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# Association Between Skeletal Malocclusion, Masseter Muscle Volume, and Bite Force: CBCT Study

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SUMMARY

***Background/Aim***: *This study aimed to evaluate the masseter muscle volume and maximum bite force in individuals with different types skeletal malocclusion. The researchers conducted a comparative analysis to assess the relationship between skeletal malocclusion groups and masseter muscle volume, as well as maximum bite force. By examining these variables, the study aimed to provide insights into the underlying mechanisms of craniofacial deformities.* ***Materials and Methods:*** *The study was conducted on a sample of 60 young adult patients (18-30) years. These patients were referred to the clinic for Cone Beam Computed Tomography (CBCT) imaging. Radiological measurements were taken using CBCT images, and bite force was measured using a force measurement sensor.* ***Results:*** *The results of the study indicated a statistically significant relationship in both muscle volume and bite force among the different skeletal malocclusion groups. However, no correlation was observed between muscle volume and other variables. The statistically significant relationship between vertical groups and muscle volume/bite force suggests that these measures could potentially serve as supplementary diagnostic tools. However, the uneven distribution of vertical directional groups indicates that they may not be entirely reliable as diagnostic tools. Therefore, further investigation using larger sample sizes is necessary to better understand the relationship between skeletal malocclusion, bite force, muscle volume.* ***Conclusions:*** *The absence of correlation between muscle volume and bite force suggests that CBCT may not be reliable method for soft tissue imaging. This implies inadequacy of CBCT in capturing soft tissue details.*

**Keywords:** Cone Beam Computed Tomography, Bite Force, Masseter Volume, Malocclusion

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## Introduction

The relationship between masticatory muscles and skeletal malocclusion has not been extensively studied in the past. However, recent advancements in dental imaging techniques have allowed for non-invasive investigations into the relationship between masticatory muscles and skeletal malocclusion and craniofacial morphology[1]. The masticatory muscles play a crucial role in jaw growth, both in terms of bone formation at the muscle attachment site and as a major component of the soft tissue matrix that facilitates jaw movement during growth[2].

Reduced muscle activity can lead to increased anterior facial height, distortion of facial-mandibular form, and anterior open bite.[3] Animal studies have also demonstrated that interference with masticatory muscle development can result in changes in jaw bone shape[4]. Various methods have been described in recent studies to evaluate muscle size, including measuring masseter muscle volume, cross-sectional area, and length using techniques such as CT, CBCT, MRI, and ultrasonography[5, 6].

The use of 3D cone beam computed tomography (CBCT) and advanced visualization capabilities have made it possible to define the orientation of the masseter muscle from the zygomatic process to the mandible. This allows for an understanding of the role of the masseter muscle in craniofacial morphology, particularly in different types of skeletal malocclusion. The literature describes different indicators of jaw muscle function, including maximum bite force (MBF), electromyography (EMG), cross-sectional area (CSA), muscle thickness, and muscle volüme[7-9].

Maximum bite force 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 bite force and muscle thickness, as well as between masseter-temporal muscle thickness and facial morphology. Subjects with malocclusion generally exhibit decreased masticatory performance compared to those with normal occlusion[10-12].

Most studies in the literature have focused on evaluating the size and volume of the masseter muscle and drawing conclusions about individuals' facial patterns. Few studies have specifically investigated modern imaging techniques and the role of craniofacial morphology. The objective of this study was to assess masseter muscle volume and molar bite force measurements in different types of malocclusions. We hypothesize that volume and bite forces will vary significantly among different types of malocclusion.

## Materials and Methods

The study included a total of 60 young adult patients, with 30 females and 30 males, ranging in age from 18 to 30 years. The sample consisted of patients who sought treatment at the Oral and Maxillofacial Surgery Department and Orthodontics Department of Kirikkale University Faculty of Dentistry, as well as those referred to the clinic for Cone Beam computed tomography (CBCT) imaging. The study was approved by the Kirikkale University Clinical Research Ethics Committee.

Exclusion criteria were applied to eliminate 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.

Lateral cephalometric images were obtained from the CBCT scans using the ray sum technique with the I-Cat Invision program. 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.

Based on the sagittal skeletal pattern determined by the ANB angle range analysis on lateral cephalograms, the participants were categorized into three groups. The Class I group included subjects with an ANB angle range of 0 to 5 degrees, the Class II group comprised subjects with an ANB angle greater than 5 degrees, and the Class III group consisted of subjects with an ANB angle less than 0 degrees.

Furthermore, based on the vertical skeletal pattern estimated using the Frankfurt-mandibular plane angle (FMA) through the Tweed cephalometric analysis on lateral cephalograms, the participants were divided into three groups. The hypodivergent group had an FMA angle below 20°, the normodivergent group had an FMA angle ranging from 21° to 28°, and the hyperdivergent group had an FMA angle greater than 29°.

The CBCT images of each patient, in DICOM format, were transferred to 3D-Doctor software (Able Software Corp. Lexington, MA, USA) for analysis. Since the densities of the masticatory muscles were similar on CBCT images, the automatic segmentation method was not utilized. Manual segmentation was performed on the sagittal images, with the border of the masticatory muscle marked in each section (Figure 1). An independent observer who was blinded to the patients' clinical conditions performed the measurements. To ensure reliability, measurements were carried out by the observer once per day to minimize fatigue-related errors. Intraobserver reliability was assessed by repeating the measurements on CBCT images of 10 patients one week after the initial measurements. The collected data were recorded in an Excel worksheet for further analysis.

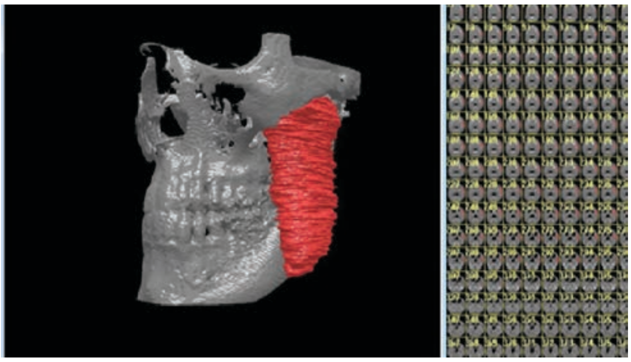

*Figure 1.*

The bite force measurements were conducted using a portable bite force sensor designed for medical purposes (Viste, Hong Kong, China). The sensor consists of stainless steel plates covered with rubber on the outer surface, which facilitates comfortable biting for patients. Disposable plastic covers were used for hygiene purposes for each patient (Figure 2). The device displays force values in Newtons (N) after converting the measurements from kilograms. To ensure that the modified bite surface did not affect the recorded bite force values, weights with known masses were measured using both surfaces. The analysis confirmed that the bite surfaces did not have any impact on the weight measurements.


*Figure 2.*

Bite force measurements were taken between the maxillary and mandibular first molars on both the right and left sides (Figure 3).

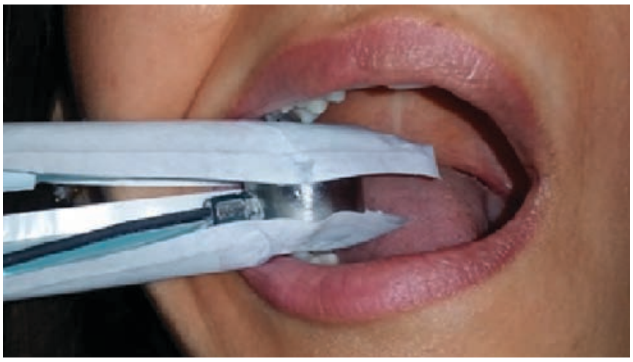

*Figure 3.*

Prior to the measurements, the patients were seated in a dental chair with their heads in a comfortable upright position, maintaining the Frankfort plane nearly parallel to the floor. Patients were instructed to bite the sensor with maximum force without moving their heads. The process was concluded when the bite force reached its maximum value as displayed on the digital screen. Bite force measurements were performed three times on each side (right and left), and the average value of each measurement was recorded. The analysis of the data showed that the bite surfaces do not affect the weight measurements.

The collected data were analyzed using the Statistical Package for Social Sciences (SPSS Inc. Chicago, Illinois, USA) version 18. The normality of the data distribution was assessed using the Kolmogorov-Smirnov test. Since the data did not follow a normal distribution ($p < 0.05$), the non-parametric Kruskal-Wallis test was utilized for statistical comparisons between groups. However, when the data showed a normal distribution, parametric tests such as one-way ANOVA were employed for the analysis.

## Results

Age distribution did not differ significantly between genders ($p > 0.05$). However, there was a statistically significant difference in BMI distribution between men and women ($p < 0.05$) (Table 1). No significant differences were observed in the average age and BMI values among subjects based on skeletal sagittal and vertical classifications ($p > 0.05$).

*Table 1: Comparison of age and BMI of subjects by gender*

| | Female Mean±SD | Male Mean±SD | P |
|---|---|---|---|
| Age | 22.2 ± 1.09 | 22.7 ± 1.29 | 0.11 |
| BMI | 21.63 ± 2.12 | 24.93 ± 4.07 | 0.00* |

*p<0.05: Statistically significant difference

Regarding bite force measurements based on skeletal sagittal classification, no significant differences were found between the groups for both the right and left sides ($p > 0.05$). However, Class I subjects exhibited higher bite force measurements compared to the other groups (Table 2).

*Table 2: Comparison of bite force and muscle volume measurements according to skeletal sagittal direction classification of subjects*

| | Skeletal Class I Mean±SD | Skeletal Class II Mean±SD | Skeletal Class III Mean±SD | P |
|---|---|---|---|---|
| Bite Force (N) | | | | |
| Right side | 471.60±51.58 | 455.02±33.93 | 451.41±40.89 | 0.939 |
| Left Side | 755.89±273.89 | 435.61±33.73 | 405.99±48.73 | 0.223 |
| Mean | 613.79±144.64 | 445.31±29.32 | 428.64±42.95 | 0.252 |
| Masseter Volume (cm3) | | | | |
| Right side | 27.266±1.319 | 32.227±2.108 | 30.547±2.034 | 0.178 |
| Left Side | 26.550±1.454 | 30.566±1.756 | 28.041±1.412 | 0.191 |
| Mean | 26.908±1.218 | 31.396±1.697 | 29.294±1.581 | 0.126 |

One-way Anova Test
*p<0.05: Statistically significant difference

When evaluated based on vertical classification, the hyperdivergent group demonstrated significantly lower bite force compared to the other groups ($p < 0.05$). Within the Class I subjects, the normodivergent group exhibited slightly higher bite force than the hypodivergent group (Figure 4).

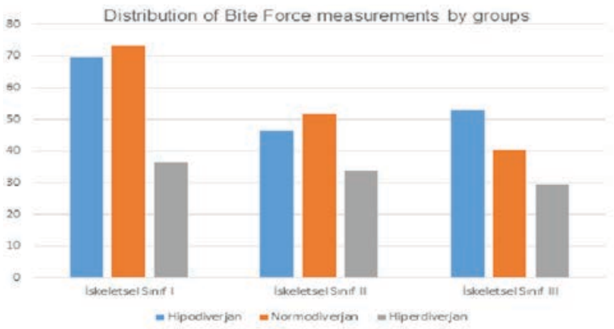


*Figure 4.*

Analysis of masseter muscle volume measurements based on skeletal sagittal classification revealed no significant differences between the groups. However, there was a significant difference among the groups based on vertical classification. Class II subjects had the highest masseter muscle volume measurements, followed by Class III subjects, and Class I subjects had the lowest measurements (Table 2). According to the vertical classification, the masseter muscle volume was 34.12 ± 1.61 cm3 in hypodivergent subjects, 27.81 ± 1.00 cm3 in normodivergent subjects, and 24.37 ± 1.28 cm3 in hyperdivergent subjects (Table 3). Bite force and masseter muscle volume measurements on the right and left sides were related to each other. However, there was no significant correlation between bite force and masseter muscle volume measurements (Table 4).

*Table 3: Comparison of bite force and muscle volume measurements according to the vertical direction classification of the subjects*

| | Hypodivergent Mean±SD | Normodivergent Mean±SD | Hyperdivergent Mean±SD | P |
|---|---|---|---|---|
| Bite Force (N) | | | | |
| Right side | 527.69±45.79 | 470.81±30.59 | 324.40±36.18 | 0.005* |
| Left Side | 538.09±50.70 | 612.52±201.91 | 338.91±42.26 | 0.032* |
| Mean | 532.86±44.81 | 541.71±105.02 | 331.66±34.42 | 0.010* |
| Masseter Volume (cm3) | | | | |
| Right side | 35.39±2.26 | 28.49±1.04 | 24.73±1.59 | 0.003* |
| Left Side | 32.85±1.61 | 27.12±1.13 | 24.00±1.39 | 0.002* |
| Mean | 34.12±1.61 | 27.81±1.00 | 24.37±1.28 | 0.000* |

Kruskal Wallis Test
*p<0.05: Statistically significant difference

*Table 4: Correlation between right and left side measurements*

| | p | Right Bite force | Left Bite force | Right masseter volüme | Left masseter volume |
|---|---|---|---|---|---|
| Right Bite force | 0.354 | 1 | 0.261 | 0.185 | 0.147 |
| Left Bite Force | 0.190 | 0.261 | 1 | 0.051 | 0.033 |
| Right masseter volüme | -0.160 | 0.185 | 0.051 | 1 | 0.598 |
| Left masseter volume | -0.042 | 0.147 | 0.033 | 0.598 | 1 |

** significant correlation at the 0.01 level.

These findings suggest that there are differences in bite force and masseter muscle volume among different skeletal malocclusion groups, particularly in relation to vertical classification. However, further research with larger sample sizes is needed to provide more conclusive evidence and to explore the relationship between skeletal malocclusion, bite force, and masseter muscle volume in greater detail.

Distribution of masseter muscle volume measurements showed higher values in Class II subjects and the hypodivergent group within the vertical classification. This suggests that Class II subjects and those with a hypodivergent skeletal pattern may have larger masseter muscle volumes compared to other groups. It would be beneficial to include the actual data or a visual representation of for more comprehensive understanding of the results (Figure 5).

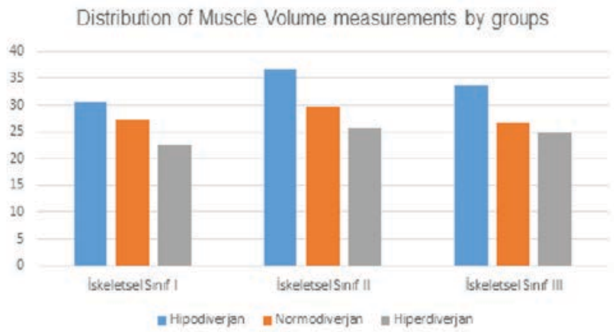


*Figure 5.*

## Discussion

The findings of our study regarding bite force are consistent with previous research that suggests a relationship between malocclusion and maximum bite force. Specifically, we found that Class I individuals had higher bite force compared to other groups based on sagittal classification. In terms of vertical classification, normodivergent and hypodivergent individuals had higher bite forces than hyperdivergent individuals. These results indicate that bite force can be influenced by vertical skeletal patterns.

The association between bite force and craniofacial morphology has been utilized as an auxiliary diagnostic tool for identifying craniofacial disorders. Our study adds to the existing literature by providing evidence of the relationship between bite force and skeletal malocclusion patterns. These findings highlight the potential utility of bite force measurements in diagnosing and assessing craniofacial morphology.

It is worth noting that the relationship between BMI and bite force remains a subject of debate in the literature. While Roldan et al. have suggested a correlation between

BMI and bite force[13], Our study did not find a significant relationship between BMI and sagittal groups regarding Takaki *et al*.[14] To minimize the potential impact of BMI on bite force measurements, we maintained an equal distribution of males and females within the sagittal classification groups.

Studies clearly demonstrate that bite force is strongest when the anterior opening is measured between 14 and 20 mm and the posterior opening is measured between 8 and 12 mm in different populations. In terms of methodology, our study utilized a bite block made of silicone material that is gentle on the teeth to measure bite force. The height of the bite block was adjusted to create a 10 mm gap between the teeth, which aligns with the optimal range for anterior and posterior openings based on previous research[15, 16]. Moreno *et al*. found that the left side had a higher bite force when evaluating the relationship between both sides of the jaw, but Melo et al. stated that the right and left bite forces were consistent with each other[17, 18]. Additionally, we found consistency between the bite forces measured on the right and left sides, supporting the reliability of our measurements.

Previous studies have shown that malocclusion are associated with maximum bite force[12, 19]. Roldan *et al.* found higher bite force in Class I individuals compared to other groups in patients classified according to a sagittal direction[13]. Regarding bite force, Proffit and Fields as well as Proffit *et al*. reported no difference in bite force levels among children with different vertical growth patterns[20, 21].

On the other hand, Sathyanarayana *et al*. found no significant difference in bite force according to sagittal direction groups, but they noted a significant relationship between bite force and vertical direction groups, indicating that bite force is higher in hypodivergent individuals compared to hyperdivergent individuals[22]. The relationship between bite force and craniofacial morphology is used as an auxiliary method in diagnosing disorders occur in craniofacial morphology. Regarding masseter muscle volume, our results did not show a significant difference between the sagittal groups but demonstrated a significant difference among the vertical groups.

The hypodivergent group had the highest masseter muscle volume, followed by the normodivergent group, and the hyperdivergent group had the lowest volume. There was no significant relationship between bite force and sagittal direction classification, but a higher bite force was observed in Class I individuals compared to with others. This suggests a relationship between masseter muscle volume and vertical skeletal patterns, with larger volumes observed in hypodivergent individuals.

In our study, we examined the relationship between masseter muscle volume, bite force, and craniofacial morphology. Kitai *et al*. have shown that specific masticatory muscle activity and volume can exert mechanical stress on neighboring skeletal regions[23]. Antonarakis *et al.* found a correlation between muscle thickness and bite force, suggesting that individuals with lower muscle thickness may exhibit lower bite force[24]. Bakke *et al.* and Raadsheer *et al.* also reported a significant relationship between bite force magnitude and masseter muscle thickness measured using ultrasound[9, 23, 25]. They all have found correlations between muscle thickness/volume and bite force magnitude, suggesting that variations in craniofacial morphology may impact these relationships.

Our study contributes to the understanding of the relationship between skeletal malocclusion, bite force, and masseter muscle volume. The findings suggest that bite force measurements can be influenced by both sagittal and vertical skeletal patterns, while masseter muscle volume is primarily associated with vertical skeletal patterns[26,27]. These findings highlight the potential of bite force and masseter muscle volume as diagnostic tools for assessing craniofacial morphology. Further research with larger sample sizes is needed to confirm and expand upon these findings.

However, recent technological advancements have improved soft tissue visualization in CBCT images, allowing for more precise measurements. Studies by Fourie *et al,*. Januario *et al.* and Gupta *et al.* have demonstrated the reliability and superiority of CBCT in measuring soft tissues, including facial soft tissues and masseter muscle volume. These studies have utilized CBCT with a slice thickness of 0,3 mm and high-resolution computer screens to enhance soft tissue visualization and obtain more accurate measurements[28-30].

It is important to note that despite following the recommendations of previous studies and using CBCT with optimized settings, our study yielded different results compared to the aforementioned studies. This discrepancy may be attributed to various factors, including sample characteristics, measurement techniques, and potential confounding variables that were not accounted for in our study.

Overall, while the relationship between masseter muscle volume and bite force has been established in previous research, our study's findings may be influenced by the limitations of CBCT in visualizing soft tissues. Further studies with larger sample sizes and more advanced imaging techniques are needed to provide a clearer understanding of the relationship between masseter muscle volume and bite force in different craniofacial morphologies.

CBCT (Cone Beam Computed Tomography) is indeed a promising technology for measuring masseter muscle volume. While our study did not find a correlation between muscle volume and bite force, it is important to note that CBCT has shown reliability in measuring the morphology and volume of various masticatory muscles in previous studies. While CBCT holds potential for measuring masseter muscle volume, our study suggests that there may be limitations in its ability to correlate muscle volume with bite force accurately. Nonetheless, 3D software programs like 3D-Doctor offer valuable tools for visualizing and measuring structures in 3D using original DICOM data, enabling reliable volume measurements[31]. These software programs have been utilized in studies examining masseter muscle volume. In our study, we employed the 3D-Doctor software in combination with CBCT data to measure the volume of the masseter muscles, allowing for non-invasive examination. Our findings demonstrated a positive correlation between the volumes of the masseter muscles on both sides, aligning with previous studies[7, 32].

Comparisons between conventional cephalometric films and those obtained from CBCT have also been conducted. Studies by Van Vlijmen *et al*.[33] and Moshiri *et al*.[34] have shown that cephalometric images obtained from CBCT are comparable or even more reliable than conventional cephalometric imaging methods. Lateral cephalometric films can be created from vertical MPR images of full thickness (130-150 mm).The ray-sum technique used in CBCT images allows for the creation of lateral cephalometric films without magnification and distortion, enhancing the reliability of skeletal measurements[34, 35].

It is important to recognize that skeletal malocclusions in the craniofacial system can have a cascading effect on surrounding tissues, leading to functional changes and biomechanical stresses and strains. CBCT provides valuable insights into these complex interactions and allows for a comprehensive assessment of craniofacial morphology and related structures.

Further research is warranted to explore the potential applications and refine the accuracy and reliability of CBCT in measuring masseter muscle volume, as well as its relationship with bite force. By advancing our understanding of these relationships, CBCT can contribute to the diagnosis and treatment planning of craniofacial disorders.

## Conclusions

Malocclusions are prevalent and understanding the role of the masseter muscle in detail can enhance the success of orthodontic treatments. However, our study, which had a small patient population, revealed limitations in using masseter muscle volume and bite force measurements as diagnostic tools for skeletal sagittal classification in malocclusion. On the other hand, significant findings between the vertical direction groups and muscle volume and bite force suggest that these measurements can be valuable as auxiliary diagnostic tools for determining the vertical dimension in malocclusion cases.

Although our study yielded results in line with other studies regarding masseter muscle volume measurements using CBCT, the lack of correlation with other measurements highlights potential limitations in the reliability of these measurements. This discrepancy may be attributed to the limited soft tissue imaging capability of CBCT. Future research comparing the reliability of CBCT with other imaging modalities such as MRI, ultrasound, and cadaveric studies for muscle volume measurements is warranted.

Overall, further investigation is needed to refine the use of masseter muscle volume and bite force measurements in diagnosing malocclusion and to explore alternative imaging techniques for accurate assessment of muscle volume. Advancements in imaging technology will contribute to a better understanding of the complex relationship between muscle function and craniofacial morphology, ultimately improving orthodontic treatment outcomes.

## References


1. Kiliaridis S, Katsaros C (1998). "The effects of myotonic dystrophy and Duchenne muscular dystrophy on the orofacial muscles and dentofacial morphology." *Acta Odontol Scand.* **56** (6): 369-374. doi: 10.1080/000163598428347. PMID: 10066119.
2. Nishi SE, Basri R, Alam MK, Komatsu S, Komori A, Sugita Y, et al. (2017). "Evaluation of Masticatory Muscles Function in Different Malocclusion Cases Using Surface Electromyography". *J Hard Tissue Biol*. **26** (1): 23-28. doi.org/10.2485/jhtb.26.23.
3. Piancino MG, Isola G, Merlo A, Dalessandri D, Debernardi C, Bracco P (2012). "Chewing pattern and muscular activation in open bite patients". *J Electromyogr Kinesiol*. **22** (2): 273-279. doi: 10.1016/j.jelekin.2011.12.003. PMID: 22236764.
4. Chan HJ, Woods M, Stella D (2008). "Mandibular muscle morphology in children with different vertical facial patterns: A 3-dimensional computed tomography study". *Am J Orthod Dentofacial Orthop.* **133** (1): 10.e1-13. doi: 10.1016/j.ajodo.2007.05.013. PMID: 18174063.
5. Eckardt L, Harzer W (1996). "Facial structure and functional findings in patients with progressive muscular dystrophy (Duchenne)". *Am J Orthod Dentofacial Orthop*. **110** (2): 185-190. doi: 10.1016/s0889-5406(96)70107-5. PMID: 8760845.
6. Proffit WR. and Ackerman JL (1982). Diagnosis and Treatment Planning. In: Graber, T.M. and Swain, B.F., Eds., Current Orthodontic Concepts and Techniques, Chapter 1, Mosby, St. Louis, 3-100.
7. Becht MP, Mah J, Martin C, Razmus T, Gunel E, Ngan P (2014). "Evaluation of masseter muscle morphology in different types of malocclusions using cone beam computed tomography". *Int Orthod*. **12** (1): 32-48. doi: 10.1016/j.ortho.2013.12.003. PMID: 24456631.

8. Benington PC, Gardener JE, Hunt NP (1999). "Masseter muscle volume measured using ultrasonography and its relationship with facial morphology". *Eur J Orthod*. **21** (6): 659-670. doi: 10.1093/ejo/21.6.659. PMID: 10665195.
9. Raadsheer MC, Van Eijden TM, Van Ginkel FC, Prahl-Andersen B (2004). "Human jaw muscle strength and size in relation to limb muscle strength and size". *Eur J Oral Sci*. **112** (5): 398-405. doi: 10.1111/j.1600-0722.2004.00154.x. PMID: 15458497.
10. García-Morales P, Buschang PH, Throckmorton GS, English JD (2003). "Maximum bite force, muscle efficiency and mechanical advantage in children with vertical growth patterns". *Eur J Orthod*. **25** (3): 265-272. doi: 10.1093/ejo/25.3.265. PMID: 12831216.
11. Mukhopadhyay M, Thakur A, Verma S, Chitra P (2023). "Evaluation of stress distribution patterns produced with the Advansync2 class II corrector - A finite element analysis". *J Oral Biol Craniofac Re*s. **13** (3): 418-423. doi: 10.1016/j.jobcr.2023.04.003. PMID: 37168737.
12. Tsai CY, Yang LY, Chen KT, Chiu WC (2010). "The influence of masticatory hypofunction on developing rat craniofacial structure". *Int J Oral Maxillofac Surg*. **39** (6): 593-598. doi: 10.1016/j.ijom.2010.02.011. PMID: 20219321.
13. Roldán SI, Restrepo LG, Isaza JF, Vélez LG, Buschang PH (2016). "Are maximum bite forces of subjects 7 to 17 years of age related to malocclusion?" *Angle Orthod*. **86** (3): 456-461. doi: 10.2319/051315-323.1. PMID: 26347948.
14. Takaki P, Vieira M, Bommarito S (2014). "Maximum bite force analysis in different age groups". *Int Arch Otorhinolaryngol*. **18** (3): 272-276. doi: 10.1055/s-0034-1374647. PMID: 25992105.
15. Shinogaya T, Bakke M, Thomsen CE, Vilmann A, Matsumoto M (2000). "Bite force and occlusal load in healthy young subjects--a methodological study". *Eur J Prosthodont Restor Dent.* **8** (1): 11-15. PMID: 11307384.
16. Arima T, Takeuchi T, Honda K, Tomonaga A, Tanosoto T, Ohata N, et al. (2013). "Effects of interocclusal distance on bite force and masseter EMG in healthy participants". *J Oral Rehabil.* **40** (12): 900-908. doi: 10.1111/joor.12097. PMID: 24033381.
17. Moreno I, Sánchez T, Ardizone I, Aneiros F, Celemin A (2008). "Electromyographic comparisons between clenching, swallowing and chewing in jaw muscles with varying occlusal parameters". *Med Oral Patol Oral Cir Bucal*. *13* (3): E207-213. PMID: 18305445.
18. Melo DG, Bianchini EM (2016). "Relationship between electrical activity of the temporal and masseter muscles, bite force, and morphological facial index". *Codas*. **28** (4): 409-416. doi: 10.1590/2317-1782/20162014233. PMID: 27556824.
19. Ahlberg JP, Kovero OA, Hurmerinta KA, Zepa I, Nissinen MJ, Könönen MH (2003). "Maximal bite force and its association with signs and symptoms of TMD, occlusion, and body mass index in a cohort of young adults". *Cranio*. **21** (4): 248-252. doi: 10.1080/08869634.2003.11746258. PMID: 14620696.
20. Proffit WR, Fields HW, Nixon WL (1983). "Occlusal forces in normal- and long-face adults". *J Dent Res.* **62** (5): 566-570. doi: 10.1177/00220345830620051201. PMID: 6573373.
21. Proffit WR, Fields HW (1983). "Occlusal forces in normal- and long-face children". *J Dent Res*. **62** (5): 571-574. doi: 10.1177/00220345830620051301. PMID: 6573374.
22. Sathyanarayana HP, Premkumar S, Manjula WS (2012). "Assessment of maximum voluntary bite force in adults with normal occlusion and different types of malocclusions". *J Contemp Dent Pract*. **13** (4): 534-538. doi: 10.5005/jp-journals-10024-1181. PMID: 23151705.
23. Kitai N, Fujii Y, Murakami S, Furukawa S, Kreiborg S, Takada K (2002). "Human masticatory muscle volume and zygomatico-mandibular form in adults with mandibular prognathism". *J Dent Res.* **81** (11): 752-756. doi: 10.1177/0810752. PMID: 12407089.
24. Antonarakis GS, Kiliaridis S (2015). "Predictive value of masseter muscle thickness and bite force on Class II functional appliance treatment: a prospective controlled study". *Eur J Orthod*. **37** (6): 570-577. doi: 10.1093/ejo/cju089. PMID: 25582592.
25. Bakke M, Tuxen A, Vilmann P, Jensen BR, Vilmann A, Toft M (1992). "Ultrasound image of human masseter muscle related to bite force, electromyography, facial morphology, and occlusal factors". *Scand J Dent Res*. **100** (3): 164-171. doi: 10.1111/j.1600-0722.1992.tb01734.x. PMID: 1631486.
26. Sasidhar YN, Varma NS, Prasad GK, Talasila U, Puvvula N, Ravuri P (2021). "Evaluation of Volume Width and Thickness of Masseter Muscle in Different Facial Patterns Using Magnetic Resonance Imaging: A Comparative Study". Annals RSCB. **25** (6): 11468-11473.
27. Yang Ji Ho, Dong Sun Shin, Jeong-Hun Yoo, Hun Jun Lim, Jun Lee, Bong Chul Kim (2021). "Anatomical Characteristics of the Masseter Muscle in Mandibular Prognathism". *Applied Sciences* **11** (10): 4444. doi.org/10.3390/app11104444.
28. Januário AL, Barriviera M, Duarte WR (2008). "Soft tissue cone-beam computed tomography: a novel method for the measurement of gingival tissue and the dimensions of the dentogingival unit". *J Esthet Restor Dent*. **20** (6): 366-373. doi: 10.1111/j.1708-8240.2008.00210.x. PMID: 19120781.
29. Fourie Z, Damstra J, Gerrits PO, Ren Y (2010). "Accuracy and reliability of facial soft tissue depth measurements using cone beam computer tomography". *Forensic Sci Int*. **199** (1-3): 9-14. doi: 10.1016/j.forsciint.2010.02.018. PMID: 20236780.
30. Gupta M, Makhija P. Quantitative evaluation of masseter muscle volume in different growth patterns and its correlation with facial morphology: Cone beam computed tomography study. J Indian Orthod Soc. 2016; **50** (2): 106. doi:10.4103/0301-5742.179942.
31. Kamburoğlu K, Kurşun Ş, Kılıç C, Özen T. Accuracy of virtual models in the assessment of maxillary defects. *Imaging Sci Dent*. 2015 Mar;**45**(1):23-29. doi: 10.5624/isd.2015.45.1.23. PMID: 25793180.
32. Ng HP, Foong KW, Ong SH, Goh PS, Huang S, Liu J, Nowinski WL (2009). "Quantitative analysis of human masticatory muscles using magnetic resonance imaging". *Dentomaxillofac Radiol.* **38** (4): 224-231. doi: 10.1259/dmfr/75198413. PMID: 19372110.

33. van Vlijmen OJ, Bergé SJ, Swennen GR, Bronkhorst EM, Katsaros C, Kuijpers-Jagtman AM (2009). "Comparison of cephalometric radiographs obtained from cone-beam computed tomography scans and conventional radiographs". *J Oral Maxillofac Surg*. 2009 **67** (1): 92-97. doi: 10.1016/j.joms.2008.04.025. PMID: 19070753.
34. Moshiri M, Scarfe WC, Hilgers ML, Scheetz JP, Silveira AM, Farman AG (2007). "Accuracy of linear measurements from imaging plate and lateral cephalometric images derived from cone-beam computed tomography". *Am J Orthod Dentofacial Orthop*. **132** (4): 550-560. doi: 10.1016/j.ajodo.2006.09.046. PMID: 17920510.
35. Farman AG, Scarfe WC (2006). "Development of imaging selection criteria and procedures should precede cephalometric assessment with cone-beam computed tomography". *Am J Orthod Dentofacial Orthop.* **130** (2): 257-265. doi: 10.1016/j.ajodo.2005.10.021. PMID: 16905073.

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