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Research Article

Relationship between the Mandibular Condyle Position and the Bite Force in the People with Normal Temporomandibular Joint

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Statement of the Problem. The mandibular condyle position is important in temporomandibular joint (TMJ) disorders. The bite force is a mechanical force that may affect the condylar position. *Purpose*. To investigate the relationship between condylar position in the glenoid fossa and maximum bite force in adults with normal temporomandibular joint. *Materials and Methods*. In this cross-sectional study, 23 subjects (21 females and 2 males; mean age 38.88 ± 11.7 years) with 41 joints participated. Right and left joints were examined using cone-beam computed tomography. Maximum bite force was measured using the strain gauge transducer in the regions of right molar, left molar, and incisors. Pearson correlation coefficient, paired sample t-test, and binary logistic regression were employed for analysis. *Results*. The mean maximum bite force was 169.09 ± 87.7 N. The most common position of the condyle was anterior ($n = 36$) and inferior ($n = 31$). The mean of mandibular condyle joint spaces for right and left sides were not statistically significant ($P > 0.05$). There were no relationships between the condylar positions and the mean maximum bite force ($P > 0.05$). *Conclusion*. The condylar positions in the glenoid fossa are not related to the bite force in the people with normal temporomandibular joint.

1. Introduction

Mandibular condyle position in the glenoid fossa is important. The mandibular condyle plays important roles in growth and development of the mandible as well as in the relationship between the maxilla and the mandible [1]. The significance of condyle position has been demonstrated in functional disorders of the masticatory system [2–4]. In fact, the position of the condyle in fossa has been suggested as one of the factors in the etiopathogenesis of temporomandibular joint (TMJ) disorder [5–7]. It follows that the clinicians attempt to guide the mandibular condyle into a normal position in the glenoid fossa with the aim of relieving the symptoms in patients with TMJ disorders [8, 9]. The forces exerted on the mandibular condyle and TMJ's disc varies depending on the condylar position [10]. In normal TMJ, the condylar position is in the superior-anterior region of the glenoid fossa when the occlusion is in maximum intercuspation [11].

The occlusal force is one of the important factors that can influence the growth and development of maxillofacial structures [12, 13] and the morphology of mandibular condyle [13, 14]. The occlusal stability is influenced by the muscular function, as well [15]. Considering the importance of condylar position in the fossa, the role of mechanical bite force in association with the condylar position, however, has not been investigated. Therefore, the aim of this study was to investigate the relationship between the condylar position in the glenoid fossa and the maximum bite force in molar and incisal regions in adults with normal TMJ.

2. Materials and Methods

2.1. Study Design. This study followed an observational design. Ethical approval was granted from the Ethics Committee of Shahed University (IR.SHAHED.REC.1399.103). Written informed consent was obtained from all participants prior to inclusion in this study.

2.2. Participants. Inclusion criteria were (1) people aged 18–65 years and (2) having normal TMJ based on Helkimo's index [16]. Recording symptoms according to Helkimo's index composed of two parts: anamnestic component with yes or no questions and clinical dysfunction component for examining mandibular opening, mandibular deviation, palpation, and observation of palpebral reflex.

Exclusion criteria were (1) history of jaw trauma; (2) history of occlusion reconstruction; (3) any systemic disease affecting joints (e.g., rheumatoid arthritis and systemic sclerosis) [16]; and (4) any radiographic changes which is associated with TMD such as flattening [17].

2.3. Outcome Measure. The TMJ anterior, superior, and posterior joint spaces and the maximum voluntary bite force were the main outcome measures.

2.4. Procedure. Subjects referred to cone-beam computerized tomography (CBCT) imaging centers that had the inclusion criteria were asked to participate in the study. The reasons for the referral CBCT images were based on various reasons other than the TMJ disorder. The study aims were described to the volunteers prior to take part in the study and their written informed consent was obtained. Demographic data of age and gender were recorded. Both right and left TMJs were assessed on CBCT images independently if presented no pathology, otherwise the normal side was considered for the assessment [18].

3. Measurements

3.1. Measurement of TMJ Spaces. The procedure used previously was followed to measure the superior, anterior, and posterior joint spaces of the TMJ [18, 19]. The standard view protocol for the CBCT was as follows: field of view = 150 × 130 mm, voxel size = 0.25 mm, and mAs = 81.00. On axial slices of CBCT images (WHITE FOX ACTEON, Italy), the slice with the largest mediolateral dimension of condylar head was selected. Then, true sagittal images with 2 mm thickness and interval distance on mediolateral axis of condyle were reconstructed. True central sagittal slice was chosen. Anterior, superior, and posterior joint spaces were measured on these reconstructed sagittal images. Initially, a horizontal line on the uppermost area of glenoid fossa was drawn and the intersection of this line with glenoid fossa was selected as superior reference point (S). This point was connected to the most prominent points on anterior (A) and posterior (P) aspects of the condyle. Finally, the perpendicular distance from A and P tangent points to glenoid fossa were measured as anterior (AJS) and posterior joint spaces (PJS). The right distance between S point and superior prominent point of condylar head was considered as superior joint space (Figure 1). On Demand and Romexis2.9.2 software were used for linear measurements.

The condyle position in anteroposterior plane was calculated using the formula: Condylar ratio (CR) = (PJS − AJS/PJS + AJS) × 100, where PJS denotes posterior joint space, and AJS denotes anterior joint space. The condylar ratio was interpreted as follows: $-12 < CR < +12$ (Centric position); $CR > +12$ (Anterior position); $CR < -12$ (Posterior position) [20]. Superior joint space of 1–4 mm was considered as normal, distance >4 mm inferior condyle position, and <1 mm superior condyle position, respectively [21].

3.2. Bite Force Measurement. Measurements were taken with participants in comfortable seated position. The strain-gauge transducer consists of load cell (ZEMIC, China) with a measuring capacity of 100 kg was used to measure the bite force. Strain gauge transducer was used as it has a high sensitivity and accuracy to measure the bite force [22]. The metal bite plates of the transducer were covered with condensation silicon putty consistency (Speedex COLTENE, Switzerland) to make the biting more comfortable for the participants. The bite force was recorded in 3 regions of right molar, left molar, and incisors. Participants were asked to bite as strong as they can to record the maximum bite force. The bite force in each region was measured twice with one minute rest between them; the higher bite force was recorded for analyses. The average of bite forces obtained from the three regions was calculated as an individual's mean bite force.

3.3. Sample Size Calculation. To calculate the sample size, the following formula was used:

$$n = \left\{ \frac{Z_{1-(\alpha/2)} + Z_{1-\beta}}{1/2\mathrm{Ln}\,(1 + r/1 - r)} \right\}^2 + 3. \quad (1)$$

Assuming $\alpha = 0.05$, power = 0/80, and 0.43 for the correlation coefficient obtained from a pilot study, we achieved 41 samples as adequate for this study.

3.4. Statistical Analysis. The normal distribution was assessed by the Kolmogorov–Smirnov test. The quantitative variables are presented as the mean ± standard deviation (SD). The relationship between the bite force and the joint

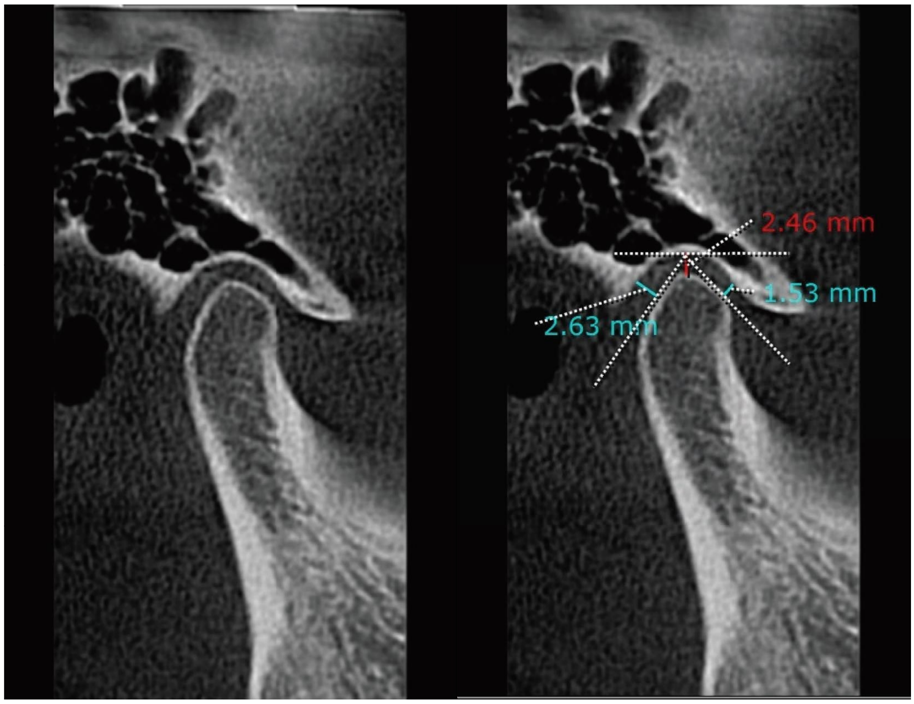

Figure 1: Linearly measurements of joint spaces between the condyle and the glenoid fossa.

spaces was determined by using the Pearson correlation coefficient. Paired sample t-test was used to compare the joint spaces of right and left condyles. Binary logistic regression was used to predict the relationship between predictors (age and bite force) and the dichotomous dependent variable of condylar position. P values <0.05 were defined as statistically significant. All analyses were performed using SPSS statistics software for windows, version 20.0 (SPSS, Inc, Chicago, IL).

4. Results

4.1. Demographic Data. Twenty-three subjects (21 female and 2 males) participated in this study. The mean age of participants was 38.88 ± 11.7 (range 19–64).

4.2. TMJ Spaces and Condylar Position. In this study, 41 TMJs were assessed. In sagittal plane, the most common condylar position was anterior ($n = 36$) followed by central ($n = 5$). Vertically, the most common condylar position was inferior ($n = 31$) followed by central ($n = 10$).

The mean of condylar joint spaces were 1.8 ± 0.5 mm (Anterior), 4.8 ± 1.7 mm (Posterior), and 4.9 ± 1.3 mm (Superior). The mean of joint spaces of anterior, posterior, and superior condylar positions for right and left sides were not significantly different, Table 1.

4.3. Bite Force. The mean ± standard deviation of bite force for all participants ($n = 23$) was 169.09 ± 87.7 N.

4.4. Relationships. The binary logistic regression showed that the association between the condylar position and the bite force as well as age was not statistically significant

Table 1: The mean and standard deviation (SD) for joint spaces of right and left condylar positions ($n = 18$).

Variables (mm)	*Right*	*Left*	*Paired T test*	
	Mean ± SD	Mean ± SD	t	P value
Anterior	1.8 ± 0.5	1.7 ± 0.5	0.278	0.784
Posterior	4.8 ± 1.8	5.1 ± 1.5	−0.761	0.457
Superior	4.8 ± 1.4	5.0 ± 1.2	−0.675	0.509

($P > 0.05$). Further analyses using the independent T-test showed that the relationship between bite force and joint spaces was not statistically significant ($P > 0.05$).

5. Discussion

The aim of the study was to investigate the relationship between the condylar position in the glenoid fossa and the maximum bite force in adults with normal TMJ. The main findings of the present study were the anterior and inferior condylar positions, which were the most common positions in this sample of participants with normal TMJ. The mean joint spaces for right and left sides were similar. There were no relationships between the bite force and condylar position, or joint spaces. The condylar positions were assessed in this study as they are important for their roles in the maxilla and mandible positions [1, 23] and in the pathology of TMJ disorder [5–7]. To the best of authors' knowledge, this is the first study that investigated the relationship between the condylar position and the maximum bite force in adults with normal TMJ.

5.1. TMJ Spaces and Condylar Position. In this study, participants had normal TMJ with no TMD-related signs or symptoms and thus met our criteria for assessing normal individuals. The condyles of individuals in this study were mostly positioned anterior and inferior in line with those of previous studies [21, 24]. However, there are studies that reported different findings [18, 25]. Differences in the positions of condyles reported in the studies might be due to the inconsistencies in sample size, participants' conditions, heterogeneity in sample age and gender, and the methodology used for evaluations. Different reports on the mandibular condyle position in the fossa point to the fact that the optimal condylar position is not defined and is a matter of controversy. Considering a large sample size of both genders in all age groups and using the robust technologies may reveal the range of normal and optimal condylar positions. Therefore, inconsistencies in condylar positions in this group of normal subjects may, in part, explain the lack of relationship between the condylar position and bite force. Further study with subjects of the same condylar positions and of sufficient sample sizes is worthy of investigation.

The mean of anterior joint space found in our study was similar, and the posterior joint space was more than those reported in the literature [1, 18, 24, 26]. The superior joint space in the present study was nearly similar with those of previous studies [1, 19, 26]. The inconsistencies in the joint spaces might be from differences in measurement methods [20, 27] or inclusion of subjects with malocclusion [20, 28, 29]. We used the CBCT scans that provide accurate, high quality images on the anatomical relationships as for the condyle fossa relationship in TMJ. However, there were no differences in the size of the joint spaces or the condylar position of right and left sides revealed in this study. While a study find a significant difference between left and right joints, mean difference 0.2 mm [18], other studies in line with our findings did not find significant differences between right and left joints [1, 28, 30].

5.2. Bite Force. Bite force was recorded as a variable in this study that indicates the efficacy of masticatory muscles [1, 2]. It was recorded to evaluate how well it is associated with the condylar positions in this sample of normal TMJ subjects. The mean of bite force was calculated low in this study compared to the previous studies [31–33]. There are various devices to measure the bite force [34]. One possible reason for the low mean bite force found in this study could be the device used. In the present study, the strain-gauge transducer was used. While the attempts were made to record the maximum bite force with the closest similarity to physiologic conditions, the subjects might not bite maximally to protect their teeth against injury. This may partly explain the low mean bite force recorded in this study. Moreover, the participants were mostly female (21 out of 23). The mean bite force in women is found lower compared to men. A literature review concluded that maximum bite force is higher in males than females [34]. Another study showed the mean of maximum bite force in men is greater than in women independent of age groups [35]. These could be another reason for lower bite force recorded in this study. Future research is needed with a large sample size with both men and women to confirm the findings. Bite force can be impaired by several factors such as malocclusion [36], facial skeleton morphology [34, 37], and reduced periodontal tissue support [34]. These factors were not evaluated in this study. Considering these factors in further studies would add new lines in this innovative topic.

5.3. Relationships. The biting force is a function of craniomandibular structures [38]. The ability to bite is thus a function of structures such as TMJ, teeth, and mastication muscles. Biting force has been reported associated with cognitive ability [39, 40] and indicates the appropriateness of functional mastication system. In fact, the mastication is a matter of quality of life [41].

This study found no association between the condylar positions and bite force as well as age in this group of subjects with normal TMJ. Also, there was no relationship between bite force and joint spaces. The findings indicate that the condylar position in the fossa and joint spaces are not related with bite force and age. The mean age of subjects in this study indicates that they were in the same range of early adulthood. Furthermore, most subjects in this study were women. These subjects' characteristics might explain the lack of associations observed in this study. A study with all age ranges including older adults and both gender with a large sample of subjects is needed to identify whether the age and gender affects the relationships between the condylar position and bite force, or essentially there are relationships between the condylar position and the bite force.

Our sample was normal individuals. The lack of relationships between the outcomes in the present study might be due to the fact that the subjects were free from signs and symptoms. A study reported with greater age, the maximal bite force is smaller, and there is a correlation with TMJ involvement and ageing [42]. Another study to evaluate the condylar position in adults with or without TMJ symptoms using CBCT found significant differences between younger and older groups in all outcomes measured [26]. These findings, along with the fact that patients with TMJ disorders have lower maximal bite force than the general population, all indicate that with the presence of pathology and age-related morphological alterations in the TMJ, one can speculate that there may be relationships between the condylar position, joint space, and maximal bite force, a hypothesis that deserves investigation.

Nevertheless, a study found that the bite force is dependent on muscle function, not osseous and teeth support or proprioception [43]. This may indicate that the bite force may be related with muscle force and not condylar position in mandibular fossa. In this study, we did not measure the muscles' forces involved in mastication and its relationship with the bite force. The capacity of mastication muscles to generate force in terms of muscles' cross sectional areas, torque values, and their relative position with respect to the TMJ may be better indicators for relationships with the bite force that deserve investigation.

The functional loads may influence the TMJ morphology, and the loads on TMJs vary with the dentofacial morphologies [44, 45]; this suggests that the morphological differences in condyles and the mandibular fossa may had roles in the lack of relationship between the condylar position and bite force in this group of subjects. Mechanistic studies considering the morphological features of mandibular condyles and mastication system may identify the associations with the bite force. Similarity in morphology of mandibular condyles and the mastication muscles may indicate a link with the bite force, an area that needs investigation.

The condylar position and the bite force are matter of biomechanics. The forces produced by the masticatory muscles and the occlusion factors should be considered. In the other words, the movements of TMJ for biting are also guided by teeth occlusion other than the bones, muscles, and ligaments. Hence, the bite force produced for mastication should be analyzed in the light of interaction between the various structural factors contributing to the TMJ movements and the biting force. An integrated approach for investigation considering the interaction among the various structures contributing to the biting force is required.

6. Limitations

This study was not without limitations. First, even though the sample of TMJs evaluated had adequate power to detect the relationships, the sample size was small for a correlation study. Second, there were unequal sample of genders, mostly being women. Third, the sample was from the age range mainly from younger adults. Fourth, there were no groups of symptomatic patients with TMJ disorders. Considering the above-mentioned limitations, further research is recommended to address these shortcomings and to establish whether our findings in this study have clinical relevance and implications, and whether there may be used as measures to differentiate asymptomatic subjects from symptomatic individuals with TMJ disorders.

7. Conclusion

In conclusion, there were no relationships between the condylar position and maximum bite force. The condylar position of the right and left TMJs were similar. The findings of the present study deserve further investigations with a larger sample size of both genders with ages from younger adults to older adults, and symptomatic patients with TMJ disorders.

Data Availability

The data used in this study are available from corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

References

[1] M. Al-koshab, P. Nambiar, and J. John, "Assessment of condyle and glenoid fossa morphology using CBCT in South-East Asians," *PLoS One*, vol. 10, no. 3, Article ID 0121682, 2015.

[2] E. H. Williamson, D. L. Evans, W. A. Barton, and B. H. Williams, "The effect of bite plane use on terminal hinge axis location," *The Angle Orthodontist*, vol. 47, no. 1, pp. 25–33, 1977.

[3] M. Imanimoghaddam, A. S. Madani, P. Mahdavi, A. Bagherpour, M. Darijani, and H. Ebrahimnejad, "Evaluation of condylar positions in patients with temporomandibular disorders: a cone-beam computed tomographic study," *Imaging Science in Dentistry*, vol. 46, no. 2, pp. 127–131, 2016.

[4] G. Cutroneo, M. G. Piancino, G. Ramieri et al., "Expression of muscle-specific integrins in masseter muscle fibers during malocclusion disease," *International Journal of Molecular Medicine*, vol. 30, no. 2, pp. 235–242, 2012.

[5] A. M. Chisnoiu, A. M. Picos, S. Popa et al., "Factors involved in the etiology of temporomandibular disorders-a literature review," *Medicine and Pharmacy Reports*, vol. 88, no. 4, pp. 473–478, 2015.

[6] S. Padala, S. Padmanabhan, and A. B. Chithranjan, "Comparative evaluation of condylar position in symptomatic (TMJ dysfunction) and asymptomatic individuals," *Indian Journal of Dental Research*, vol. 23, no. 1, p. 122, 2012.

[7] J. M. Barrera-Mora, E. E. Escalona, C. A. Labruzzi et al., "The relationship between malocclusion, benign joint hypermobility syndrome, condylar position and TMD symptoms," *CRANIO®*, vol. 30, no. 2, pp. 121–130, 2012.

[8] L. A. Weinberg, "An evaluation of occlusal factors in TMJ dysfunction-pain syndrome," *The Journal of Prosthetic Dentistry*, vol. 41, no. 2, pp. 198–208, 1979.

[9] F. Mongini, "Combined method to determine the therapeutic position for occlusal rehabilitation," *The Journal of Prosthetic Dentistry*, vol. 47, no. 4, pp. 434–439, 1982.

[10] H. J. Yang, D. S. Kim, W.-J. Yi, and S. J. Hwang, "Reduced joint distance during TMJ movement in the posterior condylar position," *Journal of Cranio-Maxillofacial Surgery*, vol. 41, no. 7, pp. e159–e164, 2013.

[11] H. Shillingburg, D. Sather, E. Wilson, J. Cain, D. Mitchel, and L. Blanco, "Fundamentals of fixed prosthodontics 4th Ed," *Chicago*, vol. 13, p. 4, 2012.

[12] S. Kreiborg, B. L. Jensen, E. Møller, and A. Björk, "Craniofacial growth in a case of congenital muscular dystrophy: a roentgencephalometric and electromyographic investigation," *American Journal of Orthodontics*, vol. 74, no. 2, pp. 207–215, 1978.

[13] A. Kurusu, M. Horiuchi, and K. Soma, "Relationship between occlusal force and mandibular condyle morphology," *The Angle Orthodontist*, vol. 79, no. 6, pp. 1063–1069, 2009.

[14] C. Kuo, M. Takahashi, and K. Maki, "Relationships among occlusal force, condylar surface area, and facial patterns," *Dental medicine research*, vol. 33, no. 2, pp. 169–177, 2013.

[15] R. Cannavale, G. Matarese, G. Isola, V. Grassia, and L. Perillo, "Early treatment of an ectopic premolar to prevent molar-premolar transposition," *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 143, no. 4, pp. 559–569, 2013.

[16] S. Rani, S. Gupta, S. Garg, and M. Bakshi, "Infection control knowledge and practice: a cross-sectional survey on dental laboratories in dental institutes of North India," *Journal of Indian Prosthodontic Society*, vol. 17, no. 4, p. 348, 2017.

[17] S. Shahab, Z. Azizi, F. T. Damghani, and F. T. Damghani, "Prevalence of osseous changes of the temporomandibular joint in CBCT images of patients with and without temporomandibular disorders," *Biosci Biotech Res Comm*, vol. 10, no. 3, pp. 518–524, 2017.

[18] Z. Dalili, N. Khaki, S. J. Kia, and F. Salamat, "Assessing joint space and condylar position in the people with normal function of temporomandibular joint with cone-beam computed tomography," *Dental Research Journal*, vol. 9, no. 5, p. 607, 2012.

[19] K. Ikeda and A. Kawamura, "Assessment of optimal condylar position with limited cone-beam computed tomography," *American Journal of Orthodontics and Dentofacial Orthopedics*, vol. 135, no. 4, pp. 495–501, 2009.

[20] A. Pullinger and L. Hollender, "Variation in condyle-fossa relationships according to different methods of evaluation in tomograms," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 62, no. 6, pp. 719–727, 1986.

[21] A. Shokri, H. Hosseini Zarch, F. Hafezmaleki, R. Khamechi, P. Amini, and L. Ramezani, "Comparative assessment of condylar position in patients with temporomandibular disorder (TMD) and asymptomatic patients using cone-beam computed tomography," *Dental and medical problems*, vol. 56, no. 1, pp. 81–87, 2019.

[22] Y. Gu, Y. Bai, X. Xie, T. Bite Force, and M. Devices, "Bite Force Transducers and Measurement Device," *Frontiers in Bioengineering and Biotechnology*, vol. 9, p. 253, 2021.

[23] W. R. Proffit, H. W. Fields, D. M. Msd, B. Larson, and D. M. Sarver, *Contemporary Orthodontics, 6e: south Asia Edition-E-Book*, Elsevier, Gurugram, India, 2019.

[24] L. F. Merigue, "Conti ACdCF, Oltramari-Navarro PVP, Navarro RdL, Almeida MRd. Tomographic evaluation of the temporomandibular joint in malocclusion subjects: condylar morphology and position," *Brazilian Oral Research*, vol. 30, 2016.

[25] M. Paknahad, S. Shahidi, S. Iranpour, S. Mirhadi, and M. Paknahad, "Cone-beam computed tomographic assessment of mandibular condylar position in patients with temporomandibular joint dysfunction and in healthy subjects," *International Journal of Dentistry*, vol. 2015, Article ID 301796, 6 pages, 2015.

[26] L. K. de Oliveira, A. J. F. Neto, I. M. M. Prado, J. C. G. Henriques, K. B. Kim, and G. de Araújo Almeida, "Evaluation of the condylar position in younger and older adults with or without temporomandibular symptoms by using cone beam computed tomography. The Journal of Prosthetic Dentistry," *Journal of Prosthetic Dentistry*, vol. 127, no. 3, pp. 445–452, 2020.

[27] R. y. Wang, X. c. Ma, W. l. Zhang, and D. g. Liu, "Investigation of temporomandibular joint space of healthy adults by using cone beam computed tomography," *Beijing da xue xue bao Yi xue ban= Journal of Peking University Health Sciences*, vol. 39, no. 5, pp. 503–506, 2007.

[28] H. O. Kim, W. Lee, Y.-A. Kook, and Y. Kim, "Comparison of the condyle-fossa relationship between skeletal class III malocclusion patients with and without asymmetry: a retrospective three-dimensionalcone-beam computed tomograpy study," *The Korean Journal of Orthodontics*, vol. 43, no. 5, p. 209, 2013.

[29] Z. Krisjane, I. Urtane, G. Krumina, and K. Zepa, "Three-dimensional evaluation of TMJ parameters in Class II and Class III patients," *Stomatologija*, vol. 11, 2009.

[30] Q. Liu, X. Wei, J. Guan, R. Wang, D. Zou, and L. Yu, "Assessment of condylar morphology and position using MSCT in an Asian population," *Clinical Oral Investigations*, vol. 22, no. 7, pp. 2653–2661, 2018.

[31] R. Amid, N. Ebrahimi, M. Kadkhodazadeh, M. Mirakhori, P. Mehrinejad, and F. Nematzadeh, "Clinical evaluation of a new device to measure maximum bite force," *Dentist Case Report*, vol. 2, no. 2, pp. 26–29, 2018.

[32] M. M. Srikanth, B. P. Kumar, V. Venkatesh, and V. V. Devi, "Evaluation of bite forces in healthy individuals," *Indian Journal of Dental Advancements*, vol. 10, no. 3, pp. 101–104, 2018.

[33] L. Jansen van Vuuren, J. M. Broadbent, W. J. Duncan, and J. N. Waddell, "Maximum voluntary bite force, occlusal contact points and associated stresses on posterior teeth," *Journal of the Royal Society of New Zealand*, vol. 50, no. 1, pp. 132–143, 2020.

[34] D. Koc, A. Dogan, and B. Bek, "Bite force and influential factors on bite force measurements: a literature review," *European Journal of Dermatology*, vol. 04, no. 2, pp. 223–232, 2010.

[35] P. Takaki, M. Vieira, and S. Bommarito, "Maximum bite force analysis in different age groups," *International Archives of Otorhinolaryngology*, vol. 18, no. 3, pp. 272–276, 2014.

[36] H. Kaur, N. Singh, H. Gupta et al., "Effect of various malocclusion on maximal bite force-a systematic review," *Journal of Oral Biology and Craniofacial Research*, vol. 12, no. 5, pp. 687–693, 2022.

[37] Ł Sidorowicz and J. Szymanska, "The relationship between facial skeleton morphology and bite force in people with a normal relation of the bases of jaws and skull," *Folia Morphologica*, vol. 74, no. 4, pp. 508–512, 2015.

[38] C. P. Fernandes, P.-O. J. Glantz, S. A. Svensson, and A. Bergmark, "A novel sensor for bite force determinations," *Dental Materials*, vol. 19, no. 2, pp. 118–126, 2003.

[39] F. B. Teixeira, L. de Melo Pereira Fernandes, P. A. T. Noronha et al., "Masticatory deficiency as a risk factor for cognitive dysfunction," *International Journal of Medical Sciences*, vol. 11, no. 2, pp. 209–214, 2014.

[40] K. Ikebe, Y. Gondo, K. Kamide et al., "Occlusal force is correlated with cognitive function directly as well as indirectly via food intake in community-dwelling older Japanese: from the SONIC study," *PLoS One*, vol. 13, no. 1, Article ID 0190741, 2018.

[41] D. Flanagan, "Bite force and dental implant treatment: a short review," *Medical Devices: Evidence and Research*, vol. 10, pp. 141–148, 2017.

[42] E. M. Kogawa, P. S. Calderon, J. R. P. Lauris, C. R. P. Araujo, and P. C. R. Conti, "Evaluation of maximal bite force in temporomandibular disorders patients," *Journal of Oral Rehabilitation*, vol. 33, no. 8, pp. 559–565, 2006.

[43] J. W. Kleinfelder and K. Ludwig, "Maximal bite force in patients with reduced periodontal tissue support with and without splinting," *Journal of Periodontology*, vol. 73, no. 10, pp. 1184–1187, 2002.

[44] F. Mongini, "Remodelling of the mandibular condyle in the adult and its relationship to the condition of the dental arches," *Cells Tissues Organs*, vol. 82, no. 3, pp. 437–453, 1972.

[45] F. Mongini, "Dental abrasion as a factor in remodeling of the mandibular condyle," *Cells Tissues Organs*, vol. 92, no. 2, pp. 292–300, 1975.