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## Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

Hwang, Hyeon-Shik; Choe, Seon-Yeong; Hwang, Ji-Sup; Moon, Da-Nal; Hou, Yanan; Lee, Won-Joon

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**Reproducibility of facial soft tissue thickness measurements  
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## Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

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## Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

**ABSTRACT:** The purpose of this study was to establish the reproducibility of facial soft tissue (ST) thickness measurements by comparing three different measurement methods applied at 32 landmarks on three-dimensional cone-beam computed tomography (CBCT) images. Two observers carried out the measurements of facial ST thickness of 20 adult subjects using CBCT scan data, and inter- and intra-observer reproducibility were evaluated. The measurement method of 'perpendicular to bone' resulted in high inter- and intra-observer reproducibility at all 32 landmarks. In contrast, the 'perpendicular to skin' method, and 'direct' method which measures a distance between one point on bone and the other point on skin presented low reproducibility. The results indicate that reproducibility could be increased by identifying the landmarks on hard tissue images, rather than on ST images, and the landmark description used in this study can be used in the establishment of reliable tissue depth data using CBCT images.

**KEYWORDS:** forensic science, facial reconstruction, soft tissue thickness, reproducibility, cone-beam computed tomography, three-dimensional image

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5 In forensic facial reconstruction, the facial features of unknown individuals are estimated  
6  
7 from an unidentified skull (1,2). In order to recreate an individual's face, the establishment of  
8  
9 reliable facial soft tissue (ST) thickness data is necessary. In the past, such reference data  
10  
11 were obtained from needle puncture measurement on cadavers, which has been criticized due  
12  
13 to some inevitable differences between cadaver-based and in-vivo measurements relating to  
14  
15 post-mortem tissue changes such as dehydration and shrinkage (2-4). For large-scale studies  
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17 on ST thickness measurements, ultrasound has been utilized, which has its advantages in cost  
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19 and accessibility, but has its drawbacks in being time-consuming and in that additional  
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21 measurements cannot be made at a later date (3,5-8).  
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27 To overcome these disadvantages, computed tomography (CT) has been used to measure the  
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29 ST thickness. Use of a three-dimensional (3D) image program allowed the realization of 3D  
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31 images of facial soft tissues as well as hard tissues. ST thickness can be measured as a  
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33 distance between a point of the soft tissue and its corresponding point on the hard tissue  
34  
35 image. Kim et al. (9) reported that CT images can be used to accurately measure the ST  
36  
37 thickness in the facial region. Despite this, widespread use was limited because of high  
38  
39 radiation dose and gravity-related effects on soft tissues of the subjects in a supine position  
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41 (8,10,11). Recently-developed cone-beam CT (CBCT), however, enables us to obtain images  
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43 with the subjects in an upright position and the reported radiation dose is much less in a  
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45 CBCT scan compared to multi-slice CT (8,10-13). Fourie et al. (14) showed that the facial ST  
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47 thickness can be measured on CBCT images with high accuracy through comparison with  
48  
49 digital caliper measurements using cadaver subjects. Hwang et al. (15) reported that the  
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51 CBCT images can be used to measure the ST thickness with high reproducibility in their  
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53 study using living subjects.  
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6 While forensic facial reconstruction is a process of rebuilding facial soft tissues onto the  
7 surface of an unidentified skull, CBCT gives us information about both soft and hard tissues,  
8 and the ST thickness can, therefore, be measured along a line where the starting point is  
9 either on the ST, on the hard tissue, or on both. While a reliable tissue depth data is needed  
10 for a facial reconstruction, there has been little study regarding the reproducibility of ST  
11 thickness measurements, particularly its differences according to the measurement methods.  
12 The purposes of this study were to evaluate the reproducibility of ST thickness measurements  
13 on 3D CBCT images, and to compare the reproducibility according to three different  
14 measurement methods: (1) measurement taken 'perpendicular to bone', (2) measurement  
15 taken 'perpendicular to skin', and (3) 'direct measurement' which measures a distance between  
16 a point of the bone and its corresponding point of the skin image.  
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### 33 **Materials and Methods**

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37 Twenty adult individuals (10 males, 10 females) without facial asymmetries and deformities  
38 were used as the subjects of this study. This research was approved by the Institutional  
39 Review Board for the Medical Science at the Chonnam National University Hospital,  
40 Gwangju, Korea. Informed consent was obtained from all subjects. The mean age of the  
41 subjects was 27.6 years. The CT scans were obtained using a CBCT scanner (Alphard Vega:  
42 Asahi Roentgen Co., Kyoto, Japan), with a voxel size of 0.39 mm and a field of view of 200  
43 x 179 mm. The subject was scanned in the seated position with a neutral, relaxed facial  
44 expression. The maxillofacial 3D images were created from DICOM data using V Works 4.0  
45 (CyberMed, Seoul, Korea). A pair of 3D object files was created with an adjustment of the  
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4 Hounsfield units (HU): one for the hard tissue image with 550~650 HU and another for the  
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6 ST image with -570 to -550 HU.  
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#### 10 *Landmark Selection and Description*

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12 In order to evaluate the reproducibility of ST thickness measurements, 32 (8 midline and  
13 24 bilateral) landmark sites were selected as in Figures 1 and 2. All landmarks were selected  
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15 with a pair, one on hard tissue and another on soft tissue, so that they correspond to each  
16  
17 other. The landmarks were first adopted from De Greef et al. (7) which performed a large-  
18  
19 scale study at a number of landmark sites using ultrasound system, and then modified  
20  
21 according to Hwang et al. (15) which used CBCT images for the measurement of ST  
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23 thickness. An emphasis was placed on increasing reproducibility in landmark identification.  
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25 In cases where the ST landmark was not able to be delineated from 3D CBCT image, it was  
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27 defined as the point on the skin extrapolated by a perpendicular line from its hard tissue  
28  
29 counterpart. The name and description of the landmarks are seen in Tables 1 and 2 ( Figs. 1  
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31 and 2, Tables 1 and 2).  
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#### 40 *Measurement of Soft Tissue Thickness*

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42 In order to obtain ST thickness measurement, a specific software named Skull Measure  
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44 (CyberMed, Seoul, Korea) was used in this study (15,16). Both soft and hard tissue images  
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46 reconstructed from CBCT scan data were imported into the software program in order to  
47  
48 measure the distance between a point on the hard tissue image and corresponding point on the  
49  
50 ST image. The ST thickness was measured using three different methods: (1) measurement  
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52 taken 'perpendicular to bone', (2) measurement taken 'perpendicular to skin', and (3) 'direct  
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54 measurement' which measures a distance between a point on bone and another point on skin.  
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6 For the 'perpendicular to bone' method, the landmarks were identified on the hard tissue  
7 images according to the definition of hard tissue landmarks. Then, the corresponding points  
8 were designated automatically on the ST images as to meet the line starting perpendicularly  
9 from the identified hard tissue point. The computer calculated the distance between the two  
10 points using Euclidean distance (Fig. 3A). For the 'perpendicular to skin' method, the  
11 landmarks were identified on the soft tissue images according to the ST landmark definitions.  
12 Once a point is identified on the ST image, the corresponding point is designated  
13 automatically on the hard tissue image by the program. The distance between the two points  
14 is obtained as the ST thickness (15,16) (Fig. 3B). In case of 'direct measurement', one point  
15 was identified on the hard tissue image, and the corresponding point was established on the  
16 ST image according to the landmark definitions. In other words, both hard and soft tissue  
17 landmarks were identified by the investigator. The distances between the two points were  
18 calculated by the program as the ST thickness with the 'direct measurement' method (Fig. 3C).  
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37 All three measurements were carried out by one observer to find if the results differ  
38 according to the methods. Another observer followed the same measurement protocol to  
39 evaluate the inter-observer reproducibility, and one of the observers performed the  
40 measurement twice with a 3-week interval to evaluate the intra-observer reproducibility.  
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#### 48 *Statistical Analysis*

49  
50 The means and standard deviation of the measurements for all three measurement methods  
51 were calculated. The three measurement methods were then compared using ANOVA. To  
52 calculate the inter-observer reproducibility, a paired *t*-test and intraclass correlation analysis  
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4 were used. A paired *t*-test was used to calculate the intra-observer reproducibility. The  
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6 correlation coefficients were calculated using Pearson correlation and reliability coefficient  
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8 analyses. Statistical data analysis was carried out using SPSS software, version 17.0 for  
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10 Windows (SPSS Inc, Chicago, IL).  
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## 14 15 **Results**

### 16 17 18 19 *Comparison of the Measurement According to Methods*

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21 Table 3 shows the results of the calculation of means, standard deviations and ANOVA at  
22  
23 each landmark. Sixteen out of 32 landmarks were identified with statistically significant  
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25 differences between the three measurement methods (Table 3).  
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### 30 31 *Inter-observer Reproducibility According to Methods*

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33 Tables 4, 5, and 6 show the results of paired *t*-test and intraclass correlation analysis  
34  
35 showing the inter-observer reproducibility in case of 'perpendicular to bone' method,  
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37 'perpendicular to skin' method, and 'direct measurement' method, respectively.  
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42 In the 'perpendicular to bone' method, there were no significant differences between the two  
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44 observers for all landmark measurements. The results of intraclass correlation analysis at all  
45  
46 landmarks were  $>0.7$ , indicating high reproducibility for the 'perpendicular to bone' method  
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48 (Table 4).  
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53 In case of 'perpendicular to skin' method, the results of the *t*-test identified 14 out of 32  
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55 landmarks with significant differences and intraclass correlation analysis showed that  
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4 correlation coefficients of 9 landmarks were  $<0.7$ . Some landmarks showed low  
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6 reproducibility for either  $t$ -test or intraclass correlation analysis, whereas 6 landmarks (ST B  
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8 point, ST Mental tubercle, ST Mid-lateral orbit, ST Supra-M1, ST Infra-M1, ST Sub-  
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10 mandibular) were identified with low reproducibility for both  $t$ -test and intraclass correlation  
11  
12 analysis (Table 5).  
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18 In case of 'direct measurement' method, the results of the  $t$ -test identified 18 out of 32  
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20 landmarks with significant differences, which was higher than the other two measurement  
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22 methods. Intraclass correlation analysis showed 13 landmarks with the correlation  
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24 coefficients less than 0.7, indicating the lowest reproducibility among the three measurement  
25  
26 methods (Table 6).  
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### 30 31 *Intra-observer Reproducibility According to Methods*

32  
33 Tables 7, 8, and 9 show the results of the evaluation of intra-observer reproducibility in case  
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35 of 'perpendicular to bone', 'perpendicular to skin', and 'direct measurement', respectively.  
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40 In case of 'perpendicular to bone' method, no significant differences were found between  
41  
42 the two measurements when analyzed using  $t$ -test, and the results of correlation analyses also  
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44 showed high values, 0.826~0.994 and 0.904~0.996 for Pearson correlation analysis and  
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46 reliability analysis respectively, indicating high reproducibility for the 'perpendicular to bone'  
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48 method (Table 7).  
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53 In case of 'perpendicular to skin' method, the results of the  $t$ -test identified 1 landmark with  
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55 a significant difference. While most landmarks showed statistically significant correlations  
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4 between the two measurements for the Pearson correlation and reliability analyses, three  
5 landmarks (ST Lateral nasion, ST Lateral rhinion, ST Supra-M1) showed low reproducibility  
6 (Table 8).  
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12 In case of 'direct measurement' method, the reproducibility showed high values, 0.636~  
13 0.969 and 0.768~0.985 for Pearson correlation analysis and reliability analysis respectively.  
14 However, the results of the *t*-test showed several landmarks with statistically significant  
15 differences between the two measurements, which indicated lower reproducibility than  
16 'perpendicular to bone' method (Table 9).  
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## 27 Discussion

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30 Use of CBCT creates images of both soft and hard tissues according to computer algorithm,  
31 and this makes possible for the ST thickness measurements to be based not only on soft  
32 tissues but also on hard tissues. Moreover, hard and soft tissues can together be the basis if  
33 the ST thickness measurements are carried out by directly calculating the distance between  
34 two landmarks, one on the image of hard tissues and the other on the image of soft tissues.  
35 After Kim et al. (9) reported that CT images are accurate for the measurement of facial ST  
36 thickness, Hwang et al. (15) used CBCT to make measures and reported on the  
37 reproducibility of these results according to landmarks. The study showed a generally high  
38 reproducibility of the measurements and suggested the potentialities of using CBCT for  
39 accurate measurement of facial ST thickness. However, on some of the landmarks, it reported  
40 low reproducibility as well, and the reason for this result might have been due to the use of  
41 landmarks that are defined for studies using ultrasound, not CBCT, as their measurement  
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4 device. This study, therefore, modified these landmarks into what CBCT investigators can  
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6 identify on their 3D images of soft and hard tissues with high consistency, and compared the  
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8 reproducibility of facial ST thickness measurements according to three different measurement  
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10 methods, so that a reasonable measurement protocol can be established.  
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15 Comparison of the above 3 measurements by ANOVA showed that 16 out of 32 landmarks  
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17 presented with statistically significant differences between the methods. In other words, the  
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19 ST thickness measurements differed according to the measurement methods. This result  
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21 indicates that description on the used measurement method should be stated together if the  
22  
23 measurement data were obtained with CBCT images.  
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28 As the results of *t*-test and intraclass correlation analysis, ‘perpendicular to bone’ method  
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30 showed higher inter-observer reproducibility than the other two methods. In case of  
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32 ‘perpendicular to bone’ method, no significant difference was seen at all landmarks according  
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34 to *t*-test, and intraclass correlation analysis resulted in correlation coefficients higher than 0.7  
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36 at all landmarks, as well. In case of ‘perpendicular to skin’ method and ‘direct measurement’  
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38 method, however, several landmarks were identified with significant differences by *t*-test.  
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40 The results of intraclass correlation analysis also showed smaller value of correlation  
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42 coefficients than in case of ‘perpendicular to bone’. The reason for higher inter-observer  
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44 reproducibility of ‘perpendicular to bone’ method than that of ‘perpendicular to skin’ method  
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46 seems to lie in clearness of landmark definitions. Anatomical structures are easily identified  
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48 on hard tissues whereas a landmark is not identified easily on soft tissue surface. As examples,  
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50 landmarks such as ST Mental tubercle and ST Mid-lateral orbit did not clearly represent the  
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52 actual anatomical structure of soft tissues and thus were identified with low inter-observer  
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4 reproducibility. Meanwhile, their corresponding landmarks on hard tissues, which were  
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6 Mental tubercle and Mid-lateral orbit respectively, clearly expressed their actual anatomical  
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8 structures which can be verified by the high reproducibility of the measurements. Farkas (17)  
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10 and Cavalcanti et al. (18) examined both the hard and soft tissue landmarks in the 3D images,  
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12 and reported that the hard tissue points were easier to localize than soft tissue landmarks. All  
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14 these results suggest that approach based on hard tissue, rather than ST, would be better for  
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16 obtaining reliable tissue depth data using CBCT images.  
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21 Other landmarks that were identified with low inter-observer reproducibility in case of using  
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23 ‘perpendicular to skin’ method were proven to be located where variations in ST thickness  
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25 are great between the subjects. Among previous studies using ultrasound systems, Manhein et  
26  
27 al. (3), Wilkinson (6), and De Greef et al. (7) reported on high standard deviations identified  
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29 for the ST thickness measurements made at cheek area. Also in this study, the landmarks  
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31 located at the cheek area, such as ST Supra-M1 and ST infra-M1 showed large standard  
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33 deviations and low reproducibility.  
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40 On the other hand, the intra-observer reproducibility showed higher values than the inter-  
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42 observer reproducibility regardless of the measurement methods. In case of ‘perpendicular to  
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44 skin’ method, inter-observer reproducibility showed 14 landmarks with significant differences  
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46 based on *t*-test and 9 landmarks with intraclass coefficients smaller than 0.7. However, intra-  
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48 observer reproducibility presented only 1 landmark with significant difference and 3  
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50 landmarks with low correlation coefficients indicating a higher intra-observer reproducibility  
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52 than the inter-observer reproducibility. Also, in case of ‘direct measurement’ method, inter-  
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54 observer comparison showed 18 landmarks with significant differences whereas intra-  
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4 observer reproducibility presented only 9 landmarks with significant differences based on *t*-  
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6 test. The reason of higher reproducibility in the intra-observer evaluation than in the inter-  
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8 observer evaluation seems to be that identifying landmarks is a subjective process, and can be  
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10 affected by individual's recognition of anatomical structures. Regardless of the difference of  
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12 reproducibility between inter- and intra-observer evaluation, 'perpendicular to bone'  
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14 method was superior to other two measurement methods in both intra- and inter-observer  
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16 reproducibility. This indicates that landmarks on hard tissues are more objectively recognized  
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18 than landmarks on soft tissues are.  
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24 Analysis of intra-observer reproducibility in case of 'direct measurement' method, which  
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26 uses two manually identified landmarks on soft and hard tissue image each, resulted in  
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28 generally high values by Pearson correlation analysis and reliability analysis, but several  
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30 landmarks showed significant differences by *t*-test. However, the actual differences between  
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32 the averages of first and second measurements at these landmarks were of more or less than  
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34 0.5mm, a clinically insignificant value. It is believed that 'direct measurement' method might  
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36 be used as a reliable method when needed. In addition, this measurement method has another  
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38 advantage of short measurement time, compared to the other two methods where repeated  
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40 measurements required until the automatically designated points suit the definition of  
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42 landmarks.  
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48 The results of the present study indicate that the ST thickness measurements using CBCT  
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50 images show the highest reproducibility when they are obtained by 'perpendicular to bone'  
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52 method. This finding is believed to be a favorable result to actual forensic facial  
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54 reconstruction considering that soft tissues are built on to the surface of hard tissue. However,  
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4 the measurement data of 'perpendicular to skin' or 'direct measurement' method might be  
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6 required in some landmark areas for a facial reconstruction. The ST thickness data in CBCT  
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8 images should be established according to all three methods, 'perpendicular to bone',  
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10 'perpendicular to skin', and 'direct measurement' between bone and skin, and the present study  
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12 can be a good reference on evaluating the reliability of each measurement method. The  
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14 measurement methods in this study can be used reasonably in the establishment of reliable  
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16 tissue depth data using CBCT images.  
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TABLE 1 - Description of hard tissue landmarks used for soft tissue thickness measurement using cone-beam CT images.

Landmarks <sup>†</sup>	Description
Midline landmarks	
1	Glabella Most anterior point of forehead
2	Infra-glabella Crosspoint between the midline and the line connecting both superior orbital margins
3	Nasion Midpoint of the fronto-nasal suture
4	Rhinion Tip of nasal bone
5	Mid-philtrum Inferior one third of the line between anterior nasal spine and supradentale
6	B point Most posterior point of bony curvature of the mandible between infradentale and pogonion
7	Pogonion Most anterior point on the bony contour of the chin
8	Menton Most inferior point on the bony contour of the chin
Bilateral landmarks	
9	Frontal eminence Most anterior point of the frontal bone, horizontally centered on the orbit
10	Supra-orbit Horizontally centered on the orbit, just above superior orbital margin
11	Lateral nasion Below the midpoint of fronto-maxillary suture
12	Lateral nasal end Vertically at the level of end of nasal bone and horizontally on a vertical line with the mesial wall of the orbital rim
13	Infra-orbit Horizontally centered on the orbit, under inferior orbital margin
14	Maxillare Maximum concavity point on maxilla, centered on the orbit, just under the zygomatic process of maxilla
15	Lateral nostril Vertically at the level of bottom of nasal aperture, and horizontally on a vertical line with the lateral margin of the aperture
16	Incisor alveolus Inferior one third of nasal floor and alveolar margin of the central incisor
17	Supra-canina Most prominent point on alveolar margin of upper canine
18	Upper incisor Central point on labial surface of upper central incisor crown
19	Lower incisor Central point on labial surface of lower central incisor crown
20	Infra-canina Most prominent point on alveolar margin of lower canine
21	Mental tubercle Most prominent point on the mental tubercle
22	Mid-lateral orbit Vertically centered on the orbit, next to the lateral orbit border
23	Supraglenoid Root of the zygomatic arch above the condylar head
24	Zygomatic arch Most lateral curvature of the zygomatic arch
25	Lateral zygoma Center of the zygoma, horizontally lined up with the lateral border of the orbital rim
26	Supra-M1 Most prominent point on alveolar margin of the maxillary first molar
27	Ante-ramus Anterior border of the mandibular ramus at the level of occlusal plane
28	Mid-ramus Center of the ramus, horizontally middle point between anterior and posterior border of mandibular ramus, vertically the halfway point between mandibular notch and antegonial notch
29	Infra-M1 Most prominent point on alveolar margin of the mandibular first molar
30	Gonion lateralis Most lateral point on gonial area
31	Mid-mandibular Center of the mandibular body, horizontally lined up with mandibular first molar and vertically at the level of mental foramen
32	Sub-mandibular Most lateral point on the inferior border of the mandible at the level of mandibular first molar

<sup>†</sup>The number which precedes the landmark name is corresponded to the number represented in the Figure 1.

TABLE 2 - Description of soft tissue landmarks used for soft tissue thickness measurement using cone-beam CT images.

Landmarks <sup>†</sup>	Description
Midline landmarks	
1 ST Glabella	Most anterior point of soft tissue forehead
2 ST Infra-glabella	Crosspoint between midline and corresponding to soft tissue of superior orbital margin
3 ST Nasion	Deepest point on the concavity overlying the area of the frontonasal suture
4 ST Rhinion	Closest point from tip of nasal bone, on the dorsum of nose
5 Mid-philtrum	Centered between nose and mouth
6 ST B point	Deepest point on the concavity between labiale inferius and soft tissue pogonion
7 ST Pogonion	Most prominent point of the soft tissue chin
8 Beneath chin	Vertical measure of the soft tissue on the lower edge of the chin
Bilateral landmarks	
9 ST Frontal eminence	Most anterior point of the forehead, horizontally centered on eyepupil
10 ST Supra-orbit	Horizontally centered on eyepupil, above eyebrow
11 ST Lateral nasion	Midpoint of inner canthus of the eye and soft tissue nasion
12 ST Lateral rhinion	Side of the bridge of nose, vertically at the level of end of nasal bone and horizontally on a vertical line with the inner canthus of the eye
13 ST Infra-orbit	Horizontally centered on eyepupil, under inferior orbital margin
14 ST Maxillare	Horizontally centered on eyepupil and vertically at the level of nose tip
15 Lateral nostril	Next to the most lateral point of ala nasi
16 Naso-labial ridge	The prominence next to the mid-philtrum
17 ST Supra-canina	Vertically lined up with the cheilion, on the horizontal level of the mid-philtrum
18 Upper lip	Most prominent point of the upper lip, vertically lined up with naso-labial ridge
19 Lower lip	Most prominent point of the lower lip, vertically lined up with naso-labial ridge
20 ST Infra-canina	Vertically lined up with the cheilion, on the horizontal level of the chin-lip fold
21 ST Mental tubercle	Most prominent point on the lateral bulge of the chin mound
22 ST Mid-lateral orbit	Vertically centered on the eye pupil, next to the outer canthus of the eye
23 ST Supraglenoid	Overlying soft tissue point corresponding to hard tissue Supraglenoid
24 ST Zygomatic arch	Overlying soft tissue point corresponding to hard tissue Zygomatic arch
25 ST Lateral zygoma	Center of the malar area, horizontally lined up with the outer canthus
26 ST Supra-M1	Vertically lined up with the outer canthus, on the horizontal level of the bottom of nose
27 Ante-masseter	Anterior border of the masseter, at the level of oral commissure
28 Mid-masseter	Center of the masseter, the most prominent point of the masseter area
29 ST Infra-M1	Vertically lined up with the outer canthus, on the horizontal level of the chin-lip fold
30 ST Gonion lateralis	Overlying soft tissue point corresponding to hard tissue Gonion lateralis
31 ST Mid-mandibular	Overlying soft tissue point corresponding to hard tissue Mid-mandibular
32 ST Sub-mandibular	Overlying soft tissue point corresponding to hard tissue Sub-mandibular

<sup>†</sup>The number which precedes the landmark name is corresponded to the number represented in the Figure 2. ST, Soft tissue.

TABLE 3 – Data of soft tissue thickness measurements and their comparison by measurement methods (n=20).

Measurement (Hard tissue / Soft tissue)	Perp HT (mm)		Perp ST (mm)		HT to ST (mm)		ANOVA (p value)
	Mean	SD	Mean	SD	Mean	SD	
Midline landmarks							
Glabella / ST Glabella	5.1	1.0	5.4	0.9	5.8	1.0	NS
Infra-glabella / ST Infra-glabella	5.7	0.7	5.6	0.8	6.6	1.1	0.002
Nasion / ST Nasion	6.3	1.1	5.7	1.2	7.9	1.7	0.000
Rhinion / ST Rhinion	2.6	1.0	2.4	0.9	3.0	1.0	NS
Mid-philtrum / Mid-philtrum	12.7	1.9	12.0	2.1	12.4	1.6	NS
B point / ST B point	13.0	1.5	12.3	1.2	13.2	1.6	NS
Pogonion / ST Pogonion	10.9	1.8	12.9	1.9	13.1	2.3	0.001
Menton / Beneath chin	8.0	2.0	7.1	1.4	8.1	1.8	NS
Bilateral landmarks							
Frontal eminence / ST Frontal eminence	6.5	1.2	6.7	1.3	7.3	1.2	NS
Supra-orbit / ST Supra-orbit	7.3	0.9	7.1	0.9	8.5	1.0	0.000
Lateral nasion / ST Lateral nasion	7.6	1.4	10.2	4.9	8.3	1.4	0.017
Lateral nasal end / ST Lateral rhinion	6.7	1.4	6.7	1.4	8.0	1.5	0.035
Infra-orbit / ST Infra-orbit	7.6	1.1	7.4	0.9	8.6	1.2	0.001
Maxillare / ST Maxillare	19.4	2.5	16.7	2.4	20.2	2.1	0.000
Lateral nostril / Lateral nostril	15.1	2.8	13.9	1.7	14.1	1.6	NS
Incisor alveolus / Naso-labial ridge	12.2	1.7	12.4	1.7	13.1	1.7	NS
Supra-canina / ST Supra-canina	11.1	1.2	11.1	1.1	11.1	1.2	NS
Upper incisor / Upper lip	10.1	2.1	14.0	3.0	11.5	1.6	0.000
Lower incisor / Lower lip	12.8	1.3	14.0	1.4	13.0	1.3	0.014
Infra-canina / ST Infra-canina	11.1	1.5	12.1	1.3	12.0	1.1	0.032
Mental tubercle / ST Mental tubercle	8.7	1.7	11.0	2.4	8.7	1.7	0.000
Mid-lateral orbit / ST Mid-lateral orbit	4.8	0.7	5.4	1.0	6.7	1.4	0.000
Supraglenoid / ST Supraglenoid	11.8	1.9	11.7	2.1	11.6	2.0	NS
Zygomatic arch / ST Zygomatic arch	8.2	1.4	8.3	1.3	9.0	1.5	NS
Lateral zygoma / ST Lateral zygoma	9.3	1.5	9.5	1.5	10.7	1.9	0.016
Supra-M1 / ST Supra-M1	23.5	2.5	27.2	3.8	27.2	3.3	0.001
Ante-ramus / Ante-masseter	21.9	2.7	21.1	2.7	22.0	2.7	NS
Mid-ramus / Mid-masseter	20.1	3.2	19.2	3.1	20.7	2.6	NS
Infra-M1 / ST Infra-M1	20.6	2.6	18.2	3.8	19.5	2.6	NS
Gonion lateralis / ST Gonion lateralis	11.0	2.8	14.8	2.9	10.9	2.4	0.000
Mid-mandibular / ST Mid-mandibular	14.7	2.7	13.7	2.4	13.9	1.8	NS
Sub-mandibular / ST Sub-mandibular	7.0	1.2	7.2	1.3	7.5	1.1	NS

Perp HT, Perpendicular to hard tissue; Perp ST, perpendicular to soft tissue; HT to ST, direct measurement between hard tissue and soft tissue landmarks SD, standard deviation; ST, soft tissue; NS, not significant.

TABLE 4 - Inter-examiner reproducibility of measurements according to landmarks in case of 'perpendicular bone' method (n=20).

Measurement	Examiner A (mm)		Examiner B (mm)		Difference	Significance by t-test	ICC
	Mean	SD	Mean	SD			
Midline landmarks							
Glabella	5.1	1.0	5.1	0.9	0.0	NS	0.932
Infra-glabella	5.7	0.7	5.7	0.7	0.0	NS	0.988
Nasion	6.3	1.1	6.2	1.2	0.1	NS	0.902
Rhinion	2.6	1.0	2.7	0.9	-0.1	NS	0.937
Mid-philtrum	12.7	1.9	12.8	2.1	-0.1	NS	0.978
B point	13.0	1.5	13.1	1.4	-0.1	NS	0.771
Pogonion	10.9	1.8	11.1	1.7	-0.2	NS	0.944
Menton	8.0	2.0	7.9	1.6	0.1	NS	0.750
Bilateral landmarks							
Frontal eminence	6.5	1.2	6.3	1.0	0.2	NS	0.936
Supra-orbit	7.3	0.9	7.2	0.9	0.1	NS	0.917
Lateral nasion	7.6	1.4	7.6	1.0	0.0	NS	0.795
Lateral nasal end	6.7	1.4	6.8	1.5	-0.1	NS	0.845
Infra-orbit	7.6	1.1	7.5	1.1	0.1	NS	0.932
Maxillare	19.4	2.5	19.3	3.0	0.1	NS	0.922
Lateral nostril	15.1	2.8	14.2	1.5	0.9	NS	0.708
Incisor alveolus	12.2	1.7	12.8	1.7	-0.6	NS	0.857
Supra-canina	11.1	1.2	10.8	1.0	0.3	NS	0.812
Upper incisor	10.1	2.1	10.5	2.1	-0.4	NS	0.969
Lower incisor	12.8	1.3	13.0	1.2	-0.2	NS	0.847
Infra-canina	11.1	1.5	11.2	1.2	-0.1	NS	0.920
Mental tubercle	8.7	1.7	8.7	1.4	0.0	NS	0.936
Mid-lateral orbit	4.8	0.7	4.7	0.9	0.1	NS	0.934
Supraglenoid	11.8	1.9	12.0	1.7	-0.2	NS	0.812
Zygomatic arch	8.2	1.4	8.3	1.3	-0.1	NS	0.979
Lateral zygoma	9.3	1.5	9.4	1.5	-0.1	NS	0.964
Supra-M1	23.5	2.5	24.2	2.8	-0.7	NS	0.923
Ante-ramus	21.9	2.7	22.3	2.5	-0.4	NS	0.937
Mid-ramus	20.1	3.2	20.0	3.2	0.1	NS	0.989
Infra-M1	20.6	2.6	20.3	2.7	0.3	NS	0.920
Gonion lateralis	11.0	2.8	11.6	2.4	-0.6	NS	0.878
Mid-mandibular	14.7	2.7	14.8	2.3	-0.1	NS	0.975
Sub-mandibular	7.0	1.2	7.2	1.4	-0.2	NS	0.910

SD, Standard deviation; ICC, intraclass correlation coefficient; NS, not significant.

TABLE 5 - Inter-examiner reproducibility of measurements according to landmarks in case of 'perpendicular to skin' method (n=20).

Measurement	Examiner A (mm)		Examiner B (mm)		Difference	Significance by t-test	ICC <sup>†</sup>
	Mean	SD	Mean	SD			
Midline landmarks							
ST Glabella	5.4	0.9	5.2	0.9	0.2	NS	0.823
ST Infra-glabella	5.6	0.8	5.7	0.7	-0.1	NS	0.971
ST Nasion	5.7	1.2	5.9	1.2	-0.2	NS	0.825
ST Rhinion	2.4	0.9	2.6	0.9	-0.2	NS	0.790
Mid-philtrum	12.0	2.1	12.3	1.8	-0.3	NS	0.916
ST B point	12.3	1.2	11.7	1.2	0.6	0.009	<u>0.675</u>
ST Pogonion	12.9	1.9	12.4	1.6	0.5	0.046	0.878
Beneath chin	7.1	1.4	7.9	2.0	-0.8	0.018	0.708
Bilateral landmarks							
ST Frontal eminence	6.7	1.3	6.2	1.0	0.5	0.009	0.871
ST Supra-orbit	7.1	0.9	7.1	0.9	0.0	NS	0.948
ST Lateral nasion	10.2	4.9	7.8	1.7	2.4	0.049	<u>0.676</u>
ST Lateral rhinion	6.7	1.4	7.2	1.6	-0.5	NS	<u>0.117</u>
ST Infra-orbit	7.4	0.9	7.4	0.8	0.0	NS	0.807
ST Maxillare	16.7	2.4	18.3	2.7	-1.6	0.000	0.918
Lateral nostril	13.9	1.7	13.9	1.7	0.0	NS	0.848
Naso-labial ridge	12.4	1.7	12.3	1.8	0.1	NS	0.970
ST Supra-canina	11.1	1.1	11.1	1.2	0.0	NS	<u>0.629</u>
Upper lip	14.0	3.0	12.7	2.3	1.3	0.011	0.832
Lower lip	14.0	1.4	14.3	1.4	-0.3	NS	0.749
ST Infra-canina	12.1	1.3	11.6	1.2	0.5	NS	0.786
ST Mental tubercle	11.0	2.4	12.2	1.6	-1.2	0.040	<u>0.516</u>
ST Mid-lateral orbit	5.4	1.0	4.7	1.0	0.7	0.006	<u>0.595</u>
ST Supraglenoid	11.7	2.1	12.1	1.7	-0.4	NS	0.807
ST Zygomatic arch	8.3	1.3	8.4	1.4	-0.1	NS	0.943
ST Lateral zygoma	9.5	1.5	9.6	1.7	-0.1	NS	0.896
ST Supra-M1	27.2	3.8	25.8	3.2	1.4	0.037	<u>0.674</u>
Ante-masseter	21.1	2.7	21.5	2.6	-0.4	0.005	0.976
Mid-masseter	19.2	3.1	20.8	3.2	-1.6	0.000	0.905
ST Infra-M1	18.2	3.8	19.9	2.8	-1.7	0.024	<u>0.568</u>
ST Gonion lateralis	14.8	2.9	14.0	2.8	0.8	NS	0.864
ST Mid-mandibular	13.7	2.4	14.2	1.9	-0.5	NS	<u>0.356</u>
ST Sub-mandibular	7.2	1.3	7.8	1.4	-0.6	0.030	0.776

SD, Standard deviation; ICC, intraclass correlation coefficient; ST, soft tissue; NS, not significant.

<sup>†</sup> The number lesser than 0.7 was underlined indicating the low inter-examiner reproducibility.

TABLE 6 - Inter-examiner reproducibility of measurements according to landmarks in case of 'direct measurement' method (n=20).

Measurement	Examiner A (mm)		Examiner B (mm)		Difference	Significance by t-test	ICC <sup>†</sup>
	Mean	SD	Mean	SD			
Midline landmarks							
Glabella	5.8	1.0	5.4	1.0	0.4	NS	<u>0.589</u>
Infra-glabella	6.6	1.1	5.8	0.7	0.8	0.002	<u>0.575</u>
Nasion	7.9	1.7	6.6	1.2	1.3	0.001	<u>0.524</u>
Rhinion	3.0	1.0	3.0	1.0	0.0	NS	<u>0.310</u>
Mid-philtrum	12.4	1.6	12.7	1.7	-0.3	0.006	0.958
B point	13.2	1.6	12.6	1.3	0.6	0.031	<u>0.695</u>
Pogonion	13.1	2.3	12.1	1.6	1.0	0.010	0.730
Menton	8.1	1.8	7.6	1.6	0.5	NS	0.748
Bilateral landmarks							
Frontal eminence	7.3	1.2	6.3	1.1	1.0	0.000	0.712
Supra-orbit	8.5	1.0	7.1	0.9	1.4	0.000	<u>0.652</u>
Lateral nasion	8.3	1.4	7.8	1.1	0.5	NS	<u>0.538</u>
Lateral nasal end	8.0	1.5	7.0	1.4	1.0	0.014	<u>0.440</u>
Infra-orbit	8.6	1.2	7.5	0.9	1.1	0.000	<u>0.589</u>
Maxillare	20.2	2.1	18.0	2.2	2.2	0.000	<u>0.640</u>
Lateral nostril	14.1	1.6	13.8	1.7	0.3	NS	0.901
Incisor alveolus	13.1	1.7	12.7	1.7	0.4	0.009	0.951
Supra-canina	11.1	1.2	11.1	0.9	0.0	NS	0.742
Upper incisor	11.5	1.6	11.2	1.9	0.3	0.028	0.949
Lower incisor	13.0	1.3	13.4	1.3	-0.4	NS	0.842
Infra-canina	12.0	1.1	11.7	1.4	0.3	NS	0.835
Mental tubercle	8.7	1.7	11.3	1.6	-2.6	0.000	0.701
Mid-lateral orbit	6.7	1.4	4.8	0.8	1.9	0.000	<u>0.044</u>
Supraglenoid	11.6	2.0	11.9	1.6	-0.3	NS	0.886
Zygomatic arch	9.0	1.5	8.4	1.4	0.6	0.001	0.939
Lateral zygoma	10.7	1.9	9.7	1.6	1.0	0.000	0.903
Supra-M1	27.2	3.3	24.5	2.6	2.7	0.001	<u>0.691</u>
Ante-ramus	22.0	2.7	22.0	2.6	0.0	NS	0.935
Mid-ramus	20.7	2.6	20.4	3.3	0.3	NS	0.945
Infra-M1	19.5	2.6	19.0	1.8	0.5	NS	0.886
Gonion lateralis	10.9	2.4	11.3	2.4	-0.4	NS	0.934
Mid-mandibular	13.9	1.8	14.0	1.9	-0.1	NS	0.896
Sub-mandibular	7.5	1.1	8.1	1.4	-0.6	0.043	<u>0.699</u>

SD, Standard deviation; ICC, intraclass correlation coefficient; NS, not significant.

<sup>†</sup> The number lesser than 0.7 was underlined indicating the low inter-examiner reproducibility.



TABLE 7 - Intra-examiner reproducibility of the measurements in case of 'perpendicular to bone' method (n=20).

Measurement	1st measure (mm)		2nd measure (mm)		Difference	Significance by paired t-test	Pearson correlation coefficient	Reliability coefficient
	Mean	SD	Mean	SD				
Midline landmarks								
Glabella	5.1	1.0	5.2	1.0	-0.1	NS	0.973*	0.986
Infra-glabella	5.7	0.7	5.8	0.7	-0.1	NS	0.982*	0.991
Nasion	6.3	1.1	6.4	1.2	-0.1	NS	0.973*	0.985
Rhinion	2.6	1.0	2.6	0.9	0.0	NS	0.917*	0.954
Mid-philtrum	12.7	1.9	12.5	2.1	0.2	NS	0.974*	0.986
B point	13.0	1.5	13.1	1.5	-0.1	NS	0.986*	0.993
Pogonion	10.9	1.8	10.8	1.7	0.1	NS	0.930*	0.963
Menton	8.0	2.0	8.0	2.0	0.0	NS	0.920*	0.958
Bilateral landmarks								
Frontal eminence	6.5	1.2	6.5	1.2	0.0	NS	0.938*	0.968
Supra-orbit	7.3	0.9	7.2	0.9	0.1	NS	0.944*	0.971
Lateral nasion	7.6	1.4	7.6	1.1	0.0	NS	0.832*	0.938
Lateral nasal end	6.7	1.4	7.0	1.4	-0.3	NS	0.913*	0.954
Infra-orbit	7.6	1.1	7.5	1.3	0.1	NS	0.966*	0.979
Maxillare	19.4	2.5	19.3	2.5	0.1	NS	0.959*	0.979
Lateral nostril	15.1	2.8	15.7	2.5	-0.6	NS	0.930*	0.949
Incisor alveolus	12.2	1.7	12.0	1.7	0.2	NS	0.953*	0.976
Supra-canina	11.1	1.2	11.2	1.4	-0.1	NS	0.919*	0.956
Upper incisor	10.1	2.1	10.3	2.1	-0.2	NS	0.964*	0.982
Lower incisor	12.8	1.3	12.8	1.1	0.0	NS	0.963*	0.974
Infra-canina	11.1	1.5	11.0	1.5	0.1	NS	0.972*	0.986
Mental tubercle	8.7	1.7	8.8	1.8	-0.1	NS	0.826*	0.904
Mid-lateral orbit	4.8	0.7	4.8	0.8	0.0	NS	0.923*	0.957
Supraglenoid	11.8	1.9	11.5	1.9	0.3	NS	0.898*	0.946
Zygomatic arch	8.2	1.4	8.2	1.3	0.0	NS	0.994*	0.995
Lateral zygoma	9.3	1.5	9.2	1.6	0.1	NS	0.990*	0.993
Supra-M1	23.5	2.5	23.6	2.8	-0.1	NS	0.938*	0.964
Ante-ramus	21.9	2.7	21.8	2.6	0.1	NS	0.993*	0.996
Mid-ramus	20.1	3.2	20.1	3.1	0.0	NS	0.989*	0.995
Infra-M1	20.6	2.6	20.5	2.5	0.1	NS	0.915*	0.956
Gonion lateralis	11.0	2.8	11.1	2.7	-0.1	NS	0.916*	0.956
Mid-mandibular	14.7	2.7	14.4	2.4	0.3	NS	0.968*	0.980
Sub-mandibular	7.0	1.2	6.9	1.1	0.1	NS	0.861*	0.922

SD, Standard deviation; NS, not significant; \*p < 0.05.

TABLE 8 - Intra-examiner reproducibility of the measurements in case of 'perpendicular to skin' method (n=20).

Measurement	1st measure (mm)		2nd measure (mm)		Difference	Significance by paired t-test	Pearson correlation coefficient	Reliability coefficient
	Mean	SD	Mean	SD				
Midline landmarks								
ST Glabella	5.4	0.9	5.4	0.9	0.0	NS	0.989*	0.994
ST Infra-glabella	5.6	0.8	5.7	0.7	-0.1	NS	0.960*	0.976
ST Nasion	5.7	1.2	5.4	1.1	0.3	0.032	0.924*	0.960
ST Rhinion	2.4	0.9	2.4	0.9	0.0	NS	0.949*	0.973
Mid-philtrum	12.0	2.1	12.1	2.1	-0.1	NS	0.978*	0.989
ST B point	12.3	1.2	12.4	1.1	-0.1	NS	0.933*	0.964
ST Pogonion	12.9	1.9	12.8	1.8	0.1	NS	0.976*	0.988
Beneath chin	7.1	1.4	7.2	1.4	-0.1	NS	0.833*	0.904
Bilateral landmarks								
ST Frontal eminence	6.7	1.3	6.9	1.3	-0.2	NS	0.929*	0.963
ST Supra-orbit	7.1	0.9	7.1	0.9	0.0	NS	0.944*	0.946
ST Lateral nasion	10.2	4.9	8.1	1.4	2.1	NS	0.315	0.296
ST Lateral rhinion	6.7	1.4	7.6	1.7	-0.9	NS	0.213	0.202
ST Infra-orbit	7.4	0.9	7.6	1.1	-0.2	NS	0.790*	0.871
ST Maxillare	16.7	2.4	16.7	2.5	0.0	NS	0.972*	0.985
Lateral nostril	13.9	1.7	13.8	2.0	0.1	NS	0.835*	0.902
Naso-labial ridge	12.4	1.7	12.3	1.8	0.1	NS	0.941*	0.968
ST Supra-canina	11.1	1.1	11.0	1.0	0.1	NS	0.692*	0.815
Upper lip	14.0	3.0	14.2	3.2	-0.2	NS	0.929*	0.962
Lower lip	14.0	1.4	14.4	1.9	-0.4	NS	0.884*	0.918
ST Infra-canina	12.1	1.3	12.2	1.1	-0.1	NS	0.904*	0.956
ST Mental tubercle	11.0	2.4	10.7	2.3	0.3	NS	0.955*	0.975
ST Mid-lateral orbit	5.4	1.0	5.7	1.0	-0.3	NS	0.601*	0.751
ST Supraglenoid	11.7	2.1	11.9	2.0	-0.2	NS	0.889*	0.941
ST Zygomatic arch	8.3	1.3	8.4	1.5	-0.1	NS	0.964*	0.979
ST Lateral zygoma	9.5	1.5	9.5	1.5	0.0	NS	0.856*	0.922
ST Supra-M1	27.2	3.8	30.7	3.6	-3.5	NS	0.228	0.337
Ante-masseter	21.1	2.7	21.0	2.7	0.1	NS	0.971*	0.985
Mid-masseter	19.2	3.1	19.4	2.9	-0.2	NS	0.943*	0.970
ST Infra-M1	18.2	3.8	18.2	4.0	0.0	NS	0.971*	0.937
ST Gonion lateralis	14.8	2.9	14.6	3.2	0.2	NS	0.852*	0.918
ST Mid-mandibular	13.7	2.4	14.1	2.1	-0.4	NS	0.817*	0.893
ST Sub-mandibular	7.2	1.3	7.5	1.2	-0.3	NS	0.796*	0.885

SD, Standard deviation; ST, soft tissue; NS, not significant; \*p < 0.05.

TABLE 9 - Intra-examiner reproducibility of the measurements in case of 'direct measurement' method (n=20).

Measurement	1st measure (mm)		2nd measure (mm)		Difference	Significance by paired t-test	Pearson correlation coefficient	Reliability coefficient
	Mean	SD	Mean	SD				
Midline landmarks								
Glabella	5.8	1.0	5.7	1.0	0.1	NS	0.785*	0.879
Infra-glabella	6.6	1.1	6.2	1.0	0.4	0.037	0.785*	0.874
Nasion	7.9	1.7	8.1	1.5	-0.2	NS	0.746*	0.853
Rhinion	3.0	1.0	2.8	0.9	0.2	NS	0.693*	0.818
Mid-philtrum	12.4	1.6	12.2	1.7	0.2	NS	0.926*	0.960
B point	13.2	1.6	13.2	1.6	0.0	NS	0.948*	0.973
Pogonion	13.1	2.3	12.9	2.6	0.2	NS	0.967*	0.980
Menton	8.1	1.8	8.1	1.7	0.0	NS	0.873*	0.931
Bilateral landmarks								
Frontal eminence	7.3	1.2	7.4	1.4	-0.1	NS	0.809*	0.890
Supra-orbit	8.5	1.0	8.0	1.1	0.5	0.004	0.790*	0.882
Lateral nasion	8.3	1.4	8.1	1.2	0.2	NS	0.804*	0.883
Lateral nasal end	8.0	1.5	7.9	1.4	0.1	NS	0.757*	0.860
Infra-orbit	8.6	1.2	8.0	1.2	0.6	0.005	0.724*	0.840
Maxillare	20.2	2.1	20.4	1.8	-0.2	NS	0.877*	0.930
Lateral nostril	14.1	1.6	13.6	1.6	0.5	0.019	0.855*	0.921
Incisor alveolus	13.1	1.7	12.9	1.9	0.2	NS	0.923*	0.957
Supra-canina	11.1	1.2	10.9	1.0	0.2	NS	0.855*	0.918
Upper incisor	11.5	1.6	11.0	1.7	0.5	0.007	0.902*	0.948
Lower incisor	13.0	1.3	12.7	1.4	0.3	0.003	0.962*	0.980
Infra-canina	12.0	1.1	12.1	1.2	-0.1	NS	0.760*	0.861
Mental tubercle	8.7	1.7	8.6	1.7	0.1	NS	0.922*	0.959
Mid-lateral orbit	6.7	1.4	7.2	1.6	-0.5	0.048	0.780*	0.874
Supraglenoid	11.6	2.0	11.7	1.9	-0.1	NS	0.969*	0.983
Zygomatic arch	9.0	1.5	8.4	1.5	0.6	0.004	0.880*	0.936
Lateral zygoma	10.7	1.9	10.7	1.6	0.0	NS	0.842*	0.909
Supra-M1	27.2	3.3	27.3	3.3	-0.1	NS	0.931*	0.964
Ante-ramus	22.0	2.7	21.6	2.7	0.4	0.014	0.971*	0.985
Mid-ramus	20.7	2.6	20.5	2.9	0.2	NS	0.928*	0.960
Infra-M1	19.5	2.6	19.5	2.6	0.0	NS	0.943*	0.971
Gonion lateralis	10.9	2.4	10.7	2.6	0.2	NS	0.894*	0.942
Mid-mandibular	13.9	1.8	13.7	2.0	0.2	NS	0.849*	0.915
Sub-mandibular	7.5	1.1	7.9	1.3	-0.4	NS	0.636*	0.768

SD, Standard deviation; NS, not significant; \*p < 0.05.

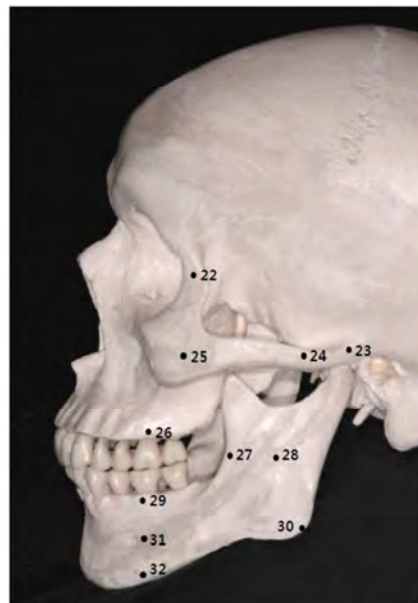
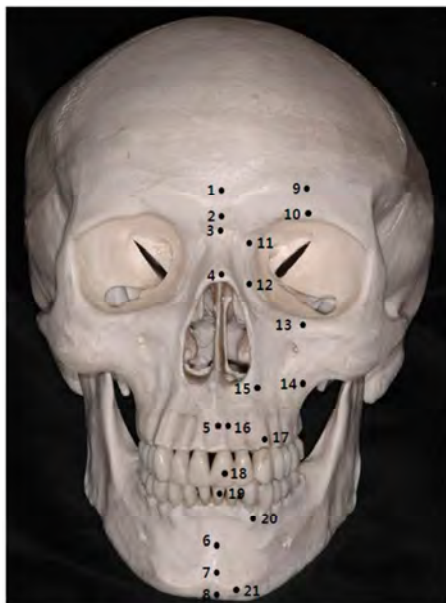
**Figure legends**

FIG. 1 - *Thirty two (8 midline and 24 bilateral) hard tissue landmarks used in this study. Their definitions are described on Table 1.*

FIG. 2 - *Thirty two (8 midline and 24 bilateral) soft tissue landmarks used in this study. All landmarks were corresponded to the hard tissue landmarks seen in Figure 1 and their definitions are described on Table 2.*

FIG. 3 - *Schematic diagram showing three measurement methods used in this study. Landmarks used by each method are expressed as dots. A, measurement perpendicular to bone; B, measurement perpendicular to skin; C, direct measurement between the two landmarks, one on bone and the other on skin.*

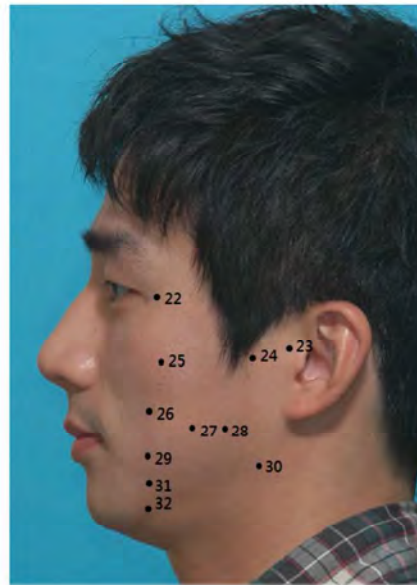
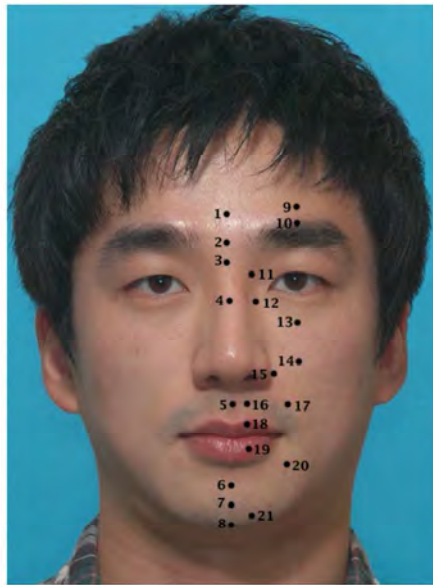
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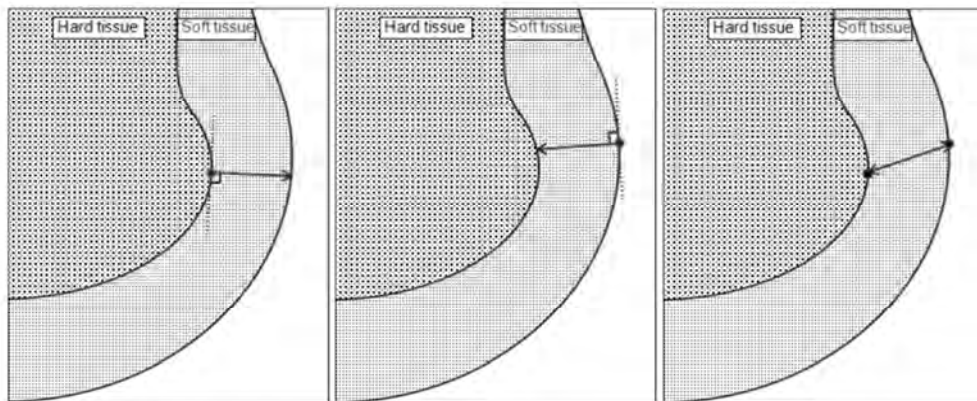
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