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Research article

Soft tissue compensation evaluation in patients with facial asymmetry using cone-beam computed tomography combined with 3D facial photographs

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A B S T R A C T

Objectives: This study aimed to evaluate bilateral soft tissue, hard and soft-tissue thickness at various anatomical levels in patients with facial asymmetries. Moreover, we attempted to find out correlation between soft-tissue compensation and severity of asymmetry by using cone-beam computed tomography (CBCT) combined with 3D facial photographs.

Study design: Based on menton deviation (MD), twenty-four subjects were divided into: mild-asymmetry group (n=12) and moderate-to-severe-asymmetry group (n = 12). CBCT images were superimposed with 3D facial photographs. Distance from the midsagittal plane to the outermost point of soft-tissue and hard-tissue were measured and calculated soft-tissue thickness. Comparison of soft-tissue thickness between deviated and contralateral side at any anatomical levels were performed within group, and correlation between bilateral soft-tissue thickness subtractions (soft-tissue compensation) and MD values was evaluated.

Results: Within group, Soft- and hard-tissue distances were greater in deviated side than contralateral side at any levels. In moderate-to-severe group, significant differences were found at gonion and body of mandible level, whereas soft-tissue thickness was only found to be higher on deviated side at the level of mandibular ramus. Soft tissue compensation was negatively correlated with MD value at level of mandibular ramus ($R = -0.5$, $P < 0.05$).

Conclusions: Asymmetry was found to be larger in the lower third of the face and was notably remarkable in the moderate-to-severe group. Soft-tissue thickness was thicker on the deviated side of the mandibular ramus. Thus, the soft-tissue compensation seems to be minimized in patients with more severe asymmetry.

1. Introduction

Recently, perceived esthetic problems have become a major driver for orthodontic treatment as individuals feel that certain imperfections affect how they are regarded by others [1–3]. One of the aspects that influences one's facial esthetic or facial attractiveness is facial asymmetry, which is responsible for 25% of the cases in which people seek orthodontic treatment. It also plays a crucial role in the front-view esthetic [3–5]. Normal human faces do not feature a truly symmetrical bilateral structure [2], and the slight deviations of a normal face within limits are defined as fundamental asymmetries that are common in healthy individuals [1,3,5,6]. Asymmetry can develop in either hard or soft tissue, or in both and the determination of facial asymmetry is subjective; it depends on the perception of patients and clinicians and the region of asymmetry. Some facial asymmetries are imperceptible due to slight deviations

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[5].

Conventional cephalometric radiographs combined with photographs have been commonly used in the analysis and assessment of facial asymmetry [7–9] but limitations exist in determining the structural landmarks because these methods reveal only two-dimensional (2D) aspects that do not truly reflect the three-dimensional (3D) structures of the skull [10]. Moreover, the distortion of the image and unsteadiness in the point of reference from overlapped facial architectures remain problematic [10–12]. An innovative method, cone-beam computed tomography (CBCT), has been introduced to improve the assessment of both hard- and soft-tissue morphology and the diagnosis of facial asymmetry. In addition, a recent method to overcome these limitations is 3D photogrammetry via facial scanners, such as the Morpheus 3D® scanner, which has important benefits: the image from the 3D facial scan is captured at an angle and distance that are independent and measurable, and an analysis in three planes of the axis can be adjusted by users. Thus, the soft-tissue image from a 3D facial scan is widely used in combination with the hard-tissue image from CBCT to evaluate the relationship between the soft and hard tissue and achieve a definitive diagnosis of facial asymmetry [13–15]. However, the hard- and soft-tissue relationships are not always harmonious. The soft tissue can either compensate or worsen the degree of hard-tissue asymmetry [6,12]. Additionally, the soft-tissue thickness, which is compensated for or masked by one's facial or masticatory muscle, body mass, aging, and skin tissue, varies in different regions of the face [3,4,6,12,16].

Many previous studies have investigated soft-tissue thickness in patients with asymmetry, as mentioned above. However, the association between the asymmetry of soft tissue and the severity of hard tissue asymmetry using a 3D facial photograph has not been clearly established. Furthermore, the current treatment paradigm emphasizes facial aesthetics rather than skeletal correction. With the use of more precise procedures, we can determine the relationship between hard tissue and soft tissue in the manner of soft tissue compensation in patients with asymmetry, leading to precise diagnosis and treatment plans for these individuals. Therefore, the purpose of this study was to evaluate differences in the soft tissue, hard tissue, and soft-tissue thickness between the deviated side and contralateral side in different regions of patient with facial asymmetry and to determine the correlation between soft-tissue compensation and skeletal asymmetry using CBCT combined with 3D facial photos.

2. Materials and methods

2.1. Study and subjects

All methods in this study were approved by the Ethics Committee of the institution (Approval No. EC/E−227/2563). Orthodontic patients who had an asymmetrical face with 1) ages 20–55; 2) a normal body mass index (BMI) according to the BMI Asian standard (value 18.5–22.9); 3) no functional shift due to dental interference; and 4) no facial deformities, facial malformations, congenital abnormalities in the maxillofacial region, history of facial trauma and/or infection, and prior facial surgery were recruited. Only thirty-five subjects who had a menton (Me) deviation based on screening PA cephalograms (Fig. 1) [9] and had some indications for CBCT were included. All subjects were informed about the purposes and methods of the study. Informed consent was obtained from all subjects.

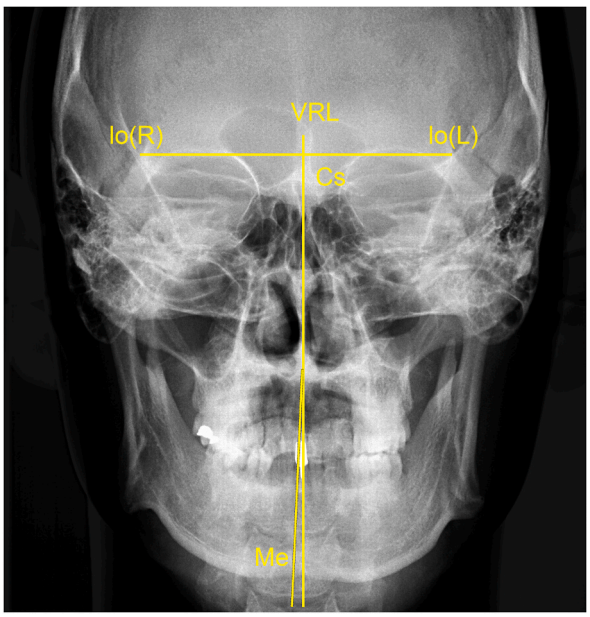

Fig. 1. The screening for facial asymmetry in this study used data from PA cephalometry; the deviation of the menton (Me) point from the vertical reference line (VRL), which was perpendicular to the horizontal reference line: lateral orbitale (Lo) left to right and intersecting crista galli (Cs).

2.2. Data acquisition and image reconstruction

Prior to orthodontic treatment, the left and right Alare (Al) were marked on the subjects' faces, and the interalar width was recorded to calibrate the scale during the measurement process. All of the subjects' weight and height were measured to confirm the individual's BMI. CBCT (Acteon Whitefox, Italy) was used for craniofacial hard-tissue data acquisition. The subjects' head position was set following the manufacturer's instructions in the maximum intercuspal position without an occlusal bite block. A single 360° rotation with an 18-s scan (tube voltage 105 kVp; current 10 mA) was taken. The Morpheus 3D® scanner (Morpheus Co., Seoul, Korea) was used to construct 3D facial images in the sitting position. This device has a short capturing time (approximately 0.8 s) and employs white light from light-emitting diodes as a light source. The scanning procedures were carried out in accordance with the manufacturer's instructions. Subjects sat 60–70 cm in front of the camera in the maximum intercuspation bite position (Fig. 2A). The entire face was then captured from three different horizontal angles (frontal, right oblique, and left oblique) (Fig. 2B). 3D images from these different orientations were fused, and the virtual 3D image was rendered by the Morpheus 3D® simulation software.

To superimpose CBCT images and 3D facial images, the DICOM file was opened in the Morpheus 3D software. The surface of the skin was determined by extracting the air boundary since the skin is surrounded by air. The acquired images were first modified by a thresholding step, excluding all pixels with densities less than −1024 HU and more than −670 HU. The CBCT and 3D facial surface images were then automatically registered using the surface-based registration algorithm (Fig. 3). The region of interest selected for registration was not subject to positional changes, such as the glabellar area and nasal bridge.

2.3. Reference planes and landmarks selection

The 3D reference plane was established by a midsagittal plane perpendicular to the horizontal plane. The midsagittal reference plane (MSP) was defined by the plane connecting two landmarks: Opisthion (Op) and Crista galli (Cg). The Frankfurt horizontal plane (FHP) was used as a horizontal reference plane, which was defined by the plane connecting three landmarks: the right and left Porion (Po) and the right Orbitale (Or). To identify asymmetry and allocate the study groups, we modified methods described by Lima et al. [17] Subjects who had a menton deviation (MD) of more than 2 mm from MSP in CBCT were defined as having "Asymmetry". The subjects were then divided into two groups depending on the severity of asymmetry: a mild group (MD between 2 and 3.5 mm) and a moderate-to-severe group (MD more than 4.5 mm).

After the reference plane was constructed, 11 subjects whose menton deviation was less than 2 mm and between 3.5 and 4.5 mm were excluded from our study to minimize measurement errors. Finally, a total of twenty-four subjects (N = 24) were included: a mild group (n = 12) and a moderate-to-severe group (n = 12).

The "deviated side" was referred to as the side on which the menton point deviated from the MSP, and the "contralateral side" was referred to as the opposite side. After automatic surface registration, hard-tissue landmarks, the Zygonion (Zy), the midpoint of the ramus (R), the Gonion (Go), and the midpoint of the mandibular body (B), were indicated on the skeletal part to represent each anatomical level on both sides of the face. Soft-tissue landmarks Zy', R′, Go', and B' were established by projecting the hard-tissue landmarks to the outermost soft-tissue boundary in the same coronal plane and perpendicular to the MSP. The left and right Al were marked in a 3D facial photograph (Fig. 4A and B). The definitions of all landmarks and reference planes are explained in Table 1.

2.4. Measurement and calculation

After all landmarks were located, the superimposed images were imported into the ImageJ Java-based image-processing program. The clinical interalar width was used to calibrate the dimensional scale in the software. The measurement conducted in this study was modified from Lima et al. [17] The distance from the O-point on the MSP perpendicular to each soft-tissue landmark (O-Soft) was

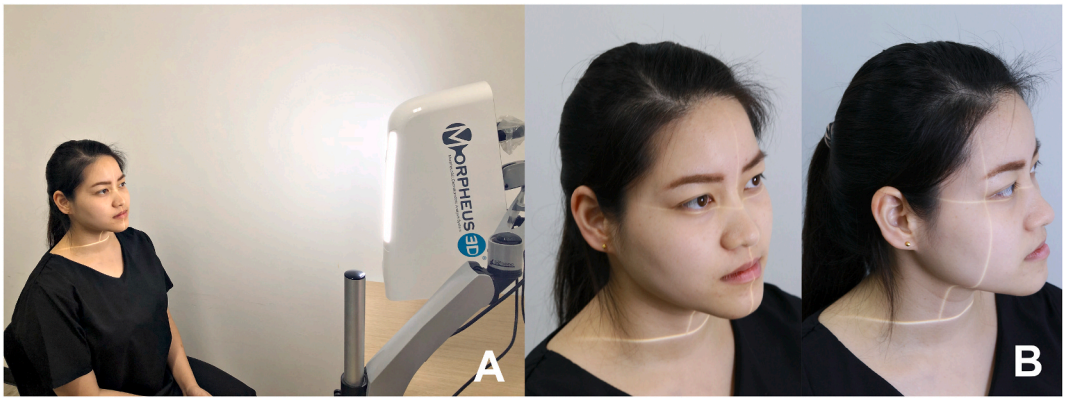

Fig. 2. During 3D facial image acquisition, the subject sat in front of the Morpheus 3D scanner approximately 60–70 cm (A), and the face was scanned in oblique views (B).

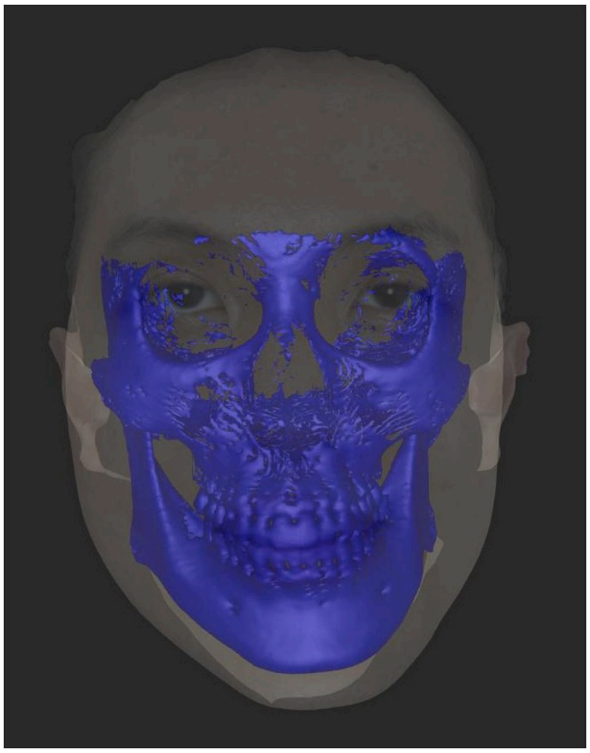

Fig. 3. The CBCT and 3D facial surface images were automatically registered by the surface-based registration algorithm.

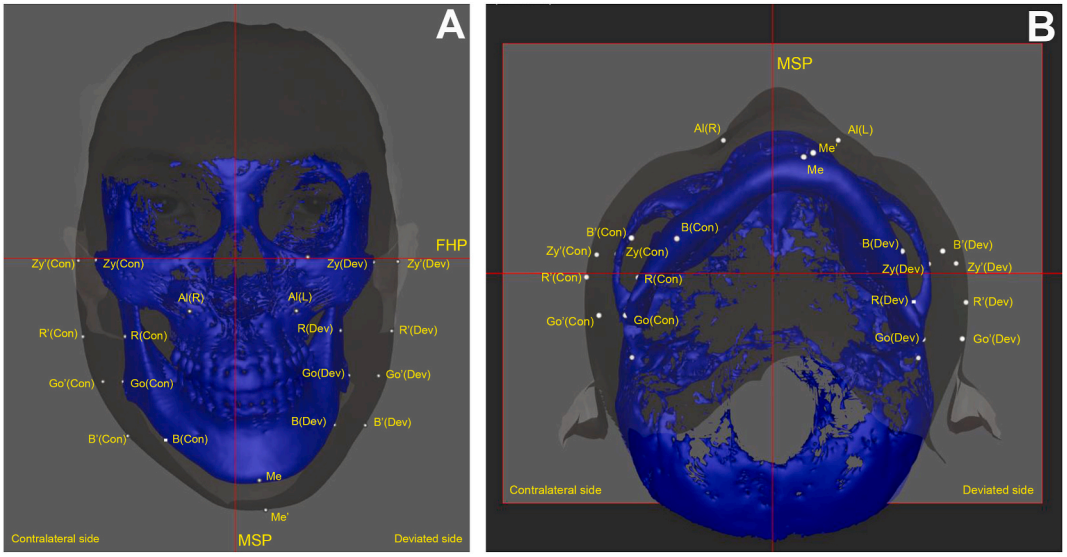

Fig. 4. The face was divided into two sides based on the menton deviation: deviated (Dev) and contralateral side (Con). All anatomical landmarks were located on CBCT imaging in the 3D Morpheus program. Hard tissue landmarks: Zy, zygonion; R, ramus of mandible; Go, gonion; B, body of mandible; Me, menton. Soft tissue landmarks: Zy', soft tissue zygonion; R′, soft tissue at ramus level; Go', soft tissue at gonion level; B′, soft tissue at body level; Me', soft tissue menton; Al(R), right alare; Al(L), left alare. Reference planes: MSP, midsagittal plane; FHP, Frankfort horizontal plane. In frontal view (A) and in transverse view (B).

measured both on the deviated side and contralateral side, known as "DeSoft" and "ConSoft", respectively (Fig. 5A), and from the O-point to each hard-tissue landmark (O-hard) on both sides, known as "DeHard" and "ConHard", respectively (Fig. 5B). The difference of DeSoft-DeHard and ConSoft-ConHard referred to the soft-tissue thicknesses, which were represented as "DeSoft-Th" and "ConSoft-Th", respectively (Fig. 5C). These differences were converted into soft-tissue compensation according to the following

Table 1
Definition of reference planes and landmarks used in this study.

Planes and landmarks	Definition
Reference planes	
Midsagittal plane (MSP)	The plane connecting the two landmarks, opisthion (Op), crista galli (Cg), and perpendicular to the horizontal plane
Horizontal plane	The plane connecting right and left porion and right orbitale
Midline landmarks	
Cg (Crista galli)	Most superior point of crista galli of ethmoid bone
Op (Opisthion)	The midpoint on the posterior margin of the foramen magnum
Me (Menton)	Lowest median landmark on the mandibular symphysis
O-point	The imaginary point on the midsagittal plane perpendicular to any point
Bilateral landmarks	
Po (Porion)	Most superior point of the external auditory maetus
Or (Orbitale)	Midpoint of the infraorbital margin
Alare (Al)	Most lateral point on each alar contour
Zy (Zygonion)	Most prominent point of the cheek area
Zy'	Soft tissue landmark at the level of zygonion
R	Midpoint of mandibular ramus indicated by intersection of the line passing through the coronoid notch and sigmoid notch
R'	Soft tissue landmark at the level of R
Go (Gonion)	Most lateral point on the mandibular angle
Go'	Soft tissue landmark at the level of gonion
B	Midpoint of mandibular body indicated by midpoint of the lower border of mandible
B'	Soft tissue landmark at the level of B
O-soft	The distance from O-point to any point on soft-tissue landmark
O-hard	The distance from O-point to any point on hard-tissue landmark

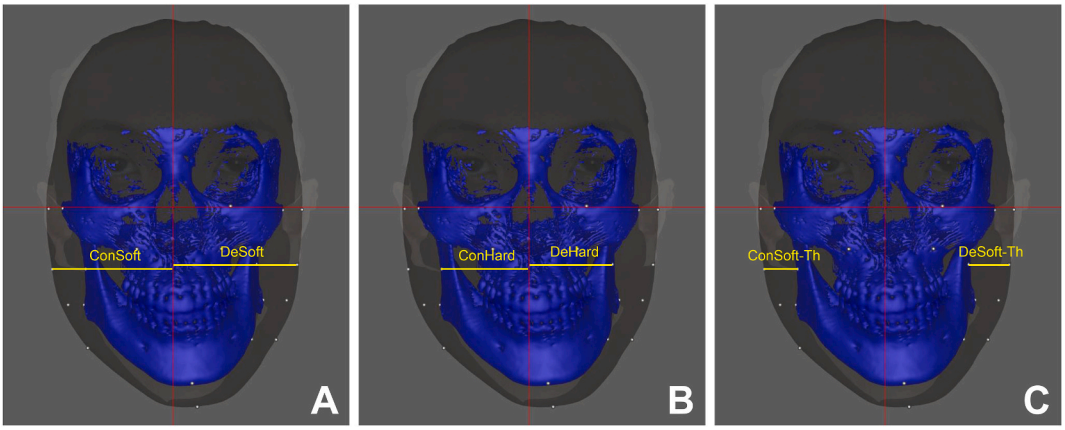

Fig. 5. Linear measurements were obtained from MSP perpendicular to all anatomical landmarks of soft tissue (A), hard tissue (B), and soft-tissue thickness (Soft-Th) is represented by the difference in distance between A and B (C).

formula:

Soft-tissue compensation = soft-tissue thickness (Con) – soft-tissue thickness (Dev)

A value ≤ 0 represents facial asymmetry without soft tissue compensation (the facial asymmetry could be similar to or more severe than the underlying skeletal asymmetry). A value > 0 represents facial asymmetry with soft tissue compensation (the underlying skeletal asymmetry might be concealed by covering soft tissue) (Fig. 6A–C).

All measurements were taken by one examiner (YS) and were repeated twice in 24 subjects within a two-week interval to evaluate the reproducibility. The intraexaminer reliability was analyzed using intraclass correlation coefficients (ICCs) and Bland–Altman plots.

2.5. Statistical analysis

The sample size was calculated with G*power software version 3.0.10 (Universitat Kiel, Universität Düsseldorf, Universität Mannheim, Germany), assuming the effect size of the correlation by Cohen's D was 0.5. A minimum of 24 subjects were required to provide an 80% statistical power of $\alpha = 0.05$.

All data were analyzed using IBM SPSS Statistics for Windows, Version 20.0 (IBM, Armonk, NY). A P value < 0.05 was considered statistically significant. The normality of the data variables was confirmed by the Shapiro–Wilk test. A descriptive analysis was used to report the mean difference in soft tissue, hard tissue, and soft-tissue thickness at different anatomical levels. The paired *t*-test was used to verify intragroup differences in soft tissue, hard tissue and soft-tissue thickness between the deviated and contralateral sides at all levels of the face (Zy, R, Go, B), and the correlation between soft-tissue compensation at each anatomical level and the menton

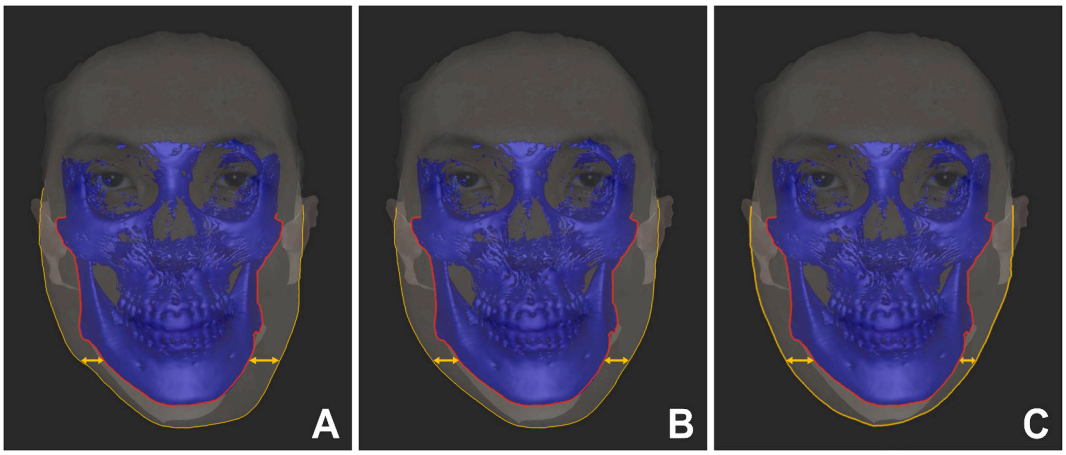

Fig. 6. Soft-tissue compensation calculated from soft-tissue thickness (Con) minus soft-tissue thickness (Dev). No soft-tissue compensation is represented by a zero or negative value (A and B). Soft-tissue compensation is represented by a positive value (C).

deviation from the MSP was observed using Pearson's correlation.

3. Results

The ICC calculated for repeated measurements ranged between 0.983 and 0.991 ($p < 0.001$), and the Bland–Altman plots revealed that difference measurement results fell within the 95% limits of agreement with few exception outliers, which is highly acceptable for intrarater reliability. Thirty-five subjects were included in the study, but only data from 24 subjects were analyzed. The cohort included 10 men and 14 women, with a mean age of 27.79 ± 7.41, mean MD of 4.57 ± 2.07, and mean BMI of 20.72 ± 1.92. The patients' demographic characteristics are presented in Table 2.

A descriptive data analysis of the deviated side and the contralateral side is shown in Table 3. On the deviated side, the mean soft-tissue thicknesses at the level of the zygonion, ramus, gonion, and body of the mandible were 9.95 ± 1.80, 18.14 ± 3.18, 11.35 ± 2.64, and 11.46 ± 2.24, respectively. On the contralateral side, the mean soft-tissue thicknesses at the level of the zygonion, ramus, gonion, and body of the mandible were 9.25 ± 1.67, 17.11 ± 3.10, 10.86 ± 2.83, and 11.55 ± 2.73, respectively.

In the mild-asymmetry group (MD between 2 and 3.5 mm), DeSoft and DeHard were statistically significantly greater than ConSoft and ConHard at the level of the body of the mandible ($P < 0.05$). Moreover, differences between DeSoft-Th and ConSoft-Th were not statistically significant at any anatomic level (Table 4).

In the moderate-to-severe-asymmetry group (MD > 4.5 mm from the MSP), DeSoft was greater than ConSoft at all levels of the mandible ($P < 0.05$) and DeHard was greater than ConHard at the level of the gonion and the body of the mandible ($P < 0.05$). Moreover, DeSoft-Th was significantly thicker than ConSoft-Th only at the level of the ramus of the mandible ($P < 0.05$) (Table 4).

The correlation between menton deviation and soft-tissue compensation was determined. A significant moderate negative correlation ($R < -0.5$) was found at the level of the ramus of the mandible (Tables 5 and 6). The regression plots are shown in Fig. 7.

4. Discussion

This cross-sectional study evaluated soft tissue, hard tissue, and soft-tissue thickness in any anatomical region of individuals with

Table 2
Demographic characteristics of the sample.

Characteristic	Total	Mild group	Moderate-to-severe group
Patients (n)	24	12	12
Male (n)	10	3	7
Female (n)	14	9	5
Age (y), mean ± SD	27.79 ± 7.41	27.00 ± 6.80	28.58 ± 8.20
Skeletal classification (n)			
Class I	9	4	5
Class II	5	3	2
Class III	10	5	5
ANB (°), mean ± SD	1.56 ± 4.36	2.01 ± 4.91	1.12 ± 3.90
Amount of deviation (Me deviation) (mm)	4.57 ± 2.07 (2.57–11.26)	3.10 ± 0.44 (2.57–3.47)	6.04 ± 2.03 (4.51–11.26)
• mean ± SD			
• range (min-max)			
BMI (value), mean ± SD	20.72 ± 1.92	20.16 ± 2.39	21.28 ± 1.14

Table 3
Mean soft-, hard-tissue distance and soft-tissue thickness between deviated side and contralateral side.

Anatomic region	*Deviated side (N = 24)*				*Contralateral side (N = 24)*				
	Min	Max	Mean	SD	Min	Max	Mean	SD	P
Zygonion									
Soft tissue	54.32	79.30	63.59	5.23	56.04	75.76	63.02	4.76	0.203
Hard tissue	47.29	65.71	53.64	4.56	47.58	66.27	53.77	4.61	0.719
Soft-tissue thickness	6.06	13.59	9.95	1.80	6.42	12.11	9.25	1.67	0.029
Ramus of mandible									
Soft tissue	52.71	74.48	59.73	5.21	51.17	69.74	58.20	4.76	0.005*
Hard tissue	35.88	49.67	41.59	3.16	35.65	48.06	41.10	3.13	0.423
Soft-tissue thickness	12.07	24.81	18.14	3.18	11.86	22.60	17.11	3.10	0.025
Gonion									
Soft tissue	45.40	65.07	52.79	4.73	45.02	58.06	50.13	3.92	0.000*
Hard tissue	35.05	57.57	41.14	3.73	32.64	48.45	39.27	3.94	0.007
Soft-tissue thickness	7.51	16.28	11.35	2.64	7.06	17.70	10.86	2.83	0.282
Body of mandible									
Soft tissue	42.56	57.57	47.48	4.20	38.52	51.04	43.56	3.32	0.000*
Hard tissue	30.82	43.25	36.02	3.14	25.00	37.35	32.01	2.65	0.000*
Soft-tissue thickness	7.84	15.96	11.46	2.24	6.38	16.31	11.55	2.73	0.788

*Statistically significant, which was defines as $P < 0.05$.

Table 4
Comparison of soft tissue, hard tissue, and soft-tissue thickness between deviated and contralateral side within group at different anatomical levels of the face.

Anatomic region	Mean differences (Deviated side - Contralateral side)					
	Mild group (n = 12)			*Moderate to severe group (n = 12)*		
	Mean	SD	P	Mean	SD	P
Zygonion						
Soft tissue difference	0.30	2.11	0.627	0.84	2.21	0.218
Hard tissue difference	−0.26	0.91	0.342	0.01	2.31	0.995
Soft-tissue thickness difference	0.57	1.50	0.219	0.83	1.49	0.080
Ramus of mandible						
Soft tissue difference	0.88	2.35	0.219	2.18	2.47	0.011*
Hard tissue difference	0.63	2.28	0.359	0.36	3.64	0.739
Soft-tissue thickness difference	0.25	1.36	0.534	1.82	2.50	0.028*
Gonion						
Soft tissue difference	1.50	2.81	0.092	3.82	2.52	0.000*
Hard tissue difference	1.49	2.94	0.107	2.25	3.30	0.038*
Soft-tissue thickness difference	0.01	1.70	0.989	0.97	2.53	0.213
Body of mandible						
Soft tissue difference	2.23	2.33	0.007*	5.61	2.62	0.000*
Hard tissue difference	2.50	1.63	0.000*	5.52	2.53	0.000*
Soft-tissue thickness difference	−0.26	1.49	0.553	0.09	1.71	0.862

*Statistically significant, which was defines as $P < 0.05$.

Table 5
Descriptive data analysis of soft-tissue compensation at different anatomical levels of the face.

Anatomic region	Soft-tissue thickness difference (Contralateral side - Deviated side)				
	N	Min	Max	Mean	SD
Zygonion	24	−4.11	1.78	−0.70	1.47
Ramus of mandible	24	−4.94	2.71	−1.04	2.12
Gonion	24	−4.56	4.82	−0.49	2.16
Body of mandible	24	−2.84	3.52	0.09	1.58

facial asymmetry, and the correlation between the amount of menton deviation and soft-tissue compensation was also analyzed. The subjects were divided into two groups: mild asymmetry and moderate-to-severe asymmetry. We observed that soft tissue and hard tissue tended to be more asymmetric to the deviated side in the lower face region of both groups. However, soft-tissue compensation was not observed.

Asymmetry refers to a condition in which any structure deviates from theoretically perfect symmetry, which can be found in any part of the human body, including the craniofacial complex. Asymmetry can be divided into three categories based on its cause:

Table 6
Pearson correlation coefficient between amount of deviation (menton deviation) and soft-tissue compensation in any levels of the face.

Soft-tissue compensation		Soft-tissue thickness difference (contralateral side - deviated side)			
		Zygonion	Ramus of mandible	Gonion	Body of mandible
Amount of deviation	R	−0.196	−0.513	−0.161	−0.121
	Sig.(2-tailed)	0.360	0.010[a]	0.451	0.574
	N	24	24	24	24

[a] Correlation significant at the 0.05 level (2-tailed).

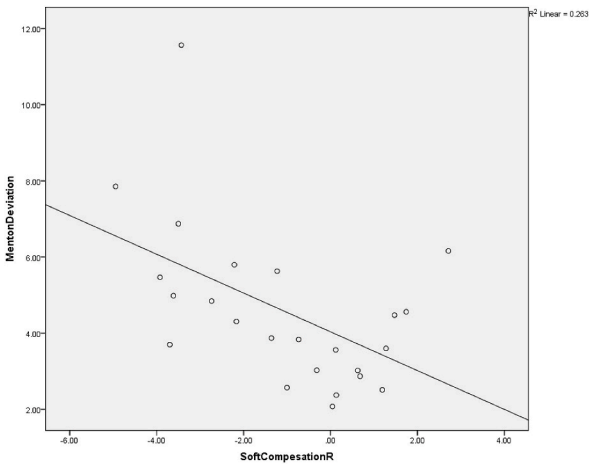

Fig. 7. - Regression plots quantifying the relationship between MD (mm) and soft-tissue compensation at the R level (mm). MD, menton deviation; R, ramus of mandible.

congenital, developmental, and acquired [5,18]. Bishara et al. classified the etiology of asymmetry into five categories based on structural involvement: dental, skeletal, muscle, functional, and combination [19]. Minor facial asymmetry, also known as relative symmetry or fundamental asymmetry, is a condition typically found in the human face due to imbalanced growth during maturity [3,6,18]. More severe asymmetry can be detected by the patient's or clinician's perception of facial soft-tissue imbalance and the patient's abnormal head posture [1,5].

Epidemiological studies of soft-tissue morphology in facial asymmetry have been widely assessed in different ethnic groups and sexes, along with various skeletal patterns. Haragushi et al. found no difference in asymmetry between skeletal Class I, II, or III malocclusion [20]. Our study recruited patients with asymmetry in all anteroposterior skeletal relationships, and we found that moderate-to-severe asymmetry was mostly observed in the Class III skeletal pattern, which corroborated studies by Good et al. [21] and Gribel et al. [22] However, the skeletal class II appeared to be the least common [23].

Facial asymmetry can be independently detected depending on personal perceptions and the severity of asymmetry. The perception of chin asymmetry has been researched, and the authors discovered that orthodontists could diagnose chin deviation more accurately than laypeople. Two degrees, or approximately 2 mm of chin deviation, can be identified by orthodontists, while the threshold for laypeople is approximately 3° or 3.5 mm, according to Krystian et al. [3,24,25] Many studies have suggested that a difference of more than 2 mm from the facial midline is considered asymmetric [8,17,26]. In our method, subjects with a menton deviation greater than 2 mm from PA cephalograms were screened, and thirty-five orthodontic patients were recruited for the study. Although asymmetry resulted from many contributing factors with respect to maxillary height, ramus length, ramus inclination, body height, and body length, the menton point was chosen for group categorization because it demonstrated the greatest effect of deviation and was readily apparent [27–30]. The severity of asymmetry in all subjects was categorized into two groups based on the amount of deviation in CBCT: mild group (menton deviation between 2 and 3.5 mm) and moderate-to-severe group (menton deviation greater than 4.5 mm), which corresponded with the study of Lum et al. that divided asymmetry into three groups (surface area deviation $\leq$2 mm, 2–5 mm, and >5 mm for mild, moderate, and severe asymmetry, respectively) [31]. Furthermore, subjects with menton deviations between 3.5 and 4.5 mm were excluded from our study group to minimize measurement error, which could affect categorization, as recommended by Lima and colleagues. They divided subjects into a symmetric group with menton deviations of less than 2 mm and an asymmetric group with menton deviation greater than 3.5 mm and rejected those with menton deviations between 2 and 3.5 mm [17].

Given the many disadvantages of PA cephalometry, such as imaging distortion, magnification errors, inconsistency of reference points from overlapped architectures, and the inability to adequately reflect the three-dimensional hard-tissue structures, we decided to use 3D-CBCT to confirm the menton deviation. CBCT was superior to PA cephalometry in comprehending the craniofacial complex and was suggested to provide a more accurate diagnosis for asymmetry [27,32]. Thus, five individuals with menton deviations of less than 2 mm were excluded from our study after the amount of menton deviation was validated by CBCT.

Soft tissue data have traditionally been gathered using two-dimensional photogrammetry. However, this method can only display one-angle views that are influenced by the capturing distance and angle, resulting in inconsistent results. Since the early 2000s, 3D photogrammetry has been gradually developed, and has provided numerous advantages over traditional 2D photographs. First, user-guided landmark localization can be used to obtain linear measurements. Second, angles, surface area, and volume may be quantified, allowing x-axis, y-axis, and z-axis translation and rotation to be separated and studied separately. Additionally, the high-resolution images in color and texture at a relatively fast speed are the main reasons for its popularity [13,14]. Even though this method has had some distortions in overlapping areas and has failed to accurately represent the submental area, several investigations revealed that the Morpheus 3D® scanner was sufficiently accurate for clinical application, diagnosis, and attaining satisfactory treatment outcomes [13,15]. Few studies have reported the high accuracy and consistency of this method, and the discrepancy in the interalar width between direct measurement and 3D facial photography was less than 0.2 mm [13,15,33]. As a result, we used this distance as a measurement calibration reference.

CBCT has been used in many previous studies for skeletal and soft tissue examination. However, soft tissue investigation in CBCT might be problematic due to the longer capturing time and the existence of surface distortions caused by patient movement and CBCT stabilizers. In this study, we used surface images from 3D face scans, which could resolve these problems and provide notable supplemental missing anatomical data from CBCT, such as for the nose and chin [34]. We utilized surface-based registration to superimpose DICOM skin from CBCT with 3D surfaces from 3D facial photographs, with an average surface discrepancy of 0.6 mm, suggesting that the method is highly accurate [35].

The selection of a reference plane for 3D analysis is crucial in determining the severity of asymmetry. Patients with facial asymmetry commonly place their heads in a compensating posture to mask the asymmetric characteristics. Moreover, the spatial localization between the left and right anatomic structures may be modified among different reference planes. Many previous studies have proposed various landmarks for identifying the reference plane both in a 2D cephalogram and a 3D-CBCT image. For example, Hwang et al. recommended using midline landmarks as references to assess facial asymmetry due to their constant positions [6].

In our study, we used the Frankfort horizontal reference plane, which was constructed from the left and right porion and the right side of the orbitale, because it consisted of sufficiently stable landmarks and was suitable for identifying the reference plane [25,27,36]. The MSP should consist of the central structures because their positions are stable and constant [6]. The Crista gali, and opisthion, which have a higher stability and reproducibility because they reach more than 85% of their total size by the age of five [27,28,32,37] were chosen for our study. We avoided using any landmarks on the maxilla, such as the anterior nasal spine (ANS) or zygomaticomaxillary suture, because of the possibility of maxillary asymmetry [36]. Furthermore, Baek et al. discovered a strong correlation between MD and ANS deviation [25]. Hence, we selected midline structures on the cranial base as reference planes since they are more consistent than those in the maxilla or mandible. However, a variety of midsagittal planes are available for CBCT analysis, and the results must be interpreted considering the use of various reference planes. Specifically, other varieties of the midsagittal plane have not been compared to the vertical reference plane used in this study. Further studies may be necessary to validate the midsagittal plane used in this study.

In our study, we compared the differential distance - the linear measurement from the MSP to the hard-tissue (Zy, R, Go, B) and soft-tissue landmark (Zy', R′, Go', B') - between the deviated side and the contralateral side at any anatomical level of the face to represent the amount of asymmetry. We found that the amount of asymmetry gradually increased from the upper to lower region both in soft tissue and hard tissue, in accordance with many previous studies that showed that the hard-tissue deviation was mostly found to be greater in the lower region of the face [3–5,7,17,18,38]. This difference is probably caused by the longer period of mandibular growth and the fact that the mandible is more movable than midface structures which adhere rigidly to the cranial base [18]. Similarly, soft-tissue deviation was more likely to occur in the lower and lateral regions of the landmarks, both in terms of distance and frequency [2,8,16,39].

In the mild group, only the region of the body of the mandible had a remarkable deviation in both hard- and soft tissue. Moreover, the moderate-to-severe group shared the same characteristics as the mild group, but soft- and hard-tissue differences in the gonion region and only a soft-tissue difference in the ramus region were also observed. Lima et al. evaluated asymmetric differences in the posterior region of the mandible between the deviated and contralateral sides in the asymmetric group, which can be attributed to the level of gonion in our study [17]. Duran et al. also stated that the most deviated areas in hard and soft tissues were the corpus of the mandible and the lower cheek, respectively, which might have occurred at the body of the mandible in our study [38]. However, Nur et al. found no difference in soft-tissue thickness at the gonion level between the symmetric and asymmetric groups, which could be due to discrepancies in reference plane selection and soft-tissue landmark localization in different coronal planes [3].

Our findings revealed that the soft tissue on the deviated side was thicker than that on the contralateral side, specifically at the level of the mandibular ramus in the moderate-to-severe group. This finding is supported by the literature, where no difference in bilateral soft-tissue thickness of an asymmetrical face was reported. The authors concluded that soft-tissue did not compensate for the underlying skeletal asymmetry [17,38,40]. Unlike several studies where the soft tissue on the deviated side was reported to be thinner than that on the contralateral side, leading to the presence of soft-tissue compensation [6,12]. This variation observed might be attributed to differences in measuring methodologies and the severity of menton deviation of sample groups. In the study of Lee et al. (2013), they included only patients with skeletal class III who had significant mandibular asymmetry. Mean menton deviation was reported as 7.7 mm in their study, whereas the average menton deviation of our samples was 6.04 mm. Although, a greater soft tissue thickness in non-deviated side was observed at the middle of mandibular ramus, Tam et al. (2023) noted that it might not be clinically significant [41].

The soft tissue layer commonly consists of skin, fat, and muscle layers [42]. These factors could influence soft-tissue asymmetry. Our study attempted to eliminate the body-fat factor by including only subjects with a normal BMI and discovered that soft-tissue

compensation was absent. This finding could imply that the fat layer might be a factor that could disguise underlying skeletal asymmetry. In addition, we assumed that the masseter muscle could also have an effect on these soft-tissue asymmetries because this muscle is mostly located at the ramus and angle of the jaw. Lima and colleagues believed that facial asymmetry could be influenced by the masseter muscle [17], especially in patient with unilateral posterior crossbite [43], which could impact soft-tissue thickness, muscle asymmetry, and alter the severity of skeletal asymmetry [3].

In our study, we discovered a negative correlation between menton deviation and soft-tissue compensation at the level of the mandibular ramus. This finding suggests that an increase in menton deviation could exacerbate facial contour irregularities. Interestingly, our results contrast with a report by Lima et al. [17], who observed no correlation between menton deviation and soft-tissue thickness. They speculated that their findings might be attributed to a limited variability in menton deviation values in their study. In contrast, our research demonstrated a broad range of menton deviations, ranging from 2.57 to 11.26 mm.

Our findings could have practical implications in clinical practice, particularly for patients undergoing orthognathic surgery for asymmetry. Notably, orthognathic surgery significantly improves menton deviation but does not have a substantial impact on gonion. Some asymmetries may persist following surgery because soft-tissue changes are smaller than hard-tissue changes, and soft-tissue responses vary in different areas of the face [44,45]. Thus, postoperative soft-tissue contour correction with free-fat transfer, fat-graft injection, alloplastic implants, liposuction, and botulinum toxin injection may be necessary to rectify this residual asymmetry [46]. We recommend focusing on the ramus area, characterized by thicker soft tissue compared to the rest of the face. This area may still exhibit some facial asymmetry post-surgery, particularly in patients with moderate to severe asymmetry and/or a menton deviation exceeding 4.5 mm.

Nevertheless, predicting the state of soft tissue clinically proves challenging, given its susceptibility to various influencing factors, including skin tissue, muscle elongation, muscle orientation, mastication preference, and an individual's vertical facial pattern [6,47,48]. Patients demonstrating marked facial asymmetry commonly manifest a unilateral or bilateral posterior crossbite, altering the performance of masticatory muscles during the process of mastication. This compromised muscular coordination may contribute to asymmetry in soft tissue thickness [43]. Evidence suggested that the early correction of these posterior crossbite through maxillary expansion had the potential to restore two-arch coordination and muscle function, facilitated by the spontaneous adaptive dentoalveolar compensation observed in the lower arch [49]. The re-centering of the menton point was attributed to this compensatory mechanism, whereby the contralateral hemi-mandibular demonstrated a greater growth rate compared to the deviated side, resulting in an observable improvement in soft-tissue symmetry in the lower face [49,50].

In our study, when soft-tissue menton or chin point deviation were identified in patients with facial asymmetry, a PA cephalogram was proposed. This landmark is critical for the initial evaluation of asymmetry since it serves as a reference point. Although 3D facial photographs have many advantages over 2D photographs, image processing distortions restrict us from precisely determining the soft-tissue menton deviation and submental area in 3D photographs, and research on the accuracy of the chin point in 3D images remains limited. Recently, there were many 3D imaging technologies which could aid clinicians to precisely diagnose of facial asymmetry and be valuable for further research. A superimposition of bilateral color-coded distance map by surface-based registration seems to be the most accurate and validate method for using stereophotogrammetry, laser scanning, and 3D optical sensors [51]. However, this type of method requires an adequate software and be quite expensive. Future research should encompass soft- and hard-tissue mentons, employing more refined methods to effectively evaluate asymmetry in a larger sample size. Exploring changes in soft-tissue thickness before and after orthognathic surgery across various facial levels using 3D technologies, tailored to individual skeletal patterns, could enhance our comprehension of soft-tissue compensation.

5. Conclusions

1. Facial asymmetry increased gradually from the upper to the lower part of the face. The mean difference in soft- and hard-tissue between the deviated and contralateral sides was significantly different only at the level of the body of the mandible in mild asymmetry but it was significantly different at the level of the gonion and the body of the mandible in moderate-to-severe asymmetry.
2. The soft-tissue was significantly thicker on the deviated side of the mandibular ramus. A moderate level of inverse correlation was observed between the menton deviation and soft-tissue compensation. Thus, soft-tissue compensation seems to be minimized in patients with more severe asymmetry, which may indicate the possibility of facial asymmetry after orthognathic surgery.

CRediT authorship contribution statement

Yannapat Supmaneenukul: Writing – original draft, Software, Project administration, Methodology, Formal analysis, Data curation. **Chinnachote Khemla:** Visualization, Software, Resources. **Kulthida Parakonthun:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

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

References

[1] M.S. Lee, et al., Assessing soft-tissue characteristics of facial asymmetry with photographs, Am. J. Orthod. Dentofacial Orthop. 138 (1) (2010) 23–31.
[2] T.G. Kwon, et al., A comparison of craniofacial morphology in patients with and without facial asymmetry–a three-dimensional analysis with computed tomography, Int. J. Oral Maxillofac. Surg. 35 (1) (2006) 43–48.
[3] R.B. Nur, D.G. Cakan, T. Arun, Evaluation of facial hard and soft tissue asymmetry using cone-beam computed tomography, Am. J. Orthod. Dentofacial Orthop. 149 (2) (2016) 225–237.
[4] S. Olate, et al., Soft and hard tissue relations in facial asymmetry, Int. J. Morphol. 34 (3) (2016).
[5] D. Srivastava, et al., Facial asymmetry revisited: Part I- diagnosis and treatment planning, J Oral Biol Craniofac Res 8 (1) (2018) 7–14.
[6] H.S. Hwang, et al., Three-dimensional soft tissue analysis for the evaluation of facial asymmetry in normal occlusion individuals, Korean J Orthod 42 (2) (2012) 56–63.
[7] V.F. Ferrario, et al., Distance from symmetry: a three-dimensional evaluation of facial asymmetry, J. Oral Maxillofac. Surg. 52 (11) (1994) 1126–1132.
[8] S. Haraguchi, K. Takada, Y. Yasuda, Facial asymmetry in subjects with skeletal Class III deformity, Angle Orthod. 72 (1) (2002) 28–35.
[9] N. Masuoka, et al., Can cephalometric indices and subjective evaluation be consistent for facial asymmetry? Angle Orthod. 75 (4) (2005) 651–655.
[10] G.R. Swennen, et al., A new method of 3-D cephalometry Part I: the anatomic Cartesian 3-D reference system, J. Craniofac. Surg. 17 (2) (2006) 314–325.
[11] A. Katsumata, et al., 3D-CT evaluation of facial asymmetry, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 99 (2) (2005) 212–220.
[12] S.T. Lee, et al., Does skeletal surgery for asymmetric mandibular prognathism influence the soft tissue contour and thickness? J. Oral Maxillofac. Surg. 71 (9) (2013) 1577–1587.
[13] S.H. Kim, et al., Accuracy and precision of integumental linear dimensions in a three-dimensional facial imaging system, Korean J Orthod 45 (3) (2015) 105–112.
[14] K.Y. Nahm, et al., Accurate registration of cone-beam computed tomography scans to 3-dimensional facial photographs, Am. J. Orthod. Dentofacial Orthop. 145 (2) (2014) 256–264.
[15] S.H. Oh, et al., Linear accuracy of cone-beam computed tomography and a 3-dimensional facial scanning system: an anthropomorphic phantom study, Imaging Sci Dent 48 (2) (2018) 111–119.
[16] V.F. Ferrario, et al., The effect of sex and age on facial asymmetry in healthy subjects: a cross-sectional study from adolescence to mid-adulthood, J. Oral Maxillofac. Surg. 59 (4) (2001) 382–388.
[17] L.S. de Lima, D.P. Brunetto, M.d.C.G. Nojima, Evaluation of facial soft tissue thickness in symmetric and asymmetric subjects with the use of cone-beam computed tomography, Am. J. Orthod. Dentofacial Orthop. 155 (2) (2019) 216–223.
[18] G. Thiesen, B.F. Gribel, M.P. Freitas, Facial asymmetry: a current review, Dental Press J Orthod 20 (6) (2015) 110–125.
[19] S.E. Bishara, P.S. Burkey, J.G. Kharouf, Dental and facial asymmetries: a review, Angle Orthod. 64 (2) (1994) 89–98.
[20] S. Haraguchi, Y. Iguchi, K. Takada, Asymmetry of the face in orthodontic patients, Angle Orthod. 78 (3) (2008) 421–426.
[21] S. Good, et al., A computerized photographic assessment of the relationship between skeletal discrepancy and mandibular outline asymmetry, Eur. J. Orthod. 28 (2) (2006) 97–102.
[22] B.F. Gribel, et al., Prevalence of mandibular asymmetry in skeletal Class I adult patients, Journal of Research in Dentistry 2 (2) (2014) 189–197.
[23] T. Severt, W. Proffit, The prevalence of facial asymmetry in the dentofacial deformities population at the University of North Carolina, Int. J. Adult Orthod. Orthognath. Surg. 12 (3) (1997) 171–176.
[24] K.F. Jarosz, et al., Perceptions of chin asymmetries among dental professionals and laypersons, Am. J. Orthod. Dentofacial Orthop. 154 (2) (2018) 201–212.
[25] S.H. Baek, et al., Skeletodental factors affecting chin point deviation in female patients with class III malocclusion and facial asymmetry: a three-dimensional analysis using computed tomography, Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 104 (5) (2007) 628–639.
[26] H.-K. Noh, H.-S. Park, Does maxillary yaw exist in patients with skeletal Class III facial asymmetry? Am. J. Orthod. Dentofacial Orthop. 160 (4) (2021) 573–587.
[27] H.-S. Hwang, et al., Maxillofacial 3-dimensional image analysis for the diagnosis of facial asymmetry, Am. J. Orthod. Dentofacial Orthop. 130 (6) (2006) 779–785.
[28] R.M. Yáñez-Vico, et al., Three-dimensional evaluation of craniofacial asymmetry: an analysis using computed tomography, Clin. Oral Invest. 15 (5) (2011) 729–736.
[29] S. Tyan, et al., Three-dimensional analysis of molar compensation in patients with facial asymmetry and mandibular prognathism, Angle Orthod. 86 (3) (2016) 421–430.
[30] K.-A. Kim, et al., Targeted presurgical decompensation in patients with yaw-dependent facial asymmetry, The korean journal of orthodontics 47 (3) (2017) 195–206.
[31] V. Lum, et al., Three-dimensional assessment of facial asymmetry using dense correspondence, symmetry, and midline analysis, Am. J. Orthod. Dentofacial Orthop. 158 (1) (2020) 134–146.
[32] J. Damstra, et al., A three-dimensional comparison of a morphometric and conventional cephalometric midsagittal planes for craniofacial asymmetry, Clin. Oral Invest. 16 (1) (2012) 285–294.
[33] J.R. Gwilliam, S.J. Cunningham, T. Hutton, Reproducibility of soft tissue landmarks on three-dimensional facial scans, Eur. J. Orthod. 28 (5) (2006) 408–415.
[34] S.A. Schendel, C. Lane, 3D orthognathic surgery simulation using image fusion, in: Seminars in Orthodontics, Elsevier, 2009.
[35] K.-Y. Nahm, et al., Accurate registration of cone-beam computed tomography scans to 3-dimensional facial photographs, Am. J. Orthod. Dentofacial Orthop. 145 (2) (2014) 256–264.
[36] C. Baek, et al., Morphologic evaluation and classification of facial asymmetry using 3-dimensional computed tomography, Journal of Oral and maxillofacial Surgery 70 (5) (2012) 1161–1169.
[37] K.W. Yoon, et al., Deviation of landmarks in accordance with methods of establishing reference planes in three-dimensional facial CT evaluation, Imaging science in dentistry 44 (3) (2014) 207–212.
[38] G.S. Duran, F. Dĭndaroğlu, P. Kutlu, Hard-and soft-tissue symmetry comparison in patients with Class III malocclusion, Am. J. Orthod. Dentofacial Orthop. 155 (4) (2019) 509–522.
[39] V.F. Ferrario, et al., Craniofacial morphometry by photographic evaluations, Am. J. Orthod. Dentofacial Orthop. 103 (4) (1993) 327–337.
[40] N.M. Young, et al., Facial surface morphology predicts variation in internal skeletal shape, Am. J. Orthod. Dentofacial Orthop. 149 (4) (2016) 501–508.
[41] T.K.M. Tam, et al., Hard and soft tissue asymmetry in patients with skeletal class III malocclusion: a cone-beam computed tomography study, Diagnostics 13 (5) (2023) 869.
[42] K.-M. Park, et al., The relationship between masseter muscle thickness measured by ultrasonography and facial profile in young Korean adults, Imaging science in dentistry 48 (3) (2018) 213–221.
[43] G. Iodice, et al., Association between posterior crossbite, skeletal, and muscle asymmetry: a systematic review, EJO (Eur. J. Orthod.) 38 (6) (2016) 638–651.
[44] H.-L. Cao, et al., Quantification of three-dimensional facial asymmetry for diagnosis and postoperative evaluation of orthognathic surgery, Maxillofacial Plastic and Reconstructive Surgery 42 (1) (2020) 1–11.
[45] D.H. Ajmera, et al., Three-dimensional evaluation of soft-tissue response to osseous movement after orthognathic surgery in patients with facial asymmetry: a systematic review, J. Cranio-Maxillofacial Surg. 49 (9) (2021) 763–774.
[46] D. Srivastava, et al., Facial asymmetry revisited: Part II-Conceptualizing the management, J Oral Biol Craniofac Res 8 (1) (2018) 15–19.
[47] Y. Gomez, et al., Cross-sectional human study of soft tissue chin (STC) thickness in adult patients in relation to sex, facial pattern and skeletal class, J. Cranio-Maxillofacial Surg. 45 (8) (2017) 1205–1211.
[48] T.-G. Kwon, et al., Relationship between the masticatory muscles and mandibular skeleton in mandibular prognathism with and without asymmetry, J. Oral Maxillofac. Surg. 65 (8) (2007) 1538–1543.

[49] M. Macrì, F. Festa, Three-dimensional evaluation using CBCT of the mandibular asymmetry and the compensation mechanism in a growing patient: a case report, Front. Public Health 10 (2022) 921413.
[50] A. Lo Giudice, et al., Transverse dentoalveolar response of mandibular arch after rapid maxillary expansion (RME) with tooth-borne and bone-borne appliances: a CBCT retrospective study, Angle Orthod. 90 (5) (2020) 680–687.
[51] L. Pedersoli, et al., Facial asymmetry detected with 3D methods in orthodontics: a systematic review, Open Dent. J. 16 (Special issue 2) (2022).