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Comparison of CBCT and elastographic values of musculoskeletal structures of tooth-borne and tooth-bone-borne rapid palatal expansion patients: a short-term prospective comparative study

Ismayil Malikov
melikovismayil@gmail.com

Aksaray University
Türkan Sezen Erhamza
Dokuz Eylül University
Mikail İnal
Kırıkkale University
Mehmet Emir Çevik
Kırıkkale University

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Abstract

Objective

To compare transverse skeletal changes and orofacial muscle stiffness following tooth-borne rapid palatal expansion (TB-RPE) and tooth-bone-borne RPE (TBB-RPE) using a combined cone-beam computed tomography (CBCT) and ultrasonographic elastography (UE) approach.

Materials and Methods

Twenty-four adolescents with transverse maxillary deficiency were treated with TB-RPE (n = 12) or TBB-RPE (n = 12). CBCT scans were obtained at baseline (T0) and after active expansion (T1) as part of routine clinical assessment to evaluate skeletal changes. UE, including strain elastography (SE) and shear-wave elastography (SWE), was performed for the masseter, temporalis, geniohyoid, and anterior digastric muscles.

Results

Both groups exhibited significant transverse skeletal expansion without significant between-group differences in midpalatal or pterygopalatine suture separation, or maxillary and nasal width changes ($p > 0.05$). Muscle thickness remained stable. SE values increased in several muscles in both groups, whereas SWE values showed variable changes; however, no significant intergroup differences were observed, except for two isolated reductions in the TB-RPE group.

Conclusion

TB-RPE and TBB-RPE produced comparable short-term skeletal expansion and similar elastographic muscle responses. Early musculoskeletal adaptations during active expansion appear independent of anchorage design.

Clinical Relevance

In adolescents, appliance selection for rapid palatal expansion may be guided primarily by skeletal considerations, as short-term neuromuscular responses do not differ significantly between tooth-borne and tooth-bone-borne designs.

1. INTRODUCTION

Transverse maxillary constriction is a frequent finding in orthodontic patients and is commonly associated with posterior crossbite, a condition affecting approximately 7% to 23% of individuals [1]. Rapid palatal expansion (RPE) is a well-established orthopedic intervention for correcting transverse maxillary deficiency and is traditionally performed using tooth-tissue–borne appliances, such as the Haas expander, or tooth-borne (TB-RPE) designs like the Hyrax [2] The concept of maxillary expansion has been recognized for more than 140 years, with widespread clinical adoption occurring after the mid-1960s [3, 4]. Despite its effectiveness, RPE may induce undesirable dentoalveolar effects, including buccal molar tipping and thinning or dehiscence of the buccal cortical plate [5]. Mini-screw–assisted RPE (MARPE) was introduced to enhance skeletal expansion and reduce dental side effects [6]. Depending on anchorage design, MARPE devices may rely exclusively on skeletal support (BB-RPE) or distribute forces between bone and teeth, as in tooth-bone–borne (TBB-RPE) configurations [2, 7].

Cone-beam computed tomography (CBCT) enables precise three-dimensional evaluation of skeletal and dentoalveolar changes, as well as detailed assessment of the circummaxillary sutures [8–10].

Ultrasonography (USG) provides a noninvasive and radiation-free method for evaluating orofacial muscle morphology and allows real-time visualization of muscular architecture and functional parameters, including thickness and cross-sectional characteristics [11–14]. Ultrasonographic elastography (UE) extends USG by quantifying soft-tissue stiffness through strain- and shear-wave–based techniques and has been validated across various medical applications [15–18]. Strain- and shear-based techniques generate quantitative or semiquantitative indices of tissue elasticity, allowing visualization of relative stiffness within the region of interest [18, 19]. Despite increasing interest in craniofacial applications, the use of UE to characterize neuromuscular adaptations to RPE remains unexplored.

Previous investigations have assessed skeletal responses to maxillary expansion using CBCT and examined masticatory muscle activity with electromyography (EMG); however, no prior study has concurrently evaluated skeletal changes and orofacial muscle stiffness within a unified analytical framework [20, 21].

Masticatory and orofacial musculature responds rapidly to alterations in mandibular posture, with evidence demonstrating load-dependent modulation in both elevator and tongue-related muscles [22]. RPE perturbs this neuromuscular system by inducing a characteristic downward-and-backward mandibular rotation during active expansion, thereby altering muscle length–tension relationships and functional loading patterns. These biomechanical adjustments reflect the well-documented plasticity of orofacial muscles under changing transverse constraints [23]. Neuromuscular alterations are also consistently reported in patients with posterior crossbite. The masseter (MM) and temporalis (TM) muscles, primary mandibular elevators, exhibit functional asymmetries in transverse maxillary deficiency, whereas the geniohyoid (GH) and anterior digastric (AD) muscles play key roles in tongue posture and

suprahyoid stability—functions closely linked to maxillary transverse morphology and orofacial equilibrium [24, 25]. Together, these muscles form a physiologically coherent set for evaluating RPE-related neuromuscular adaptation.

Despite extensive literature on skeletal responses to RPE, its potential effects on orofacial muscle properties remain unclear. Previous studies have mainly relied on EMG, which reflects muscle activity but does not provide information on intrinsic tissue characteristics such as stiffness. Moreover, there is a lack of studies combining CBCT-based structural assessment with elastographic evaluation of muscle properties. This limitation restricts a comprehensive understanding of how expansion protocols influence both skeletal structures and associated musculature. Importantly, this study does not aim to reconfirm known skeletal effects, but to determine whether these structural changes are accompanied by measurable alterations in muscle stiffness. The aim of this short-term prospective comparative study was therefore to quantify transverse skeletal changes and orofacial muscle stiffness alterations induced by TB-RPE and TBB-RPE using a multimodal CBCT–UE approach.

Based on these considerations, the following a priori hypotheses were formulated:

H1: TBB-RPE would result in greater transverse skeletal enlargement quantified on CBCT by midpalatal suture opening and maxillary and nasal width changes compared with TB-RPE.

H2: TBB-RPE would produce larger increases in strain elastography (SE) derived muscle stiffness of the MM, TM, GH, and AD muscles.

H3: TBB-RPE would yield greater increases in shear-wave elastography (SWE) derived elastic modulus values of the same muscles.

The primary outcomes were changes in orofacial muscle stiffness assessed with UE and transverse skeletal changes evaluated on CBCT.

2. MATERİAL AND METHODS

This short-term prospective comparative study was reviewed and approved by the Clinical Research Ethics Committee of XXX University (Approval No: 22/02; date of approval: 16 November 2023). In compliance with the Declaration of Helsinki, informed consent was provided in writing by all participants, and by guardians on behalf of minors, before inclusion in the research. Study samples were prospectively collected from patients attending the Department of Orthodontics at the Faculty of Dentistry, XXX University, between December 2023 and June 2024. All identifying information was excluded to preserve anonymity.

The inclusion criteria for patients in both groups were as follows: (1) individuals aged 11–17 years; (2) transverse maxillary deficiency confirmed on posteroanterior cephalometric assessment (> 5 mm maxillary constriction and frontal convexity > 11.5 mm [26]); (3) successful opening of the midpalatal suture; and (4) maturation stages A–B for patients treated with TB-RPE and C–D for those treated with TBB-RPE, in accordance with the classification proposed by Angelieri et al. [27]. Group allocation was primarily determined by midpalatal suture maturation stage assessed on CBCT, which constituted the main clinical criterion for selection of the expansion modality. Chronological age was not used as a primary allocation variable and was considered secondary to suture maturation status in treatment planning. The exclusion criteria were: (1) a history of previous orthodontic treatment; (2) craniofacial trauma, systemic disease, or syndromic conditions; (3) hemimandibular hyperplasia or severe skeletal asymmetry; and (4) cases involving facemask-assisted RPE or Alt-RAMEC protocols.

According to the sample size calculation performed using G*Power software (v. 3.1.9.2; Franz Faul, Universität Kiel, Germany), assuming an alpha level of 0.05 and an effect size (d) of 1.44, a total of 24 patients–12 per group was determined to be sufficient to achieve 90% statistical power. The assumed effect size (d = 1.44) was derived from previously reported transverse skeletal and dental changes in comparable RPE studies [28]. Participants were allocated to groups based on midpalatal suture maturation stage and clinical indication.

CBCT and UE evaluations were performed at two time points: baseline (T0) and at the end of active expansion (T1). All CBCT scans were acquired using a CBCT system (DENTRI 3D; HDX WILL Corp., Korea) at 100 kV, 6 mA, a 16 × 10 cm FOV, 12.5 s exposure time, pitch 1, and CTDIvol 2.5 mGy. Images were reconstructed at 0.20-mm voxel size. A standardized low-dose protocol was used (CTDIvol: 2.5 mGy) to minimize radiation exposure. All scans were acquired by the same radiology technician, who was blinded to group allocation. CBCT imaging at T0 was clinically indicated for individualized treatment planning, particularly for assessing midpalatal suture maturation according to Angelieri et al., which directly guided appliance selection [27]. CBCT imaging at T1 was performed to verify the presence and pattern of skeletal expansion at the midpalatal and circummaxillary sutures. This is clinically relevant, as conventional clinical indicators (e.g., diastema formation or occlusal changes) cannot reliably differentiate true skeletal expansion from dentoalveolar tipping. Therefore, three-dimensional imaging was considered necessary to confirm the skeletal response to treatment. All CBCT scans were acquired in accordance with the ALARA principle, and no additional imaging was performed solely for research purposes. Midpalatal suture separation was measured at ANS and PNS. Pterygopalatine suture separation, nasal width (between lateral nasal walls), and maxillary width (between jugale points) were also measured. A single examiner performed all CBCT measurements on axial, coronal, and cross-sectional slices using dedicated software (Ondemand3D; Cybermed Inc., Korea). To minimize measurement variability, all CBCT measurements were performed using a prespecified landmark definition and a standardized viewing protocol (axial, coronal, and cross-sectional slices) within the same software environment (Fig. 1). All CBCT measurements were completed in a single measurement session after completion of data collection. Because repeated measurements were not obtained, intra-observer reliability statistics were not calculated.

Maxillary digital scans were obtained using an intraoral scanner (TRIOS 3; 3Shape, Denmark). CBCT DICOM data and maxillary STL files were registered using a surface-based superimposition protocol to design expansion appliances digitally. In both groups, expanders were fabricated as cast-metal appliances extending from the first molars to the first premolars and incorporated a 10-mm expansion screw activated at 0.25 mm/day. In the TBB-RPE group, mini-implant sites were digitally planned to avoid vital anatomical structures. Two mini-implants (FastDrive Anchor, İzmir, Türkiye) measuring 2.0 × 12

mm were inserted using an implant motor (ISD900; NSK Nakanishi Inc., Japan) with an insertion torque of approximately 20 N·cm at 25 rpm. Active expansion was terminated when the palatal cusps of the maxillary posterior teeth aligned with the buccal cusps of the mandibular posterior teeth.

USG examinations were performed by a single experienced radiologist, who was blinded to both treatment group allocation and measurement time point (T0 or T1), using a 6–15 MHz linear transducer on a USG system (LOGIQ E9; GE Healthcare, USA). All assessments were performed with participants in natural head posture, with the mandible at rest and in maximum intercuspation. B-mode muscle thickness was defined as the perpendicular distance between the superficial and deep fascial borders (Fig. 2). The TM, MM, and AD muscles were evaluated bilaterally, while the GH muscle was assessed at the midline. For SWE, the thickest mid-belly portion of each muscle was identified in B-mode in the same position, after which elastography mode was activated. A circular region of interest (ROI) was positioned in the central muscle belly on three consecutive frames. ROI diameters were 3–7 mm for the TM, GH, and AD muscles, and 5–10 mm for the MM. The mean of three measurements was recorded. ROIs were placed to avoid superficial and deep fascial layers. A manufacturer-recommended quality factor of ≥ 60 was required for SWE analysis (Fig. 3). For SE, muscle stiffness was classified using a five-level color scale: red (very soft), red-green (soft), green (intermediate), green-blue (firm), and blue (very stiff) (Fig. 4). All USG and UE examinations were conducted according to a standardized acquisition protocol. Examinations were performed in a randomized, non-sequential order across patients and time points, and no repeat acquisitions at the same time point were obtained; therefore, intra-observer reliability statistics were not calculated.

Descriptive statistics for continuous variables included mean, standard deviation, median, minimum, and maximum values; categorical variables were summarized as frequencies and percentages. Normality was assessed using the Shapiro–Wilk test. Within-group comparisons (T0 vs. T1) were performed using paired t-tests or Wilcoxon signed-rank tests. Between-group comparisons (TB-RPE vs. TBB-RPE) were conducted using independent-samples t-tests for normally distributed variables or Mann–Whitney U tests for non-normal variables. No correction for multiple comparisons (e.g., Bonferroni) was applied. Statistical analyses were performed using IBM SPSS (version 20; Chicago, IL, USA), with significance set at $p < 0.05$.

3. RESULTS

A total of 24 patients were included, 12 treated with TB-RPE and 12 with TBB-RPE. The mean age was significantly higher in the TBB-RPE group (16.11 ± 1.33 years) than in the TB-RPE group (12.94 ± 1.03 years; U = 6.0, $p < 0.001$), whereas sex distribution did not differ significantly between groups ($p = 0.40$). Consistent with the clinical protocol, all individuals in the TB-RPE group exhibited midpalatal suture maturation stages A–B, whereas the TBB-RPE group comprised only stage C patients (no stage D cases). Baseline characteristics are summarized in Table 1. Accordingly, the between-group age difference should be interpreted as a consequence of the maturation-stage–based selection strategy rather than as an independent determinant of the short-term transverse response.

Table 1
Demographic and baseline clinical characteristics of the TB-RPE and TBB-RPE groups

	TB-RPE (n = 12)		**TBB-RPE (n = 12)**		**Test statistic**	**p-value**
	Mean ± SD **Median (Min-Max)**		**Mean ± SD** **Median (Min-Max)**			
Age	12.94 ± 1.03 13.1 (11.0-14.4)		16.11 ± 1.33 16.5 (13.7-17.42)		U = 6.0	< 0.001
	n	**%**	**n**	**%**		
Sex						
Female	6	50.0	9	75.0	$\chi^2 = 1.600$	0.400
Male	6	50.0	3	25.0		
Maturation Stage						
A	1	8.3	0	0	-	-
B	11	91.7	0	0		
C	0	0	12	100		

TB-RPE–tooth-borne rapid palatal expansion; **TBB-RPE**–tooth-bone-borne rapid palatal expansion; **Max**–maximum; **Min**–minimum; **SD**–standard deviation; **n**–sample size; **U**–Mann-Whitney U test statistic; χ^2–chi-squared test; Statistically significant at $p < 0.001$.

Both groups demonstrated transverse expansion across all skeletal parameters. Mean opening at the ANS was 5.39 ± 2.21 mm in the TB-RPE group and 5.78 ± 2.38 mm in the TBB-RPE group ($p = 0.687$), while PNS was 2.85 ± 1.32 mm and 3.40 ± 1.56 mm, respectively ($p = 0.365$). In both groups, separation was greater anteriorly than posteriorly, with PNS/ANS ratios of 52.67 ± 9.28% and 59.09 ± 15.91% ($p = 0.240$). Pterygopalatine separation increased on both sides, with right-side widening of 1.32 ± 0.56 mm in the TB-RPE group and 1.56 ± 0.81 mm in the TBB-RPE group ($p = 0.418$), and corresponding left-side values of 1.36 ± 0.51 mm and 1.50 ± 0.66 mm ($p = 0.568$). Nasal width increased by 3.37 ± 1.33 mm and 3.39 ± 1.25 mm ($p = 0.978$), and maxillary width by 3.88 ± 1.35 mm and 4.19 ± 1.74 mm ($p = 0.624$). There were no statistically significant between-group differences for any maxillary or nasal transverse parameters (Table 2).

Table 2
CBCT-based skeletal changes (Δ T1–T0) between groups

	TB-RPE (n = 12)	TBB-RPE (n = 12)	Test statistic	p-value
	Mean ± SD	**Mean ± SD**		
	Median (Min-Max)	**Median (Min-Max)**		
ANS widening (mm)	5.39 ± 2.21	5.78 ± 2.38	t=-0.409	0.687 [b]
	4.74 (2.41–10.67)	5.99 (2.17–10.66)		
PNS widening (mm)	2.85 ± 1.32	3.40 ± 1.56	t=-0.926	0.365 [b]
	2.70 (1.27–6.13)	3.10 (1.07–6.27)		
PNS/ANS ratio	52.67 ± 9.28	59.09 ± 15.91	t=-1.208	0.240 [b]
	54.06 (33.41–65.80)	56.03 (41.83–96.65)		
Right pterygopalatine suture (mm)	1.32 ± 0.56	1.56 ± 0.81	t=-0.826	0.418 [b]
	1.47 (0.39–2.09)	1.21 (0.46–3.37)		
Left pterygopalatine suture (mm)	1.36 ± 0.51	1.50 ± 0.66	t=-0.580	0.568 [b]
	1.45 (0.46–2.13)	1.40 (0.29–2.70)		
Δ Nasal width	3.37 ± 1.33	3.39 ± 1.25	t=-0.028	0.978 [b]
	2.86 (1.84–5.80)	3.11 (1.53–5.37)		
Δ Maxillary width	3.88 ± 1.35	4.19 ± 1.74	t=-0.496	0.624 [b]
	3.77 (2.12–6.12)	3.82 (1.78–7.21)		

TB-RPE–tooth-borne rapid palatal expansion; **TBB-RPE**–tooth-bone-borne rapid palatal expansion; **Max**–maximum; **Min**–minimum; **SD**–standard deviation; **n**–sample size; **mm**–millimeter; **b**–independent samples t-test; Statistically significant at $p < 0.05$.

USG measurements demonstrated that muscle thickness did not differ significantly over time in either group. In contrast, SE scores increased from T0 to T1 in both groups. However, the magnitude of these changes was comparable between TB-RPE and TBB-RPE. For the TM, mean SE change on the relaxed right side was 0.58 ± 1.24 in the TB-RPE group and 0.91 ± 0.90 in the TBB-RPE group ($p = 0.630$), with similarly nonsignificant differences across all other relaxed and contracted conditions bilaterally. Parallel patterns were observed in the MM, GH, and AD muscles, with ΔSE values typically close to one unit on the five-point scale and all P values exceeding 0.05. Within-group analyses confirmed that SE increases from T0 to T1 were significant for multiple muscles in both groups, yet these adaptations were not appliance dependent (Table 3).

Table 3
SE changes (Δ T1–T0) in masticatory and suprahyoid muscles between groups

	TB-RPE (n = 12)	TBB-RPE (n = 12)	Test statistic	p-value
	Mean ± SD Median (Min-Max)	Mean ± SD Median (Min-Max)		
Δ Right TM R	0.58 ± 1.24 1 (-1)- (2)	0.91 ± 0.90 1 (-1-2)	U = 63.5	0.630 [g]
Δ Right TM C	0.83 ± 0.71 1 (0–2)	1.00 ± 0.60 1 (0–2)	U = 62.0	0.590 [g]
Δ Left TM R	1.08 ± 0.90 1 (0–3)	1.00 ± 0.73 1 (0–2)	U = 70.5	0.932 [g]
Δ Left TM C	0.75 ± 1.05 1 (-1)- (3)	1.50 ± 1.16 1.5 (0–3)	U = 46.5	0.143 [g]
Δ Right MM R	0.83 ± 0.83 1 (-1)- (2)	1.00 ± 0.73 1 (0–2)	U = 66.0	0.755 [g]
Δ Right MM C	0.66 ± 1.30 1 (-1)- (3)	0.83 ± 0.71 1 (0–2)	U = 66.0	0.755 [g]
Δ Left MM R	0.83 ± 0.38 1 (0–1)	0.91 ± 0.51 1 (0–2)	U = 67.0	0.799 [g]
Δ Left MM C	0.91 ± 0.66 1 (0–2)	1.16 ± 0.83 1 (0–3)	U = 61.5	0.551 [g]
Δ GH R	1.00 ± 1.04 1 (0–3)	0.75 ± 0.75 1 (-1-2)	U = 66.5	0.755 [g]
Δ GH C	0.83 ± 0.71 1 (0–2)	1.08 ± 0.99 1 (0–3)	U = 65.0	0.713 [g]
Δ Right AD R	0.91 ± 0.79 1 (0–2)	0.83 ± 0.71 1 (0–2)	U = 68.0	0.843 [g]
Δ Right AD C	0.91 ± 1.08 1 (-1)- (3)	1.08 ± 0.51 1 (0–2)	U = 63.0	0.630 [g]
Δ Left AD R	0.75 ± 1.13 1 (-2)- (2)	0.75 ± 0.75 1 (0–2)	U = 66.0	0.755 [g]
Δ Left AD C	1.08 ± 0.79 1 (0–2)	1.00 ± 0.85 1 (0–3)	U = 65.0	0.713 [g]

SWE findings were more variable, with some muscles showing increases and others decreases in elasticity values between time points. Nevertheless, no statistically significant differences between TB-RPE and TBB-RPE were observed for any muscle in either relaxed or contracted states. For example, elasticity of the relaxed right TM increased by 3.50 ± 12.21 kPa in the TB-RPE group and by 6.91 ± 12.83 kPa in the TBB-RPE group ($p = 0.511$), whereas the relaxed right MM decreased by − 8.50 ± 23.23 kPa in the TB-RPE group and increased by 2.66 ± 8.89 kPa in the TBB-RPE group ($p = 0.134$). Similar nonsignificant differences were observed for the remaining muscles (all $p > 0.05$). Within-group comparisons identified only two statistically significant SWE reductions, both in the TB-RPE group: a decrease in the contracted GH and a decrease in the relaxed left anterior AD ($p < 0.05$). Overall, SWE did not reveal a consistent directional change in muscle stiffness following expansion, and the two appliances produced comparable elastographic responses (Table 4).

Table 4
SWE changes (Δ T1–T0) in masticatory and suprahyoid muscles between groups

	TB-RPE (n = 12)	TBB-RPE (n = 12)	Test statistic	p-value
	Mean ± SD Median (Min-Max)	Mean ± SD Median (Min-Max)		
Δ Right TM R	3.50 ± 12.21 5 (-23)- (17)	6.91 ± 12.83 9.5 (-26)- (21)	t=-0.668	0.511 [b]
Δ Right TM C	-8.58 ± 25.58 -0.5 (-61)- (15)	2.58 ± 23.61 6 (-41)- (38)	t=-1.154	0.261 [b]
Δ Left TM R	-0.75 ± 14.35 0 (-20)- (31)	0.33 ± 28.36 -3 (-46)- (63)	t=-0.118	0.907 [b]
Δ Left TM C	-4.41 ± 20.87 -5.0 (-41)- (42)	6.91 ± 34.92 1.0 (-44)- (83)	t=-0.965	0.345 [b]
Δ Right MM R	-8.50 ± 23.23 -3.5 (-50)- (28)	2.66 ± 8.89 2.5 (-7)- (2)	t=-1.554	0.134 [b]
Δ Right MM C	-4.33 ± 27.13 -0.5 (-49)- (44)	-7.33 ± 22.99 -1.0 (-50)- (27)	t = 0.292	0.773 [b]
Δ Left MM R	-10.83 ± 22.64 -14 (-37)- (22)	0.08 ± 21.01 3 (-40)- (31.0)	t=-1.224	0.234 [b]
Δ Left MM C	-13.66 ± 28.43 -22.5 (-53)- (34)	-0.16 ± 17.87 0 (-29)- (32)	t=-1.393	0.180 [b]
Δ Right GH R	-5.75 ± 10.53 -5.5 (-28)- (12)	-1.16 ± 14.40 1 (-34)- (19)	t=-0.890	0.383 [b]
Δ Right GH C	-18.75 ± 22.37 -11 (-67)- (10)	-8.16 ± 22.69 -1 (-76)- (12)	t=-1.150	0.262 [b]
Δ Right AD R	-9.25 ± 19.34 -6.5 (-50)- (13)	-9.08 ± 16.86 -4.5 (-43)-(13)	t=-0.022	0.982 [b]
Δ Right AD C	-7.33 ± 28.67 -14 (-46)- (44)	-5.91 ± 25.35 -3.5 (-47)- (40)	t=-0.128	0.899 [b]
Δ Left AD R	-10.27 ± 9.12 -9.0 (-25.0)- (1.0)	-5.58 ± 16.56 0.0 (-32)- (13)	t=-0.830	0.407 [b]
Δ Left AD C	-9.36 ± 14.84 -11 (-36)- (21)	-5.83 ± 19.71 -5 (-38)- (17)	t=-0.482	0.635 [b]

4. DISCUSSION

The present study introduces a multimodal framework combining CBCT-derived structural metrics with elastographic assessment of muscle properties, offering a more comprehensive evaluation of both skeletal and neuromuscular adaptations following RPE. The skeletal effects of RPE have been extensively investigated using CBCT, with numerous studies demonstrating midpalatal suture separation and transverse increases in maxillary and nasal dimensions [29, 30]. In contrast, ultrasonographic assessments of masticatory muscles—whether based on muscle thickness measurements or elastographic evaluations of tissue stiffness—have primarily been conducted in contexts such as muscle dysfunction, parafunctional habits, and therapeutic interventions [31–34]. However, no previous study has examined how different types of RPE, specifically TB-RPE and TBB-RPE, influence both skeletal outcomes and short-term changes in masticatory muscle morphology and biomechanical properties. By integrating CBCT-based skeletal assessments with measurements of muscle thickness, SE, and SWE, the present investigation addresses this gap.

CBCT-based studies have shown wide variability in anteroposterior patterns of midpalatal suture opening. Silva Filho et al. reported that posterior separation represented only 43% of anterior displacement, whereas Ghoneima et al. documented a substantially higher posterior proportion of approximately 75% [35, 36]. Weissheimer et al. similarly found that the anterior suture accounted for about half of the total separation compared with one-third posteriorly [37]. In contrast, some studies have reported nearly parallel expansion, especially in younger patients; Christie et al. and Podesser et al. observed minimal posteroanterior discrepancy, while Elkenawy et al. documented a 95.7% ANS–PNS correspondence in young adults [38–40]. Habersack et al. showed that

expansion morphology may depend on age and appliance design, noting a parallel opening pattern in an 11-year-old treated with a Hyrax but a triangular pattern in a 16-year-old treated with an acrylic cap-splint expander [9]. Hybrid expander studies further support this heterogeneity: Akin et al. reported greater anterior than posterior separation with TBB-RPE; Cho et al. demonstrated that PNS-level expansion is positively correlated with medial pterygopalatine suture displacement; and Colak et al. recorded an 84% pterygopalatine opening success rate under TBB-RPE [41–43]. Comparative studies reinforce the influence of anchorage design, with Cantarella et al. documenting parallel opening in TBB-RPE and triangular opening in TB-RPE, and Jia et al. reporting similar appliance-dependent differences in post-pubertal patients [44, 45].

Previous CBCT investigations of transverse skeletal responses following TB-RPE and TBB-RPE have revealed variable increases in maxillary and nasal widths, often reflecting differences in patient age, suture maturation, and appliance biomechanics. Mehta et al. found that both approaches produced significantly greater nasal widening than controls, with TBB-RPE showing a more pronounced effect [30]. Chun et al. likewise reported significantly larger nasal and maxillary width gains with TBB-RPE [20]. Conversely, Gunyuz Toklu et al. observed comparable outcomes between the two modalities, suggesting that skeletal effects may converge when baseline characteristics are similar [46]. Pasqua et al. also found greater transverse maxillary increases in younger TBB-RPE patients [47].

In the present study, CBCT findings demonstrated comparable short-term skeletal responses between TB-RPE and TBB-RPE across midpalatal suture, maxillary and nasal transverse dimensions. Although some previous studies have reported greater posterior displacement or larger skeletal increases with TBB-RPE, others have shown minimal differences between anchorage types, particularly in younger patients or those with favorable suture morphology. The similarity observed in this study may reflect comparable suture maturation stages and the use of digitally designed cast-metal expanders with standardized geometry, which may have reduced biomechanical variability. Additionally, inherent circummaxillary resistance—particularly within the pterygopalatine region and along the zygomatic crest—may limit posterior displacement regardless of anchorage type, contributing to the consistent ANS–PNS patterns observed here. These factors suggest that, during early expansion, individual anatomic and maturational characteristics may have a greater influence on skeletal response than appliance design alone. In this context, midpalatal suture maturation appears to be a more relevant determinant of early transverse skeletal response than chronological age alone, particularly during the active expansion phase.

Previous UE research on the masticatory system has primarily focused on neuromuscular disorders, dentofacial deformities, and functional loading rather than orthodontic expansion. In skeletal Class III patients undergoing orthognathic surgery, combined EMG, USG, and UE assessments have shown increased MM hardness after surgery that persists long term despite minimal morphologic changes and incomplete EMG recovery [48]. Studies in patients with dentofacial deformities have demonstrated that SE values vary with mandibular posture but are not globally different from controls, indicating functional sensitivity without strong diagnostic discrimination [49]. Similarly, USG and UE assessments in growing Class I, II, and III subjects have revealed modest inter-class differences, suggesting that sagittal skeletal pattern alone does not produce large baseline variations in muscle stiffness [50]. Reference-value studies in healthy adults have established normative ranges for MM and TM thickness and SWE stiffness, showing expected increases from rest to contraction and supporting SWE as a quantifiable, less operator-dependent measure. In contrast, temporomandibular disorder (TMD) research has consistently demonstrated elevated muscle stiffness in symptomatic individuals, with reductions following conservative therapy. Experimental chewing studies have shown transient increases in MM and TM stiffness that revert with rest, illustrating the sensitivity of elastographic metrics to short-term functional demands [31]. A recent systematic review confirmed that UE—particularly SWE—provides reliable and clinically meaningful quantification of masticatory muscle elasticity, despite ongoing methodological heterogeneity [51].

EMG studies help contextualize the absence of short-term elastographic differences in the present study. Some investigations have shown increased MM and TM activation following correction of transverse discrepancies, whereas others have documented immediate reductions in muscle activity after expansion with gradual normalization during early retention [24, 52–54]. When baseline neuromuscular coordination is normal, EMG indices may remain unchanged despite correction of transverse deficiencies [21]. Taken together, these findings indicate that neuromuscular responses to RPE are variable, often modest, and sometimes transient—patterns consistent with the minimal early-phase elastographic changes observed here.

Broader SE and SWE literature also supports the lack of short-term changes in muscle stiffness or thickness. Studies across multiple muscle systems consistently show that substantial or repetitive loading—such as eccentric exercise, chronic parafunction, or neuromuscular pathology—is required to produce measurable stiffness alterations, whereas low-intensity or transient loading produces minimal or temporary effects [55–57]. Morphologic parameters such as muscle thickness typically remain stable over short intervals, even when stiffness changes occur, indicating that structural remodeling requires longer-term mechanical stimuli. The viscoelastic principles governing these responses are conserved across skeletal muscles, supporting the interpretation that RPE, which does not impose high-intensity or repetitive loading, would not be expected to elicit short-term adaptations in stiffness or thickness [32, 48, 58, 59]. In this context, early neuromuscular adaptations are unlikely to occur unless the applied mechanical stimulus exceeds a physiological threshold, and the forces generated during active expansion clearly fall below this level. This mechanistic framework further reinforces that the comparable SE, SWE, and thickness values observed in both appliance groups reflect insufficient muscular loading to trigger measurable remodeling.

The absence of intergroup differences in elastographic measures further suggests that neither TB-RPE nor TBB-RPE imposes sufficient short-term muscular demand to generate differential adaptive responses. In our sample, SE scores increased by approximately one unit across several muscles in both groups, whereas SWE values fluctuated in both directions without demonstrating a consistent pattern, and muscle thickness remained stable from T0 to T1. These within-group SE increases, in the absence of corresponding SWE or thickness changes, mirror prior research indicating that qualitative strain patterns may fluctuate with minor functional perturbations, whereas quantitative SWE and morphological parameters remain stable in the absence of meaningful mechanical loading [31, 51, 55–57]. These findings suggest that short-term RPE effects are predominantly skeletal, with minimal immediate influence on masticatory or suprahyoid muscle biomechanics [32, 48, 55–59]. Clinically, appliance selection during active expansion may therefore be guided primarily by skeletal and dental objectives rather than concerns regarding differential myofascial impact. Moreover, the preservation of SWE and thickness values underscores the short-term functional safety of RPE and suggests that routine elastographic monitoring is unnecessary in otherwise healthy adolescents.

The lack of significant differences may also be related to the short-term evaluation period. However, this finding is clinically relevant, as it indicates that early-phase RPE does not produce immediate alterations in muscle stiffness despite measurable skeletal changes.

This study has several limitations. Although midpalatal suture maturation was the primary determinant of expansion modality, the significant age difference between groups represents an inherent characteristic of the maturation-based protocol, and residual confounding by chronological age cannot be completely excluded. The relatively small sample size may have reduced the power to detect subtle intergroup differences, particularly in elastographic parameters. The short assessment window captures only the active expansion phase and does not reflect potential medium- or long-term adaptations. Elastography, especially SE, remains partially operator-dependent despite standardized protocols, and the use of a single device may limit generalizability. Future investigations with larger samples, extended follow-up, and broader muscular assessment are warranted. Although CBCT imaging involves ionizing radiation, all scans were obtained based on clinical indications using a low-dose protocol, and no additional imaging was performed exclusively for research purposes, thereby adhering to the ALARA principle.

5. CONCLUSION

Both TB-RPE and TBB-RPE produced comparable short-term skeletal expansion across the anterior, posterior, nasal, and maxillary transverse dimensions. Neither appliance generated measurable changes in masticatory or suprahyoid muscle thickness. Although SE demonstrated increased muscle stiffness from T0 to T1 in both groups, these adaptations were not appliance dependent, and SWE did not reveal consistent directional changes in elasticity. Overall, the two expansion protocols yielded similar skeletal and elastographic responses, indicating that short-term musculoskeletal adaptations are comparable regardless of whether tooth-borne or tooth-bone-borne anchorage is used.

Declarations

Conflict of interest

The authors declare that there are no conflicts of interest.

Ethics Approval and Consent to Participate

The study was approved by the Clinical Research Ethics Committee of XXX University (Approval No: 22/02; Date: 16 November 2023) and conducted in accordance with the Declaration of Helsinki.

Informed Consent

Written informed consent was obtained from all participants and from the parents or legal guardians of minors prior to inclusion in the study.

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DATA AVAILABILITY

All data generated and/or analysed for the current study will be made available from the corresponding author upon reasonable request.

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Figures

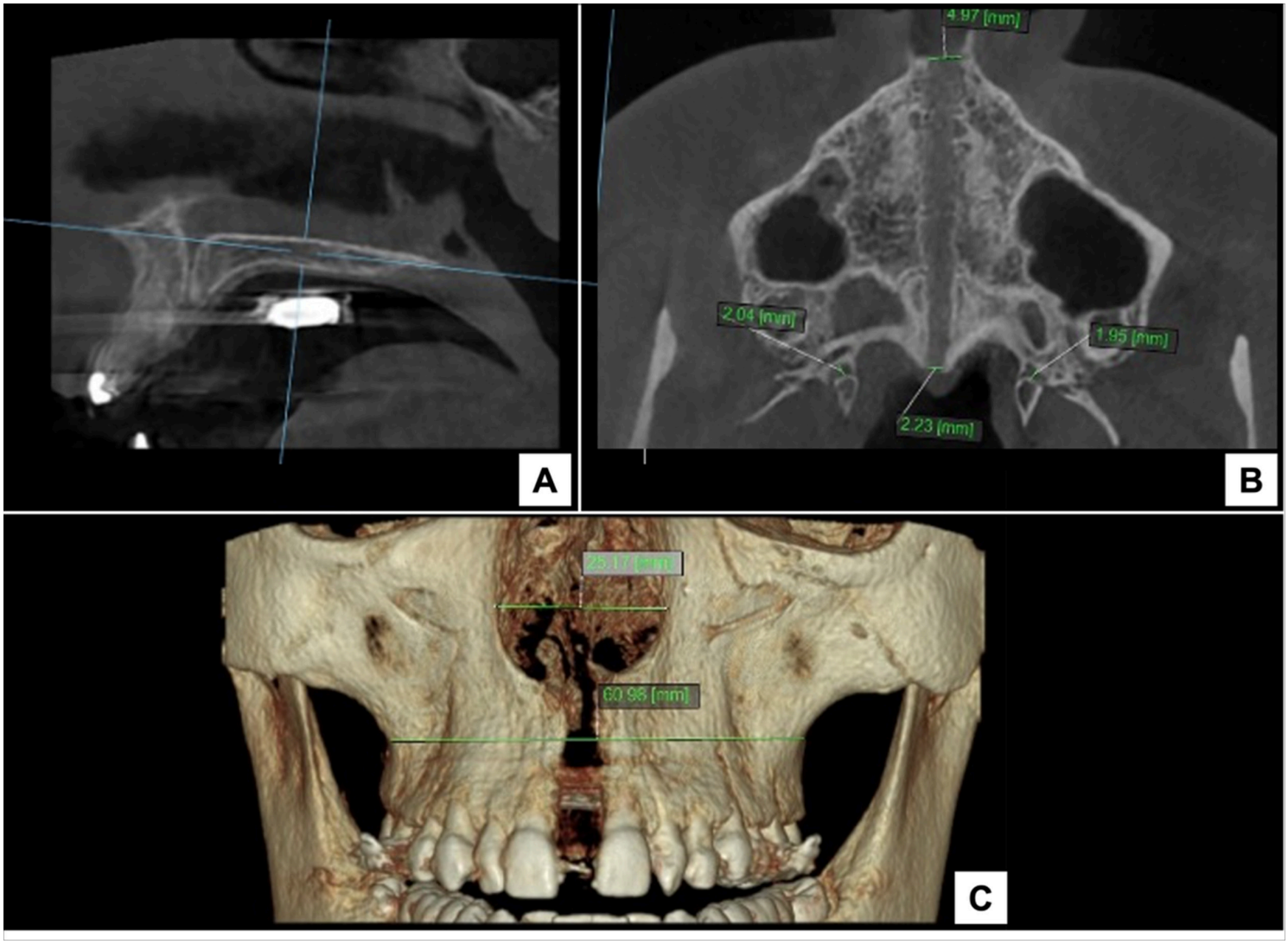


Figure 1

CBCT evaluation of skeletal structures, illustrating (A) palatal plane alignment in axial orientation, (B) suture separation measurements at ANS and PNS levels and (C) transverse maxillary and nasal width assessments on cross-sectional images.

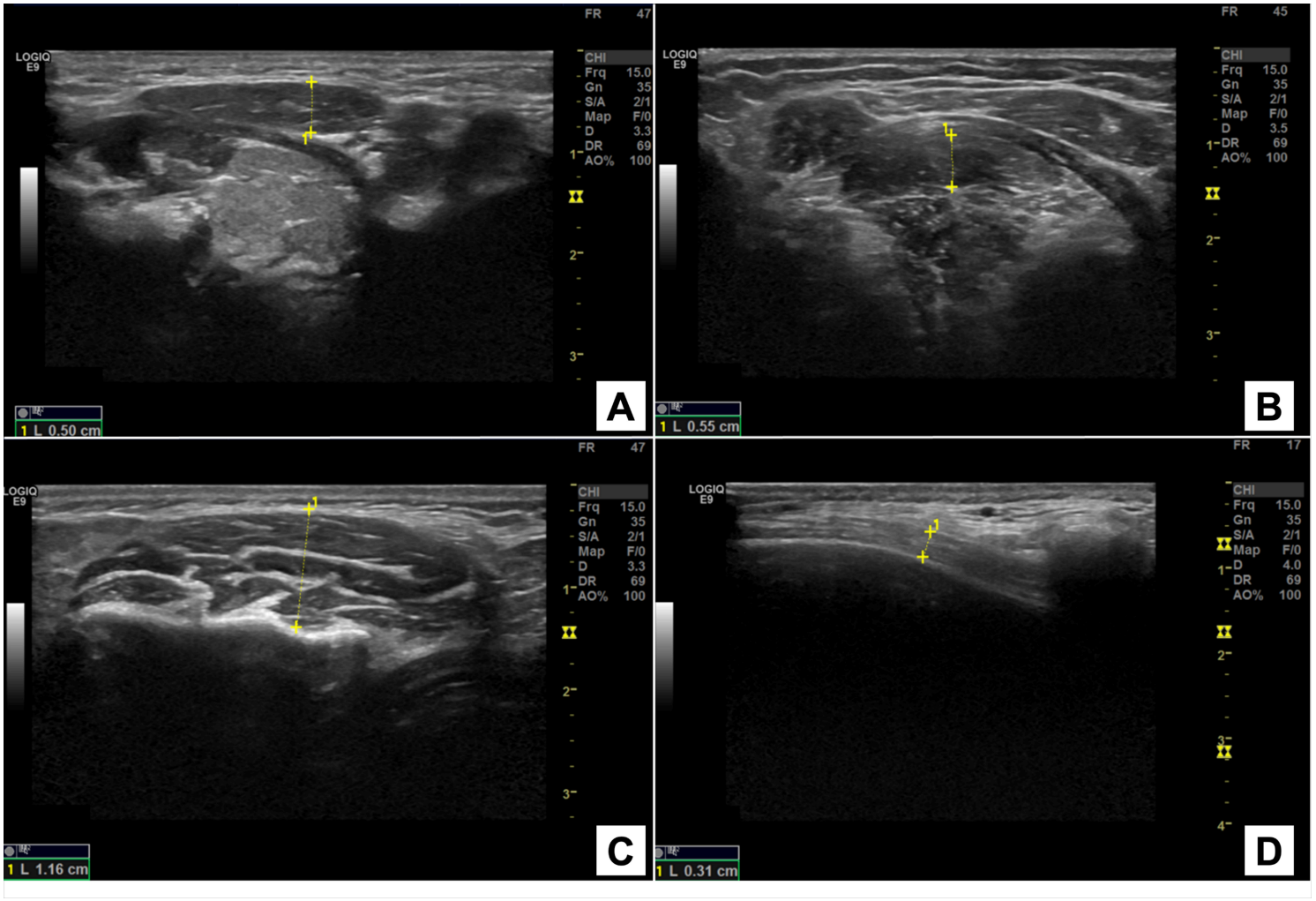


Figure 2

B-mode ultrasonographic assessment of orofacial muscle thickness at rest: (A) anterior digastric, (B) geniohyoid, (C) masseter, and (D) temporalis muscles.

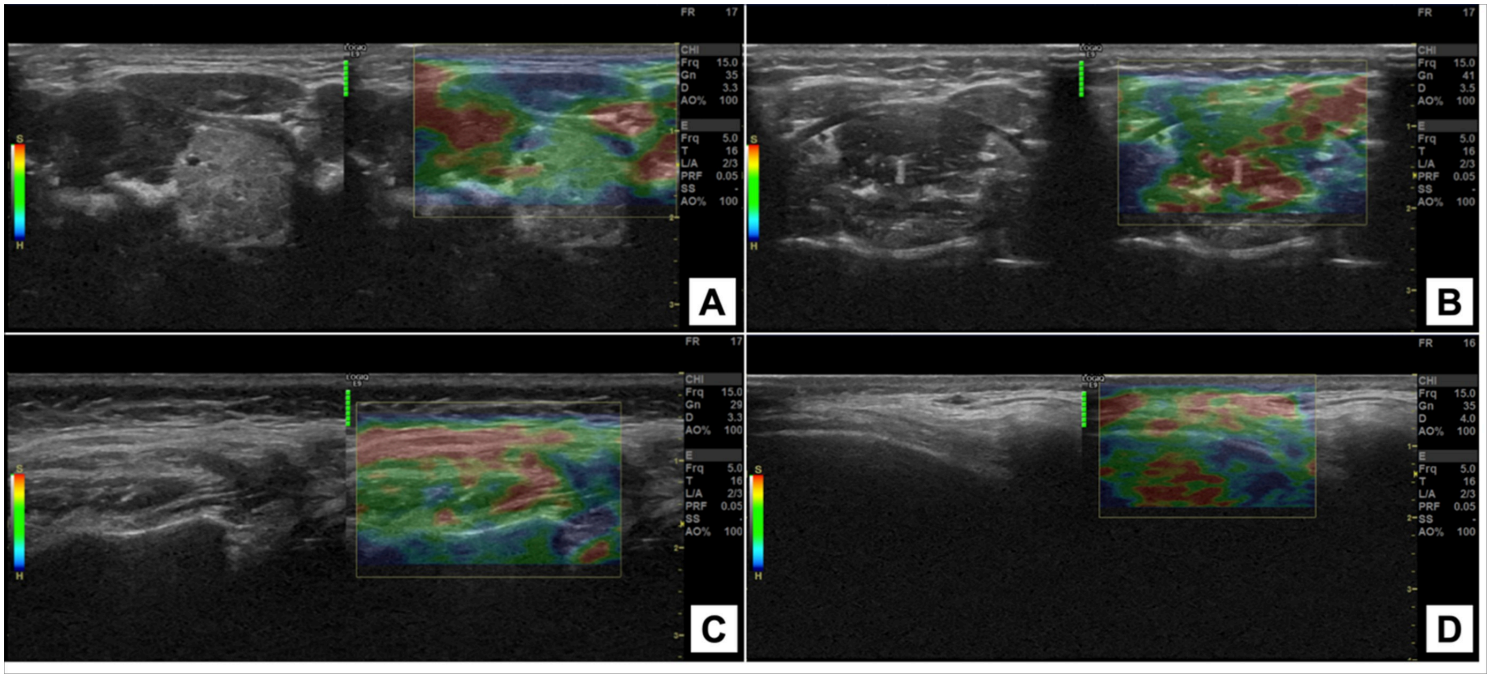


Figure 3

Strain elastography assessment of orofacial muscle stiffness at rest: (A) anterior digastric, (B) geniohyoid, (C) masseter, and (D) temporalis muscles.

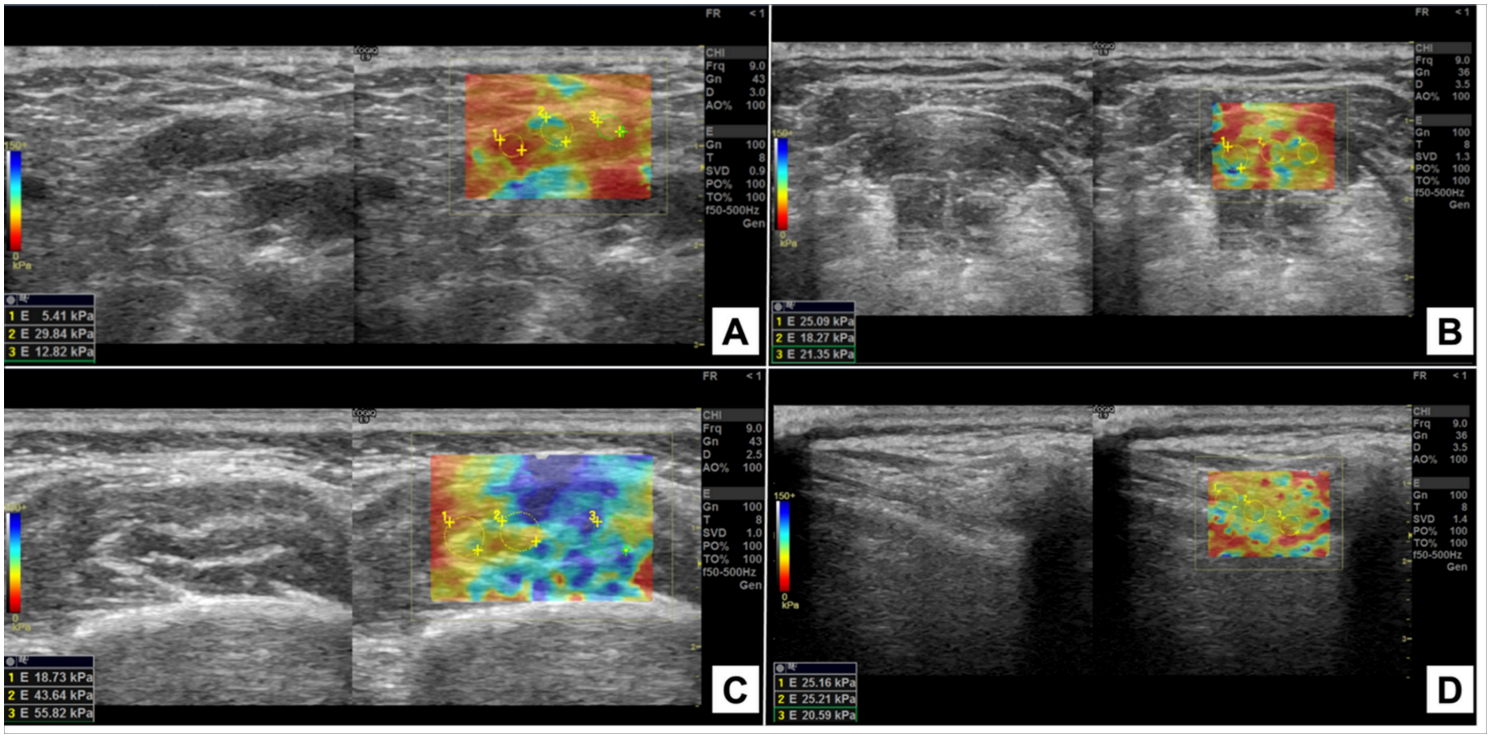


Figure 4

Shear-wave elastography assessment of orofacial muscle stiffness at rest, demonstrating quantitative elasticity measurements of the (A) anterior digastric, (B) geniohyoid, (C) masseter, and (D) temporalis muscles.