Journal of Orthopedics Research and Rehabilitation

Original Article

DOI: 10.51271/JORR-0027

Evaluation of cranio-cervical muscle activity in adolescents with different malocclusions: a pilot surface EMG study

Refik Hilmi Barış[1], Nevin Atalay Güzel[1], Nihan Kafa[1], Sonay Gürühan[1], Mehmet Okan Akçam[2]

[1]Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Gazi University, Ankara, Turkiye
[2]Department of Orthodontics, Faculty of Dentistry, University of Ankara, Ankara, Turkiye

Received: 02/02/2024 • Accepted: 31/03/2024 • Published: 26/04/2024

Corresponding Author: Refik Hilmi Barış, r.hilmibaris@gmail.com

ABSTRACT

Aims: This study aimed to investigate potential differences in cranio-cervical muscular activation among adolescents with different types of malocclusion.

Methods: This study involved thirty-two adolescents aged 10-15 years, categorized into three groups based on angle classification: angle class I/control group (n=10), angle class II (n=12), and angle class III (n=10). Surface electromyography (EMG) was utilized to evaluate the activation levels of the masseter, temporalis anterior, cervical erector spinae, sternocleidomastoid, and upper trapezius (UT) muscles. Measurements were obtained during mandibular rest, maximum clenching, and chewing tasks.

Results: The surface EMG activity of the UT muscle exhibited significant elevation in participants with class III malocclusions relative to the other groups ($p<0.05$). While cranio-cervical muscle activities tended to be higher in the groups of angle class II and class III in comparison to the angle class I, these differences did not achieve statistical significance, with the exception of the UT muscle ($p>0.05$).

Conclusion: These findings indicate a link between malocclusion types and modified muscle activation patterns in the cranio-cervical region, specifically involving the UT muscle. Insights into cranio-cervical muscle activity can enhance the comprehensive evaluation of malocclusion effects and provide valuable guidance for orthodontic and rehabilitation interventions.

Keywords: Craniocervical, adolescents, muscle activity, EMG, malocclusion

INTRODUCTION

The stomatognathic system, which encompasses the teeth, jaws, masticatory muscles, and associated soft tissues, plays a crucial role in essential functions such as speech, swallowing, and harmonious chewing.[1] However, dysfunctions within this system can lead to occlusal problems, particularly during adolescence, a period marked by rapid bodily growth and changes.[2,3]

Malocclusion refers to an abnormality in the alignment of the teeth and jaws, encompassing dental disorders and skeletal disharmony.[3,4] The classification system for occlusions, introduced in 1889 by Dr. Edward H. angle, categorizes the interrelationship between the maxillary and mandibular dental arches into three distinct classes. Angle class I represents a normal occlusion, where the upper and lower dental arches exhibit a proper alignment, particularly in the interrelationship between the molars. Specifically, the mesiobuccal cusp of the upper first molar aligns with the buccal groove of the lower first molar, indicating an ideal occlusal relationship. It should be noted that minor deviations or discrepancies in other teeth, excluding the molars, may still be considered within the normal range. However, the classification criteria primarily rely on the alignment of the molars as the defining factor for angle class I occlusion. Angle class II refers to a condition where the upper first molar occludes anteriorly to the lower first molar, while angle class III indicates a situation where the upper first molar occludes posteriorly to the lower first molar.[5]

In the field of orthodontics, understanding the classification of malocclusions is crucial for assessing and treating occlusal abnormalities. The angle classification system provides a standardized framework to describe and differentiate various occlusal relationships. By identifying the specific class of malocclusion, orthodontic professionals can tailor their treatment plans accordingly, aiming to achieve proper alignment and functional occlusion.

Cite this article: Barış RH, Atalay Güzel N, Kafa N, Gürühan S, Akçam MO. Evaluation of cranio-cervical muscle activity in adolescents with different malocclusions: a pilot surface EMG study. *J Orthop Res Rehabil.* 2024;2(2):22-26.

Numerous studies have focused on the potential effects of different malocclusion types. Various malocclusions can result in distinct muscle activities, which may exacerbate occlusal problems or interfere with the treatment process.[6] Consequently, electromyography (EMG) has been employed in several studies to examine muscle activities associated with different malocclusions.[7-9] However, these studies have predominantly focused on assessing the activities of masticatory muscles. Considering the potential interplay between dentofacial deformities and the musculature of the neck region, it is beneficial to assess the entire craniocervical region. Hence, the main aim of the current research was to explore and analyze the craniocervical muscle activity across different malocclusion types utilizing surface EMG techniques.

METHODS

Participants

The sample for this preliminary investigation comprised a total of thirty-two adolescent individuals who were recruited from those seeking orthodontic treatment at the Department of Orthodontics, Faculty of Dental Medicine, Ankara University. The subjects were recruited from a pool of applicants within a specific timeframe, meeting the predetermined inclusion criteria. The surface EMG analysis was conducted at a physiotherapy and rehabilitation clinic located within the Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Gazi University. Prior to the study, a participant's agreement was obtained from each participant and his or her legal guardians, and the research ethics committee granted ethical approval (Date: 11.01.2019, Decision No: 77092166-302.08.01-4715). The study adhered to the ethical guidelines for human experimentation and followed the 2013 edition of the Declaration of Helsinki.

Inclusion criteria stipulated that participants should be adolescents presenting with orthodontic craniofacial anomalies, while possessing normal vertical facial dimension values. Exclusion criteria entailed individuals with congenital tooth agenesis, hereditary or inborn craniofacial abnormalities, temporomandibular joint dysfunctions, prior orthodontic intervention history, surgical procedures involving the upper body, persistent pain limiting activity, scoliosis, and systemic disorders. Additionally, as part of the inclusion criteria, participants were required to exhibit no neck pain or limitations in joint range of motion during the evaluation process. The participants were allocated into three distinct groups (angle class I: 10 participants, angle class II: 12 participants, angle class III: 10 participants) based on cephalometric measurements.

Assessments

Surface EMG measurement: The Noraxon MiniDTS system (Noraxon U.S.A. Inc.) equipped with eight-channel surface EMG was utilized for data collection in this study. Disposable self-adhesive Ag/AgCl electrodes with a width of one centimeter (Noraxon Dual EMG Electrode) were employed to capture the EMG signals. The system demonstrated a differential input impedance exceeding 10 Mohm, while the sampling rate ranged from 1500 to 3000 Hz per channel. Moreover, the common-mode rejection ratio exceeded 80 dB, ensuring robust signal quality. Prior to electrode placement, the skin surface was meticulously cleansed with alcohol to minimize skin-electrode impedance. Subsequently, the surface electrodes were carefully positioned on the targeted muscles following the guidelines outlined in the European Recommendations for Surface Electromyography (SENIAM).[10]

The placement of electrodes for muscle assessment was as follows:

Sternocleidomastoid (SCM): The electrodes were bilateral positioned at a location approximately one-third of the distance between the sternal notch and the mastoid process. It was placed in a parallel orientation over the muscle belly.[11]

Cervical erector spinae (CES): The electrodes were bilateral placed laterally, 2 cm away from the C4 spinous process.[12]

Upper trapezius (UT): The electrodes were bilateral positioned laterally to the midpoint of an imaginary line formed by the posterior aspect of the acromion and the spinous process of C7.[12]

Previous studies[13-15] did not report any significant difference between the right and left anterior temporalis (AT) and masseter (MS) muscle activities. Therefore, the AT and MS muscles were evaluated unilaterally, specifically on the right side, by positioning the electrode on the belly of the muscles and parallel to the direction of the muscle f ibers. By employing this methodology, the utilization of an 8-channel surface EMG system enabled the investigation and assessment of a broader range of muscles, thereby facilitating the examination of a greater diversity of muscle activities.

The acquired EMG data were processed utilizing the Noraxon MyoResearch XP Master Edition software (Noraxon USA Inc). In the preprocessing stage, the raw EMG signals underwent rectification and band-pass filtering within the frequency range of 20-500 Hz. Subsequently, the signals were subjected to a root-mean-square moving-window function with a time constant of 100 ms to achieve smoothing. In order to normalize the surface EMG data, reference activation signals were recorded, while the participants engaged in maximal voluntary isometric contraction (MVC) trials lasting for 5 seconds in the manual muscle testing positions for the SCM, UT, and CES muscles. For the normalization of the AT and MS muscle data, signals were captured during a 5-second maximum voluntary teeth clenching maneuver, while bilateral interposition of two cotton rolls occurred between the second mandibular premolars and first molars.[14] A resting period of 3 minutes was allowed between each MVC trial. The recorded values corresponded to the average of three successful repetitions, and the median value obtained during the 5-second trial at the 3rd second was selected for further analysis.

Surface EMG data were obtained across four distinct conditions: I) the mandibular resting position while in a seated posture, II) the mandibular resting position while in a standing posture, III) during chewing while in a seated position, and IV) during maximum teeth clenching while in a seated position.

Sitting position: Each participant assumed a comfortable seated posture on a chair while maintaining their habitual position, fixing their gaze straight ahead, and refraining from any mandibular, head, or body movements during the data collection. Three 10-second recordings were conducted.

Standing position: Participants were instructed to stand in a relaxed and comfortable manner with their arms by their sides, maintaining a forward gaze without any mandibular, head, or body movements throughout the recording. Three 10-second recordings were performed.

Chewing position: Prior to the chewing recordings, participants were provided with a medium soft, sugar-free gum and asked to chew it for two minutes to soften the gum. Following a one-minute rest period, participants were instructed to chew the gum using their normal chewing pattern, and three 10-second recordings were obtained while in a seated position.

Maximum teeth clench: Bilateral placement of cotton rolls between the second mandibular premolars and first molars was performed. Subsequently, participants were instructed to perform a maximum teeth clenching action for five seconds while in a seated position. This procedure was repeated three times.

A two-minute resting interval was allowed between each of the four recording positions to prevent potential fatigue.

Statistical Analysis

The data analysis was conducted using the Statistical Package for Social Sciences (SPSS; 22.0, Chicago, USA). The normal distribution of the data was examined using the ShapiroWilk test and visualization of histograms. Descriptive statistics were presented as medians and interquartile ranges (IQR 25/75). The gender data was subjected to chi-square test for comparison. To analyze the differences among the three groups, Kruskal-Wallis analysis was performed, and post-hoc pairwise comparisons were performed if significant differences were observed. Statistical significance was determined as $p<0.05$ for the chi-square and Kruskal-Wallis analyses. Post-hoc comparisons were conducted using MannWhitney U test, and a significant level of $p<0.017$ was applied after adjusting for multiple comparisons using the Bonferroni correction.

RESULTS

The mean age of the participants was 12.47±1.74 years, and the mean body mass index (BMI) was 18.37±3.44 kg/m^2. Comprehensive details regarding the participants characteristics are provided in Table 1. There were no statistically significant differences observed between the groups in terms of gender, age, and BMI ($p>0.05$). The surface EMG activities recorded under the four different conditions are summarized in Table 2. The surface EMG activity of the cervical muscles is illustrated in Figures 1-4. The EMG activity of the UT muscle was significantly higher in the angle class III group relative to the other two groups in all positions ($p<0.05$, Table 2).

Table 1. Physical characteristics of the groups

	Angle class I	Angle class II	Angle class III	p*
	Median (IQR 25/75)	Median (IQR 25/75)	Median (IQR 25/75)	
Age (years)	12.50	12.00	13.00	0.997
BMI (kg/m^2)	18.40 (16.32/20.25)	16.65 (14.85/19.77)	18.60 (15.65/22.62)	0.652

*: Kruskal-Wallis analysis, IQR 25/75: The interquartile range 25/75, BMI: Body mass index, $p<0.05$.

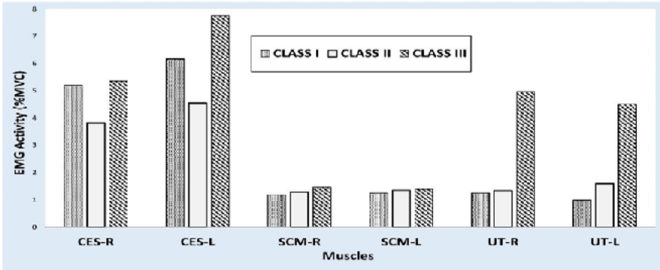

Figure 1. SEMG activity of cervical muscles at mandibular rest position during standing

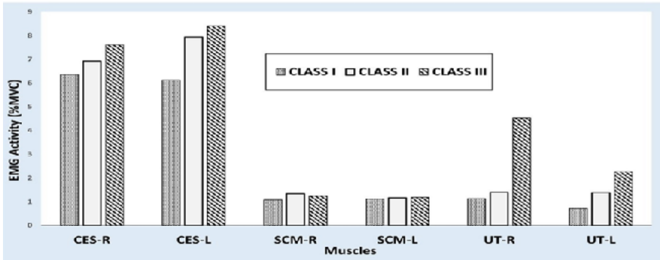

Figure 2. SEMG activity of cervical muscles at mandibular rest position during sitting

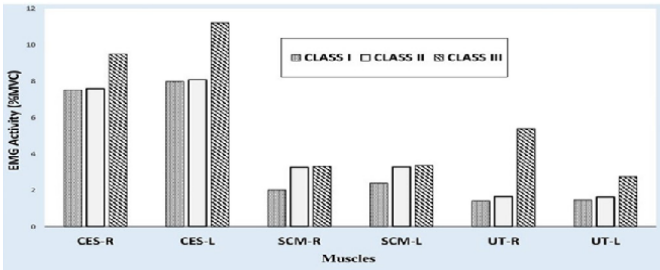

Figure 3. SEMG activity of cervical muscles during chewing

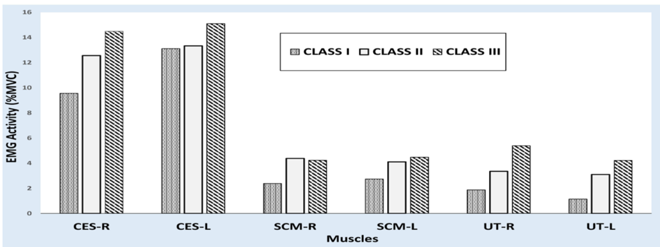

Figure 4. SEMG activity of cervical muscles during maximum teeth clenching

When pairwise comparisons were considered, the analysis revealed that the activation values of the UT muscle were significantly higher in the class III group compared to the class I group ($p<0.017$); however, no statistically significant differences were found between the class I and class II groups ($p>0.017$), or between the class II and class III groups ($p>0.017$)(Table 2).

Table 2. Muscle activities of the muscles in groups

		Mandibular rest at sitting median (IQR 25/75)				Mandibular rest at sitting median (IQR 25/75)				Chewing median (IQR 25/75)				Maximum teeth clench median (IQR 25/75)			
		Class I	Class II	Class III	p*	Class I	Class II	Class III	p*	Class I	Class II	Class III	p*	Class I	Class II	Class III	p*
CES	R	6.35 (3.90/8.90)	6.92 (3.37/10.13)	7.60 (3.62/18.16)	0.694	5.19 (2.73/7.82)	3.82 (2.50/8.81)	5.35 (2.85/20.70)	0.694	7.51 (4.75/10.71)	7.59 (4.70/12.28)	9.50 (3.96/18.14)	0.848	9.55 (6.36/14.42)	12.55 (5.53/19.19)	14.48 (8.62/30.56)	0.212
	L	6.12 (3.93/8.58)	7.94 (4.00/12.04)	8.41 (4.20/12.80)	0.693	6.16 (2.53/9.22)	4.54 (3.22/14.59)	7.75 (3.27/13.50)	0.823	7.98 (6.47/11.02)	8.08 (5.69/16.46)	11.21 (6.59/14.82)	0.665	13.10 (8.12/24.34)	13.33 (8.29/19.86)	15.09 (12.24/18.54)	0.709
SCM	R	1.08 (0.90/1.66)	1.33 (0.87/2.20)	1.24 (0.97/1.80)	0.644	1.17 (0.95/1.66)	1.27 (0.87/2.54)	1.45 (1.05/1.79)	0.809	2.01 (1.37/2.72)	3.26 (2.46/3.67)	3.31 (1.82/4.83)	0.127	2.83 (1.62/6.34)	4.37 (2.68/5.99)	4.22 (2.75/6.39)	0.520
	L	1.12 (0.77/1.54)	1.16 (0.89/1.48)	1.18 (0.93/1.83)	0.764	1.24 (0.97/1.77)	1.34 (0.79/1.83)	1.38 (1.08/1.69)	0.786	2.38 (1.73/3.22)	3.28 (2.07/4.17)	3.38 (2.11/3.99)	0.346	2.73 (2.14/5.09)	4.10 (2.32/5.61)	4.46 (2.33/6.40)	0.646
UT	R	1.13 (0.77/1.50)	1.39 (0.76/6.09)	4.52 (1.61/6.81)	0.049 p^1:0.418 p^2:0.004 p^3:0.314	1.24 (0.93/2.22)	1.33 (0.70/3.56)	4.96 (1.62/8.58)	0.027 p^1:0.923 p^2:0.009 p^3:0.036	1.42 (1.12/2.08)	1.64 (0.97/4.75)	5.39 (2.55/6.42)	0.028 p^1:0.456 p^2:0.005 p^3:0.093	1.87 (1.07/2.89)	3.35 (2.04/5.85)	5.38 (3.27/10.10)	0.008 p^1:0.036 p^2:0.004 p^3:0.140
	L	0.71 (0.55/0.92)	1.38 (0.45/5.98)	2.27 (1.51/4.36)	0.034 p^1:0.283 p^2:0.003 p^3:0.314	0.98 (0.49/1.5)	1.58 (0.57/4.70)	4.51 (1.71/9.58)	0.012 p^1:0.228 p^2:0.002 p^3:0.080	1.46 (1.12/1.87)	1.63 (0.70/4.85)	2.74 (1.81/5.94)	0.084	1.14 (0.82/2.47)	3.09 (1.42/6.71)	4.21 (1.93/8.61)	0.019 p1:0.017 p^2:0.015 p^3:0.539
MS		1.84 (1.00/2.62)	1.19 (0.99/2.15)	1.53 (0.89/2.13)	0.413	1.7 (1.00/1.95)	1.22 (0.98/1.67)	1.57 (0.87/2.14)	0.517	30.96 (24.03/40.48)	33.13 (21.81/43.53)	36.99 (26.21/50.88)	0.616	136.83 (123.00/261.66)	206.16 (168.33/278.25)	165.50 (129.90/282.25)	0.342
TEMPORALIS		3.68 (2.27/5.20)	2.77 (2.08/3.73)	5.12 (2.95/7.18)	0.205	3.35 (2.23/4.34)	2.65 (1.81/3.87)	4.43 (3.09/5.48)	0.245	35.63 (28.71/44.81)	40.45 (22.29/57.18)	37.40 (26.94/43.49)	0.861	122.00 (94.39/144.08)	135.33 (98.76/179.00)	112.53 (74.65/144.75)	0.430

*: Kruskal-Wallis analysis, IQR 25/75: The interquartile range 25/75, R: right, L: left, p < 0.p1: class I, class II, p2: class I, class III, p3: class II, class III, p1-3<0.01

DISCUSSION

The main aim of the current research was to ascertain potential disparities in craniocervical muscle activities among adolescents exhibiting various types of malocclusions. The findings of our investigation revealed a statistically significant elevation in the UT muscle activity among adolescents diagnosed with angle class III malocclusion relative to those with angle class I and class II malocclusions across diverse actions. This finding suggests that craniocervical muscle activity may vary depending on the malocclusion type.

According to available information, this research represents a pioneering investigation that offers a comprehensive evaluation encompassing both the jaw muscles and the musculature of the neck region in adolescents presenting with malocclusions. Prior research endeavors have predominantly concentrated on assessing the muscle activities specific to the jaw region, particularly the MS and AT muscles.[9] Nevertheless, it is essential to recognize the functional interrelationships that exist among the masticatory, neck, and trunk muscles, owing to the reciprocal innervation mediated by the trigeminal nerve and cervical nerves.[16] Therefore, in order to achieve a thorough evaluation, it becomes imperative to examine not only the masticatory muscles but also the musculature within the craniocervical region. This holistic approach allows for a more comprehensive understanding of the neuromuscular dynamics associated with malocclusions in adolescents.

The existing literature exploring the muscle activity of masticatory muscles in various malocclusion types has generated divergent outcomes.[6,8,13,17] Nevertheless, majorities of studies have reported an increased masticatory muscle activity in individuals with angle class II or angle class III malocclusions relative to those with angle class I malocclusions.[8,13,17] In line with these findings, our investigation demonstrated that participants with angle class II or angle class III malocclusions exhibited heightened activation of masticatory muscles, particularly during mastication and maximum voluntary clenching. The outcomes obtained in this study are in line with previous investigations, indicating increased activation of masticatory muscles in individuals with specific malocclusion types. These results contribute to our understanding of the relationship between malocclusion and heightened engagement of the masticatory muscles.

A study conducted by Tecco et al.[15] in adult females showed similar results to our study. Their study revealed significantly higher EMG activities in the posterior cervical and UT muscles among participants with angle class III malocclusion, in contrast to the other two groups. However, in our study, the statistically significant difference was only observed in the UT muscle. The divergence in results may be attributed to variations in the age composition of the study populations and the duration of malocclusion. Previous studies have reported that angle class II and angle class III malocclusions could contribute to craniocervical postural maladaptations when compared to angle class I malocclusions.[3,18,19] Therefore, prolonged periods of malocclusion may exert an influence on muscle activity and potentially impact posture. It is plausible that the prolonged duration of malocclusion affects muscle activity, which in turn may have implications for cranio-cervical postural adaptations. These findings suggest that individuals with angle class II and angle class III malocclusions may be more prone to experiencing postural changes in the cranio-cervical region relative to those with angle class I malocclusions.

The SCM muscle plays a crucial role in maintaining optimal head and neck posture. Previous research has shown that SCM muscle activation is altered, particularly in individuals with forward head posture.[20] However, there is limited literature investigating the activity of the SCM muscle in relation to occlusal problems.[7,21] Bergamini et al.[7] suggested that achieving occlusal balance may have a positive impact on SCM muscle activity. Ferrario et al.,[21] on the other hand, reported that complete or partial angle class I dental relationships did not significantly affect the muscle activities of the MS, temporalis, and SCM muscles. In contrast, even in the absence of statistically significant differences, our study found that participants with angle class II and angle class III malocclusions exhibited higher SCM muscle activity relative to those with angle class I malocclusion. Considering the association between SCM muscle and forward head posture, our findings suggest that class II and class III malocclusions may be more prone to forward head posture.

Although statistically significant differences were not observed, the present study uncovered higher CES muscle activities in individuals with angle class II or angle class III malocclusions. This observation implies that occlusal abnormalities may exert an influence not only on muscle activation within the jaw region but also in other regions of the cranio-cervical complex. The observed increase in CES muscle activities among individuals with class II and class III malocclusions may indicate compensatory mechanisms or adaptations to accommodate occlusal discrepancies. These findings suggest that the neuromuscular system undergoes adjustments in response to malocclusion, potentially influencing muscle activation patterns. Additionally, these findings raise interesting questions regarding the potential interplay between occlusal factors and the neuromuscular system beyond the scope of mastication. Understanding the broader implications of occlusal defects on muscle activity may provide valuable insights for orthodontic intervention strategies.

Limitations

The primary limitation encountered in this research was the limited sample size, which led us to consider it as a pilot study. Conducting future studies with a similar design and a larger number of participants would enable us to draw more definitive conclusions. Additionally, owing to the restricted participant pool, potential gender-based variations were not examined in this study. Further studies focusing on normalizing higher muscle activity through various approaches such as exercise and physiotherapy methods may provide further insights into this issue.

CONCLUSION

Our findings indicate a statistically significant increase in UT muscle activation in diverse positions among adolescents diagnosed with angle class III malocclusion. This highlights the potential role of the UT muscle in the cranio-cervical muscle activity of individuals with malocclusions. These findings support the notion that adolescents with angle class II and class III malocclusions may exhibit increased activation of craniocervical muscles relative to those with angle class I malocclusion. This suggests the presence of potential neuromuscular adaptations in response to malocclusion severity. It would be beneficial for future studies to examine muscle activations in the cranio-cervical region during different activities to gain a comprehensive understanding of the effects of malocclusion.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of Ethical Committee of Gazi University (Date: 11.01.2019, Decision No: 77092166-302.08.01-4715).

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation

Process Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The Authors declare that they have no known competing financial interests or personal relationships that could have appeared the work reported in this paper.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that theyave approved the final version.

REFERENCES

1. Cuccia A, Caradonna C. The relationship between the stomatognathic system and body posture. *Clinics*. 2009;64(1):61-66.
2. Carini F, Mazzola M, Fici C, et al. Posture and posturology, anatomical and physiological profiles: overview and current state of art. *Acta Biomed*. 2017;28;88(1):11-16.
3. Michelotti A, Buonocore G, Manzo P, Pellegrino G, Farella M. Dental occlusion and posture: an overview. Prog Orthod. 2011;12(1):53-58.
4. Hassan R, Rahimah A. Occlusion, malocclusion and method of measurements-an overview. *Arch Orofac Sci*. 2007;2:3-9.
5. Gravely J, Johnson D. Angle's classification of malocclusion: an assessment of reliability. *Br J Orthod*. 1974;1(3):79-86.
6. Nishi SE, Basri R, Alam MK, et al. Evaluation of masticatory muscles function in different malocclusion cases using surface electromyography. *J Hard Tissue Biol*. 2017;26(1):23-28.
7. Bergamini M, Pierleoni F, Gizdulich A, Bergamini C. Dental occlusion and body posture: a surface *EMG study*. CRANIO® 2008;26(1):25-32.
8. Moreno I, Sanchez T, Ardizone I, Aneiros F, Celemin A. Electromyographic comparisons between clenching, swallowing and chewing in jaw muscles with varying occlusal parameters. *Med Oral Patol Oral Cir Bucal*.2008;13(3):207.
9. WoŶniak K, Piątkowska D, Lipski M, Mehr K. Surface electromyography in orthodontics–a literature review. *Med Sci Monit*. 2013;19:416-423.
10. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol*. 2000;10(5):361-374.
11. Sommerich CM, Joines SM, Hermans V, Moon SD. Use of surface electromyography to estimate neck muscle activity. *J Electromyogr Kinesiol*. 2000;10(6):377-398.
12. Burnett A, O'Sullivan P, Caneiro JP, Krug R, Bochmann F, Helgestad GW. An examination of the flexion-relaxation phenomenon in the cervical spine in lumbo-pelvic sitting. *J Electromyogr Kinesiol*. 2009;19(4):e229-e236.
13. Gadotti I, Berzin F, Biasotto-Gonzalez D. Preliminary rapport on head posture and muscle activity in subjects with class I and II. *J Oral Rehabil*. 2005;32(11):794-799.
14. Mapelli A, Tartaglia GM, Connelly ST, Ferrario VF, De Felicio CM, Sforza C. Normalizing surface electromyographic measures of the masticatory muscles: comparison of two different methods for clinical purpose. *J Electromyogr Kinesiol*. 2016;30:238-242.
15. Tecco S, Caputi S, Festa F. Electromyographic activity of masticatory, neck and trunk muscles of subjects with different skeletal facial morphology–a cross-sectional evaluation. *J Oral Rehabil*. 2007;34(7):478-486.
16. Tecco S, Tetè S, Festa F. Electromyographic evaluation of masticatory, neck, and trunk muscle activity in patients with posterior crossbites. *Eur J Orthod*. 2010;32(6):747-752.
17. Miralles R, Hevia R, Contreras L, Carvajal R, Bull R, Manns A. Patterns of electromyographic activity in subjects with different skeletal facial types. *Angle Orthod*. 1991;61(4):277-284.
18. D'Attilio M, Caputi S, Epifania E, Festa F, Tecco S. Evaluation of cervical posture of children in skeletal class I, II, and III. *CRANIO®* 2005;23(3):219-228.
19. Manfredini D, Castroflorio T, Perinetti G, Guarda-Nardini L. Dental occlusion, body posture and temporomandibular disorders: where we are now and where we are heading for. *J Oral Rehabil*. 2012;39(6):463471.
20. Kim MS. Neck kinematics and sternocleidomastoid muscle activation during neck rotation in subjects with forward head posture. *J Phys Ther Sci*. 2015;27(11):3425-3428.
21. Ferrario V, Tartaglia G, Galletta A, Grassi GP, Sforza C. The influence of occlusion on jaw and neck muscle activity: a surface EMG study in healthy young adults. *J Oral Rehabil*. 2006;33(5):341-348.