The effect of head posture on facial soft tissue changes captured by white-light facial scanning

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Objective: To investigate whether changes in head posture have significant effects on facial soft tissues during white-light scanning.
Materials and methods: Thirty-four adult patients participated in the study in which 22 soft tissue landmarks were marked on the face of each subject using an oil-based pen. The subjects wore digital inclinometers on top of their heads, and sat relaxed with their heads orientated in natural head position (NHP), while a facial scan was captured. The subjects underwent a second facial scan in an upward 5°(U5), upward 10°(U10), downward 5°(D5), or a downward 10°(D10) direction with respect to the NHP. The NHP image was superimposed on the images taken at the different head postures and a single co-ordinate system was obtained. The axial reference plane (x-axis), the sagittal reference plane (y-axis) and the coronal plane (z-axis) were set with N′ as the zero point (0, 0, 0). The changes in position of each landmark caused by the change of head posture were measured.
Results: When the subject's head was in the U5 and D5 posture, changes in landmark identification were not statistically significantly different. When the subject's head was in the U10 posture, soft tissue Stmi and Li moved downward significantly. Soft tissue pogonion moved forward significantly in the D10 posture.
Conclusions: Soft tissue changes within 5° of the natural head posture were clinically negligible. If efforts to reproduce natural head position are carried out, reliable facial scanning images can be obtained without the support of any special head positioning tools.
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Introduction

An evaluation of the soft and hard tissue configurations of the craniofacial complex is an essential requirement for the diagnosis and treatment of dento-facial disharmony. Clinicians and patients are aware and focus on the possible soft tissues changes that might occur during treatment. Therefore, an objective assessment of facial soft tissues is important when planning orthodontic treatment, evaluating post-treatment outcomes, and analysing facial growth.[1,2]

In the past, facial soft tissue morphology was evaluated primarily using two-dimensional (2D) lateral cephalometric radiographs.[3-6] However, an evaluation of three-dimensional (3D) facial morphology using conventional 2D cephalometry has several limitations because of the latter's mid-sagittal projection.[7] The conventional lateral head film distorts the geometric images and displays only the soft tissue configurations of the midline structures, which is a critical drawback in an appreciation of the soft tissue changes from the frontal aspect.

Alternatively, the acquisition of facial soft tissue data via pre- and post-treatment photographs is an easy and intuitive way to analyse changes. However, photographs do not provide sufficient information, and are highly influenced particularly by the distance from and the angle at which the photographs are taken.[8]

Recently, 3D imaging techniques have been developed to evaluate facial soft tissues more accurately.[8] Acquisition methods in 3D imaging can be divided into cone-beam computed tomography (CBCT) and facial scanning. CBCT, which is widely used in dentistry, provides information about the hard and soft tissues. However, the disadvantages of CBCT are the potential radiation risk[9] and the voxel sizes of the captured images not having satisfactory resolution. Furthermore, photo-realistic soft tissue images cannot be obtained.

Facial surface scanning is less invasive, has superior high-speed capture, has lower cost, creates more accurate 3D facial images, and produces more photo-realistic images compared with the radiation-based systems. In particular, the high speed and the safe light source mean that this approach can be used in long-term studies and those involving children and large population samples.[10] There have been several reports that have discussed the use of surface scanners to examine the changes in the facial soft tissues after orthodontic treatment in patients undergoing premolar-extraction treatment and orthognathic procedures.[11,12] In addition, there have been past evaluations of the precision and accuracy of the facial scanners.[10,13,14] However, because facial scanning is generally performed without the use of head positioning tools, it is important to determine the possible change in the facial soft tissues as a result of changes in head posture during scanning. Previous studies have identified soft tissue changes with respect to different head postures,[15,16] varying from supine head position to natural head position (NHP). However, no study has evaluated the soft tissue changes within the range of clinically-changeable head postures, and so the purpose of the present study was to investigate whether changes in head posture have significant effects on facial soft tissues when captured by white-light scanning.

Materials and methods

The sample comprised a total of 34 subjects (21 men and 13 women; mean age, 29.0 ± 2.8 years).

Subjects with beards and moustaches were not included, and subjects with craniofacial syndromes, severe facial asymmetry (menton deviation > 3 mm), myofascial disorders, centric occlusion/centric relation discrepancies, subjects undergoing treatment with intraoral orthodontic appliances, as well as subjects with a BMI (body mass index) greater than 30 kg/m^2, were also excluded. This prospective study was reviewed and approved by the institutional review board (IRB) of Kyung Hee University Medical Center (IRB No: KHD IRB 1404-1). The subjects were informed about the procedure and provided written consent.

To evaluate facial soft tissue changes according to head posture, 3D facial images were acquired using the Morpheus 3D® scanner (Morpheus 3D®, Morpheus Inc., Gyeonggi, Korea) (Figure 1A).

Twenty-two soft tissue landmarks (Table I, Figure 2) were marked on the face of each subject using an oil-based pen to avoid landmark identification errors. Of the 22 landmarks, five were in the upper face, six in the middle face, and 11 in the lower face.

The subjects wore digital inclinometers (Level Box®, Angle Sensor Technology, Shanghai, China) (Figure 1B) on top of their heads, and sat on a revolving chair with their lips relaxed and their heads in NHP during scanning. NHP was determined by the patients

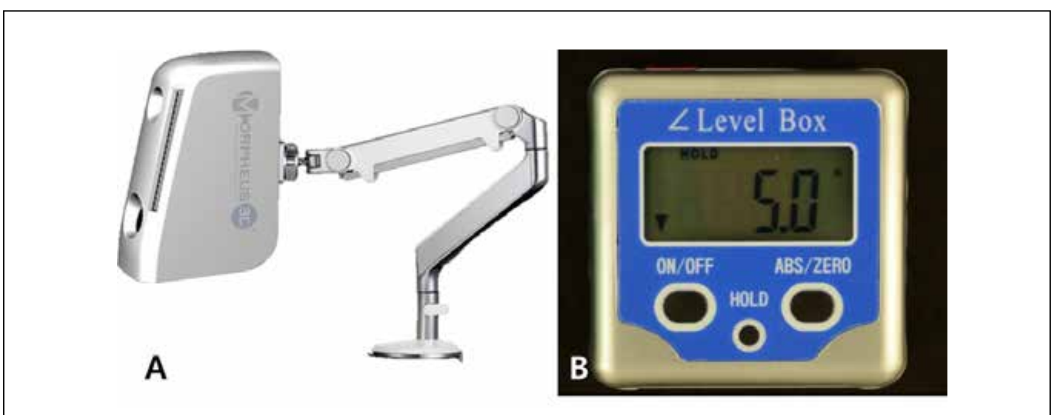

Figure 1. The structured light scanner (Morpheus 3D®) (A), and digital inclinometer (Level Box®) used in this study (B).

Table I. Description of 3D soft tissue landmarks in the study.

Landmarks	Definition
Nasion′ (Na′)	The soft tissue nasion
Exocanthion (Ex) R / L	The outer corner of the eye fissure where the eyelids meet (right side / left side)
Endocanthion (En) R / L	The inner corner of the eye fissure where the eyelids meet (right side / left side)
Zygomatic point (Zy) R / L	The midpoint of a vertical line drawn from the exocanthion and exactly located between the exocanthion horizontal line and the nasal alar horizontal line (right side / left side)
Pronasale (Pn)	The most protruded point of the apex nasi
Nasal ala (Al) R / L	The most lateral point on each alar contour (right side / left side)
Subnasale (Sn)	The midpoint of the angle at the columella base where the lower border of the nasal septum and the surface of the upper lip meet
Labrale superius (Ls)	The midpoint of the upper vermilion line
Stomion superius (Stms)	The lowest point of upper lip vermilion
Stomion inferius (Stmi)	The highest point of lower lip vermilion
Cheilion (Ch) R / L	The point located at each labial commissure (right side / left side)
Labrale inferius (Li)	The midpoint of the lower vermilion line
Cheek point (Ck) R / L	The point where a vertical line from exocanthion and a horizontal line from cheilion meet (right side / left side)
B′ point (B′)	The deepest point from lateral view, on the facial midline, between the lower lip and chin in NHP (Natural Head Position)
Pogonion′ (Pog′)	The most anterior midpoint of chin from lateral view in NHP
Gnathion′ (Gn′)	The most outward and everted point on the profile curvature of the chin

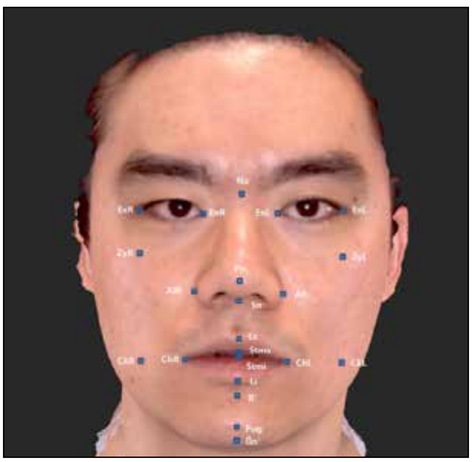

Figure 2. Soft tissue landmarks in the frontal view: Nasion′ (Na′); Exocanthion (Ex R/L); Endocanthion (En R/L); Zygomatic point (Zy R/L); Pronasale (Pn); Nasal ala (Al R/L); Subnasale (Sn); Labrale superius (Ls); Stomion superius (Stms); Stomion inferius (Stmi); Cheilion (Ch R/L); Labrale inferius (Li); Cheek point (Ck R/L); B′ point (B′); Pogonion′ (Pog′); Gnathion′ (Gn′).

looking directly at the image of their eyes in a mirror,[17] which was located on a wall facing the cephalostat at a distance of 5 feet.[18] NHP was recorded by resetting the digital inclinometer to a 0° inclination (Figure 3A).

For each subject, scans were performed at three different horizontal angles (−45°, 0°, and +45°) (Figure 3B), and a 3D facial image (NHP1) was obtained by merging the three images (Figure 3C).

Facial scanning was carried out shortly thereafter in the upward 5° (U5-1), upward 10° (U10-1), downward 5° (D5-1), and downward 10° (D10-1) directions (Figure 4).

Similar to the initial NHP1 scanning, additional facial scanning (NHP2) of the head position was performed to test the reliability and validity of the facial scanning one week after the 3D facial image (NHP1) was obtained. Facial scanning was carried out to test measurement errors shortly thereafter in the upward 5° (U5-2), upward 10° (U10-2), downward 5° (D5-2), and downward 10° (D10-2) directions.

Superimposition of the NHP1 images with the images generated from the different head postures was conducted with reference to left and right exocanthion, endocanthion, soft tissue nasion and the expanse of the forehead using 3D Image Overlay.[11] Therefore, a single co-ordinate system using the NHP1 images and images for different head postures was obtained (Figure 5).

Camper's plane runs from the tip of the anterior nasal spine to the centre of the bony external auditory meatus on the right and left side. In the present study, Camper's plane was rotated 7.5° upward on an axis that connected both tragi, and was moved until it met soft tissue nasion. This plane was set as the axial reference plane (x-axis). A plane perpendicular to

Table II. Changes in the upper facial soft tissue landmarks according to head posture change.

Upper face		NHP		U5		U10		D5		D10		*P*
mean		SD	mean	SD	mean	SD	mean	SD	mean	SD		
Na'	x	0.00	0.00	0.11	0.11	0.22	0.18	-0.11	0.21	0.1	0.18	0.606
	y	0.00	0.00	-0.13	0.19	0.1	0.13	-0.13	0.18	-0.2	0.27	0.255
	z	0.00	0.00	0.12	0.16	0.13	0.29	0.02	0.29	0.03	0.29	0.056
	D	0.00	0.00	0.21	0.07	0.27	0.11	0.17	0.07	0.23	0.14	0.705
ExR	x	0.00	0.00	-0.24	0.23	-0.37	0.36	0.24	0.36	-0.27	0.4	0.686
	y	0.00	0.00	0.11	0.26	-0.26	0.56	-0.26	0.34	-0.35	0.71	0.151
	z	0.00	0.00	-0.09	0.29	-0.05	0.51	0.08	0.7	-0.2	0.51	0.370
	D	0.00	0.00	0.28	0.13	0.45	0.21	0.36	0.14	0.49	0.32	0.218
ExL	x	0.00	0.00	0.23	0.21	0.28	0.33	-0.27	0.29	-0.22	0.41	0.639
	y	0.00	0.00	-0.16	0.35	-0.22	0.43	-0.32	0.31	-0.39	0.7	0.340
	z	0.00	0.00	-0.07	0.27	-0.1	0.4	0.15	0.5	-0.05	0.5	0.330
	D	0.00	0.00	0.29	0.14	0.37	0.14	0.44	0.18	0.45	0.21	0.279
EnR	x	0.00	0.00	-0.21	0.16	-0.25	0.27	-0.25	0.24	-0.23	0.34	0.735
	y	0.00	0.00	0.1	0.16	-0.21	0.39	-0.1	0.22	-0.39	0.49	0.485
	z	0.00	0.00	0.03	0.19	0.12	0.35	-0.23	0.42	-0.31	0.37	0.182
	D	0.00	0.00	0.23	0.11	0.35	0.16	0.35	0.14	0.55	0.20	0.348
EnL	x	0.00	0.00	-0.23	0.15	-0.23	0.28	0.2	0.21	-0.25	0.27	0.777
	y	0.00	0.00	0.12	0.2	-0.22	0.37	-0.12	0.2	-0.31	0.47	0.326
	z	0.00	0.00	0.04	0.2	0.23	0.37	-0.25	0.46	-0.32	0.41	0.216
	D	0.00	0.00	0.26	0.11	0.39	0.15	0.34	0.14	0.51	0.21	0.370

Figure 3. Facial scans at different head posture angles measured with a digital inclinometer (A). Facial scanning performed in three different horizontal angles (-45°, 0°, 45°) and six selected circumjacent points to merge three images (B), to create a reconstructed three-dimensional facial image (C).

the x-axis and passing through the N' was set as the sagittal reference plane (y-axis). A plane perpendicular to the axial and sagittal planes and passing through N' was set as the coronal plane (z-axis). These planes corresponded to a co-ordinate system that had N' as the zero point (0, 0, 0). In other words, the right and left sides of the subject were recorded on the x-axis (left: +, right: –), above and below the subject (above: +, below: –) were recorded on the y-axis, and the front and back of the subject (front: +, back: –) were recorded on the z-axis.[12]

Statistical analysis

All statistical analyses were performed using SPSS ver. 18.0 software for Windows (SPSS, Inc., IL, USA).

The measurement errors of all landmarks between the two images (between NHP1 and NHP2; between U5-1 and U5-2; between U10-1 and U10-2; between D5-1 and D5-2; and between D10-1 and D10-2) were calculated using the Dahlberg's formula. The paired *t*-test of the co-ordinate values of the two images was used to test reliability. No significant

Table III. Changes in the middle facial soft tissue landmarks according to head posture change.

Middle face		NHP		U5		U10		D5		D10		*P*
mean		SD	mean	SD	mean	SD	mean	SD	mean	SD		
ZyR	x	0.00	0.00	-0.26	0.24	-0.24	0.24	0.24	0.19	0.25	0.24	0.681
	y	0.00	0.00	0.22	0.12	0.2	0.26	0.23	0.19	0.26	0.21	0.526
	z	0.00	0.00	-0.14	0.28	-0.14	0.4	-0.01	0.4	0.01	0.38	0.392
	D	0.00	0.00	0.37	0.17	0.34	0.11	0.33	0.13	0.36	0.18	0.499
ZyL	x	0.00	0.00	0.22	0.25	0.28	0.25	-0.21	0.25	-0.29	0.18	0.480
	y	0.00	0.00	-0.22	0.19	-0.24	0.28	0.24	0.18	-0.28	0.18	0.483
	z	0.00	0.00	-0.09	0.27	-0.23	0.32	-0.04	0.32	0.03	0.31	0.054
	D	0.00	0.00	0.32	0.18	0.43	0.17	0.32	0.14	0.40	0.18	0.427
Pn	x	0.00	0.00	0.22	0.11	0.23	0.19	0.22	0.18	-0.22	0.16	0.706
	y	0.00	0.00	0.1	0.11	0.12	0.18	0.1	0.17	0.12	0.13	0.808
	z	0.00	0.00	0.03	0.17	0.04	0.31	0.09	0.29	0.11	0.26	0.594
	D	0.00	0.00	0.24	0.10	0.26	0.10	0.26	0.11	0.27	0.13	0.661
AlR	x	0.00	0.00	-0.18	0.33	-0.11	0.35	-0.24	0.29	-0.16	0.29	0.253
	y	0.00	0.00	0.19	0.12	-0.12	0.32	0.12	0.21	0.16	0.19	0.255
	z	0.00	0.00	0.29	0.39	0.21	0.68	0.01	0.83	-0.19	0.62	0.483
	D	0.00	0.00	0.39	0.19	0.27	0.10	0.27	0.10	0.30	0.13	0.581
AlL	x	0.00	0.00	0.11	0.25	0.22	0.27	-0.11	0.32	0.13	0.26	0.169
	y	0.00	0.00	-0.13	0.2	-0.12	0.29	0.12	0.25	-0.12	0.19	0.585
	z	0.00	0.00	0.01	0.29	-0.02	0.63	-0.02	0.63	-0.23	0.46	0.269
	D	0.00	0.00	0.17	0.09	0.25	0.11	0.16	0.07	0.29	0.15	0.694
Sn	x	0.00	0.00	0.22	0.22	0.2	0.25	-0.21	0.24	-0.26	0.22	0.530
	y	0.00	0.00	-0.22	0.22	-0.22	0.32	-0.29	0.25	-0.31	0.34	0.233
	z	0.00	0.00	-0.19	0.27	-0.21	0.5	-0.08	0.55	0.06	0.4	0.267
	D	0.00	0.00	0.36	0.16	0.36	0.14	0.37	0.14	0.41	0.21	0.389

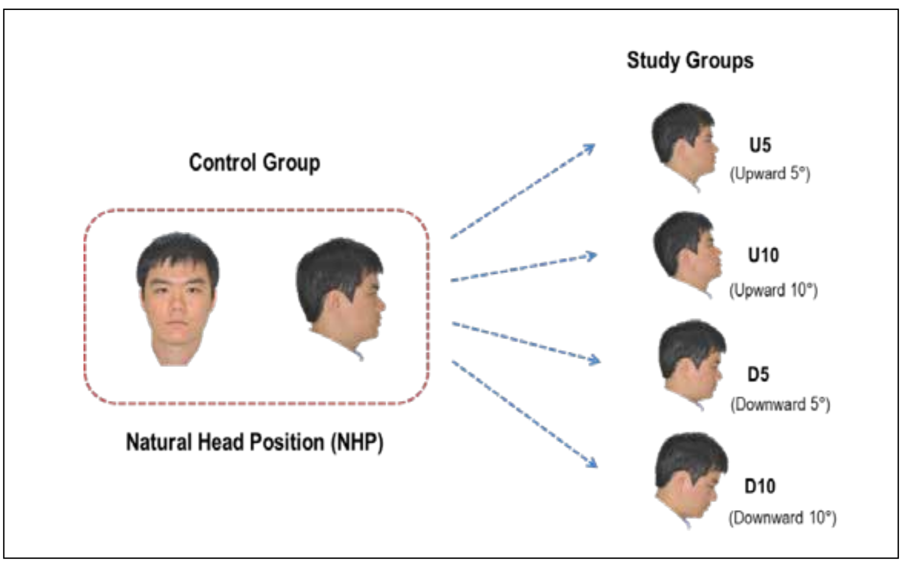

Figure 4. Facial scans performed at five different head postures.

Table IV. Changes in the lower facial soft tissue landmarks according to head posture change (*$p<0.05$).

Lower face mean		NHP		U5		U10		D5		D10		*P*
		SD	mean	SD	mean	SD	mean	SD	mean	SD		
Ls	x	0.00	0.00	-0.26	0.31	0.23	0.44	0.23	0.5	-0.3	0.5	0.554
	y	0.00	0.00	-0.11	0.42	0.24	0.48	-0.12	0.57	0.11	0.55	0.527
	z	0.00	0.00	0.09	0.35	0.22	0.44	0.21	0.54	0.33	0.5	0.160
	D	0.00	0.00	0.30	0.13	0.40	0.16	0.33	0.14	0.46	0.23	0.401
Stms	x	0.00	0.00	-0.24	0.23	0.21	0.4	-0.35	0.5	-0.4	0.36	0.515
	y	0.00	0.00	-0.12	0.45	0.26	0.58	-0.34	0.61	0.04	0.57	0.468
	z	0.00	0.00	-0.24	0.3	0.04	0.74	-0.32	0.71	0.27	0.52	0.117
	D	0.00	0.00	0.40	0.17	0.34	0.13	0.58	0.26	0.48	0.26	0.160
Stmi	x	0.00	0.00	-0.35	0.34	-0.25	0.39	-0.22	0.41	-0.29	0.45	0.629
	y	0.00	0.00	-0.2	0.39	-1.19	0.27	0.19	0.51	0.39	0.47	**0.013***
	z	0.00	0.00	0.16	0.34	-0.25	0.62	0.25	0.64	0.32	0.6	0.442
	D	0.00	0.00	0.43	0.20	1.24	0.23	0.38	0.17	0.58	0.30	0.021*
ChR	x	0.00	0.00	-0.01	0.5	0.05	0.41	0.36	0.53	0.36	0.52	0.211
	y	0.00	0.00	-0.33	0.55	-0.43	0.61	0.1	0.51	0.23	0.61	0.086
	z	0.00	0.00	0.06	0.5	0.15	0.7	0.33	0.65	0.34	0.59	0.224
	D	0.00	0.00	0.34	0.14	0.46	0.20	0.50	0.21	0.55	0.21	0.102
ChL	x	0.00	0.00	0.1	0.51	0.23	0.51	-0.33	0.6	-0.36	0.63	0.079
	y	0.00	0.00	-0.34	0.5	-0.51	0.8	0.12	0.59	0.2	0.62	0.078
	z	0.00	0.00	0.11	0.51	-0.22	0.72	0.25	0.71	0.32	0.53	0.210
	D	0.00	0.00	0.37	0.13	0.60	0.22	0.43	0.21	0.52	0.21	0.076
Li	x	0.00	0.00	-0.22	0.4	-0.13	0.35	-0.2	0.38	-0.17	0.33	0.495
	y	0.00	0.00	-0.15	0.46	-1.08	0.23	0.19	0.51	0.39	0.31	**0.016***
	z	0.00	0.00	-0.1	0.41	-0.31	0.75	0.19	0.68	0.26	0.52	0.587
	D	0.00	0.00	0.28	0.13	1.13	0.21	0.33	0.13	0.50	0.24	**0.028***
CkR	x	0.00	0.00	0.32	0.28	0.38	0.38	0.35	0.34	0.36	0.38	0.525
	y	0.00	0.00	-0.17	0.39	-0.28	0.49	-0.11	0.38	0.27	0.47	0.369
	z	0.00	0.00	-0.14	0.38	-0.23	0.7	0.13	0.61	0.24	0.58	0.424
	D	0.00	0.00	0.39	0.19	0.53	0.23	0.39	0.15	0.51	0.20	0.119
CkL	x	0.00	0.00	-0.38	0.33	-0.3	0.39	-0.25	0.32	-0.35	0.37	0.408
	y	0.00	0.00	-0.18	0.33	-0.21	0.44	0.15	0.37	0.15	0.5	0.434
	z	0.00	0.00	-0.12	0.42	-0.25	0.62	0.14	0.55	0.28	0.49	0.459
	D	0.00	0.00	0.44	0.21	0.44	0.21	0.32	0.15	0.47	0.21	0.181
B′	x	0.00	0.00	-0.28	0.3	0.2	0.24	-0.25	0.31	-0.26	0.28	0.516
	y	0.00	0.00	-0.27	0.45	-0.48	0.52	0.1	0.49	0.39	0.5	0.118
	z	0.00	0.00	-0.13	0.31	-0.38	0.55	0.15	0.45	0.28	0.47	0.355
	D	0.00	0.00	0.41	0.18	0.80	0.33	0.31	0.20	0.45	0.20	0.062
Pog′	x	0.00	0.00	-0.22	0.3	0.25	0.24	0.22	0.28	0.26	0.28	0.654
	y	0.00	0.00	-0.29	0.34	-0.55	0.45	0.23	0.45	0.55	0.22	0.090
	z	0.00	0.00	-0.19	0.32	-0.43	0.45	0.24	0.27	0.99	0.21	**0.020***
	D	0.00	0.00	0.41	0.17	0.82	0.21	0.40	0.14	1.16	0.21	**0.011***
Gn′	x	0.00	0.00	-0.23	0.26	0.22	0.26	0.23	0.33	0.26	0.3	0.664
	y	0.00	0.00	-0.14	0.42	-0.29	0.67	0.14	0.57	0.26	0.72	0.160
	z	0.00	0.00	-0.22	0.29	-0.34	0.63	-0.1	0.46	0.17	0.63	0.203
	D	0.00	0.00	0.35	0.15	0.50	0.22	0.29	0.12	0.41	0.15	0.296

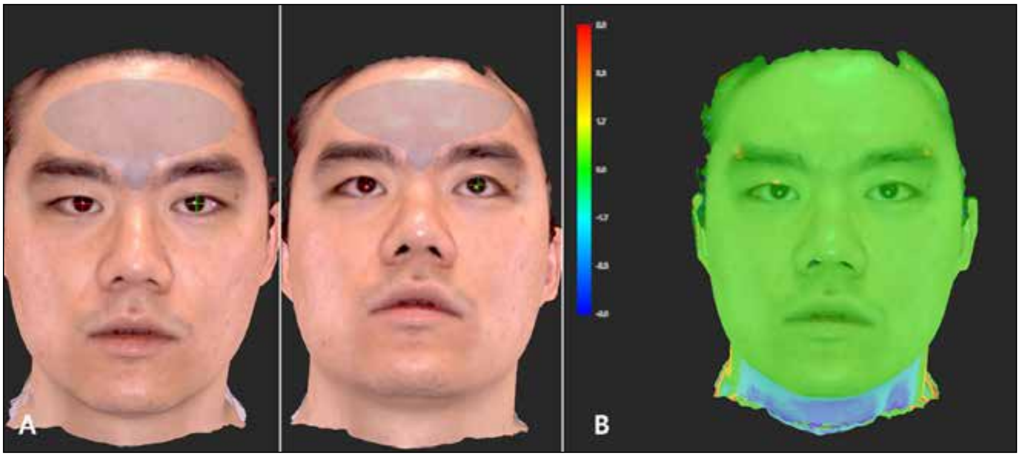

Figure 5. Superimposition of each different head posture with natural head position 1 (NHP1) was executed with reference to a wide forehead using a chamfer mapping algorithm, (A) Superimposed colour map image, (B) Green indicates a deviation within 1 mm. Increase in the blue colour gradient indicates a greater inward deviation. Increase in the red colour gradient indicates a greater outward deviation.

differences between the two images were found ($p > 0.05$ for all), and NHP1, U5-1, U10-1, D5-1 and D10-1 measurements were used in this study.

Δx, Δy, Δz, and distance (D) values were calculated from each of the head posture images using the NHP1 co-ordinates. The Shapiro–Wilk test for normality showed that all variables were normally distributed, and the Levene's test showed all variables were homogeneous.

Co-ordinate values for each head posture were compared and analysed using one-way analysis of variance. Multiple comparisons were made using the Tukey's method. A $p < 0.05$ was considered statistically significant.

Results

Changes in the upper facial soft tissue landmarks according to head posture changes (Table II)

In a consideration of the upper facial soft tissue landmarks, there were no statistically significant differences in the x-, y-, z-axis co-ordinates and distance between the NHP1 and all other head postures (U5-1, U10-1, D5-1, and D10-1) ($p > 0.05$).

Changes in the middle facial soft tissue landmarks according to head posture changes (Table III)

With respect to the middle facial soft tissue landmarks, there were no statistically significant differences in the x-, y-, z-axis co-ordinates and distance between the NHP1 and all other head postures (U5-1, U10-1, D5-1, and D10-1) ($p > 0.05$).

Changes in the lower facial soft tissue landmarks according to head posture changes (Table IV)

With respect to the lower facial soft tissue landmarks, there were no statistically significant differences between the NHP1 and U5-1 and between the NHP1 and D5-1 in the x-, y-, z-axis co-ordinates and distance ($p > 0.05$).

However, with respect to the y-axis co-ordinates and distance, there were statistically significant differences between NHP1 and U10-1: Stmi (-1.19 mm, $P = 0.013$; 1.24 mm, $P = 0.021$) and Li (-1.08 mm, $P = 0.016$; 1.13 mm, $P = 0.028$). There were significant differences in the z-axis co-ordinates and distance between NHP1 and D10-1 in Pog' (0.99 mm, $P = 0.020$; 1.16 mm, $P = 0.011$).

Discussion

An accurate assessment of a patient's soft tissue is crucial in the planning of orthodontic treatment. Past assessments started with 2D data obtained by lateral cephalography and shifted to the use of clinical photographs, 3D CBCT, and facial scanning, which is currently widely applied for soft tissue evaluation during orthodontic or orthognathic treatment. Using structured light-based scanners, Ahn et al. described the 3D perioral soft tissue changes in patients with dentoalveolar protrusion who underwent orthodontic treatment with the extraction of the four first premolars,[11] while Baik et al. showed that a 3D analysis using a facial scanner can be used to estimate the soft tissue changes in Class III patients who underwent orthognathic surgery.[19]

In order to obtain accurate soft tissue data from a facial scanner, not only is mechanical precision required, but also the patient's exact head posture should be reproducible when scanning is undertaken. NHP is a consistent patient orientation and is defined as the orientation estimated by a trained clinician while the subject stands in a state of body and head relaxation. Moorrees and Kean[3] defined NHP as "a standardised and reproducible orientation of the head in space when focusing on a distant point at eye level." Mølhave[4] used the term "orthoposition" to describe the transitional position from standing to walking. Solow and Tallgren[5] used mirror-guided positioning to determine NHP because it was considered more reproducible than a self-balanced position. Eventually, the concept of NHP focused on head-posture reproducibility.

The stability and reproducibility of NHP have been investigated and demonstrated in a guiding method based on visual cues from an external reference. Subjects are required to position their head so that their eyes are observed in a mirror at a horizontal distance ahead.

In practice, it is challenging to exactly reproduce head posture even when an experienced clinician guides a subject. Hence, gaining data on soft tissue changes as well as statistical errors is of benefit in relation to the possible likely change in head posture.

This is the first known study to evaluate differences in soft tissue landmarks according to NHP and a head position change that is within a clinical range of less than 10°. In the present study, to test the reliability of images captured in the same head posture at different time points, NHP, U5, U10, D5, and D10 images were taken twice, and the image differences calculated. Previous facial scanning validity indicated the mean shell deviation between images taken at different time-points using a laser scanner was < 0.4 mm.[13] Ma et al.[10] reported that the precision of facial scanning using a structural light scanner was 0.79 mm, whereas Kim et al.[14] reported that 3D scanned images have high precision and good congruence with traditional anthropometric methods, with a mean difference of < 1 mm. In the present study, no significant differences were detected in any landmarks (the biggest difference was 0.4 mm) while recording the same posture at different time intervals.

The effect of head position during facial scanning might lead to an erroneous outcome following an evaluation of an orthodontic or orthognathic procedure. Hoogeveen et al.[15] reported that a clinically significant difference was found between natural and supine head positions with respect to the throat-chin area. Iblher et al.[16] suggested that there was more soft tissue deformability in the lower face in natural and supine head positions in young adults than in older adults. However, clarifying the reproducibility of natural and supine head positions is not important in facial scanning. This is because facial soft tissue scanning, unlike CBCT imaging, is mostly performed in an upright position. Therefore, in the present study, head posture was controlled within a range of 10° from NHP, which determined that all of the soft tissue landmarks of the upper and middle face were not affected significantly by an alteration of head postures (U5, U10, D5, and D10). All of the soft tissue landmarks of the lower face were also not affected significantly by the U5 and D5 postures. This means that a change in head posture of less than 5° had little effect on the soft tissues. However, some landmarks of the lower face were significantly different when the head posture was changed by 10°. Stmi and Li moved downward significantly when the head was tilted 10° upward (U10). Pog' moved forward significantly when the head was tilted 10° downward (D10). It is assumed that gravity and flexion/extension of the neck muscles affect the soft tissues.

Previous studies have shown that NHP varies by 3° in the 3D plane.[3,6-8,20,21] The present results indicate that the changes in the soft tissues within 3° of the changes in head posture were negligible. While NHP in the sagittal plane varies from 1.3° to 2.2°,[3,6-8,20] Weber et al.[21] reported that the NHP is reproducible, but is limited by its 3D variation.

The limitation of the Weber et al. study was that soft tissue menton was not included as a landmark. The 3D area around soft tissue menton could not be obtained when the subject's head was tilted downward because the beam of white light created a "dead zone" in the submental area. Soft tissue menton is assumed to undergo a large change related to head posture because of its proximity to the neck muscles and submandibular tissues.

The present results do not suggest that facial scanning can be performed freely regardless of head posture. However, the results indicate that reliable facial scanning images can be obtained within the variation of NHP without the use of special head-positioning tools.

Conclusions

Changes were examined in the facial soft tissues with respect to different head postures during facial scanning. Facial soft tissue changes were observed in the lower face rather than in the upper and middle face. Soft tissue changes within 5° of natural head posture were clinically negligible. When the head posture was changed by more than 10°, the landmarks on the lower lip, such as Stmi and Li point, tended to move downward when the head was tilted upward. Pogonion point, a soft tissue landmark of the chin, tended to move anteriorly when the head was tilted downward.

If efforts to reproduce NHP are carried out, reliable facial scanning images can be obtained without the support of any special head positioning tools.

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