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Review Article

Masticatory Muscle Responses to Mandibular Forward Positioning Appliances

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Abstract

An understanding of how the masticatory muscles respond to functional appliances that move the mandibular forward, i.e. activator, Herbst, Forsus appliance, etc. provides a necessary physiologic detail and it is essential to the field of orthodontics and oral physiology. Electromyography (EMG) has been used to assess both qualitative and quantitative muscle functions. A number of studies attempted to find out the response of masticatory muscles during the use of mandibular forward positioning appliances, but the results have been inconsistent. The purpose of this article is to present research findings related to the masticatory muscle responses to mandibular forward positioning appliances assessed by EMG.

Keywords: Electromyography, Functional, Masticatory Muscles, Orthodontic Appliances

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Introduction

Class II malocclusion is a common pattern worldwide[1-3] which comes to orthodontists with a variety of configurations that are skeletal, dental, or both.[4] The skeletal problem, most common with mandibular skeletal retrusion[5,6], has been treated with functional appliances for decades to alter the neuromuscular activity around the mandible.[7-10] The function of masticatory muscles is believe to affect craniofacial growth, orthodontic treatment, and dentofacial orthopedic treatments.[11-13] Therefore, the objective of this kind of treatment is to improve the quilibrium of the muscles and correctly balance the forces inducing the growth and the development of craniofacial skeletal morphology.[14,15]

The effect of orofacial musculature on the facial morphology and dentoalveolar position has been widely studied. The main muscles that are attached to the mandible are the masticatory muscles, e.g., masseter, temporalis, medial, and lateral pterygoid muscles, and other associated muscles such as suprahyoid muscles. These muscles may play a part in the dentoskeletal

morphology and also the possible cause of relapse after orthodontic treatment.[16-20] To determine the activity of these muscles, electromyography (EMG) is used because it is the most objective and reliable technique for evaluating muscle function.[21]

Electromyography (EMG)

EMG is an electrical technique to assess neuromuscular activity using electrodes which basically determine how active a muscle is during both static and dynamic conditions. It has been widely used in the research field and medical practices as a diagnostic tool in a nerve conduction study called an electrodiagnostic study[22], as a treatment method called biofeedback training[23] and in neurophysiological studies to understand the activation pattern of muscles. Dentistry commonly uses EMG in studies of temporomandibular joint disorder, muscle disease of the head and neck region, cranial nerve lesion, seizure disorders, and in muscle response to various activities and appliances.[7,24-27]

The EMG signal is an electrical current that is generated by the flow of ions across the membrane of muscle fibers which can activate a potential action to produce muscle contraction. The signal is transmitted through the surrounding tissues to reach the electrode detection surface.[28] Once the signal has been amplified and filtered, it is displayed in the time domain along with amplitude, duration, and frequency of muscle activity. The visual representation is called an electromyogram.[29] The electromyogram can be processed in various types depending on its application such as a mathematical analysis, like an integrated value, root mean square value, or frequency domain transformation to measure muscle fatigue.[28,30,31]

There are two kinds of EMGs: surface EMG and intramuscular EMG. The intramuscular EMG can be performed using either needle or fine-wire electrodes that penetrate into the target muscle with a surface electrode as the reference. When the electrode is inserted into the muscle, the motor unit action potential can be recorded.[28] This represents the summated electrical activity of action potentials of all muscle fibers which are innervated by the same motor nerve fiber. In contrast, surface EMG (sEMG), which is safer, easier and non-invasive, represents all electrical activity beneath the surface electrodes. Therefore, this method is very sensitive and easily affected by noise and environmental factors, like hair or a fat pad beneath the skin.[28,31] Moreover, it cannot record the activity of deep muscles like the medial and lateral pterygoid muscles and can hardly assess muscles under unfavorable skin conditions, such as the posterior part of temporalis muscles which are covered with hair. Thus, the masseter muscle and the anterior temporalis muscle are more favorable for the surface EMG studies.[32]

The EMG signal is affected by physiological, anatomical, biochemical, and technical factors. Carlo De Luca[30] described thoroughly these factors including the electrode structure, its placement, the intrinsic factors, e.g., muscle fiber type, diameter, subcutaneous tissue, and also other factors like age and sex. Therefore, comparisons of EMG both within and between individuals is potentially fraught with reliability problems unless a normalization technique is used.[33] Several forms of normalization exist, the most common method is to compare the raw signal with maximum voluntary isometric contraction. Due to the inconsistency of maximum effort, submaximal voluntary contraction is used instead in some studies.[34-36] For comparison between participants, Ferrario *et al.*[37] also invented indices which were the asymmetry index, activity index, and torque index, which have been used in many studies of masticatory muscles.[38-44]

Mandibular forward positioning appliances

Since the 1930s, a wide range of functional appliances, designed to correct class II malocclusion with retrognathic mandible, gained popularity in Europe and spread throughout the rest of the world.[4,45,46] These appliances aimed to stimulate mandibular growth by forward posturing of the mandible and they are effective to correct this type of skeletal and occlusal disharmony in preadolescent patients. The appliances can be either removable, activator or bionator, or fixed, Herbst appliance,

Forsus appliance, tooth borne, or tissue borne appliance (Frankel-II appliance).

The understanding is that a functional appliance in a growing patient can be very effective in reducing even a very large overjet[47] but some authors believe there is little evidence to support the fact that functional appliances significantly alter mandibular growth.[48,49] In any case, there is still controversy.[47] From a systematic review of functional appliances in class II malocclusion[4], most previous studies reported clinically significant supplementary elongation in the total mandibular length as a result of overall active treatment with functional appliances. The Herbst appliance showed the highest coefficient of efficiency (0.28 mm per month) followed by the Twin-block appliance (0.23 mm per month). On the other hand, some studies claimed that the main changes caused by functional appliances were of dentoalveolar nature that included distalization of the maxillary posterior segment, lingual inclination of maxillary incisors, mesialization of the mandibular posterior segment, and buccal inclination of mandibular incisors.[50,51] Janson *et al.*[52] reported that most changes were dentoalveolar with fewer skeletal effects in patients treated with the Frankel appliance, in contrast with Toth and McNamara.[53] The Frankel appliance can also rotate the mandible either forward or downward which may stretch the surrounding muscles which could initiate bone modeling at muscle-attached site.

The aim of this article was to present the masticatory muscle responses to mandibular forward positioning appliances in terms of EMG changes. Furthermore, the results of previous studies are discussed.

Masticatory muscle responses to mandibular forward positioning appliances

Table 1 summarizes all studies related to the use of EMG in studying the effect of mandibular forward positioning appliances.

Lateral pterygoid muscle

In 1973, McNamara[10] was the first to study neuromuscular adaptation of mandibular forward-positioning appliance therapy using needle EMG to evaluate the lateral pterygoid muscles in rhesus monkeys *(Macaca mulatta)* during postural and functional movement. He found an increase in lateral pterygoid activity from forward positioning of the mandible during the experimental period but after 8-12 weeks the activity decreased or disappeared. The results were used to develop the "lateral pterygoid muscle hypothesis" which stated that after the insertion of a functional appliance, an increase in postural activity of the lateral pterygoid muscle was responsible for increased condylar growth. In contrast, Sessle *et al.*[7] reported a decrease in postural EMG activity of the masseter, digastric, and lateral pterygoid muscles in monkeys during the six-week experiment that gradually returned to the pretreatment level. Also, Yamin-Lacouture *et al.*[9] demonstrated similar results as Sessle *et al.* by using implanted hook electrodes in monkeys with the Herbst, Frankel, and simulated Clark Twin-block appliances and demonstrated a decrease in EMG activity within the experimental period of 12 weeks which then returned to pretreatment levels. They reported that the decrease of EMG activity was possibly due to shortening of the lateral pterygoid after the insertion of the mandibular forward positioning appliances and the altered masticatory muscles changed the swallowing patterns. In 2000, Hiyama *et al.*[54] tried to develop a painless and non-invasive surface EMG technique to evaluate the lateral pterygoid muscle in humans and used it to evaluate the Herbst appliance during therapy. The results showed an increase in lateral pterygoid muscle activity immediately after insertion and removal of the appliance which supported the lateral pterygoid muscle hypothesis[10] and then decreased to the previous level in 4-6 months which was presumed to be the lateral pterygoid muscle adaptation period.

Though these studies were not totally concordant, they concluded that there is a period of time when lateral pterygoid muscle activity rebounded to the original level which could imply that this muscle had an adaptability potential of around six weeks to six months.

Jaw-closing muscles: masseter and temporalis muscles

Research by Sessle *et al.*[7] and Yamin-Lacouture *et al.*[9] also studied the masseter muscles in monkeys. They reported the same results as the lateral pterygoid muscle which demonstrated decreased activity in 6-12 weeks and rebounded later. They reported that an

increase in the vertical dimension could elongate the masseter muscle and alter the swallowing pattern of the monkeys.

Rest position

In early human studies[55-58], increased postural jaw elevator muscle activity was found during the use of an activator but other researchers[59-62] found no difference or even decreased activity. In 1988, the results of a cross-sectional study designed by Miraelles *et al.*[59] showed no significantly different integrated EMG values of the masseter and anterior temporalis muscles between activator users and non-users in the rest position. However, as discussed above, it is not recommended to compare the EMG values between participants. Later in 1999, Aggarval *et al.*[57] conducted a longitudinal study to observe ten young patients (ages between 9-12 years old) with Twin-block appliances. The locations of the electrodes were standardized to allow a comparison between participants over a period of time.[63] The results of the treatment at 1, 3, and 6 months showed an increase in peak-to-peak amplitude at rest in both muscles but the differences were not statistically significant ($p>0.05$) in the anterior temporalis muscle. The improvement in temporalis muscle activity was in agreement with other investigators[64,65] who reported that the values at each recording were higher with the appliance due to the intervening signal from posterior temporalis muscle, which tried to retract the mandible back. The increased postural activity of the masseter muscle was thought to be a stretching reflex due to the protrusion of the mandible.[57]

A recent longitudinal study by Cuevas *et al.*[43] in 2013, investigated 27 patients treated with a Teuscher activator with high-pull headgear. The mean EMG values of the masseter, anterior and posterior temporalis muscles at rest after finishing the first phase of treatment (mean activator treatment time = 1.1 year) were not significantly different from the pretreatment values. By using Ferrario's EMG indices[37], the asymmetry index showed more symmetrical muscular condition after functional treatment. The activity index showed more predominance of the anterior temporalis muscle in the rest position which supported the role that the temporalis muscles were important in positioning the mandible in normal young patients.[37] Two years after orthodontic treatment had finished, the mean EMG values increased and the author claimed that was due to good neuromuscular adaptation of the mandible. From another point of view, that possibly resulted from increased age of the children.

Isometric contraction

Another way to evaluate muscle activity is isometric contraction which can be performed while clenching the teeth with maximum or constant submaximal force.[30,66,67] Similar to the rest position, various results were demonstrated in previous studies. Miraelles *et al.*[59] also reported no significant difference of integrated EMG values of the masseter and temporalis muscles between activator users and non-users. The results from a study by Aggarval *et al.*[57] were contrary to the results of a study by Miraelles in that an increase in peak-to-peak amplitude of both muscles during maximal voluntary clenching after six months of using a Twin-block appliance was found. Interestingly, when clenching immediately after the insertion, the muscle activity was lower in both the anterior temporalis and masseter muscles which was assumed to be the abrupt change of these muscles.

In 2011, Sood *et al.*[62] designed a longitudinal study with 15 female patients with fixed functional appliances (Forsus™). The patients were evaluated periodically for two years with standardized placement of the electrodes.[63] During maximum voluntary clenching, the EMG values significantly decreased in 1-3 months ($p<0.05$) after ligating the Forsus™ apparatus which concurred with other studies with functional appliances[61,68,69], then gradually started to increase and returned to pretreatment levels within six months and remained stable until the end of the two-year observation period. It was believed that this was due to muscle adaptation.

Cuevas *et al.*[43] also observed decreased left masseter activity after functional treatment. This finding was probably caused by unstable occlusion or less occlusal

contact area of the posterior teeth during maximum voluntary clenching after the position of the teeth and mandible were changed. In the 2-year observation period after finishing orthodontic treatment, left masseter activity increased to the pretreatment level, and the other jaw-elevated muscles had increased activity compared to the pretreatment level. These findings were associated with improvement in the occlusal conditions, i.e. contact quality and stability, after orthodontic treatment as well as the increase in age.

A recent randomized controlled trial study in 2014 by Satygo *et al.*[70] demonstrated a significant increase in sEMG activity of the masseter and anterior temporalis muscles during clenching after treatment with a pre-orthodontic trainer for 12 months. Thirty-six patients with class II division 1 with mandibular retrognathism were functionally treated. Twenty-two patients who had the same diagnosis were also included in the study but were untreated. The normal control group included 20 participants who had normal occlusion. The EMG recordings was analyzed without normalization. At the beginning of the study, the participants with a Class II, division 1 malocclusion (treated and untreated groups) showed EMG activity that was approximately 1.5-fold less than the control group. After 12 months, the control group remained with similar values in both masseter and anterior temporalis muscle. However, the treated group reported a significant increase in the activity of both muscles ($p<0.001$) that reached the values of the control group. On the other hand, the untreated controls reported no significant change in the EMG activity compared to baseline. The authors cited Moss's functional matrix theory[56] and claimed that improvement in muscular activity would accelerate bone remodeling at the condyle and lead to adaptive mandibular growth and improvement in the Class II sagittal relationship. Similar to a previous experimental study, Erdem *et al.*[14] demonstrated increased masseter and anterior temporalis activity during clenching after 12 months of activator treatment compared with the untreated group. This increase in muscle activity might be a result of a more stable occlusion after functional therapy.

In 2017, Di Palma *et al.*[71] measured masticatory muscle coordination after functional treatment with a Sander appliance for 12 months without normalization technique by calculating the EMG indices, e.g. percentage overlapping coefficient, torque coefficient, and activity index, which were recommended due to the limitation to fix the position of the electrodes. A symmetrical activity was shown before and after treatment without alteration. They reasoned that a stable treatment outcome resulted from a good muscular equilibrium.

The findings of most aforementioned studies indicated that adaptation of these jaw closing muscles occurred within a certain period of time (six weeks to three months) whether the muscle activity was observed to increase or decrease.

Functional movement and other associated muscles

Many studies not only evaluated the masticatory muscles but also the other associated muscles, e.g., orbicularis and suprahyoid muscles[7,9,43,61], since their functions are related to mastication and deglutition. In an animal study, Yamin-Lacouture *et al.*[9] also evaluated intramuscular EMG during swallowing at the anterior portion of the digastric muscles. As with other muscles, digastric muscle activity gradually decreased within 12 weeks and then was restored to the original value.

Again in a study by Cuevas *et al.*[43], the suprahyoid and jaw-closing muscles were studied during the swallowing and mastication. During both movements after functional treatment, all muscle activities increased continuously until two years after completion of orthodontic treatment which was assumed by the authors to be good adaptability of the jaw muscles to the new jaw position. Similar results were found in an experimental study by Erdem *et al.*[14] during a 12-month observation period that compared 15 class II division 1 patients treated with an activator with ten untreated participants. The masseter and anterior temporalis muscle activities were increased during

chewing in the treated group after functional treatment, but there was no significant difference in the activity during swallowing compared with the untreated group which was contrary to the study by Cuevas *et al.*[43] However, Cuevas *et al.*[43] claimed that the suprahyoid muscle activity eventually decreased significantly and the authors discussed that it was probably related to more mature swallowing.

Erdem *et al.*[14] found an increased orbicularis oris activity during whistling after 12 months of functional treatment compared with the untreated group with a 12 month observation period. Moreover, Saccucci *et al.*[72] evaluated the upper and lower orbicularis oris muscles between 13 Class II division 1 children with deep bite and lip incompetence and 15 normal children. The sEMG was recorded before treatment with a preformed orthodontic/functional device (Occlus-o-Guide™Ortho-Tain Inc. – Toa Alta, Puerto Rico) and at 3 and 6 months after treatment in many activities: at rest, during kissing, swallowing, mouth opening, clenching, and mandibular protrusive position. Before the treatment, the treated group showed lower activity of the lower orbicularis oris muscle in most activities except during swallowing. At 6 months after treatment, the treated group seemed to reach similar muscle activity as the normal children which claimed to be an improvement in form and function of the orofacial muscle structure.

Summary

This review presents the neuromuscular activity and adaptation associated with various types of mandibular forward positioning appliances and discusses the uses of EMG as a tool to clarify the neurophysiology of the orofacial complex.

Due to the inconsistent findings among the studies, a standardized protocol to measure EMG is needed. For example, the normalization technique can reduce the factors which affect the reliability and allow between-participants comparisons. A multi-national consensus initiative called SENIAM (Surface Electromyography or Non-Invasive Assessment of Muscles) and the ISEK (International Society of Electromyography and Kinesiology) have unified the methodology of sEMG recordings which could be a consistent standard for future studies. To apply the investigations in dentistry, the diagnostic tool, treatment outcome evaluation, and even biofeedback training have been developed. The scientific devices and processing methods have also allowed the researcher to create interesting novel investigations concerning EMG that are more accurate and effective under a qualified methodology.

In conclusion, due to technological factors, research design, and other limitations in previous studies, the studies on EMG have no clear-cut agreement. As reviewed above, there was some reported improvement in EMG activity while other investigators reported different results in muscle activity, different appliances, and different periods of observation times. Thus, most of these results showed that the appliances could alter the orofacial neuromuscular activities by either improvement or reduction, and the adaptation of the muscles might occur within a few months or in a half year.

Table 1 *Studies of masticatory muscle responses to mandibular forward positioning appliances*

Author (s)	Study groups	Sample	Age	Material	Muscle (s)	Appliance (s)	Duration	Main finding
McNamara[10]		28 rhesus monkeys (*Macaca mulatta*)		Needle EMG	Lateral pterygoid	Functional mandibular displacement	13 weeks	(I) There was increased activity of the superior head of the lateral pterygoid muscle, both at functional movements and at rest. (II) Eventually, the activity decreased and returned to baseline.
	I: infant	n=4 (control)	0.4-0.7 yrs					
		n=3 (experiment)						
	II: juvenile	n=4 (control)	1.5-2 yrs					
		n=3 (experiment)						
	III: adolescent	n=4 (control)	4-4.5 yrs					
		n=3 (experiment)						
	IV: adult	n=4 (control)	6-7 yrs					
		n=3 (experiment)						
Ahlgren[55]	Class II, Division 1 malocclusion	n=20	8-16 yrs	Wired EMG: raw data	Masseter, temporalis	Activator		(I) The activity of masseter muscles was increased, but temporalis muscles were inhibited during the daytime. (II) The increased activity was not observed during the nighttime.
Miralles, Berger *et al.*[59]	Class II, Division 1 malocclusion	n=15 (male 6, female 9)	8-15 yrs	Surface EMG; Integrated value	Masseter, anterior temporalis	Activator	Immediate	(I) There was no significant difference in EMG activity at rest and clenching between subjects with and without activator. (II) The activity in the masseter and temporalis muscles was significantly higher in subjects with the activator.
Sessle, Woodside *et al.*[7]		Juvenile female monkeys (*Macaca fascicularis*)	1.5-2 yrs	Implanted EMG	Masseter, supra-hyoid, lateral pterygoid		12-18 weeks	EMG activity of the lateral pterygoid remained decreased for approximately 6 weeks. A rebound to the pre-appliance level occurred after 6 weeks.
	I	n=2				Herbst appliance		
	II	n=2				Functional protrusive appliance		
	III: control	n=2				-		
Yamin-Lacouture, Woodside *et al.*[9]		Juvenile female monkeys (*Macaca fascicularis*)	1.5-2 yrs	Implanted hook EMG; mean area, mean maximum amplitude	Masseter, supra-hyoid, lateral pterygoid		12 months	Activity of all muscles was decreased within 3-6 weeks after wearing an appliance.
	I	n=2				Herbst appliances		
	II	n=2				Frankel appliances		
	III	n=2				Clark Twin-block appliances		
	IV: control	n=2				-		

Table 1 *Studies of masticatory muscle responses to mandibular forward positioning appliances (cont.)*

Author (s)	Study groups	Sample	Age	Material	Muscle (s)	Appliance (s)	Duration	Main finding
Uner *et al.*[60]	Angle Class II division 1 malocclusions	n=12 (treated) n=9 (untreated)	11.4±0.3 yrs 10.7±0.5 yrs	-	Masseter, anterior temporalis	Activator	-	(I) In both muscles, there was a significant decrease of activities during maximum clenching. (II) In both muscles, there was a significantly increase of activity at rest but the activity decreased at the end of treatment. (III) The activity of both muscles between the initial and the end of observation without the activator was not different.
Aggarwal, Kharbanda *et al.*[57]	Class II Division 1 malocclusion and retruded mandible	female, n=10	9-12 yrs	Surface EMG; peak-to-peak	Masseter, anterior temporalis	Twin-block appliances	Self-control 6 months, experiment 6 months	(I) At rest, both muscles had an increase in peak-to-peak amplitude but it was statistically insignificant in the anterior temporalis muscle. (II) During swallowing, the activity of both muscles was not different between patients with and without the Twin–block appliance. (III) During maximal voluntary clenching, there was a gradual increase in masseter activity.
Hiyama, Ono *et al.*[54]	Angle Class II, division 1 malocclusions	n=6 (male 1, female 5)	9.4-11.2 yrs	Intraoral surface EMG; mean integrated value	Lateral pterygoid	Herbst appliances	4-6 months	The activity of lateral pterygoid muscle immediately increased after the insertion, but it decreased after 4-6 months of treatment.
Tabe, Ueda *et al.*[61]	Variety of skeletal relations and complete dentitions without any serious malocclusions	male, n=12	26.6 yrs	Right-sided portable surface EMG; average rectified value, integrated value, T/M ratio	Masseter, anterior temporalis, digastric	Activator Spring active appliance	Immediate	(I) All muscles had more activity during clenching than during daytime and sleep. (II) The activity of the digastric muscle tended to increase, but the activity of the temporalis muscle tended to decrease. (III) The temporalis-masseter ratios decreased while biting on the appliances.
Erdem *et al.*[14]	CI division 1 malocclusions	n=15 (treated) n=10 (untreated)	11.3 ± 1.1 yrs 11.0 ± 1.3 yrs	Surface EMG; μV	Masseter, anterior temporalis	Activator	12 months	(I) The activity of the anterior temporalis and masseter muscles significantly increased in both groups. (II) In the treated group, the muscle activity increased significantly more than the untreated group during clenching and chewing, but it was not significantly different during swallowing.

Table 1 *Studies of masticatory muscle responses to mandibular forward positioning appliances (cont.)*

Author (s)	Study groups	Sample	Age	Material	Muscle (s)	Appliance (s)	Duration	Main finding
Sood, Kharbanda *et al.*[62]	Class II Division 1 malocclusion	female, n=15	10-14 yrs	Surface EMG; μV	Masseter, anterior temporalis	Flexible fixed functional appliance (FORSUS™)	24 months	(I) The activity significantly decreased during swallowing and clenching at 1 and 3 months after treatment. (II) In 6 months, the muscle activity finally returned to initial levels and remained stable for 24 months.
Cuevas, Cacho *et al.*[43]	Class II division 1 malocclusion	n=27	11.6 yrs 12.8 yrs 18 yrs	Surface EMG; mean, asymmetry index, activity index	Masseter, anterior and posterior temporalis, supra-hyoid	Teuscher activator with high-pull headgear	After functional treatment (T1) 2 years after orthodontic treatment (T2)	(I) Activity of the muscles decreased at T1 but increased at T2 during clenching. (II) Activity of the suprahyoid muscle increased at T1 but decreased at T2 during swallowing. (III) Activity of the masseter muscle increased at T1 and further increased at T2 during mastication. (IV) There was no significant change in muscle activity during left and right lateral excursions and protrusion for all study periods.
Satygo, Silin *et al.*[70]	Class II, division 1 malocclusion No dental malocclusion	n=36 (treated) n=22 (untreated) n=20	7.6±1.3 yrs	Surface EMG; μV	Masseter, anterior temporalis	Pre-orthodontic trainer functional appliance	12 months	(I) There was a significant increase in muscle activity in both sides in the treated group. (II) In the treated group, the recorded EMG values were similar to the normal controls, while the untreated group remained with lower activity.
Di Palma, Tepedino *et al.*[71]	Angle Class II, division 1 malocclusion	n=10 (male 5, female 5)	9-13 yrs	Surface EMG: percentage overlapping coefficient, torque coefficient, activity index	Masseter, anterior temporalis	Sander functional appliance	12 months	All subjects maintained a muscular equilibrium (POC index: right-left side within muscle; Activity index: masseter vs. temporalis; Torque coefficient: lateral deviant couples), without statistical significant variations.

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