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Facial soft tissue thickness differences among different vertical facial patterns

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ABSTRACT

In forensic facial approximation, facial soft tissue thickness (FSTT) measurements play a major role. These values are affected by many factors such as ethnicity, age and sex, in addition to measurement errors. We hypothesize that an additional source of error is the lack of consideration of facial type in the assessment of FSTT norms.

The purpose of this study was to: 1- evaluate the presence of significant effects of vertical facial type within the FSTT measurements in adults and 2- assess the correlations between FSTT and hard and soft tissue cephalometric measurements.

The sample consisted of the lateral cephalometric radiographs of 222 adult individuals (87 males; 135 females, 23.49 ± 6.24 years of age) with normal occlusion and balanced profiles. Hard and soft tissue cephalometric measurements were taken, in addition to FSST at 10 facial landmarks. The sample was categorized into 3 vertical pattern groups based on the MP/SN angle: hypodivergent, normodivergent and hyperdivergent. Statistical analyses included MANOVA test and Pearson moment product for associations among variables. Statistically significant effect of vertical divergence on FSTT values was limited to the levels of Stomion, Labiomentale and Pogonion and FSTT measurements were associated with measurements related to the lower face (Lm and Pog) Moderate to high correlations between mandibular length and ramus length and FSTT values related to the lower face (LL, Lm and Pog mainly) emphasize further the important role of the underlying skeleton.

1. Introduction

Craniofacial identification methods, developing over the past century, have proved useful towards forensic human identification especially when traditional records (DNA, dental records, fingerprints . . .) are absent or difficult to obtain [1,2]. Craniofacial superimposition overlays the antemortem image(s) of a suspected individual over skull remains in order to assess morphological correspondence [3–5], whereas facial approximation attempts to predict a face solely from the cranial remains [4–6]. Both methods involve the use of facial soft tissue thickness (FSTT) values at various landmarks in the reconstruction of facial features [7,8]. Measured as the distance between the respective surfaces of the skin and the underlying skeletal tissue, FSTT values set an approximate range and limit of work [7,9].

Although craniofacial identification methods are gaining momentum as viable methods for identification [4,5,10], the techniques have been shown to have inadequate reliability [11–14]. The facial approximation method has been considered inappropriate for positive scientific identification, with utility only towards public communication and gathering potential information regarding missing persons [15,16]. A major outcome of the New Methodologies and Protocols of Forensic Identification by the Craniofacial Superimposition Project (MEPROCS), the most comprehensive assessment of craniofacial superimposition (CFS)

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to date, was that the absence of a systematic CFS methodology hinders its validity as legal evidence and renders the method controversial [17,18]. Recent validation studies following the MEPROCs initiative [19–22], raise also significant concerns with respect to the reliability of CFS, especially when only one anterior view image of the individual is available.

In their extensive review of the main sources of error and uncertainty in CFS identification, Damas et al. discuss several sources of uncertainty that are inherent to the process of CFS identification, including: 1- cephalometric landmark location uncertainty; 2- landmark matching uncertainty and 3- skull-face overlay uncertainty. Among other factors, the imprecision involved in the matching of soft and hard tissue corresponding landmarks is partially attributed to the fact that FSTT values vary for each cephalometric landmark in addition to differences based on factors such as age, race and sex [18].

The increasing need to map the facial soft tissue over the skeletal hard tissue more predictably [5,23] has fueled extensive research towards estimating population-, age- and sex- specific FSTT norms at various facial points [5,24–26]. However, while several studies have illustrated the presence of considerable differences in FSTT between ethnicities and populations [7,27–29], recent research works highlight the relatively poor approximation that FSTT sample means provide to population values [7,30]. This has been attributed to the significant effects of measurement errors (including sampling errors, measurement precision, intra- and inter-rater reliability) in obscuring the variability produced by other variables. We hypothesize that an additional source of error is the lack of consideration of facial type in the assessment of FSTT norms [7,14,28,31].

Orthodontists have been studying the face in profile for over a century and described, based on lateral cephalograms, norms for the linear and angular relationships between various facial structures in addition to the skeletal structures supporting them [32–37]. These norms have been used to classify assessed individuals into 3 distinct groups based on the positional anteroposterior relationship between the upper and lower jaws: Class I (characterized by a normal relationship between the jaws translating into a straight profile); Class II (characterized by a posterior mandibular position relative to the maxilla translating into a convex profile) and Class III (characterized by an anterior position of the mandible relative to the maxilla and translating into a concave profile) [35,38]. Cephalometric measurements have also been described to classify individuals based on the profile in the vertical plane into 3 groups: Normodivergent (commonly associated with a normal lower third of the face); Hypodivergent (commonly associated with short lower third); and Hyperdivergent (commonly associated with a long lower third) [39].

Recent interest in the relationship between facial types and FSTT measurements suggests that there is an association between the three types of faces in the sagittal plane and FSTT norms [40]. However, to the authors' knowledge, there have been no assessments of the potential effects of the differing vertical facial types on FSTT values. While traditional methods of craniofacial approximation take skull remains at face value and overlay facial soft tissue based on isolated predetermined norms, based on orthodontic experience, the authors believe that skull remains possess an inherent potential to reflect considerably upon the antemortem facial soft tissue of the deceased.

The purpose of this study was to: 1- evaluate the presence of significant effects of vertical facial type within the FSTT measurements in adults and 2- assess the correlations between FSTT and hard and soft tissue cephalometric measurements.

2. Material and methods

2.1. Study population

The study sample consisted of the pre-treatment lateral cephalometric radiographs of 222 non-growing subjects (87 males, 135 females, mean age 23.49 ± 6.24 years) recruited from the database of patients attending the Department of Orthodontics at the Lebanese University Faculty of Dental Medicine (Lebanon) and the private clinics of two authors.

Females older than 16 years and males older than 18 years, presenting a normal dental (Class I molar and canine) and skeletal ($0^\circ < ANB < 4^\circ$) jaws relationship were included in the study. A balanced facial profile as judged by the two orthodontists of the research team and the presence of high-quality pre-treatment lateral cephalograms were also considered as additional inclusion criteria.

Excluded were subjects with systemic disease, craniofacial anomalies, history of orthodontic treatment and/or surgical treatment involving the head and neck.

This cross-sectional investigation was approved by the Institutional Review Board of the Lebanese University (CUEMB 35/AA).

2.2. Radiographic analysis

Digital lateral cephalometric radiographs were taken in natural head position and digitized by one investigator (RH) using the Dolphin Imaging software (Dolphin Imaging and Management Solutions, Version 11.5, La Jolla, California). The digitized hard and soft tissue landmarks and planes are illustrated in Fig. 1. Cephalometric linear and angular measurements were then automatically generated (Table 1).

The anthropological points used to generate the FSTT measurements are described in a previous publication [41]. They consisted of the FSTT at the level of the following landmarks: Glabella (G);

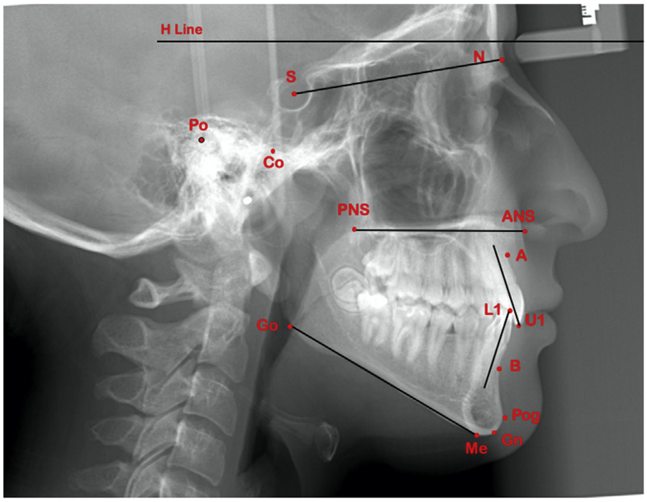

Fig. 1. Cephalometric landmarks and planes. **Landmarks:** **S:** Sella- Center of pituitary fossa; **N:** Nasion- Junction of the frontal and nasal bones; **ANS:** Anterior Nasal Spine- Tip of the bony anterior nasal spine at the inferior margin of the piriform aperture in the midsagittal plane; **PNS:** Posterior Nasal Spine- Most posterior point on the bony hard palate in the midsagittal plane; **A:** A point- Deepest midline point on the curvature between the ANS and the dental alveolus; **B**: B point- Deepest midline point on the bony curvature of the anterior mandible; **Pog**: Pogonion- The most anterior point on the contour of the bony chin in the midsagittal plane; **Me**: Menton- Most inferior point on the chin in the lateral view; **Go:** Gonion- Most posterior inferior point on the outline of the angle of the mandible.
Planes: **H**: True horizontal plane, **PP**: Palatal plane-line connecting ANS and PNS**;** **MP**: Mandibular plane-line joining Go and Me.

Table 1
Cephalometric linear and angular measurements

Skeletal measurements	
SN (mm)	Anterior cranial base length
SN/H (°)	Angle between anterior cranial base cant (SN) and true horizontal (H)
N-ANS (mm)	Upper facial height: vertical distance between N and ANS
ANS-Me (mm)	Lower facial height: vertical distance between ANS and Me
SNA (°)	Angle formed by SN and point A (most posterior point on anterior contour of maxilla)
SNB (°)	Angle formed by SN and point B (most posterior point on anterior contour of mandible)
ANB (°)	A point–nasion–B point angle
ANS-PNS (mm)	Maxillary length: distance between ANS and PNS
Co-Gn (mm)	Effective mandibular length: distance between Co and Gn
Co-Pog (mm)	Mandibular length: distance between Co and Pog
Co-Go (mm)	Ramus length: distance between Co and Go
Dental measurements	
U1/SN (°)	Maxillary incisor to SN plane: inclination of maxillary incisors to SN; the most inferior inward angle formed by the extension of the long axis of the maxillary incisor to the SN plane
L1/MP (°)	Mandibular incisor to mandibular plane: inclination of mandibular incisors to MP; the most inward angle toward the body of the mandible is measured
U1/L1(°)	Inter-incisal angle: angle measured between the extension of the maxillary and mandibular incisor long axis line
U6-PP (mm)	Perpendicular distance from maxillary first molar mesial cusp tip to PP
U1-PP (mm)	Perpendicular distance from maxillary central incisor cusp tip to PP
L6-MP (mm)	Perpendicular distance from mandibular first molar mesial cusp tip to MP
L1-MP (mm)	Perpendicular distance from mandibular central incisor tip to MP

Nasion (N); Rhinion (Rh); Subnasale (Sn); Upper lip (UL); Stomion (St); Lower lip (LL); Labiomentale (LM); Pogonion (Pog) and Gnathion (Gn) (Fig. 2).

Two commonly used angular cephalometric measurements were used to categorize the sample by vertical divergence as follows: 1- MP/SN ($<28°$ = hypodivergent, 28°–36° = normodivergent, $>36°$ = hyperdivergent) [34] and 2- PP/MP ($<21°$ = hypodivergent, 21°–29° = normodivergent, $>29°$ = hyperdivergent) [37] (Fig. 3).

Thirty randomly selected lateral cephalograms were re-digitized by the same examiner (RH) at least 14 days after initial assessment and another set of 30 radiographs was subjected to repeated measurements by another investigator (MS). Intra- and inter-examiner reliability of all measurements was then assessed.

2.3. Statistical analysis

The intra- and inter-observer errors were evaluated with the Technical Error of Measurement using Dahlberg's formula [42,43].

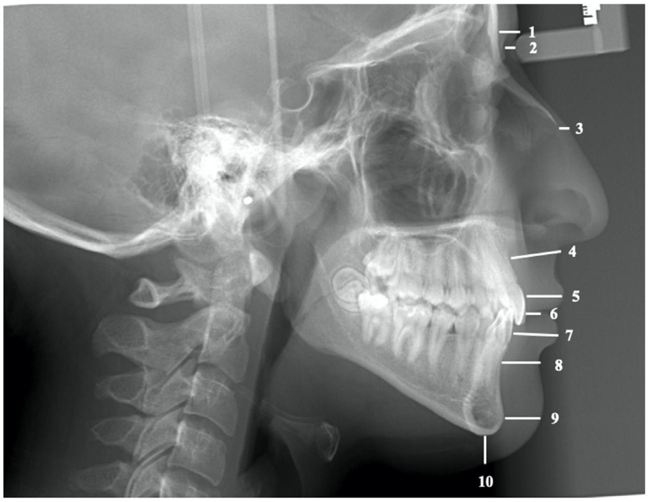

Fig. 2. Measurements of facial soft tissue thickness at: **1.** Glabella; **2.** Nasion; **3.** Rhinion; **4.** Subnasale; **5.** Upper lip; **6.** Stomion; **7.** Lower lip; **8.** Labiomentale; **9.** Pogonion; **10.** Gnathion.

The multivariate analysis of variance (MANOVA) was applied to assess the effect of facial vertical divergence on the FSTT data, since they represent multivariate measurements of single faces. In addition, the linear correlation between the various FSTT and cephalometric measurements was assessed using the Pearson product-moment correlation analysis.

Statistical analyses were processed using the Statistical Package for Social Sciences (SPSS®, version 23.0, IBM®) using the statistical significance level of 0.05. Since only one independent variable (vertical divergence as categorized by SN/PP or PP/MP) was assessed in each MANOVA model, the partial eta-squared (η^2) reported by SPSS is identical to η^2 for our data. Pillai's Trace was reported instead of Wilk's Lambda as it is more robust in cases of unequal sample sizes.

3. Results

Dahlberg's error ranged from 0.15 to 0.67 mm for intra-observer and 0.32 to 0.84 mm for the inter-observer reliability for FSTT measurements, indicating a high reliability of repeated measurements within and between operators.

3.1. FSTT norms

Mean FSTT measurements in the overall ranged between 3.07 ± 0.72 mm for Rhinion and 15.61 ± 2.38 mm for Subnasale. Mean, Short and 75-Shormax values for all assessed FSTT measurements have been presented in a previous publication [41].

3.2. Effect of vertical divergence on FSTT

The MANOVA tests assessing the effect of vertical divergence based on MP/SN and PP/MP both met the required assumptions of equality of covariance matrices (Box's M = 136.937; $p = 0.165$ and Box's M = 120.738; $p = 0.430$, respectively). There were statistically significant differences between the three levels of vertical divergence on the combined FSTT variables as assessed by MP/SN ($F(10, 210) = 1.787$; $p = 0.02$; Wilks' Lambda = 0.849; $\eta^2 = 0.078$). At the individual level, FSTT at the levels of Stomion, Labiomentale and Pogonion were statistically significantly different between the three vertical divergence groups (p = 0.043, 0.003 and 0.044, respectively; Table 2). Stomion thickness was significantly larger in

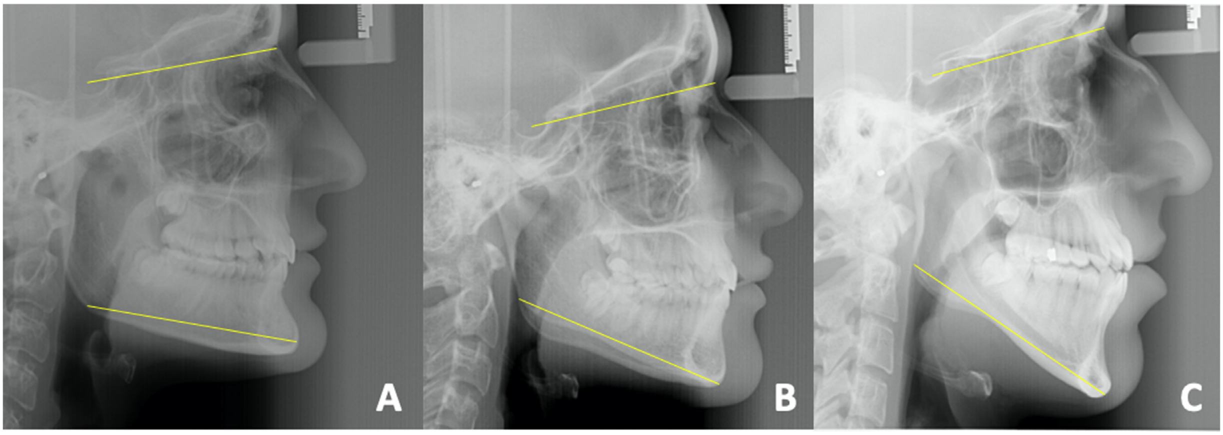

Fig. 3. Lateral cephalometric radiographs of different divergence patterns: **A.** Hypodivergent (MP/SN ≤ 27°); **B.** Normodivergent 27°< MP/SN< 37°); **C.** Hyperdivergent (MP/SN ≥ 37°).

Table 2
Comparison of FSTT measurements between hypodivergent, normodivergent and hyperdivergent individuals based on MP/SN values (n = 222)

	Hypo (1) (n = 31)		Normo (2) (n = 109)		Hyper (3) (n = 82)		Tests of Between Subjects Effects (MANOVA)			Post hoc multiple comparisons (Tukey) *P* Value		
	Mean	SD	Mean	SD	Mean	SD	F (2,219)	*P*	η^2	1 vs. 2	1 vs. 3	2 vs. 3
G	6.34	0.98	6.10	1.15	6.35	1.10	1.386	0.252	0.012	*NS*		
N	6.50	1.65	6.56	1.65	6.72	1.77	0.290	0.749	0.003	*NS*		
Rh	3.34	0.79	3.01	0.65	3.04	0.76	2.717	0.068	0.024	*NS*		
Sn	15.64	2.30	15.32	2.36	16.00	2.42	1.953	0.144	0.018	*NS*		
UL	12.37	1.71	11.81	2.21	11.86	2.07	0.886	0.414	0.008	*NS*		
St	5.85	1.64	5.18	1.84	4.89	1.79	3.194	0.043*	0.028	0.161	0.033*	0.523
LL	13.77	1.66	13.15	1.72	13.45	1.82	1.853	0.159	0.017	*NS*		
Lm	10.98	1.68	10.94	1.39	11.70	1.72	6.016	0.003**	0.052	0.992	0.074	0.003**
Pog	11.57	2.15	11.56	2.05	12.33	2.45	3.174	0.044*	0.028	1.000	0.229	0.045*
Gn	9.77	2.17	9.73	2.05	9.81	2.39	0.025	0.976	0.000	*NS*		

Notes. SD: Standard Deviation; η^2: eta squared; Vertical divergence according to MP/SN angle: Hypodivergent (Hypo): <28°; Normodivergent (Normo): 28°–36°; Hyperdivergent (Hyper): >36°.
*Significant, p < 0.05; **Significant, p < 0.01.

the hypodivergent than the hyperdivergent group (mean difference = 0.95 mm; standard error (SE) = 0.35; $\eta^2 = 0.028$) whereas mean FSTT values at Labiomentale and Pogonion were statistically significantly smaller in the normodivergent than in the hyperdivergent group (mean difference = 0.76 mm; SE = 0.33; $\eta^2 = 0.052$ and 0.78 mm; SE = 0.23; respectively).

There was also a statistically significant difference in FSTT values between the three vertical divergence groups as assessed by PP/MP (F (10, 210) = 2.125, p = 0.003; Wilks' Lambda = 0.822; $\eta^2 = 0.092$). At the individual level, only FSTT at Labiomentale and Pogonion exhibited statistically significant difference between the vertical divergence groups ($p < 0.001$ and $p = 0.004$, respectively). For both measurements, the general trend was for increasing values from hypodivergent to normodivergent to hyperdivergent. FSTT at labiomentale was statistically significantly larger in the hyperdivergent group than either of the normodivergent and hypodivergent groups ($p < 0.001$ and $p = 0.001$, respectively; mean difference = 0.93 mm; SE = 0.34 and 1.14 mm; SE = 0.28, respectively; Table 3). At the level of Pogonion, the difference was statistically significant only between the hyperdivergent and hypodivergent groups ($p = 0.003$; mean difference = 1.4 mm; SE = 0.46, Table 3).

3.3. Correlations

There was a considerable number of moderate- to high-strength correlation values between FSTT measurements and cephalometric skeletal, dental and soft-tissue measurements ($r > |0.4|$; Table 4). Among the cephalometric skeletal measurements, statistically significant and moderate to high corrections were noted between cranial base length (SN) and FSTT at Sn, LL and Pog ($r \geq 0.412$; $p < 0.001$). Upper face height (N-ANS) showed similar correlations with FSTT at Sn and LL ($r \geq 0.402$; $p < 0.001$) and lower face height (ANS-Me) with Sn, LL, Lm and Pog ($r \geq 0.424$; $p < 0.001$). The two measurements of mandibular length Co-Gn and Co-Pog were both significantly correlated with FSTT at Sn, LL, Lm and Pog ($r \geq 0.405$; $p < 0.001$) whereas mandibular ramus length Co-Go was correlated with FSTT only at LL ($r = 0.433$; $p < 0.001$).

Notable correlations between FSTT values and cephalometric dental hard-tissue measurements were vertical measures of tooth distances from their respective jaw planes. U6/PP distance was significantly correlated with FSTT at Lm and Pog ($r \geq 0.405$; $p < 0.001$) whereas L1 and L6 to MP distances were significantly correlated with FSTT at Sn, LL, Lm and Pog ($r \geq 0.440$; $p < 0.001$).

Among FSTT correlations with cephalometric soft-tissue measurements, the highest correlations were noted with UL thickness at A point ($r = 0.415$–0.783, $p = 0.001$). Among the soft tissue measurements moderately to highly correlated with FSTT values were 4 linear measurements (UL thickness at A point, Upper and lower lip lengths and inferior sulcus to H line) and 4 angular profile measurements (Nasofacial angle, nasomental angle, nasofrontal angle and mentolabial angle).

Table 3
Comparison of FSTT measurements between hypodivergent, normodivergent and hyperdivergent individuals based on PP/MP values (n = 222)

	Hypo (1) (n = 54)		Normo (2) (n = 110)		Hyper (3) (n = 58)		Tests of Between Subjects Effects (MANOVA)			Post hoc multiple comparisons (Tukey) *P* Value		
	Mean	SD	Mean	SD	Mean	SD	F (2,219)	*P*	η^2	1 vs. 2	1 vs. 3	2 vs. 3
G	6.19	1.00	6.26	1.14	6.19	1.15	0.106	0.900	0.001	*NS*		
N	6.21	1.64	6.60	1.69	6.65	1.71	0.2.243	0.109	0.020	*NS*		
Rh	3.01	0.58	3.10	0.72	3.06	0.82	0.331	0.718	0.003	*NS*		
Sn	15.34	2.23	15.53	2.26	16.03	2.72	1.288	0.278	0.012	*NS*		
UL	11.90	2.09	11.93	2.06	11.87	2.20	0.017	0.983	0.000	*NS*		
St	5.55	1.82	5.08	1.84	4.97	1.72	1.716	0.182	0.015	*NS*		
LL	13.20	1.69	13.34	1.70	13.54	1.93	0.532	0.588	0.005	*NS*		
Lm	10.82	1.53	11.04	1.34	11.96	1.86	9.394	<0.001**	0.079	0.673	0.001	<0.001**
Pog	11.18	2.07	11.78	1.92	12.58	2.72	5.723	0.004**	0.050	0.229	0.003**	0.069
Gn	9.53	2.12	9.88	2.07	9.78	2.47	0.451	0.638	0.004	*NS*		

Notes. SD: Standard Deviation; η^2: eta squared; Vertical divergence according to PP/MP angle: Hypodivergent (Hypo): <21°; Normodivergent (Normo): 21°–29°; Hyperdivergent (Hyper): >29°.
*Significant, $p < 0.05$; **Significant, $p < 0.01$.

4. Discussion

Although there are multiple problems associated with facial approximation as a method of facial reconstruction and human identification, it remains a viable complementary method.

Three defined stages have been described in the characterization of any CFS system: 1- face enhancement and skull modelling (when using digitized methods that build a 3D-model of the skull); 2- Skull-face overlay and 3- decision making [44]. Although, to our knowledge, no such descriptions have been provided for facial approximation, a similar general process may be envisioned with the following modifications: 1- skull modeling only (if creating 3D skull models) without face enhancement in the first stage and 2- building the face from the skull model or remains in the second stage rather than skull-face overlay.

While the third stage of the process may introduce human errors or bias in the decision-making process, the first two stages possess inherent sources of error and uncertainty. In addition to key questions in the FA methodology, whether practitioner-led (manual or computerized) or automated, many of the sources of error associated with the first stage of the process are related to the incorrect replication of the antemortem position of the mandible [18]. Post-mortem skull damage, incomplete preservation and loss of complete segments such as the whole mandible, are also not uncommon [18,38]. The loss of or inability to properly articulate the mandible is of significant concern since the bone is joined to the craniomaxillary complex by soft tissue that is subject to postmortem decomposition [38,45,46]. Although various statistical models and simulations dealing with mandibular bone loss have been suggested, they do not take into account the natural variation of mandibular position but rather contemplate a straight facial profile corresponding to a Class I maxilla-mandibular relationship [38,46,47].

Other errors arise from uncertainties related to the second stage of the craniofacial identification process and are mostly related to the imprecision involved in the matching of soft and hard tissue corresponding landmarks [18]. This imprecision has been attributed to some of the following factors: 1- the correspondence between hard and soft tissue landmarks is not always perpendicular; 2- there is considerable variation in FSTT values at each landmark and 3- factors such as age, sex and race contribute further towards FSTT variability [18].

Table 4
Selected correlations between facial soft tissue thickness (FSTT) points and various cephalometric measurements ($r \geq 0.4$) (n = 222).

	N	Sn	UL	LL	Lm	Pog	Gn
Cephalometric Skeletal Measurements							
SN		0.484		0.515		0.412	
N-ANS		0.448		0.402			
ANS-Me		0.424		0.449	0.556	0.502	
Co-Gn		0.482		0.489	0.464	0.440	
Co-Pog		0.486		0.479	0.436	0.405	
Co-Go				0.433			
Cephalometric Dental Measurements							
U6-PP					0.428	0.405	
L1-MP		0.450		0.440	0.555	0.486	
L6-MP		0.460		0.472	0.496	0.480	

All Correlations significant at the 0.01 level (2-tailed).

Cephalometric norms potentially build upon the traditionally employed FSTT measurements utilized in craniofacial identification techniques by incorporating valuable information regarding the angular and spatial relationships between the various facial structures including the nose and lips. In a previously published article, the authors report on the FSTT norms for non-growing adult Lebanese males and females [41]. In the current research work, the authors build on the previous publication by presenting a unique assessment of FSTT values in relation to assessments of cephalometric hard- and soft-tissue norms borrowed from the orthodontic literature. The presence of a statistically significant effect of vertical divergence on FSTT values, albeit limited to the levels of Stomion, Labiomentale and Pogonion, highlights the importance of considering the sagittal profile during craniofacial identification procedures. The presence of significant associations between FSTT measurements specifically related to the lower face (Lm and Pog) not only emphasize on the importance of the intact preservation of the mandible and correct articulation but also illustrate the variability in FSTT with varying underlying skeletal features. The presence of statistically significant, moderate to high correlations between mandibular length and ramus length and FSTT values related to the lower face (LL, Lm and Pog mainly) emphasize further the important role of the underlying skeleton. Similarly, the correlations between FSTT values and dental hard tissue cephalometric measurements that were of notable value were limited to those relating to the vertical dimension and ultimately face height (vertical distances between the upper molars and the palatal plane, and between the lower molars and incisors and the mandibular plane). It is important to note that the correlations between mandibular length and FSTT at Sn emphasize the universal role that the dimensions of the mandible have on the profile in general, including features in the upper face, rather than having effects limited to the FSTT in the lower face.

However, in terms of practical utility, it may be most interesting to assess the associations between cephalometric measurements in the cranium and upper face with FSTT measurements related to the lower face, since these would prove most useful in the craniofacial identification of skull remains when the loss of the mandible is an unavoidable source of error. Our research highlights correlations of considerable magnitude between cranial base length and FSTT at LL and Pog, in addition to correlations between upper face length and FSTT at the lower lip. The distance between upper molars and the palatal plane was similarly considerably correlated with FSTT at Lm and Pog.

Finally, the correlations between FSTT values and cephalometric soft tissue measurements presented in this work, illustrate the potential for cephalometric assessment of the skeletal remains to enhance the prediction of antemortem facial soft tissue features. While mean FSTT values (and the more recently proposed improvement of using Shorth and Shormax values) provide essential estimations at single point locations, the incorporation of cephalometric soft tissue analysis potentially supports this information by providing additional information on the areas between these points. The correlations between FSTT values and various facial angles may enable enhanced prediction of the projection and shape of the nose (nasomental, nasofacial and nasofrontal angles) and the projection and curvature of the lower lip and mental sulcus (mentolabial angle). The correlations with upper and lower lip length potentially provide valuable information regarding the localization of Stomion in the vertical dimension, which, coupled with FSTT norms in the sagittal dimension may potentially provide more accurate localization of this landmark.

It is interesting to note that FSTT values at Glabella and Rhinion showed absolutely no associations with any of the cephalometric measurements, and FSTT at the levels of N and Gn showed very limited associations. Similar results documented for FSTT at the levels of N and Rh have previously been attributed to the close adherence of soft tissue to bone at these locations [48,49]. While the absence of correlations for FSTT at G and Rh in our data might be explained by inherent lower variability, as illustrated by smaller standard deviations (1.1 mm and 0.7 mm, respectively), the standard deviations at the levels of N and Gn were higher (1.7 mm and 2.2 mm, respectively). The prediction of the face at these levels may therefore be more challenging and, given the lack of association with underlying skeleton, may require the composition of several versions of the face with varying thicknesses at the levels of N and Gn.

To our knowledge, this is the first assessment of the associations between FSTT and vertical divergence and the first comprehensive assessment of correlations with cephalometric skeletal, dental and soft tissue measurements. However, research interest has recently geared towards the assessment of FSTT values in relation to facial types based on profile in the sagittal plane [40]. Kurkcuoglu, Pelin, Ozener, Zagyapan and Sahinoglu [40] report FSTT variations between Class III, Class II and Class I Turkish males and females at the level of Sn and LL [40]. Al-Chalabi [50] reports statistically significant differences in FSTT at Sn and St between the three sagittal malocclusions in an Adult Iraqi population [50] and Utsuno, Kageyama, Uchida, Yoshino, Oohigashi, Miyazawa and Inoue [51] similarly report differences in FSTT values between the three different sagittal groups in a sample of Japanese females [51]. In a more recent assessment of Sudanese adults, Hamid and Abuaffan [48] noted that FSTT values in the upper lip region (Sn, UL and St) were smallest in subjects with class II malocclusion whereas FSTT values in the lower face region (LL, Lm and Pog) were thinnest in subjects with the Class III malocclusion [48]. Finally, in a recent novel research work presented by Niño-Sandoval, Perez, González, Jaque and Infante-Contreras [38], an automatic non-parametric method was employed as the Support Vector Machines to classify skeletal patterns using cephalometrically-assessed craniomaxillary variables. By using 10 cephalometric variables located in the craniomaxillary complex, the authors were able to classify subjects into Class I, II and III with 74.51% accuracy, allowing for more accurate simulation of the natural antemortem mandibular position in craniofacial identification procedures in cases of loss or misarticulation of mandibular skeletal remains.

5. Conclusions and research considerations

The methodologies employed for the collection of FSTT measurements have included fresh cadavers [52,53], ultrasound images [51,54], lateral cephalometric radiographs [40,55,56] and finally 3D imaging including CT, CBCT and MRI scans [57–62]. Despite the accuracy of measurements recorded from CT scans, the imaging modality necessitates placing subjects in the supine position which jeopardizes data at several landmarks [51,54,57]. Our use of lateral cephalometric radiographs avoided unnecessary radiation exposure since these radiographs were all taken as part of routine orthodontic pre-treatment records. A key point is that these radiographs are taken in the upright natural head position, which limits any potential gravitational distortion of facial tissue. It is true that these radiographs are not routinely taken on cadavers. Nevertheless, deriving FSTT measurements from ante-mortem records helps in setting an approximate range of work to reconstruct the facial features.

Stephan and coworkers have been extensively assessing FSTT variables for approximately the past decade and have illustrated relatively poor approximation the FSTT sample means provide to population values. Although there has been extensive research on FSTT values in various populations, numerous factors such as sampling errors, varying methodologies and precision of the measurement method, inter- and intra-observer errors and the non-parametric nature and inherent skewness of FSTT data limit the ability to make conclusion regarding differences in FSTT values based on age, sex, ethnicity or cranial shape [7,30]. These observations have led to the recommendation that data across populations, sexes and ages be pooled in order to increase sample size, balance out study-specific errors, and triangulate upon population means [30].

In support of the work of Stephan and co-workers, the authors of this study further incriminate the disregard for skeletal facial characteristics, including sagittal profile and vertical divergence, in propagating sampling and methodological errors and contributing towards the disparate results between different studies on the same population. In our sample of adults with well-balanced faces, we have shown statistically significant associations between vertical divergence and FSTT values at certain landmarks. The authors emphasize on the significance of this result despite the inclusion of only adults with well-balanced faces as judged by the two orthodontists of the research team. The sample was therefore exclusive of subjects whose vertical divergence would have been extreme in either direction and negatively affected the facial profile. This is likely to at least partially explain the low n2 values as the sample assessed in this study was purposely biased towards aesthetically pleasing faces. This limitation encourages further research to be more inclusive of the large spectrum of normal occlusion and malocclusions in both the vertical and sagittal dimensions in order to more comprehensively assess the possible associations between FSTT values and cephalometric measurements.

The low sensitivity that is attained by point sampling the face at sparse locations has been described as a major limitation to the commonly employed FSTT measurement methods [8]. We propose that the limitations inherent to this method may be reduced by incorporating information that is already available in the skull remains being utilized for craniofacial identification. While the presence of an intact mandible is essential towards an assessment of the facial skeleton in the vertical and sagittal dimensions, we encourage future research to further explore possible associations and correlations between components in the mandible and in the upper face in efforts to improve facial prediction even in the absence of a mandibular bone.

CRediT authorship contribution statement

Maria Saadeh: Writing - original draft, Formal analysis, Writing - review & editing. **Hasan Fayyad-Kazan:** Data curation, Software, Writing - review & editing. **Ramzi Haddad:** Visualization, Software, Writing - review & editing, Supervision. **Fouad Ayoub:** Conceptualization, Methodology, Investigation, Supervision.

Declaration of Competing Interest

The authors reported no declarations of interest.

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