Oral Radiology (2025) 41:25–32
https://doi.org/10.1007/s11282-024-00772-4

ORIGINAL ARTICLE

Assessing masseter muscle volume and activity in relation to craniofacial morphology: a 3D CBCT study

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Received: 7 February 2024 / Accepted: 24 August 2024 / Published online: 3 September 2024

Abstract

Introductions Understanding the factors influencing craniofacial structure growth is crucial for addressing craniofacial deformities. This study evaluates masseter muscle volume, activity, and maximum bite force across different skeletal malocclusion groups and aims to evaluate the masseter muscle volume, activity, and maximum bite force (BF) according to different skeletal malocclusion groups.

Methods This study aimed to assess masseter muscle volume, activity, and maximum bite force (BF) across different skeletal malocclusion groups in 60 young adults (18–30 years) seeking treatment at Kirikkale University Faculty of Dentistry. Cone-Beam Computed Tomography (CBCT) imaging, radiological measurements, surface electromyography (sEMG), and force sensor measurements were employed.

Results Results revealed significant differences in sEMG measurements based on sagittal classification. Vertical direction groups showed notable results in muscle volume and BF, though no significant differences were observed in sEMG values. A correlation was identified between BF and sEMG, but no correlation was found between muscle volume and other parameters.

Conclusions The findings obtained in this study suggest that the significant relationship between EMG and sagittal skeletal classification could be a valuable diagnostic tool. However, concerns about reliability were raised due to uneven distribution in muscle volume and BF among vertical direction groups. The lack of significant results in muscle volume, sEMG, and BF was attributed to CBCT limitations in soft tissue imaging and the small sample size, emphasizing caution in interpreting the findings.

Keywords EMG activity · Masseter muscle volume · Bite force · Cone-beam computed tomography

Introduction

Understanding the basic physiological properties of human masticatory muscles is crucial for stomatognathic system rehabilitation. Craniofacial morphology is known to have a correlation with bite force (BF) and the activity of the masticatory muscles, consequently impacting masseter muscle volume. Surface electromyography (sEMG) provides non-invasive information on muscle properties, aiding in monitoring jaw muscle activities. Functional activity and BF have been shown to differ significantly from normal subjects in patients with skeletal malocclusion. Malocclusion, disharmony between the maxilla and mandible, creates an activity that embarrasses normal muscle function and requires muscle adaptation [1].

Surface electromyography provides non-invasively information on muscle properties. In sEMG, myoelectric signals are measured through the skin surface. sEMG is useful for monitoring the activities and understanding the function of jaw muscles. It is vital to have good knowledge about the basic physiological properties of human masticatory muscles to understand the pathophysiology as well as implications for rehabilitation of the stomatognathic system [2]. The masseter muscle is superficially located in jaw-closing muscles; thus, these are readily accessible with surface electrodes. Usually resting muscular tissue is electrically inactive but during voluntary muscle contraction is a potential of action. With the increase of the rate contraction, more muscle fibers generate a potential for action, which is detected by the

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presence of varying values and different amplitudes of the electromyogram[2].

BF is an indicator of masticatory system health and can vary based on factors, such as gender, general physical structure (BMI; body mass index), tooth condition, facial morphology, and age. The relationship between these variables has shown contradictions in the literature. Some studies have found significant correlations between BF and muscle thickness, as well as between masseter–temporal muscle thickness and facial morphology [3].

The masseter muscle could be accurately segmented from computed tomography (CT) and magnetic resonance imaging (MRI). However, the hard tissue is barely visualized in the MRI, and metal implants and restorations as well as orthodontic brackets produce severe artifacts [4]. Moreover, CT has the disadvantage of a high radiation dose, which is prohibitive in the diagnosis and treatment of non-surgical patients. In contrast, cone-beam computed tomography (CBCT) has the advantages of a low radiation dose, fast imaging reconstruction speed, high spatial precision, and low cost. However, CBCT has been only reported to analyze the 2D cross-sectional area of the masseter muscle, as well as the orientation and length measured by landmarks. However, few 3D studies have been reported because robust and accurate segmentation of the masseter muscle from CBCT is challenging due to the lack of a sufficient soft tissue contrast to differentiate the masseter muscle structures from their background structures [5, 6]. Recently, studies on soft tissue measurement are frequently encountered in the literature. In the studies by Pan et al., they measured the volume of the masseter muscle using CBCT and MRI images and found no significant difference between the two measurements [7]. Manual segmentation needs to draw the muscle hundreds of cross-sectional images, which is very time-consuming and laborious [6]. Therefore, the method of segmenting the masseter muscle on CBCT images is currently considered a tedious process. However, if this method is validated and proven accurate, it could potentially lead to the development of a convenient and easily accessible route with the added benefit of low-dose radiation exposure. The purpose of our study is to evaluate muscle volume, muscle activity, and BF in skeletal malocclusion groups.

Materials and methods

The present study included young adult participants without bruxism, consisting of 30 females and 30 males within the age range of 18–30 years. The sample population consisted of individuals who sought treatment at both the Oral and Maxillofacial Surgery Department and Orthodontics Department of Kırıkkale University Faculty of Dentistry, as well as those referred to the clinic specifically for CBCT imaging. Ethical approval for the study was obtained from the Kırıkkale University Clinical Research Ethics Committee.

To ensure the reliability and specificity of this study, specific exclusion criteria were applied. Patients with syndromes or other developmental deformities, a history of head and neck trauma, previous orthodontic treatment or orthognathic surgery, cervical spine surgery, fixed prostheses or large occlusal restorations, periodontal disease, or temporomandibular disorders, patient with bruxism were excluded from this study. By implementing these exclusion criteria, we aimed to focus solely on masseter muscle without any confounding factors that could potentially influence the evaluation of masseter muscle morphology in relation to different types of malocclusions using CBCT imaging.

In this study, CBCT images with I-CAT apparatus (Imaging Sciences International, Hatfield, PA, USA) including the masseter muscle region were obtained from each patient (using the parameters of 120 kVp, 5.7 mA, an exposure time of 8.9 s). The imaging process was conducted using the i-CAT Vision software, and the reconstructed data were saved as DICOM files. Additionally, lateral cephalometric images were derived from the KIBT images using the same software. All cephalometric radiographs were saved in JPEG format and analyzed using the VistaDent OC 1.1 software (GAC International Inc. Bohemia, NY, USA) to determine the types of skeletal malocclusion present in each patient.

Mainly, the sagittal relationship was divided into skeletal Class I group ($0^0 < \text{ANB} < 4^0$), Class II group ($\text{ANB} > 4^0$), and Class III group ($\text{ANB} < 0^0$). The same patient population vertical relationship was divided into normodivergent group ($21^0 < \text{FMA} < 28^0$), hyperdivergent group ($\text{FMA} > 28^0$) hypodivergent group ($\text{FMA} < 21^0$). Samples were classified into six groups according to the values of ANB and FMA.

The DICOM data of each patient were transferred to the 3D-Doctor software for analysis. Study with high screen resolution computer in dimly lit room was conducted. Due to the similarity in density between the masseter muscle and surrounding tissues in the KIBT images, an automatic segmentation method was not employed. Manual segmentation was performed bilaterally, and measurements were made by drawing the masseter muscle in each section using manual segmentation for the masseter muscle. The sagittal slice images were used, and the boundaries of the masseter muscle were marked starting from the first identified section and consecutively in each slice. A three-dimensional representation of the segmented masseter muscle was generated, and the volume of the segmented region was recorded. To assess intra-observer agreement, measurements were repeated 1 week after the initial measurements using KIBT images from 10 randomly selected patients. Standardization of imaging parameters and analysis methods was ensured, and all measurements were performed by the same researcher to achieve reliable results (Fig. 1).

The BF measurements were conducted using a portable BF sensor designed for medical purposes (Viste, Hong Kong, China). The sensors were covered with rubber plates and were enclosed in disposable plastic for hygiene purposes for each patient. To ensure that the modified bite surface did not affect the recorded BF values, weights with known masses were measured using both surfaces. Before the measurements, the patients were seated in a dental chair with their heads in a comfortable upright position, maintaining the Frankfurt plane nearly parallel to the floor. Patients were instructed to bite the sensor with maximum force without moving their heads. BF measurements were taken between the maxillary and mandibular first molars on both sides. The process was concluded when the BF reached its maximum value as displayed on the digital screen. BF measurements were performed three times on each side (right and left), and the average value of each measurement was recorded.

First, for EMG recorded patients were informed about the procedure and warned to shave before the measurements to good recordings. Every recordings were made same morning time. The noise of each EMG channel was carefully minimized by cleaning the skin with alcohol and standardized placement of the electrodes. Each subject sat upright in a dental chair with his or her head supported and the FH (Frankfurt) plane parallel to the floor. In this study, two electrodes per side were placed to record the EMG activity of the superficial masseter muscle. The electrodes were positioned 1 cm above and below the motor point, following the direction of the masseter muscle fibers. To determine the location for electrode placement, the anterior margin of the superficial masseter belly was palpated while the participant forcefully clenched their teeth. A reference line was drawn, starting from the corner of the mouth and contacting the inferior border of the auricle. The intersection point of the anterior margin of the superficial masseter and the first reference line was marked. The reference point was then determined as one-fourth of the length from the intersection point, posteriorly towards the contact point of the first reference line with the inferior border of the auricle. Two surface electrodes were placed parallel to the line of the anterior margin of the superficial masseter. By following these electrode placement guidelines, electrode configuration on the masseter muscle was achieved to record EMG activity. Disposable surface silver bipolar electrodes (inter-electrode distance was fixed at 15 mm with adhesion tape) with electrode gel were attached to the skin overlying the center of masseter areas. In our study, sEMG (2 channel Neuro Emg Micro, Ivanovo, Russia) was used for measuring muscle activity (Fig. 2).

Interference and noise tests were conducted using the Neuro-Mep software before each measurement was taken. Patients were instructed to clench their teeth as strongly as possible during the recording. Electromyographic measurements were performed bilaterally for the masseter muscle, both on sides. The muscle activity during maximum biting same block was measured. These measurements were conducted for five seconds and repeated three times at 2-min intervals. To assess intra-observer reliability, EMG recordings, BF measurements, and masseter muscle measurements were repeated for 10 randomly selected patients from each group.

Statistical analysis was completed using the SPSS (Statistical Package for Social Sciences) software, version 18 (SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was used to evaluate the normal distribution of the variables acquired in this study. As the measurements showed a normal distribution, parametric tests, specifically the one-way ANOVA test, were used for analysis. The correlation between measurements, considering both the right and left sides and among each other, was evaluated. The Cronbach's alpha test was used to evaluate the reliability. A significance level of $p < 0.05$ was considered statistically significant to indicate a significant difference.

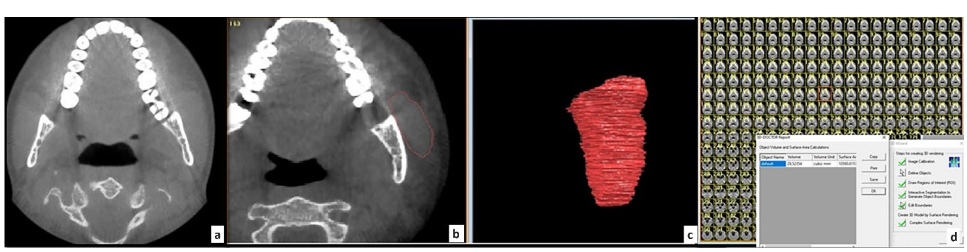

Fig. 1 **a** Manual segmentation was performed bilaterally for the masseter muscle. **b** axial slice images were used, and the boundaries of the masseter muscle were marked starting from the first identified section and consecutively in each slice. **c-d** A three-dimensional representation of the segmented masseter muscle was generated, and the volume of the segmented region was recorded

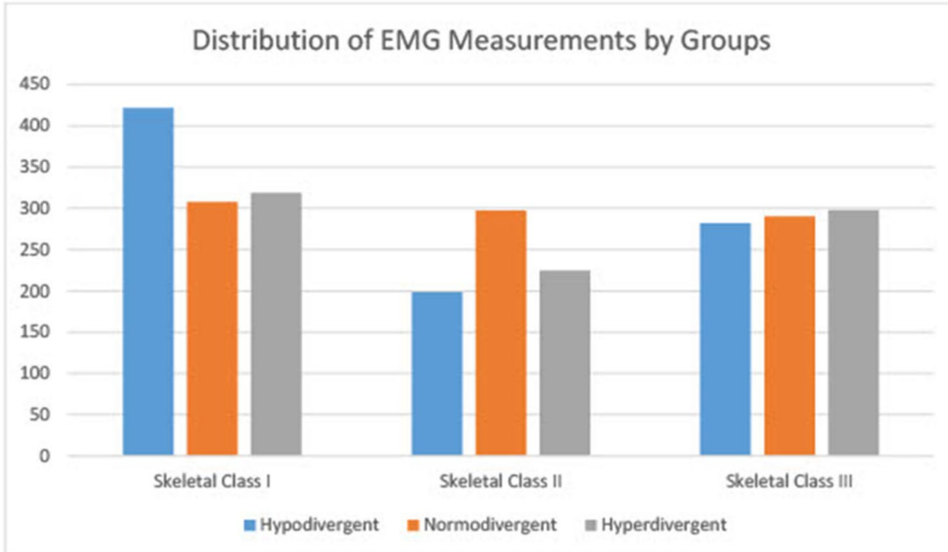

Fig. 2 Distribution of EMG measurements by groups

Results

The study group comprised 60 participants aged between 18 and 30 years, with 30 males (mean age: 227 ± 129) and 30 females (mean age: 222 ± 109). The participants were evenly distributed into groups based on skeletal sagittal classification (Class I, statistically significant difference in BMI distribution was found between females and males ($p < 0.05$). There was no statistically significant difference in the distribution of the subjects' age and BMI mean values according to skeletal sagittal direction classification ($p > 0.05$).

EMG values for both the right and left sides of the participants according to skeletal sagittal classification, a significant difference was observed between the groups ($p < 0.05$). The EMG values were higher in Class I than in the other groups. According In the analysis of the BF measurements for both the right and left sides of the participants according to skeletal sagittal classification, no significant difference was found between the groups ($p > 0.05$). However, the BF measurements were higher in Class I than in the other groups (Table 1). BF analysis on the vertical dimension classification were statistically evaluated both the right and left sides, the hyperdivergent group had significantly lower biting force compared to the other groups ($p < 0.05$).

Regarding bilateral masseter muscle volume measurements, no significant difference was found between the groups on skeletal sagittal classification ($p > 0.05$). However, the masseter muscle volume measurements were highest in Class II, followed by Class III, and lowest in Class I. According to vertical direction classification measurements for both the right and left sides, statistically a significant difference was detected among the groups ($p < 0.05$).

The BF, masseter muscle volume, and EMG measurements on the right and left sides are correlated with each other. There is a significant correlation ($p < 0.01$) between the EMG measurement on the right side and the biting force on the right side. Additionally, a significant correlation

Table 1 Correlation of right and left side measurements with each other

		Right side bite force measurement	Right side muscle volume	Left side EMG measurement	Left side bite force measurement	Left side muscle volume
Right side EMG measurement	1	0.354**	−0.160	0.744**	0.190	−0.042
Right side bite force measurement	0.354**	1	0.185	0.264*	0.261*	0.147
Right muscle volume	−0.160	0.185	1	−0.128	0.051	0.598**
Left side EMG measurement	0.744**	0.264*	−0.128	1	0.298*	−0.128
Left side bite force measurement	0.190	0.261*	0.051	0.298*	1	0.033
Left side muscle volume	−0.042	0.147	0.598**	0.128	0.033	1

**0.01 at the level significant correlation

($p < 0.05$) was found between the EMG measurement on the left side and the BF on the left side (Table 1).

According to the skeletal sagittal direction classification, the highest EMG measurement values were observed in Class I subjects. Within Class I subjects, it was found that EMG measurements were higher in hypodivergent individuals according to the vertical direction classification compared to the other groups. In Class II subjects, it was observed that normodivergent individuals had higher EMG values compared to the other groups. In Class III subjects, there was very little difference observed between the groups according to the vertical direction classification (Fig. 2).

According to the skeletal classification, Class I subjects had higher biting force measurements than the other groups. Within Class I subjects, the normodivergent group had slightly higher BF measurements than the hypodivergent group. The group with the lowest BF among Class I, Class II, and Class III groups was the hyperdivergent group (Fig. 2).

When examining the distribution of masseter muscle volume measurements among the groups, it was observed that they were higher in Class II subjects. Additionally, the highest values were found in Class II subjects according to the vertical direction groups. Looking at Class I, Class II, and Class III groups, it was found that hypodivergent groups had larger masseter muscle volume (Fig. 3).

Discussion

Muscle function can adapt to morphogenetic patterns, leading to changes in the configuration of teeth and supporting bone or exacerbating existing malocclusions. Compensatory or adaptive muscle activity is often necessary to maintain daily functions in the presence of inherent structural malocclusions. Achieving a balance between pattern, environment, and physiology, however, can be challenging, as it may not always be possible to pinpoint a specific cause-and-effect relationship. It is crucial for orthodontists to consider muscle activity and design orthodontic treatments that achieve a balance between structural changes and functional forces on teeth and surrounding tissues [8].

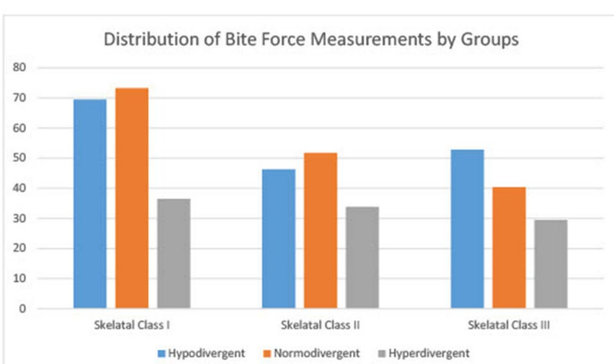

Fig. 3 Distribution of bite force measurements by groups

With technological advancements, we can now accurately and reliably evaluate soft tissues without invasive procedures. In a study by Kitai et al. [9], the findings showed that specific mechanical stress caused by chewing muscle activity and volume had a localized effect on adjacent skeletal regions. Thus, in our study, we collected sEMG recordings, BF measurements, and masseter muscle volume data from patients with different sagittal skeletal developmental patterns, comparing these values. Additionally, we classified patients based on their vertical skeletal development type for further comparison. The main goal of our study was to bridge the research gap in the literature concerning muscle activity and muscle volume related to skeletal malocclusion.

To achieve accurate results, we took measures to ensure repeatability and standardization of measurements [10]. We also considered factors that could influence BF measurements. While Roldan et al. [11] reported that body mass index (BMI) influences BF, Takaki et al. [12] found no effect of BMI on BF. To minimize the potential impact of BMI, equal numbers of men and women were kept in the sagittal groups. At the same time, according to the statistical results, when the groups were evaluated in terms of BMI, no statistically significant difference was found between them. Furthermore, we created groups based on sagittal direction classification with an equal number of males and females to avoid.

BT, the recorded force can vary depending on the position of the transducer in the dental arch and the number of teeth involved [13]. Bilateral measurements in the molar region can result in approximately 40% higher force than unilateral measurements [13, 14]. While force levels may vary with different measurement techniques, studies have generally shown good agreement and repeatability [13, 15]. Shinogaya et al. and Bakke et al. reported BF ranging from 300 to 600 N in individuals with natural dentition using unilateral measurements. Sathyanarayana et al. found an average BF of 3927 N in the molar region with a 15 mm mouth opening. Arima et al., using an 8 mm transducer, found BFs of 5469 N on the right side and 5621 N on the left side [16–18]. In other studies, different results were obtained with different vertical intermolar distances [19]. In comparative studies, it was stated that 15–20 mm inter-incisal distance is ideal in the anterior, while this value corresponds to 8–10 mm when we look at the posterior, the BF measurements were 61,379 N for Class I, 44,531 N for Class II, and 42,864 N for Class III. Although no significant relationship was found between BF and sagittal direction classification, it was determined that Class I individuals exhibited higher BF compared to other groups. Variations in study results can be attributed to differences in measurement techniques, experimental groups, and devices used.

In summary, Roldan et al. [11] found that individuals classified as Class I in the sagittal direction had higher BF, while Proffit and Fields, as well as Proffit et al. [20, 21], reported no significant differences in BF levels among children with different vertical growth patterns. Sathyanarayana et al. [22] observed no significant difference in BF among sagittal direction groups but noted a significant relationship between BF and vertical direction groups, with higher BF in hypodivergent individuals compared to hyperdivergent individuals. In our study, significant differences were found among groups when BF was evaluated based on vertical classification, with the lowest BF in hyperdivergent individuals. The relationship between BF and craniofacial morphology aids in diagnosing craniofacial disorders.

Regarding masseter muscle thickness and BF, previous studies have found a correlation [13, 23]. Koolstra et al. and Van Spronsen et al. stated that craniofacial morphology variations can influence the relationship between BF magnitude and masseter muscle volume and orientation [24, 25]. However, our study did not find a significant correlation between masseter muscle volume and BF. This discrepancy may be attributed to using low-resolution soft tissue imaging with CBCT.

Ng et al. reported a masseter muscle volume of 295 cm^3 [26], while Boom et al. found it to be 238 cm^3 [27]. However, previous studies did not specifically investigate muscle volume measurements according to different skeletal malocclusions. In our study, the results align with other studies, as we found masseter muscle volumes of 2690 cm^3 for Class I, 3139 cm^3 for Class II, and 2929 cm^3 for Class III.

Regarding muscle volume based on craniofacial morphology, previous studies have reported inconsistent findings [1, 6, 28]. In our study, when muscle volume was evaluated according to vertical direction groups, a significant relationship was observed. Specifically, the hypodivergent group exhibited a higher muscle volume of 3412 cm^3 compared to the normodivergent group (2781 cm^3) and the hyperdivergent group (2437 cm^3).

Various techniques have been used to measure the volume, thickness, and width of the masseter muscle, including CT, CBCT, MRI, USG, lateral cephalometric film, and dissection [29–32]. Although dissection provides the most accurate results, imaging techniques have the advantage of being non-invasive, non-harmful to the patient, and easy to apply.

In the literature, studies by Jiang Y et al. and Pan Y et al. reported that there is no significant difference between the measurements of the masseter muscle obtained using CT and MRI compared to CBCT, with results being similar [7, 33]. Our study results are consistent with previous studies; however, a larger sample size is recommended for obtaining more accurate data.

Bakke et al., Throckmorton et al., and Farella et al. found higher masseter muscle activity in hypodivergent individuals compared to other groups using vertical direction classification [13, 34, 35]. Ueda et al. reported a negative correlation between masseter muscle activity and vertical direction classification [36]. Proffit and Fields, as well as Farella et al., reported no difference in masseter muscle EMG activity during maximum clenching between normodivergent and hyperdivergent individuals, which is consistent with our study [20, 35]. In our study, there was no significant difference among vertical groups, but the EMG values of hypodivergent and normodivergent individuals were higher than those of hyperdivergent individuals. When evaluating the relationship between muscle activity and craniofacial morphology, the vertical and sagittal components of craniofacial morphology should be considered [37].

It has been suggested that individuals with strong chewing muscles generally have a hypodivergent facial structure. However, some studies stated that it is not possible to claim that every individual with a hypodivergent facial structure has strong chewing muscles [38]. Becht et al. [6] found a significant correlation between masseter ultrasound thickness and vertical direction classification in adults; they reported that the masseter muscle size was larger in hypodivergent subjects compared to hyperdivergent subjects. Van Spronsen et al. [25] found no significant relationship between jaw muscle volumes and facial height, mandibular size, maxillary size, or cranial base angle. Chan et al. and Van Spronsen et al. found that the mean cross-sectional areas (CSA) of the masseter and medial pterygoid muscles were significantly lower in hyperdivergent individuals compared to hypodivergent and normodivergent groups [25, 39]. According to the study by Chan et al., Class III adults had smaller masseter CSA values [39].

Bakke et al. compared their findings on masseter muscle electromyographic activity with muscle thickness and found a positive correlation between the magnitude of electromyographic activity and muscle thickness [13]. However, our study did not find a significant relationship between electromyographic activity measured during maximum voluntary clenching and muscle thickness. This may be attributed to using CBCT as the imaging method or our study using masseter volume.

In conclusion, this study contributes to the understanding of masseter muscle volume and activity related to craniofacial morphology. The use of advanced 3D imaging with CBCT allowed for non-invasive evaluation of soft tissues and provided important insights. However, it is worth noting that the findings from various studies on this topic have not always been consistent. Further investigations in this area will help establish a more precise and comprehensive understanding of the complex interactions between muscle function and craniofacial development, leading to improved orthodontic treatment planning and enhanced patient outcomes.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval 'All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study.'

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