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RESEARCH

Long-term evaluation of masseter muscle activity, dimensions, and elasticity after orthognathic surgery in skeletal class III patients

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Abstract

Objective To evaluate changes in the masseter muscle after orthognathic surgery using electromyography (EMG), ultrasonography (US), and ultrasound elastography (USE) in individuals with skeletal class III anomaly over long-term follow-up and compare with a control group.

Materials and methods The study group included 29 patients with class III dentofacial deformities scheduled to undergo orthodontic treatment and orthognathic surgery. The control group included 20 individuals with dental class I occlusion. Assessment of the masseter muscles using EMG, US, and USE was performed before orthognathic surgery (T1) and at postoperative 3 months (T2) and 1 year (T3) in the study group, and at a single time point in the control group. All assessments were performed at rest and during maximum clenching. Masseter muscle activity, dimension, and hardness were analyzed.

Results Electromyographic activity of the masseter muscle during maximum clenching was increased at postoperative 1 year but did not reach control group values. On ultrasonography, the masseter muscle showed minimal changes in dimension at postoperative 1 year compared to preoperative values and remained below control group values. The postoperative increase in masseter muscle hardness at rest and during maximum clenching persisted at postoperative 1 year.

Conclusion The results of this study suggest that after orthognathic surgery, additional interventions and much longer follow-up are needed to ensure better muscle adaptation to the new occlusion and skeletal morphology.

Clinical relevance All assessment methods are useful for comprehensively evaluating changes in the masticatory muscles after orthognathic surgery.

Keywords Electromyography · Masseter muscle · Orthognathic surgery · Ultrasonography · Ultrasound elastography

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Introduction

Skeletal class III deformity can present with different combinations of craniofacial structures. These anomalies can involve mandibular prognathism or maxillary retrognathism alone or a combination of the two [1]. Dentofacial deformities are known to have an impact on orofacial function, and many individuals have poor masticatory function and impaired nutrition because of malocclusion. Despite the body's compensatory mechanisms, speech is affected, and dysfunction may occur in the temporomandibular joint [2]. Orthognathic surgery leads to not only esthetic improvement in these individuals but also functional changes.

Studies on the efficacy of orthognathic surgery on masticatory function in class III individuals have analyzed muscle activity [3–6], masticatory efficiency [3, 7], bite strength [7], occlusal contacts [7], mandibular movements [8, 9], and morphology of the main masticatory muscles [10].

Electromyography (EMG) is commonly used to evaluate changes in masticatory muscle activity. As many muscles in the craniofacial region are superficial, the data obtained by EMG are reported to be reliable [11, 12]. Studies using EMG to examine changes in muscle activity after orthognathic surgery have shown that muscle activity generally increased [3, 5, 6] or remained stable [4].

Ultrasonography (US) enables the examination of superficial tissues in the oral and maxillofacial regions without exposure to ionizing radiation. Muscle length, thickness, cross-sectional area, and volume measurements can be made with this method. However, the view is limited by the area of the probe sensor, and it does not allow visualization of the entire organ [13–16]. One study indicated that muscle thicknesses measured by US and magnetic resonance imaging were significantly correlated and that US had high repeatability [15]. There are studies in the literature evaluating masseter muscle thickness by US [16–19] and muscle morphology, thickness, and cross-sectional area by computed tomography [11, 20] after orthognathic surgery.

Ultrasound elastography (USE) is a more recent method used to evaluate muscle hardness over a large area. It was observed that this technique could be used to assess the elasticity of the masseter muscle, one of the masticatory muscles. The elasticity index (EI) ratio was shown to be a reliable indicator of muscle hardness [21]. However, there are no studies in the literature evaluating long-term changes in the hardness of the masticatory muscles after orthognathic surgery.

This study aimed to evaluate the masseter muscle, the primary muscle responsible for masticatory function, in skeletal class III individuals after orthognathic surgery using EMG, US, and USE over long-term follow-up and compare with a class I control group.

Materials and methods

The research protocol was approved by the Ankara University Faculty of Dentistry Ethics Committee (36290600/74). All individuals were informed about the study objective, procedures and signed an informed consent form.

Twenty-nine individuals with class III dentofacial deformity (SNA: 80.30° ± 3.10°, SNB: 84.10° ± 3.70°, ANB: −3.80° ± 2.60°, GoGN/SN: 33.30° ± 4.90°) who were candidates for orthodontic-orthognathic surgical treatment were selected. The study group included 19 female and 10 male patients with a mean age of 20.37 ± 2.19 years. The selection criteria were:

- No craniofacial anomaly or cleft lip/palate
- No prior history of orthodontic/orthognathic surgery
- No missing incisors or canines
- A maximum of one missing posterior tooth
- No severe jaw asymmetry (mandibular deviation less than 4°)

All participants in the study group were treated using the same orthodontic treatment protocol, which included alignment of the dental arches and dental decompensation. To correct the dentofacial deformity, bimaxillary surgery (mean 2.27 mm maxillary impaction, 3.43 mm advancement; mean 4.44 mm mandibular set-back) was planned for 22 patients and mandibular set-back surgery (mean 3.91 mm set-back) was planned for 7 patients.

The control group included 20 patients (11 female and 9 male) with class I occlusion and a mean age of 23.60 ± 1.50 years. The selection criteria for the control group were:

- Angle class I occlusion and balanced facial profile
- No temporomandibular joint disorder or bruxism
- No prior history of orthodontic/orthognathic surgery
- No anterior or posterior crossbite
- No prosthetic restorations
- No missing teeth except for third molars

Assessment of masseter muscle activity by EMG, muscle dimensions by US, and muscle elasticity by USE was performed in the study group before orthognathic surgery (T1), at postoperative 3 months (T2), and at postoperative 1 year (T3). All measurements were obtained at a single time point in the control group.

Electromyography

Electromyography records were obtained using the BioPak BioEMG II (BioResearch Associates Inc., Milwaukee, USA) and SKINTACT® FS-RG1/10 ECG (Ag/AgCl/Solid) surface electrodes trimmed to a size of 20 × 20 mm. The skin was cleaned with alcohol before placing the electrodes. The masseter muscles were palpated during maximum jaw clenching and the electrodes were placed parallel to the muscle fibers. The ground electrode was placed over the trapezius muscle.

Records of the masseter muscle were obtained at rest and during maximum clenching. Each recording lasted 10 s and was repeated 3 times. At rest, the participants were asked to sit comfortably in a natural upright position and relax their jaws. During maximum clenching, the individuals were asked to clench their teeth as hard as possible and not swallow. To avoid the effect of muscle fatigue on the measurements, three 2-s intervals were selected on the 10-s recordings and the average activity of the first 6 s was calculated. The mean values of the three measurements taken during resting and maximum clenching were calculated.

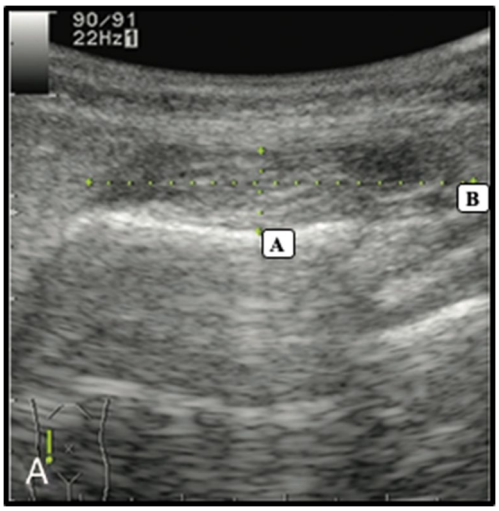

Fig. 1 Thickness (**A**) and width (**B**) measurements of masseter muscle on ultrasonography

Ultrasonography

US images were obtained using the ProSound Alpha 6 (Hitachi-Aloka Medical, Tokyo, Japan). The masseter muscle was imaged during rest and maximum clenching with the patient sitting comfortably upright with head in a neutral position.

Transverse images of the masseter muscle were obtained using a 3–5 MHz convex probe by positioning the probe perpendicular to the skin surface at the level of the occlusal plane, between the lower border of the zygomatic arch and the mandibular ramus. Medial thickness and width measurements were obtained (Fig. 1). All imaging and measurements were performed by the same radiologist.

Ultrasound elastography

USE records were obtained with an ACUSON S 2000 (Siemens, Munich, Germany) using the strain elastography measurement feature of the device and a 4–9 MHz linear probe. Records of the masseter muscle were taken at rest and during maximum clenching with the probe positioned as for US examination. All imaging and measurements were performed by the same radiologist (Fig. 2). The system defines a real-time quality factor (QF) to minimize movement artifacts while determining the EI of the tissues. As per the manufacturer's recommendation, images were obtained when the QF was 60 or higher. Elasticity index ratio (EIR) was defined as the EI of the relevant muscle divided by that of the subcutaneous adipose tissue. To

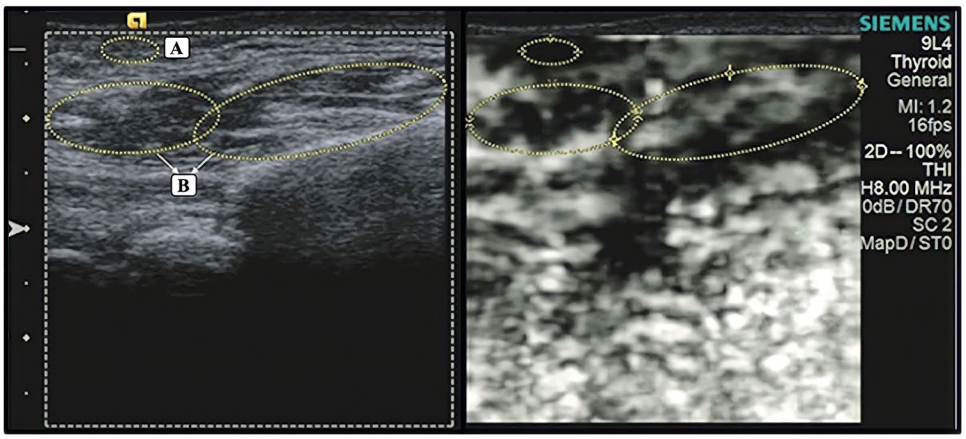

Fig. 2 Subcutaneous adipose tissue (**A**) and the elasticity index areas (**B**) of the masseter muscle on ultrasound elastography

minimize variability and obtain an EI value representing the whole muscle, the two largest areas of the muscle were selected, and the mean EI was calculated.

Statistical analysis

IBM SPSS version 21.0 package software was used for statistical analyses. The Shapiro-Wilk test was used to test the variables for normal distribution. As the data were non-normally distributed, the Mann-Whitney *U* test was used for comparisons. The Wilcoxon test was used to analyze the differences between the two dependent samples. Differences were considered statistically significant at $p < 0.05$.

Results

In this study, there were no significant differences in EMG, US, and USE measurements on the right and left sides, either at rest or during maximum clenching ($p > 0.05$). Therefore, statistical comparisons were done using the mean values of the two sides (Table 1).

Electromyographic activity of the masseter muscle during maximum clenching was significantly higher in the control

Table 1 Electromyographic (EMG) activity (μV), ultrasonographic thickness and width measurements (mm), and hardness (elasticity index ratio, EIR) of the right (R) and left (L) masseter muscles at rest and during maximum clenching (MC) in the study and control groups

		Study group (T1)			Study group (T2)			Study group (T3)			Control group		
		Mean	SD	*p*	Mean	SD	*p*	Mean	SD	*p*	Mean	SD	*p*
Rest EMG (μV)	R	2.33	0.69	0.715	2.38	1.17	0.963	2.03	0.43	0.216	2.35	0.89	0.978
	L	2.41	0.76		2.29	0.77		2.24	0.66		2.52	1.18	
MC EMG (μV)	R	76.90	42.97	0.957	71.76	53.12	0.913	111.34	63.44	0.544	132.13	63.19	0.168
	L	78.80	47.54		65.96	32.29		115.85	63.49		159.05	64.84	
Rest thickness (mm)	R	5.20	1.10	0.963	6.00	1.60	0.709	5.90	4.00	0.539	6.70	1.40	0.533
	L	5.20	1.40		5.70	1.50		5.70	3.30		6.50	1.60	
Rest width (mm)	R	41.09	2.57	0.744	40.26	2.40	0.301	40.34	32.80	0.994	46.20	2.46	0.745
	L	41.46	2.69		40.80	2.54		40.54	34.00		46.01	2.25	
MC thickness (mm)	R	8.40	1.90	0.944	8.90	1.90	0.841	9.00	5.50	0.964	10.30	2.00	0.818
	L	8.50	2.10		8.60	1.80		8.90	4.70		10.40	2.00	
MC width (mm)	R	34.90	2.30	0.335	34.30	2.80	0.111	34.50	25.50	0.957	39.30	2.60	0.756
	L	34.00	2.90		33.00	2.80		34.60	28.70		39.00	3.00	
Rest EIR	R	12.88	8.44	0.423	16.50	10.71	0.652	22.15	9.22	0.549	9.71	4.67	0.851
	L	11.56	9.10		13.11	5.35		20.62	8.67		11.91	3.27	
MC EIR	R	25.50	21.28	0.715	26.76	15.48	0.858	38.79	13.00	0.834	18.62	13.35	0.914
	L	21.59	16.32		25.44	13.38		39.40	13.90		18.37	13.13	

Table 2 Time-based comparisons of masseter muscle activity, thickness, width, and hardness (elasticity index ratio, EIR) values at rest and during maximum clenching (MC)

	Study group (T1)		Study group (T2)		Study group (T3)		Control group		T1-CG *p*	T2-CG *p*	T3-CG *p*	T1-T2 *p*	T1-T3 *p*	T2-T3 *p*
	Mean	SD	Mean	SD	Mean	SD	Mean	SD						
Rest EMG (μV)	2.37	1.57	2.33	0.82	2.14	0.48	2.43	1.01	0.654	0.737	0.576	–	–	–
MC EMG (μV)	77.85	43.52	68.86	41.31	113.6	61.46	145.9	61.84	**0.0001***	**0.0001***	**0.025***	0.395	**0.0001***	**0.0001***
Rest thickness (mm)	5.19	1.09	5.84	1.43	5.82	1.30	6.63	1.31	**0.0001***	0.061	**0.047***	**0.001***	**0.006***	0.789
Rest width (mm)	41.27	2.47	40.53	2.30	40.44	2.92	46.10	2.26	**0.0001***	**0.0001***	**0.0001***	–	–	–
MC thickness (mm)	8.49	1.85	8.74	1.74	8.97	2.04	10.38	1.96	**0.003***	**0.006***	**0.029***	–	–	–
MC width (mm)	34.41	2.30	33.64	2.38	34.53	3.46	39.29	2.61	**0.0001***	**0.0001***	**0.0001***	–	–	–
Rest EIR	12.22	7.62	14.80	7.14	21.39	8.03	10.81	6.00	0.855	**0.031***	**0.0001***	0.098	**0.0001***	**0.0001***
MC EIR	23.54	17.97	26.10	13.40	39.10	10.92	18.49	12.80	0.729	**0.017***	**0.0001***	0.127	**0.001***	**0.001***

* statistically significant

group than the study group at all time points ($p < 0.05$). In the study group, analysis of changes in activity during maximum clenching among the time points showed that masseter muscle activity was significantly higher at T3 compared to both T1 and T2 ($p < 0.05$) (Table 2).

US measurements of masseter muscle dimensions at rest showed that the control group had significantly greater thickness values at T1, T3, and width values at all time points compared to the study group ($p < 0.05$). The control group also had significantly greater masseter muscle thickness and width during maximum jaw clenching at all time points ($p < 0.05$). Within the study group, the thickness of the masseter muscle at rest increased significantly at T2 and T3 compared to T1 ($p < 0.05$) (Table 2).

EIR of the masseter muscle at rest and maximum jaw clenching was significantly higher in the study group than the control group at T2 and T3 ($p < 0.05$). Within the study group, EIR of the masseter muscle was significantly higher at T3 compared to T1 and T2 ($p < 0.05$) (Table 2).

Discussion

In the present study, resting masseter muscle activity showed no significant difference from the control group before orthognathic surgery (T1) or at postoperative 3 months (T2) and 1 year (T3). Activity during maximum clenching was increased at postoperative 1 year (T3) but remained lower than control group values.

Ko et al. examined changes in temporal and masseter muscle activity in individuals with skeletal class III deformity at postoperative 1 and 6 months compared to before orthognathic surgery [4]. As in our study, they reported no significant difference in resting muscle activity between the time points. During maximum clenching, masseter muscle activity was significantly decreased at postoperative 1 month and significantly increased at 6 months. This is consistent with the early and long-term findings in our study. However, the authors reported no significant difference between preoperative and postoperative 6-month values, whereas in our study masseter muscle activity during maximum clenching was significantly greater at postoperative 1 year compared to the preoperative value. This difference may be attributed to the longer postoperative follow-up in our study.

Trawitzki et al. evaluated activity changes in the masticatory muscles in individuals with skeletal class III deformity after interdisciplinary therapy (orthodontics-myofunctional-surgical treatment) [5]. At postoperative 6–9 months, they observed that masseter muscle activity increased but did not reach control group values. In our study, there was a nonsignificant decrease in masseter muscle activity at postoperative 3 months. As it was an interim observation, the short time of 3 months after the operation may explain this decrease in activity. In addition, the use of pre- and postoperative myofunctional therapy in the study by Trawitzki et al. may have contributed to a faster increase in muscle activity [5]. In another study by Trawitzki et al. with 3–3.67 years of follow-up after orthognathic surgery, electromyographic activity of the masseter muscle was found to increase and approach control group values in the long term [6]. These results are consistent with our results at postoperative 1 year (T3), which showed a long-term increase in activity that approached control group values.

Studies have indicated that masseter muscle thickness is the main muscle parameter determining facial morphology [14, 15]. Therefore, we performed US measurements of masseter muscle thickness and width. Although US has proven reliability and repeatability, the only disadvantage of the technique is that the probe cannot cover the entire cross-sectional area of the muscle [16–18]. Therefore, many researchers preferred to measure the medial thickness of the muscle, as in our study, rather than measuring the cross-sectional area.

As in our study, researchers have reported that masseter muscle thickness increases during maximum clenching compared to at rest [13, 14]. Masseter muscle width was also found to increase during rest compared to maximum clenching and the difference was significant.

Studies have evaluated masseter muscle thickness measured by US in patients with skeletal class III deformity treated using an interdisciplinary approach (orthodontics-myofunctional-surgical treatment). As in our study, thickness measurements were obtained at rest and during maximum clenching before and after orthognathic surgery, and significant differences in all parameters were observed between patients and controls preoperatively. The researchers reported that despite a significant increase in muscle thickness at 6–8 months of follow-up, the values did not reach control group values. In a study with a follow-up period of 3–3.67 years, masseter muscle thickness increased compared to the preoperative period, but only left masseter muscle thickness during maximum clenching was reported to reach control group values [16, 17].

Ueki et al. observed no change in masseter muscle cross-sectional area at 1 year after sagittal split ramus osteotomy in individuals with mandibular prognathism but reported increases in occlusal force and occlusal contact areas. They suggested that this may be because the masseter muscle had not yet adapted to the new occlusion and morphological changes during the follow-up period. They reported that adaptation may increase 2–3 years after the operation and that longer-term follow-up was needed. The authors also noted that the individuals did not receive any physical therapy postoperatively [20].

In their study of skeletal class III individuals undergoing bimaxillary surgery, Lee and Yu examined masseter muscle

morphology preoperatively and at postoperative 1 and 4 years [10]. Similar to our study, they observed that masseter muscle width values were significantly lower in the study group compared to the control group. They also reported that thickness measured during maximum clenching was lower in these patients compared to class I individuals. The researchers stated that their thickness and width values during maximum clenching were lower than those of controls in preoperative and postoperative 1-year measurements, while there was no significant difference at postoperative 4 years. In our study, it was observed that although masseter muscle measurements during contraction increased, the differences were not significant, and the values remained lower than the control group at postoperative 1 year.

In another study, Coclici et al. evaluated the early and long-term postoperative dimensional changes after orthognathic surgery of the masseter and suprahyoid muscles in class II and III malocclusion. The length, width, and cross-sectional area of the muscles were ultrasonographically examined in a relaxed position before the operation, 1 month, and 9 months after the operation. The researchers reported that the early and long-term postoperative dimensional changes of the masseter muscle were not statistically significant in class II and III patients. The suprahyoid muscles showed a significant dimensional change in class II patients within 9 months after surgery [19]. As in our study, the mandibular muscles showed a variable adaptive response to orthognathic surgery.

We also observed a significant difference in resting masseter muscle thickness between preoperative and postoperative measurements. The increase in thickness after surgery may be a result of significant differences in muscle thickness due to the more posterior position of the mandible postoperatively.

Facial edema occurring after orthognathic surgery was reported to decrease by 50% within the first 3 weeks, by approximately 80% at 3 months, and resolve almost completely within 6–12 months postoperatively [22]. Edema caused by orthognathic surgery increases the water content of the soft tissues and muscles. As the muscle is covered with a thick fascia, the increased water content can be expected to result in increased intramuscular pressure and muscle hardness [21]. In our review of the literature, we did not find many studies evaluating changes in muscle hardness after orthognathic surgery. Sunal Aktürk et al. performed USE measurements 3 months after orthognathic surgery and reported an increase in masseter muscle hardness. The researchers argued that this change may be due to postoperative edema and that long-term follow-up is necessary [18]. In our study, we also noted that the increase in muscle hardness after orthognathic surgery persisted in long-term follow-up and was significant compared to the control group.

In the literature, it has been observed that deformities requiring orthognathic surgery are frequently associated with temporomandibular joint pathologies [23]. Oral parafunctional habits are an important factor in the etiology of these pathologies [24]. We think that the increase in muscle activity after orthognathic surgery and the increase in the force applied to the jaws and temporomandibular joint may lead to the development of parafunction. The persistence of postoperative muscle hardness in our study suggests that this may be the case. However, the patients in the study group were not evaluated for oral parafunctional habits pre- or postoperatively.

Limitations of this study include not examining sex-based differences between the groups, the lack of pre-treatment (T0) EMG, US, USE records, and much longer-term follow-up data for the study group.

Conclusion

- The results of this study suggest that all three assessment methods are useful for comprehensively evaluating changes in the masticatory muscles after orthognathic surgery.
- We believe that myofunctional therapeutic interventions should be provided to facilitate muscle adaptation of individuals in the new stomatognathic system after orthognathic surgery, and much longer follow-up results should be evaluated.

Authors contribution Conceptualization: Ozge Muftuoglu; methodology: Ozge Muftuoglu, Tulin Ufuk Toygar Memikoglu, Ezgi Sunal Akturk; formal analysis and investigation: Ozge Muftuoglu, Hakan Eren, Bora Akat, Cansu Gorurgoz; writing—original draft preparation: Ozge Muftuoglu; writing—review and editing: Ozge Muftuoglu, Tulin Ufuk Toygar Memikoglu; funding acquisition: none; supervision: Kaan Orhan, Tulin Ufuk Toygar Memikoglu, Hakan Alpay Karasu.

Declarations

Ethical approval Ankara University Faculty of Dentistry Ethics Committee (36290600/74).

Conflict of interest The authors declare no competing interests.

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