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Original Article

Dimensional Changes of Masticatory Muscles Following Camouflage Orthodontic Treatment in Skeletal Class III Patients: A Pilot MRI-Based Clinical Trial

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Abstract

Objectives: To evaluate dimensional changes in masticatory muscles, dentoskeletal relationships, and correlations between muscular and vertical skeletal changes following Class III camouflage treatment.

Methods: This clinical trial included ten participants with skeletal Class III malocclusion who met the eligible criteria and provided them non-extraction camouflage treatment using Class III elastics. MR images (T1W) and lateral cephalograms were taken before treatment (T0) and after achieving normal occlusion (T1). Length, width, and cross-sectional area (CSA) of the masseter (MM), temporalis (TM), lateral pterygoid (LPM), and medial pterygoid (MPM) muscles were measured using MicroDicom DICOM viewer software. Dentoskeletal changes were assessed by Dolphin® imaging software. Statistical analyses were conducted using IBM® SPSS® software to analyze differences between T0 and T1, and correlations.

Results: Significant changes were observed in jaw-closing muscles, with increased length (MM 1.0±0.4 mm, TM 0.7±0.2 mm, MPM 0.5±0.5 mm), decreased thickness (MM 1.3±0.7 mm, TM 0.2±0.2 mm, MPM 0.8±0.6 mm), and decreased CSA (MM 79.3±70.5 mm^2, TM 16.2±14.9 mm2, MPM 16.2±8.8 mm^2). Minimal changes were noted in lateral pterygoid muscles. No significant correlations were found between muscular changes and vertical skeletal changes.

Conclusions: Masseter, temporalis, and medial pterygoid muscles exhibited significant changes following Class III camouflage treatment using Class III elastics, but no significant correlations were observed between muscular dimensional changes and vertical skeletal changes.

Keywords: camouflage treatment, Class III elastics, masticatory muscles, MRI, skeletal Class III

Introduction

Skeletal Class III malocclusion is widely recognized as one of the most challenging types of malocclusion to treat in orthodontic practice, particularly among adult patients who have limited treatment options.(1) While orthognathic surgery and orthodontic camouflage treatment have traditionally been considered standard approaches for these patients, many individuals are likely to opt against orthognathic surgery due to its cost and invasive nature. Camouflage treatment has emerged as a viable alternative, especially for patients with mild to moderate skeletal discrepancies.(2,3) To correct anterior crossbite and achieve a Class I relationship through camouflage treatment, several modalities are available based on the severity of malocclusion and the patient's specific needs. Treatment options include permanent tooth extraction, Class III elastics, temporary anchorage devices (TADs), the multiloop edgewise archwire (MEAW) technique, or extraoral appliances.(4) Among these, Class III elastics used with full-fixed appliances are commonly used due to their effectiveness and simplicity.

Although the effects of Class III elastics have been broadly described in previous studies, they are typically discussed in terms of lateral cephalometric changes such as mandibular clockwise rotation, increased vertical dimension, and maxillary molar extrusion.(4-8) While these positional changes of the mandible are well-documented, their impact on the entire masticatory muscles has been minimally studied. Given that all masticatory muscles predominantly insert on mandibular structures, positional changes of the mandible may contribute to dimensional and functional adaptations in these muscles. Moreover, alterations in masticatory muscle dimensions are likely to affect facial aesthetics in the frontal view following orthodontic treatment, especially the thickness of the masseter muscles.(9) Regrettably, this aspect has often been overlooked in orthodontic practice, where treatment outcome assessments have primarily focused on lateral profile changes.

The primary objective of this study was to evaluate the dimensional changes in all masticatory muscles on both sides (temporalis, masseter, lateral pterygoid, and medial pterygoid) following conventional Class III camouflage treatment using Class III elastics. The secondary objectives were to investigate the associated dentoskeletal changes after treatment and explore the correlations between these muscular adaptations and vertical skeletal changes.

Materials and Methods

Study design

This study is a clinical trial conducted as a pre-post intervention study and registered with the Thai Clinical Trials Registry under the identifier TCTR20220316003 (available at thaiclinicaltrials.org).

Ethical approval

This clinical trial was approved by the Khon Kaen University Ethics Committee for Human Research, following the guidelines outlined in the Declaration of Helsinki and the International Conference of Harmonization Good Clinical Practice (ICH GCP) Guidelines (reference number HE641561). Written informed consent was obtained from all participants.

Study sample and sample size calculation

This clinical trial focused on adult patients with skeletal Class III malocclusion, adhering to specific eligibility criteria. The inclusion criteria encompassed: (1) completion of mandibular growth (CS6); (2) skeletal Class III malocclusion (overjet < 0 mm in centric occlusion which distinguishes functional Class III cases, ANB < 0.5°, G'-Sn-Pog' > 172.8°); (3) hypodivergent or normodivergent pattern (FMA < 28.1°); (4) symmetric face (defined by the absence of significant chin deviation, i.e., ≤ 3 mm); and (5) desire for camouflage treatment.(10,11) The exclusion criteria included: (1) pre-existing temporomandibular disorder (TMD) symptoms; (2) history of craniofacial surgery; (3) presence of severe space deficiency that necessitates tooth extraction; and (4) contraindications for MRI. Withdrawal criteria comprised: (1) poor compliance with Class III elastics use; (2) administration of botulinum toxin injections during treatment; and (3) significant body weight loss during the treatment period (T0-T1).

Sample size calculation was performed using a test for difference in two dependent means, $n=[(Z\alpha+Z\beta)^2 \sigma d^2]/(\mu 1-\mu 2)^2$. The difference in primary outcomes between T0 and T1 was estimated from a previous study by Pan *et al.*,(9) and a sample size of at least 8 participants was required to achieve 80% power and 5% alpha error. Consecutive sampling method was employed to recruit participants at the Orthodontic Clinic, Faculty of Dentistry, Khon Kaen University, between January to December 2022.

A total of 36 patients with skeletal Class III malocclusion were initially evaluated for eligibility. Of these, 10 patients met the inclusion and exclusion criteria and were enrolled in the study.

Treatment protocol

Non-extraction camouflage treatment was provided in all participants under the same protocol, as the intervention in this study. The treatment employed full-fixed orthodontic appliances to address dental crowding and correct Class III malocclusion without tooth extractions, orthognathic surgery, or temporary anchorage devices (TADs). MBT 0.022″ ceramic brackets (3M™ Clarity™ Advanced Ceramic Brackets, 3M Unitek™, Monrovia, CA) was used with straight-wire technique. A sequence of nickel-titanium archwires (0.014, 0.016, 0.016×0.022, 0.017×0.025, and 0.019×0.025-inch NiTi) was utilized for leveling and aligning. Additional mechanics, such as archwire expansion, anterior tooth proclination using advancement arches with omega loops, and interproximal stripping (IPR), were employed prior to the Class III correction phase in cases where dental crowding was present. Posterior bite ramps (Ultra band-lok®, Reliance Orthodontic Products, Itasca, IL) were applied to either the maxillary or mandibular molars to disarticulate both arches during anterior crossbite correction and were subsequently removed upon correction. The correction of the dental Class III relationship and anterior crossbite was achieved through the combined use of Class III elastics and large rectangular stainless-steel archwires (0.017×0.025 or 0.019×0.025-inch SS). Class III elastics (1/4", 4.5 oz.) were worn full-time, facilitating maxillary dentition advancement, mandibular dentition retraction, and clockwise mandibular rotation to reduce the severity of the skeletal Class III relationship. Concurrently, the large rectangular stainless-steel archwires allowed for controlled proclination of the maxillary incisors through the fully expressed bracket prescription. Arch form modifications, including contouring (bending) of the main archwires, were employed to further optimize the dental alignment and arch coordination, contributing to the effective correction of the malocclusion. Class III elastics were continued until a Class I relationship was achieved bilaterally. The leveling and aligning phase and Class III correction phase are shown in Figures 1-2.

MR images of skull were taken before treatment (T0) and after normal occlusion achieved (T1) by using Achieva dStream 3.0T MR Systems (Philips®, Koninklijke Philips N.V., Amsterdam, Netherlands), under the same settings: coronal and axial spin-echo (SE) T1-weighted sequence, 2D acquisition, TR 500-625 ms, TE 10-15 ms, 332×313 matrix size, 2.0 mm slice thickness, 0.2 mm inter-slice gap, and 20×20 cm field of view (FOV). The participants were positioned supine while maintaining the maximum intercuspal position (MIP) without applying excessive clenching force during MRI acquisition. Subsequently, all MR images were exported and stored as DICOM format files.

Furthermore, lateral cephalograms captured before treatment (T0) and after achieving normal occlusion (T1) for all participants were also collected. Specifically, T1 was defined as the point at which normal occlusion was achieved, based on clinical criteria aligned with the American Board of Orthodontics Discrepancy Index (2016): (1) Proper incisor relationship with normal overjet (1-3 mm) and overbite (1-3 mm), (2) Class I canine and molar relationship with good buccal intercuspation, and (3) Overall dental alignment without significant crowding. These cephalograms are routinely prescribed as part of initial and progressive orthodontic records, in accordance with the standard protocol of our clinic.

Measurement methods and outcomes

The MR images were first imported into the Micro Dicom DICOM viewer software (version 2022.1; Micro Dicom Ltd, Sofia, Bulgaria) and then reoriented. Thereafter, the dimensions of each masticatory muscle were measured from the coronal or axial slice of the MR images, where the muscle's dimensions were maximized—that is, the slice displaying the greatest length, width, or cross-sectional area. This slice was selected for measurement in order to standardize the analysis of muscle dimensions across all participants. Length, thickness, and cross-sectional area (CSA) of the masseter, temporalis, lateral pterygoid, and medial pterygoid muscles on both sides were assessed at T0 and T1, and then compared.

Length (mm) was measured along the direction of muscle fibers, which refers to the orientation of the fibers from the muscle's origin (attachment point) to its

Figure 1: Leveling and aligning phase, using ceramic bracket, archwires, and posterior bite ramps.

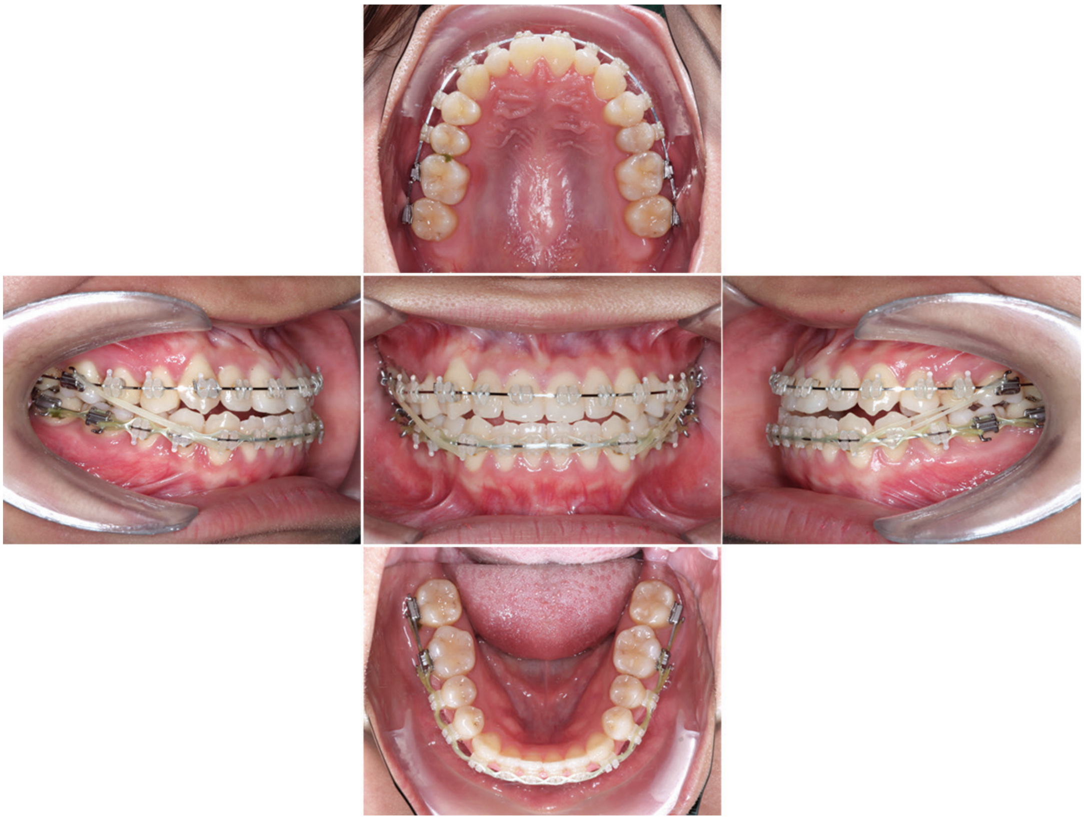

Figure 2: Class III correction phase, using the Class III elastics on rigid stainless-steel archwires.

insertion (opposite attachment point). Thickness (mm) was measured at the thickest part of the muscle and was taken perpendicular to the muscle's length. Similarly, CSA (mm^2) was measured as total area of the muscle on the same slice used for the thickness measurement of each muscle, where the muscle's cross-sectional area was maximized. These measurements were performed in accordance with the specific anatomical features of each muscle. The measurement methods, including details of the origin, insertion, and fiber orientation of each muscle, are further clarified and illustrated in Figures 3-6.

Moreover, lateral cephalometric measurements were performed using the lateral cephalograms at T0 and T1, and then compared individually. The alterations of skeletal and dental relationship were analyzed through cephalometric variables, as demonstrated in Table 3.

Statistical analysis

The examiner underwent training and standardization with radiologists and commenced measurements once acceptable agreement between the examiner and experts was achieved (intraclass correlation coefficients, ICCs>0.80). For intra-examiner reliability assessment, MR images and lateral cephalograms of 30% of all participants were randomly selected and analyzed, yielding excellent reliability (ICCs ranged between 0.90-0.99).

All variables were measured three times by a single examiner with two-week intervals and their average values were used in the statistical analysis. The statistical analysis was conducted using IBM SPSS software (version 28.0; IBM Corp., Armonk, NY). To assess normal distribution, the Shapiro-Wilk test was utilized. Comparisons between T0 and T1 data regarding muscle dimensions and lateral cephalometric measurements, were performed using either paired t-tests or Wilcoxon signed-rank tests. In addition, linear correlations between the changes in muscle dimensions and vertical skeletal changes were analyzed using the Pearson correlation coefficient or Spearman's correlation coefficient. The significance level was set at $p<0.05$.

Results

Table 1 demonstrates the demographic data of the whole sample (n=10), including sex, age, duration of elastics application, and total treatment duration. The overall characteristics of their initial malocclusion were summarized in Table 2, which indicated the anterior crossbite, deep overbite, skeletal Class III relationship, hypodivergent pattern, and concave profile.

Dentoskeletal changes following camouflage treatment were demonstrated through a comparison of lateral cephalometric measurements at T0 and T1 in Table 3. Statistically significant changes were observed in skeletal and dental components.

In terms of skeletal changes, significant improvements were observed in both antero-posterior and vertical relationships, as evidenced by increased ANB, FH-MP, and PP-MP. These improvements were primarily attributed to a clockwise rotation of the mandible, as shown by decreased SNB and SNPog, along with increased FH-MP. Furthermore, the mean ANB and FH-MP values at T1 indicated that participants achieved normodivergent pattern and nearly approached the normative value for skeletal Class I relationship following treatment, as per the Thai norm.[10,11]

Regarding dental measurements, changes were noticed in both maxillary and mandibular incisors. The maxillary incisor exhibited proclination and protrusion,

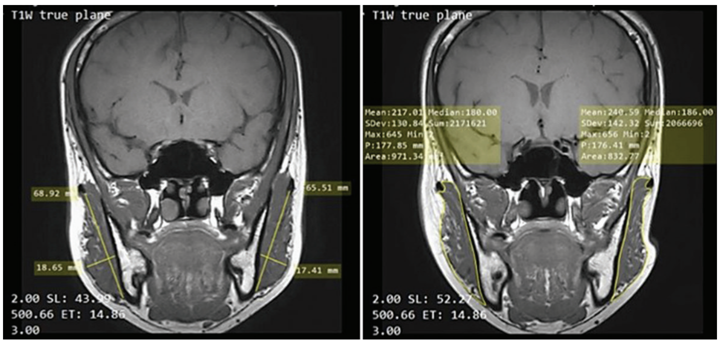

Figure 3: Measurement method of masseter muscles. (right) Length was measured from the zygomatic arch to the lateral surface of the mandibular lower border on coronal slice, while (right) thickness and (left) CSA were also measured on the same slice.

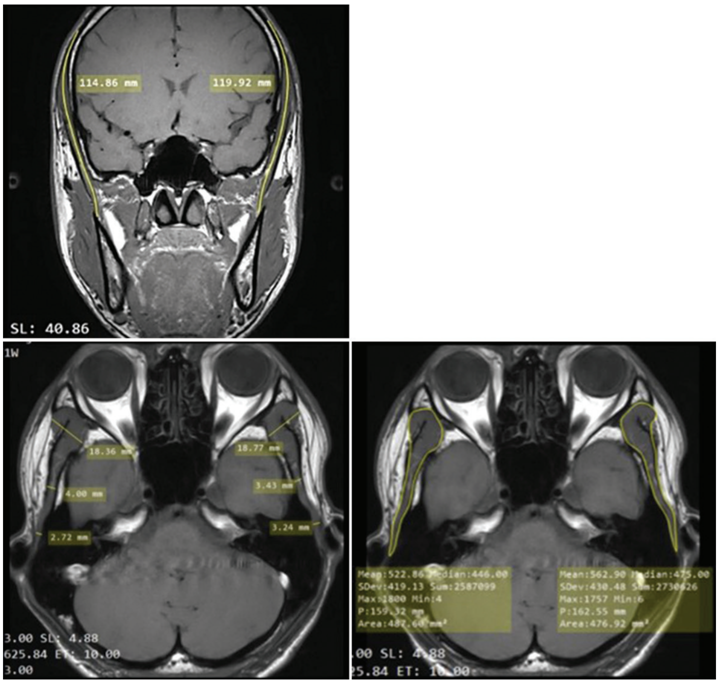

Figure 4: Measurement method of temporalis muscles. (right) Length was measured along the center of muscle thickness from the uppermost part (lying above the temporal fossa) to the coronoid process of the mandible on coronal slice. (middle) Thickness was measured as 3 subparts (anterior, middle, and posterior) due to their flat fan-shaped morphology on the axial slice, and (left) CSA were measured at same slice.

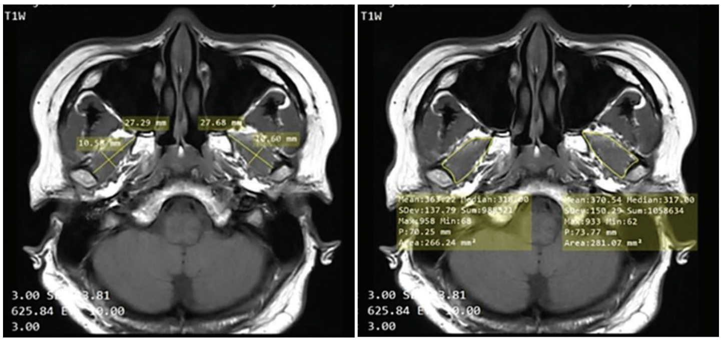

Figure 5: Measurement method of lateral pterygoid muscles. (right) Length, (right) thickness, and (left) CSA were measured on the axial slice at condylar head level. Length was measured from lateral surface of the lateral pterygoid plate to anterior part of the temporomandibular joint (TMJ) capsule, while thickness and CSA were measured on the same slice.

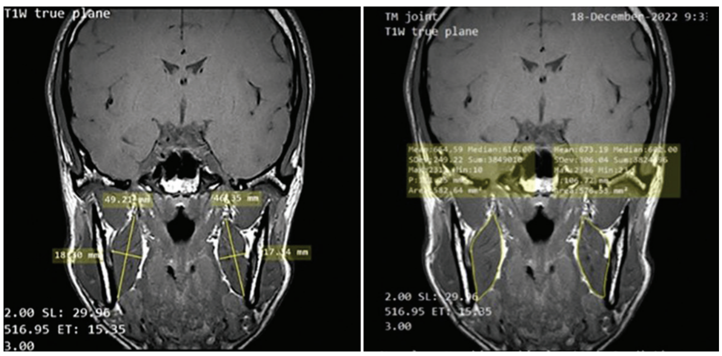

Figure 6: Measurement method of medial pterygoid muscles. (right) Length was measured from the medial pterygoid plate to the medial surface of the mandibular lower border on coronal slice, while (right) thickness and (left) CSA were also measured on the same slice.

as evidenced by increased U1-NA, while the mandibular incisor showed retroclination and retrusion, with decreased L1-MP and L1-NB, aimed at correcting anterior crossbite and compensating for skeletal Class III relationship. A slight clockwise rotation of the occlusal plane was also observed.

The comparison of muscle dimensions at T0 and T1 revealed significant changes in all masticatory muscles, including the masseter, temporalis, lateral pterygoid, and medial pterygoid muscles. These muscular changes manifested similarly, with increases in length, decreases in thickness, and reductions in CSA. Notably, the lateral pterygoid muscles exhibited relatively lesser changes (0.2±0.3 in length, 0.2±0.2 in width) compared to the other masticatory muscles, and no significant change was observed in their CSA between T0 and T1. Conversely, the greatest magnitude of dimensional changes was observed in the masseter muscles (1.0±0.4 in length, 1.3±0.7 in width). Detailed measurements of these dimensional changes can be found in Table 4.

Table 1: Demographic data (n=10).

Variables	Mean	SD	Range
Sex, n=10			
Male, 3	30%		
Female, 7	70%		
Age (year)	24.3	7.0	18–36
Elastics application duration (month)	3.8	1.8	2–7
Total treatment duration, T0 to T1 (month)	12.6	1.8	10–15

Table 2: Characteristics of initial malocclusion (n=10).

Variables	Mean	SD	Range
Overjet (mm)	(-)2.3	0.59	(-)1.5 - (-) 3
Overbite (mm)	3.7	1.9	1-5.5
CO-CR discrepancy (mm)	1.5	0.8	0-2.5
ANB (°)	(-)3.1	1.6	(-) 1.5 - (-) 6.6
FH-MP (°)	22.4	3.3	18.1-28.1
Profile angle (°)	180.45	2.4	176.8-183.2

Table 3: Comparison of lateral cephalometric measurements at T0 and T1 (Mean±SD).

Variables (n=10)	Pre-treatment (T0)	Post-treatment (T1)	Differences (ΔT0-T1)	*p*-value
Skeletal measurements				
SNA (°)	83.2±2.8	83.3±2.8	(-) 0.1±0.1	0.142
SNB (°)	86.3±2.9	84.0±2.9	2.3±0.6	<0.001*
SNPog (mm)	86.1±2.4	83.8±2.2	2.4±0.6	<0.001*
ANB (°)	(-) 3.1±1.6	(-) 0.7±1.5	(-) 2.4±0.5	<0.001*
FH-MP (°)	22.4±3.3	25.1±3.4	(-) 2.7±1.1	<0.001*
PP-MP (°)	19.5±4.7	22.1±4.8	(-) 2.6±1.2	<0.001*
Dental measurements				
U1-NA (°)	25.2±5.5	29.0±2.4	(-) 3.8±5.2	0.083
U1-NA (mm)	6.5±2.1	7.3±1.5	(-) 0.8±0.9	0.038*
L1-MP (°)	85.7±5.5	82.9±4.9	2.8±1.9	0.005*
L1-NB (°)	21.4±4.6	19.2±5.0	2.2±3.0	0.080
L1-NB (mm)	5.4±1.3	4.2±1.7	1.2±0.9	0.008*
SN-OP (°)	11.6±5.3	13.1±6.1	(-) 1.5±1.9	0.064

*Statistically significant (Paired t-test or Wilcoxon signed-rank test, $p<0.05$)

Additionally, the results of the Pearson correlation analysis denoted no significant correlations between the dimensional changes (in terms of length and width) of these four pairs of masticatory muscles and the vertical changes in skeletal components, which were entirely influenced by mandibular rotation (represented by FH-MP value). These findings are presented in Table 5.

Table 4: Comparison of muscle dimensions at T0 and T1 (Mean±SD).

Variables (n=10)	Pre-treatment (T0)		Post-treatment (T1)		Differences (ΔT0-T1)[b]		*p*-value	
	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.	Rt.	Lt.
Masseter muscles								
Length (mm)	62.9±5.6	63.5±3.1	64.0±5.3	64.5±3.2	(-) 1.15±0.7	(-) 1.0±0.4	0.003*	<0.001*
Thickness (mm)	16.9±1.4	17.4±2.4	15.6±1.4	16.1±2.0	1.3±0.7	1.3±0.8	0.001*	0.003*
CSA (mm^2)	856.1±142.9	890.3±108.7	805.4±120.2	811.0±95.1	50.8±65.5	79.3±70.5	0.065	0.015*
Temporalis muscles								
Length (mm)	107.9±7.4	110.4±7.5	108.6±7.4	111.3±7.0	(-) 0.7±0.2	(-) 0.9±0.8	<0.001*	0.011*
Thickness (mm) - anterior	18.6±1.4	18.6±1.5	18.4±1.5	18.4±1.4	0.2±0.2	0.2±0.3	0.061	0.131
Thickness (mm) - middle	4.0±1.1	4.2±1.5	3.8±1.1	3.7±1.2	0.2±0.2	0.5±0.5	0.008*	0.018*
Thickness (mm) - posterior	3.3±0.9	3.5±0.7	3.1±0.7	3.2±0.6	0.2±0.4	0.3±0.2	0.351	0.007*
CSA (mm^2)	485.7±75.9	479.5±65.9	469.5±75.4	465.6±66.8	16.2±14.9	14.0±13.8	0.018*	0.024*
Lateral pterygoid muscles								
Length (mm)	29.9±3.0	28.8±3.2	30.1±3.3	29.1±3.1	(-) 0.2±0.3	(-) 0.4±0.3	0.051	0.014*
Thickness (mm)	14.4±2.1	14.0±2.5	14.2±2.0	13.7±2.3	0.2±0.2	0.3±0.6	0.031*	0.251
CSA (mm^2)	367.6±67.9	355.7±74.2	367.3±66.6	355.5±72.9	0.3±5.3	0.2±2.9	0.869	0.877
Medial pterygoid muscles								
Length (mm)	49.4±6.9	49.6±6.3	49.9±7.1	50.1±6.6	(-) 0.5±0.5	(-) 0.5±0.6	0.026*	0.079
Thickness (mm)	15.8±1.6	15.6±1.3	15.0±1.5	15.0±1.5	0.8±0.6	0.6±0.4	0.006*	0.008*
CSA (mm^2)	492.1±95.9	488.2±66.6	475.9±93.8	471.4±70.2	16.2±8.8	16.8±19.1	0.001*	0.042*

[b] - value indicating increase, + value indicating decrease

*Statistically significant (Paired t-test or Wilcoxon signed-rank test, $p<0.05$)

Table 5: Correlations between muscular changes and vertical skeletal change (n=10).

Correlations			FH-MP difference (ΔT0-T1)	
			r	*p*-value
Masseter muscles	Length	Rt.	0.146	0.730
		Lt.	0.731	0.039 *
	Width	Rt.	(-) 0.210	0.618
		Lt.	(-) 0.052	0.902
Temporalis muscles	Length	Rt.	0.181	0.668
		Lt.	(-) 0.293	0.481
	Width (middle)	Rt.	0.111	0.793
		Lt.	(-) 0.364	0.376
Lateral pterygoid muscles	Length	Rt.	(-) 0.002	0.997
		Lt.	0.535	0.172
	Width	Rt.	(-) 0.570	0.141
		Lt.	(-) 0.054	0.900
Medial pterygoid muscles	Length	Rt.	(-) 0.319	0.441
		Lt.	(-) 0.747	0.033 *
	Width	Rt.	(-) 0.138	0.745
		Lt.	(-) 0.186	0.659

*Statistically significant correlation (Pearson or Spearman's correlation coefficient, $p<0.05$)

Discussion

Non-extraction camouflage treatment, utilizing pre-adjusted edgewise fixed appliances with Class III elastics, is widely recognized as one of the most common approaches for patients with mild-to-moderate skeletal Class III malocclusion, especially in individuals exhibiting hypo- or normo-divergent vertical patterns.(4) This technique principally addresses anterior crossbite and dental Class III malocclusion by proclining the maxillary incisors, retroclining the mandibular incisors, and notably extruding the maxillary molars.(8) As a consequence of maxillary molar extrusion, a clockwise rotation of the mandible occurs, concurrently improving skeletal Class III severity and insufficient vertical height. This leads to enhanced facial aesthetics—specifically, a less protrusive chin and longer facial height. Despite our results regarding the dentoskeletal changes and abundant evidence demonstrating mandibular clockwise rotation in this type of Class III camouflage treatment,(5-8) studies investigating changes in associated muscles remain limited, particularly the masticatory muscles that insert onto parts of the mandible and are potentially affected by this rotation.

To the best of our knowledge, no previous studies have comprehensively investigated the alterations of all masticatory muscles following orthodontic treatment, either in terms of morphological or functional changes. Most prior studies have focused solely on changes in the masseter muscles, with only a few mentioning alterations in the temporalis muscle.(9,12-17) This focus is likely due to the superficial location of both muscles, making them easier to investigate. In regard to the assessment methods employed in previous studies, surface electromyography (sEMG), cone-beam computed tomography (CBCT), and ultrasonography were often utilized to investigate muscle activity and dimension owing to their acceptable accuracy, non-invasive nature, and ease of use. However, these methods are limited in their ability to precisely investigate deep-layer muscles such as the medial and lateral pterygoid muscles.

In contrast, MRI can provide accurate results in muscular dimension assessment, both in superficial and deep layers, in a non-invasive and non-radiation manner. Furthermore, MRI can visualize the overall size and shape of each muscle, clearly display its location relative to surrounding structures, and also enable 2D-slice sections throughout the entire thickness. Although supine positioning during MRI does not replicate the upright orientation of daily functional activities, this posture is standard for craniofacial imaging. Importantly, both T0 and T1 scans were performed under identical conditions and imaging protocols for each participant, allowing for reliable within-subject comparisons. Given MRI's superior soft tissue resolution and its ability to assess both deep and superficial muscles, we believe its advantages outweighed this limitation in the present study. Nonetheless, MRI remains contraindicated in patients with claustrophobia or implanted metal prostheses.(18-21)

Therefore, this study primarily aimed to evaluate the dimensional changes in all masticatory muscles following orthodontic treatment, particularly Class III camouflage treatment which alters the position of the mandible. The muscles of interest included the masseter muscles (inserting along angle of the mandible and lateral surface of the mandibular ramus), temporalis muscles (inserting to the coronoid process of the mandible), lateral pterygoid muscles (inserting to the TMJ capsule, TMJ articular disc, and neck of the condylar process of the mandible), and medial pterygoid muscles (inserting onto medial surface of the ramus and angle of the mandible). MRI was utilized in this study due to its advantages described previously.

With regard to our findings, significant changes in masticatory muscle dimensions were observed after undergoing this camouflage treatment for an average treatment duration of 10-15 months. In the group of jaw-closing muscles (i.e., masseter, temporalis, and medial pterygoid muscle), significant increases in length and decreases in thickness were noted following treatment, even in our participants who have hypo- to normo-divergent vertical pattern (mean FH-MP=22.4°). Referring to the decreases in CSA, they were likely associated with a significantly decreased thickness of these muscles. On the contrary, only minimal changes in muscle dimensions were noted in the lateral pterygoid muscle.

Compared to previous studies, our results align with the findings of Pan *et al.*,(9) who investigated thickness changes in masseter muscles and surrounding soft tissues following full-fixed orthodontic treatment. They reported a significant decrease in masseter muscle thickness in both extraction and non-extraction groups. Similarly, our results correspond to those of Jokaji *et al.*,(16) who observed smaller width and cross-sectional area (CSA) of the masseter muscle after preoperative orthodontic treatment.

Furthermore, the correlation between reduction in muscle size and muscle activity has been reported in several studies.(16,22) Also, certain studies have reported relationships between CSA of the masseter muscle and both maximum occlusal force and muscle activity.(16,23,24) Based on these reports, the decreases in masticatory muscle dimensions and CSA observed in our results may be associated with decreased masticatory muscle activity and bite force, Therefore, it could be inferred that our findings are consistent with the results of many studies that investigated muscle activity following orthodontic treatment and indicated decreased muscle activity of the masseter and temporalis muscles after treatment.

The observed increases in muscle length and reductions in thickness and CSA in the masseter, temporalis, and medial pterygoid muscles may reflect adaptive remodeling in response to occlusal and biomechanical changes during treatment. These changes may be particularly advantageous for patients with hypo- or normo-divergent vertical patterns, by promoting better vertical control. In addition, reduced muscle thickness—particularly in the masseter—may enhance facial esthetics in patients with prominent jaw musculature and potentially support post-treatment stability by minimizing hyperactivity in overcompensating muscles.

These significant changes in the jaw-closing muscles may result from mandibular rotation. Clockwise rotation of the whole mandible leads to downward and backward movement of the mandibular angle and also downward and forward movement of the coronoid process. This movement may cause stretching of the jaw-closing muscles as their insertions move downward, leading to subsequent adaptation to compensate for increased length.(14) Conversely, the minimal change observed in the lateral pterygoid muscle may be attributed to its insertion location near the condylar head, the fulcrum of mandibular rotation. As its insertion does not move as much as those of the other jaw-closing muscles, stretching or dimensional changes may be less pronounced.

Nevertheless, correlation analysis demonstrated no significant correlations between muscular dimensional changes (i.e., length and width) and vertical changes in skeletal relationship in this study. This may be due to limitations in sample size, as the study primarily aimed to detect differences in muscle dimensions between T0 and T1 rather than correlations with other variables. However, there appears to be a trend towards greater muscle dimensional changes in participants with larger clockwise mandibular rotation. With a larger sample size, this trend may have reached statistical significance. Further investigations are necessary to confirm this finding.

In addition to changes in vertical skeletal components, the use of posterior bite-ramps and alterations in eating behavior during orthodontic treatment may also affect muscle activity and dimension. Studies by Changsiripun & Pativetpinyo(25) and Antonarakis(26) have shown that bite-raising appliances can reduce masticatory muscle activity during maximum clenching in the short term, and may lead to a decrease in muscle thickness in the long term.(27) In our study, posterior bite ramps were used to facilitate anterior bite opening during Class III correction. These bite-raising appliances may reduce occlusal force transmission and clenching activity in the short term, potentially contributing to decreased muscle thickness. Although all patients received similar bite ramp designs, individual variation in neuromuscular response cannot be ruled out. Moreover, behavioral changes to avoid chewing hard or sticky foods during treatment may contribute to reduced muscle activity and subsequent muscle size diminution.(28)

Beyond treatment-related factors and behavioral adaptations, underlying skeletal morphology may also play a role in influencing masticatory muscle dimensions. The composition of skeletal Class III discrepancy—whether predominantly due to maxillary deficiency, mandibular excess, or a combination—may potentially influence masticatory muscle morphology and response to treatment. Previous studies have shown associations between jaw muscle dimensions or activity and craniofacial factors such as vertical skeletal configuration, mandibular plane angle, gonial angle, mandibular length, Y-axis, facial width, lower anterior facial height, and facial asymmetry.(29,30) In the present pilot study, we controlled for major craniofacial variables across the three primary planes (i.e., sagittal, vertical, and transverse) by including only subjects with skeletal Class III malocclusion, normo- or hypo-divergent vertical patterns, and symmetric face, to reduce baseline variability. However, future research with a larger cohort should explore the impact of specific skeletal components and additional morphological variables on muscle adaptation following camouflage treatment.

Building upon these considerations, future studies should aim to expand the sample size to enhance statistical power and improve the generalizability of results. To gain a more comprehensive understanding of masticatory muscle adaptation during Class III orthodontic treatment and to address the limitation of MRI in assessing muscle activity, MRI could be combined with complementary tools such as electromyography (EMG) or bite force measurements to evaluate both static muscle morphology and functional dynamics. Including a matched control group would also strengthen the study design; however, ethical concerns related to delaying necessary treatment for a control arm must be carefully addressed. Moreover, although we consider T1 to be a valid and clinically relevant time point to assess the effects of Class III treatment using Class III elastics mechanics, post-debonding (T2) or long-term follow-up assessments may provide further insights into the stability and permanence of these treatment-induced muscular changes.

Conclusions

Significant alterations in the jaw-closing muscles (i.e., masseter, temporalis, and medial pterygoid muscles) were observed following Class III camouflage treatment using Class III elastics, with these muscles exhibiting increased length along with decreased thickness and CSA. In contrast, the lateral pterygoid muscles showed only minimal and statistically insignificant dimensional changes. Furthermore, no significant correlations were found between the dimensional changes in these muscles and the vertical skeletal changes.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. Stellzig-Eisenhauer A, Lux CJ, Schuster G. Treatment decision in adult patients with class III malocclusion: orthodontic therapy or orthognathic surgery?. Am J Orthod Dentofac Orthop. 2002;122(1):27–8.
2. Ngan P, Moon W. Evolution of class III treatment in orthodontics. Am J Orthod Dentofac Orthop. 2015;148(1): 22-36.
3. Park JH, Yu J, Bullen R. Camouflage treatment of skeletal Class III malocclusion with conventional orthodontic therapy. Am J Orthod Dentofac Orthop. 2017;151(4):804-11.
4. Sakoda KL, Pinzan A, Cury SEN, Bellini-Pereira S, Castillo AA-D, Janson G. Class III malocclusion camouflage treatment in adults: a systematic review. J Dent Open Access. 2019;1(1):1-12.
5. de Alba y Levy JA, Chaconas SJ, Caputo AA. Effects of orthodontic intermaxillary class III mechanics on craniofacial structures. part II - computerized cephalometrics. Angle Orthod. 1979;49(1):29-36.
6. Hisano M, Chung C ryung J, Soma K. Nonsurgical correction of skeletal class III malocclusion with lateral shift in an adult. Am J Orthod Dentofac Orthop. 2007;131(6):797-804.
7. Burns NR, Musich DR, Martin C, Razmus T, Gunel E, Ngan P. Class III camouflage treatment: what are the limits?. Am J Orthod Dentofac Orthop. 2010;137(1):9.e1-9.e13.
8. Nakamura M, Kawanabe N, Kataoka T, Murakami T, Yamashiro T, Kamioka H. Comparative evaluation of treatment outcomes between temporary anchorage devices and class III elastics in class III malocclusions. Am J Orthod Dentofac Orthop. 2017;151(6):1116-24.
9. Pan Y, Chen S, Shen L, Pei Y, Zhang Y, Xu T. Thickness change of masseter muscles and the surrounding soft tissues in female patients during orthodontic treatment: a retrospective study. BMC Oral Health. 2020;20(1):1-10.
10. Suchato W CJ. Cephalometric evaluation of the dentofacial complex of Thai adults. J Dent Assoc Thai. 1984;34(5): 233-43.
11. Sutthiprapaporn P Manosudprasit A, Manosudprasit M, Pisek P, Phaoseree N, Manosudprasit A. Establishing esthetic lateral cephalometric values for Thai adults after orthodontic treatment. Khon Kaen Dent J. 2020;23(2):31-41.
12. Uslu O, Arat ZM, Beyazoya M, Taskiran OO. Muscular response to functional treatment of skeletal open-bite and deep-bite cases: an electromyographic study. World J Orthod. 2010;11(4):85-94.
13. Piancino MG, Falla D, Merlo A, Vallelonga T, De Biase C, Dalessandri D, *et al*. Effects of therapy on masseter activity and chewing kinematics in patients with unilateral posterior crossbite. Arch Oral Biol. 2016;67:61-7.
14. Lione R, Kiliaridis S, Noviello A, Franchi L, Antonarakis GS, Cozza P. Evaluation of masseter muscles in relation to treatment with removable bite-blocks in dolichofacial growing subjects: a prospective controlled study. Am J Orthod Dentofac Orthop. 2017;151(6):1058-64.
15. Paes-Souza S de A, Garcia MAC, Souza VH, Morais LS, Nojima LI, Nojima M da CG. Response of masticatory muscles to treatment with orthodontic aligners: a preliminary prospective longitudinal study. Dental Press J Orthod.

2023;28(1):1-26.
16. Jokaji R, Ooi K, Yahata T, Nakade Y, Kawashiri S. Evaluation of factors related to morphological masseter muscle changes after preoperative orthodontic treatment in female patients with skeletal class III dentofacial deformities. BMC Oral Health. 2022;22(1):1-7.
17. Zanon G, Contardo L, Reda B. The impact of orthodontic treatment on masticatory performance: a literature review. Cureus. 2022;14(10):e30453.
18. Narici M. Human skeletal muscle architecture studied *in vivo* by non-invasive imaging techniques: functional significance and applications. J Electromyogr Kinesiol. 1999;9(2): 97-103.
19. Katti G, Ara SA, Shireen A. Magnetic resonance imaging (MRI)–a review. Int J Dent Clin. 2011;3(1):65-70.
20. Amabile C, Moal B, Chtara OA, Pillet H, Raya JG, Iannessi A, *et al*. Estimation of spinopelvic muscles' volumes in young asymptomatic subjects: a quantitative analysis. Surg Radiol Anat. 2017;39(4):393-403.
21. Murakami M, Iijima K, Watanabe Y, Tanaka T, Iwasa Y, Edahiro A, *et al*. Development of a simple method to measure masseter muscle mass. Gerodontology. 2020;37(4):383-8.
22. Georgiakaki I, Tortopidis D, Garefis P, Kiliaridis S. Ultrasonographic thickness and electromyographic activity of masseter muscle of human females. J Oral Rehabil. 2007;34(2):121-8.
23. Celakil D, Ozdemir F, Eraydin F, Celakil T. Effect of orthognathic surgery on masticatory performance and muscle activity in skeletal class III patients. Cranio. 2018;36(3):174-80.
24. Spronsen PH van, Weijs WA, Valk J, Prahl-Andersen B, Ginkel FC van. Relationships between jaw muscle cross-sections and craniofacial morphology in normal adults, studied with magnetic resonance imaging. Eur J Orthod. 1991;13(5):351-61.
25. Changsiripun C, Pativetpinyo D. Masticatory function after bite-raising with light-cured orthodontic band cement in healthy adults. Angle Orthod. 2020;90(2):263-8.
26. Antonarakis GS, Kiliaridis S. Predictive value of masseter muscle thickness and bite force on class II functional appliance treatment: a prospective controlled study. Eur J Orthod. 2015;37(6):570-7.
27. Wasinwasukul P, Thongudomporn U. Masticatory muscle responses to orthodontic bite-raising appliances. J Dent Assoc Thai. 2022;72(3):427-33.
28. Carter LA, Geldenhuys M, Moynihan PJ, Slater DR, Exley CE, Rolland SL. The impact of orthodontic appliances on eating - young people's views and experiences. J Orthod. 2015;42(2):114-22.
29. Weijs WA, Hillen B. Correlations between the cross-sectional area of the jaw muscles and craniofacial size and shape. Am J Phys Anthropol. 1986;70(4):423-31.
30. Togninalli D, Antonarakis GS, Papadopoulou AK. Relationship between craniofacial skeletal patterns and anatomic characteristics of masticatory muscles: a systematic review and meta-analysis. Prog Orthod. 2024;25(1):36.