bere i liquidi deglutendo con modalità corretta.
Esercizio del pasto con 1 elastico (1.2.3.): s'invita il soggetto a mangiare 1 pasto intero attraverso la procedura dell'1.2.3. con le labbra aperte, una volta al giorno.

Settima seduta
I muscoli della deglutizione a questo punto della terapia sono stati adeguatamente educati. L'atto deglutitorio deve gradualmente passare da atto sporadico ad atto abituale.
Esercizio 1.2.3. senza elastico: 8 volte per tre volte al giorno a labbra chiuse
“Gioia della Madre” per 60 minuti una volta al giorno con esercitatore labiale.
“Tiro alla fune”: 20 tiri per una volta al giorno.
Sollevamento pesi per una volta al giorno.
Esercizio masseteri per due volte al giorno.
Massaggi del labbro: 60 per tre volte al giorno.
Bere e masticare correttamente.

Esercizio del pasto con 1 elastico (1.2.3.): s'invita il soggetto a mangiare 1 pasto intero attraverso la procedura dell'1.2.3. con le labbra aperte, una volta al giorno.

Ottava seduta

Si consegna la “carta del tempo” dove il soggetto deve annotare ad orari stabiliti e concordati con il logopedista i controlli deglutitori e posturali.

Si consegna la “carta della notte”, allenamento subconscio, dove il soggetto, ogni sera, prima di andare a letto deve eseguire per 6 volte l'esercizio dell'1.2.3. senza elastico e poi ripetersi per sei volte a voce alta: “Voglio deglutire correttamente per tutta la notte”.

“Gioia della madre” per 60 minuti per una volta al giorno con esercitatore labiale.

Esercizio dei masseteri per una volta al giorno.

Massaggi del labbro: 75 volte al giorno.

“Tiro alla fune” per una volta al giorno.

“Sollevamento pesi” per una volta al giorno.

Esercizio del pasto con 1 elastico (1.2.3.): s'invita il soggetto a mangiare 2 pasti interi attraverso la procedura dell'1.2.3. con le labbra aperte.

Nona seduta

Si valutano la “carta del tempo” e la “carta della notte”.

Si continua con la “Gioia della Madre”, 15 minuti per due volte al giorno con l'esercitatore labiale.

Gli esercizi proseguono come sopra con diminuzione dei tempi.

“Sollevamento pesi” per una volta al giorno.

“Massaggi del labbro: 50 per due volte al giorno.

Se necessario continuare con “Carta della notte”.

Bere e masticare correttamente in tutti i pasti della giornata.

Decima seduta

Il modo di deglutire deve essere ora corretto.

Il regime di cura deve essere stato eseguito in modo sequenziale, senza interruzioni.

“Gioia della Madre” 10 minuti per due volte al giorno con esercitatore labiale.

Deglutizione corretta con tutti i solidi e liquidi.

Massaggi del labbro, esercizi dei masseteri e “tiro alla fune”

Bere e masticare correttamente in tutti i pasti della giornata.