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Facial soft tissue thicknesses in Bulgarian adults: relation to sex, body mass index and bilateral asymmetry

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Background: *The aim of the study is to measure the facial soft tissue thicknesses (STTs) in Bulgarians, to evaluate the relation of the STTs to the nutritional status, sex and bilateral asymmetry, and to examine the correlations between the separate STTs as well as between the STTs and body weight, height, and body mass index (BMI). In the present study, the facial STTs were measured on computed tomography scans of the head of Bulgarian adults.*

Materials and methods: *The STTs were measured at 7 midline and 9 bilateral landmarks. The measurements were performed in the free software InVesalius in the axial and sagittal planes. The mean, standard deviation, minimum and maximum values, median and coefficient of variation were reported for the STT at each landmark according to the sex and BMI category. The BMI, sex and bilateral differences were assessed for statistical significance. Pearson correlation analysis was applied to assess the strength and direction of the relationships between the STTs and body height, weight and BMI, as well as between separate STTs.*

Results and Conclusions: *The facial soft tissues in Bulgarian adults changed in accordance with the nutritional status of the individual and in both sexes all STTs augmented with the increasing BMI. For both normal and overweight BMI categories, males had more soft tissue at the majority of facial points than females, as the only exceptions were observed in the cheek zone, where STTs were thicker in females. Significant bilateral differences were observed in either sex and BMI category. Stronger correlations were established for the STTs in the jaw region and between the cheek and jaw soft tissues. Besides, the correlations between the homologous bilateral landmarks were among the strongest ones.* (Folia Morphol 2018; 77, 3: 570–582)

Key words: soft tissue thickness, computed tomography, sex, body mass index, bilateral asymmetry, Bulgarian adults, facial approximation

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INTRODUCTION

Facial soft tissues consist of muscles, subcutaneous fat and skin. The soft tissue thickness (STT) represents the amount of soft tissue that overlies a certain landmark of the skull. The facial STTs are of importance for plastic surgeons and orthodontists in the planning of treatment procedures [17]. Facial STT data are also used in the process of facial reconstruction. This procedure represents craniofacial approximation, consisting of recreation of an individual's face based on its skull [7]. It is a tool in forensic sciences offering additional possibilities for identifying human remains [22] based on the identification of a deceased through recognition [25].

All techniques for facial approximation are based on the cranial morphology and facial STT databases [31]. The knowledge of the approximate STTs over various anatomical points of the skull is a basis for a more accurate facial approximation. The facial STT data have been collected by various methods. The oldest method relies on the needle puncture of cadavers [21, 28, 29]. Nowadays, this method has also been applied on Australian [8, 24], Spanish [27, 32], Portuguese [5], and Brazilian cadavers [30]. STT data have been obtained on X-ray images as well, allowing these measurements to be taken *in vivo* [1, 11, 14]. However, at present, such data have been collected from living individuals using ultrasound [1, 4, 6, 13, 33], magnetic resonance imaging [23], and computed tomography (CT), including data from multislice CT [3, 10, 15, 20], spiral CT [2, 9, 19, 31] and cone-beam CT [16, 22].

Most of the previous studies have suggested that population-specific STT databases are needed for an accurate facial approximation. Thus, there are many datasets available for various population groups from Europe [5, 6, 15, 19, 31], Asia [2, 9, 16, 18, 23, 29], North America [4, 21], South America [22, 30], Africa [1, 3, 13, 20], and Australia [8, 24, 28]. For some of the population groups, the presence of significant interpopulation differences in the facial soft tissues has been established in the comparison with other close or distant populations [2, 3, 13, 20]. Nonetheless, Thiemann et al. [31] contradicted the hypothesis that population-specific databases are required for the craniofacial approximation.

The sex and age have been the most discussed factors for their influence on the facial STTs, unlike the nutritional condition of individuals, which has not been considered in many studies and only individuals with normal nutritional status were examined [1, 3, 8, 10, 13, 14, 20, 23, 24, 29, 32]. However, the nutritional status of an individual may be an important factor for a successful recognition of the reconstructed face given that the changes in the STTs in relation to the weight have been shown to affect the subjective assessment considerably [25].

Another frequently avoided issue in the facial approximation is the presence of bilateral asymmetry in the human face. Some authors agreed on the lack of bilateral differences in human facial tissues and measured the lateral STTs only on the right [4] or on the left side [3, 9, 18], and sometimes the measured side has not been specified [1, 5, 13, 20]. Numerous studies have shown the bilateral differences in facial STTs, but their results contradict each other [6, 8, 10, 22, 23, 28, 30–32].

Although there have been many studies providing information for STTs in different population groups, no such data have been available in Bulgarian population or any of the neighbouring countries, except for Turkey. Therefore, we set as study goals to provide initial data for facial STTs in Bulgarians, to evaluate the relation of the STTs to the nutritional status, sex and bilateral asymmetry, and to examine the correlations between the separate STTs as well as between the STTs and body weight, height, and body mass index (BMI).

MATERIALS AND METHODS

The study was carried out on head CT scans of Bulgarian adults. The CT scans were obtained using Toshiba Aquilion 64 CT scanner with a 0.5 mm slice thickness. The study group included 75 Bulgarian adults (34 males and 41 females) aged 20 to 74 years. All CT scans were obtained from diagnostic imaging of patients. None of the individuals showed any signs of maxillofacial pathology and facial deformities.

The height and weight of each subject were recorded prior to the CT scanning. These data were self-reported by each patient. The BMI was calculated based on the reported data [(weight (kg) / height^2 (m^2)]. According to the BMI values, the sample was separated into three subgroups: underweight (< 18.5), normal weight (18.5–24.9) and overweight (> 25). Given that only 1 female was underweight and none of the males fell in this category, the comparisons were performed taking into account only the normal (15 males and 25 females) and overweight (19 males and 15 females) groups.

The patients' personal data were preliminarily anonymised. The researchers in this study operated only with the information about gender, age, weight, and height of the individuals.

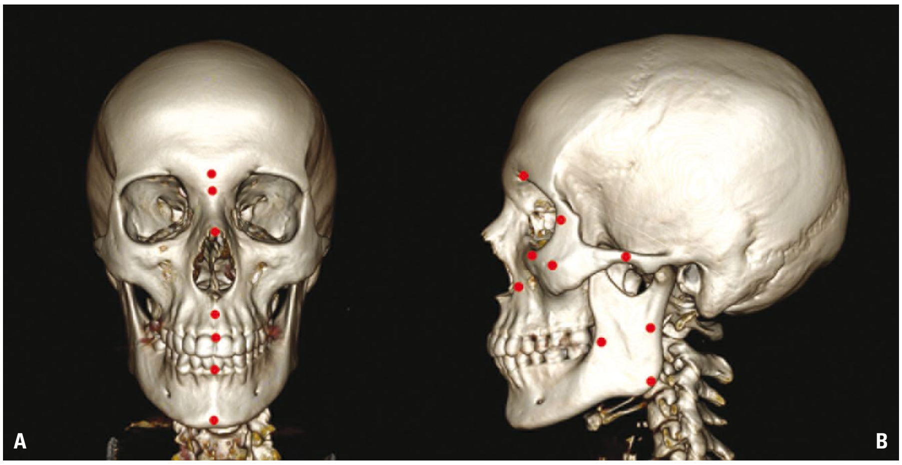

Figure 1. Locations of the landmarks for facial tissue measurements; **A.** Midline landmarks; **B.** Bilateral landmarks.

Table 1. Description of the anatomical landmarks

Landmarks	Description
Midline	
Glabella (g)	The most prominent midline point between the eyebrows, identical to the bony landmark
Nasion (n)	Midpoint of the fronto-nasal suture
Rhinion (rhi)	The end of the nasal bones at the cartilage-bone junction
Mid-philtrum (mp)	The midpoint of the philtral column
Upper lip (ul)	Midline on the upper lip
Lower lip (ll)	Midline on the lower lip
Mental eminence (me)	Centered on most anteriorly projecting point of chin
Bilateral landmarks	
Mid lateral orbit (mlo)	Vertically centered on the orbit, next to the lateral orbital border
Supraorbital (so)	Centered on the supraorbital margin, above the orbit
Suborbital (sbo)	Centered on the infraorbital margin, below the orbit
Lateral orbit (lo)	Lined up with the lateral border of the orbit on the centre of the zygomatic process
Alare (al)	The most lateral point on the margin of the anterior nasal aperture
Zygomatic arch (za)	The most lateral point of the zygomatic arch
Mid-masseter (mm)	Middle of the masseter, the halfway point between the supraglenoid and gonion
Occlusal line (ol)	Point located on anterior margin of the ramus of the mandible, in alignment with the plane of dental occlusion
Gonion (go)	At the angle of the mandible

The STTs were measured at 16 (7 midline and 9 bilateral) facial anatomical points (Fig. 1). A total of 25 soft tissue measurements were performed. The measurements were taken according to the landmarks' description in the literature [6, 9, 31] (Table 1) and were performed using the free software InVesalius. This software allowed visualisation of both bone and skin at the same time based on the Hounsfield Units. The skin was visualized in a transparent mood (Fig. 2A). The three-dimensional (3D) reconstructions were orientated in the Frankfurt horizontal plane prior the measurements. They were performed in the axial and sagittal views (Fig. 2B–D). The axial and sagittal planes were placed on each landmark so as to cross on it and to trace out its position on the two-dimensional (2D) slices. Measurements were drawn on the model visually perpendicular to the bone surface. The facial STTs at different landmarks concerned a different individual sample size (n), depending on the visibility of the landmarks. A smaller sample size was observed for measurements in the dental region, particularly in the cases of noise caused by dental fillings or evident bone resorption.

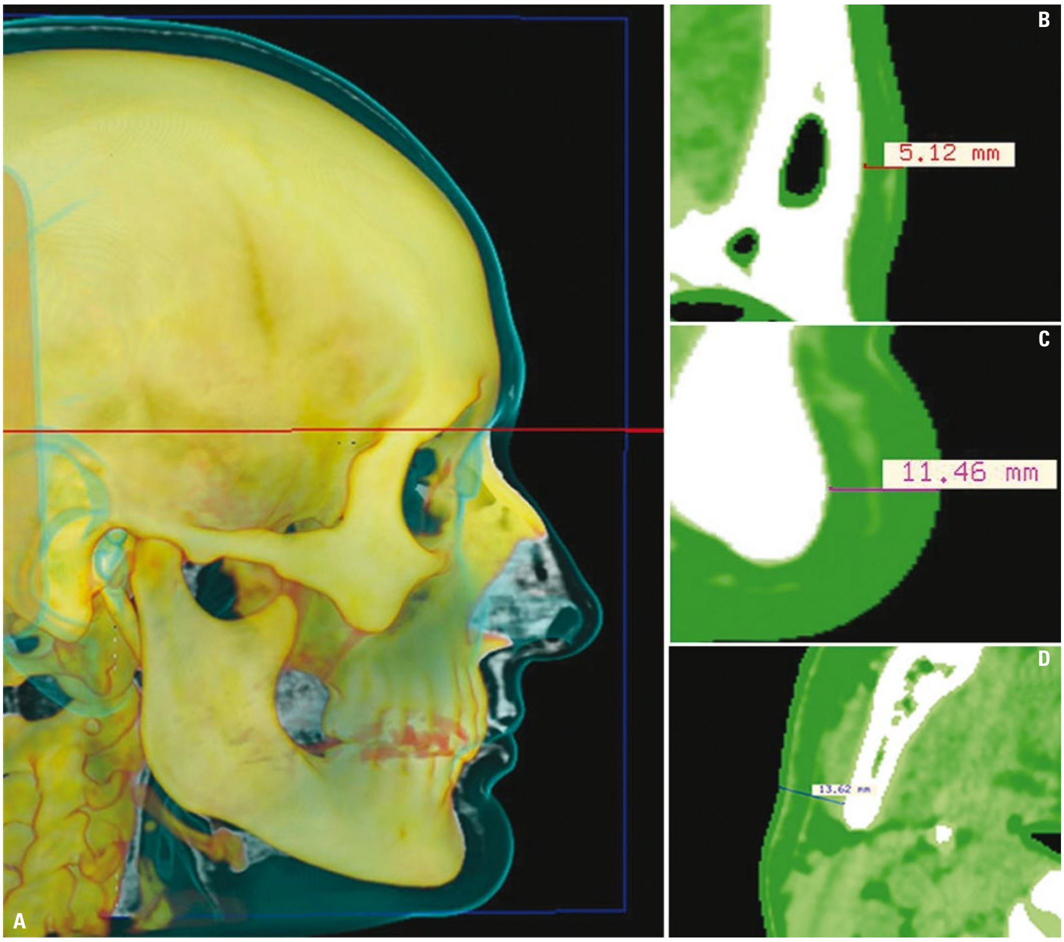

Figure 2. Three-dimensional reconstruction of head; **A.** Visualisation of the skull and skin. Facial tissue measurements at glabella in sagittal view (**B**); **C.** Mental eminence in sagittal view; **D.** Right gonion in axial view.

Statistical analysis

To assess the intraobserver reliability, an observer performed double measurements on 15 randomly selected subjects at 1-week time interval for the repeated measurements. To assess the reliability of the soft tissue measurements made by the observer, intraclass correlation coefficient (ICC) and technical error of measurement (TEM) were calculated for each STT.

The mean, standard deviation (SD), median, minimum and maximum values of the STTs were calculated for each anatomical landmark considering the gender and BMI category of the individuals. Coefficient of variation (CV) was calculated for each STT by the formula CV = (SD/Mean) × 100. The Kolmogorov-Smirnov normality test was performed to assess the distribution of the data. The BMI and sex differences were assessed using independent t-test or Mann-Whitney test, depending on the results of the normality test. For assessment of the bilateral differences, paired t-test or Wilcoxon signed-rank test were used, corresponding to the results of the normality test. The probability level was set at $p < 0.05$ for all statistical analyses.

A Pearson bivariate correlation analysis was applied to evaluate the strength and direction of the relationships between the STTs and body height, weight and BMI as well as between the separate STTs. The strength of the correlations was classified as follows: "very weak" (0.00–0.19), "weak" (0.20–0.39), "moderate" (0.40–0.59), "strong" (0.60–0.79), and "very strong" (0.80–1.00). A positive value indicated a positive correlation and a negative one denoted a negative correlation.

RESULTS

Intraobserver reliability

Most of the ICCs were above 0.98, indicating a high correlation between the double measurements of the observer (Fig. 3A). All TEMs were within 0.50 mm and within the voxel resolution (Fig. 3B). The lowest value was obtained for the left mid lateral orbit

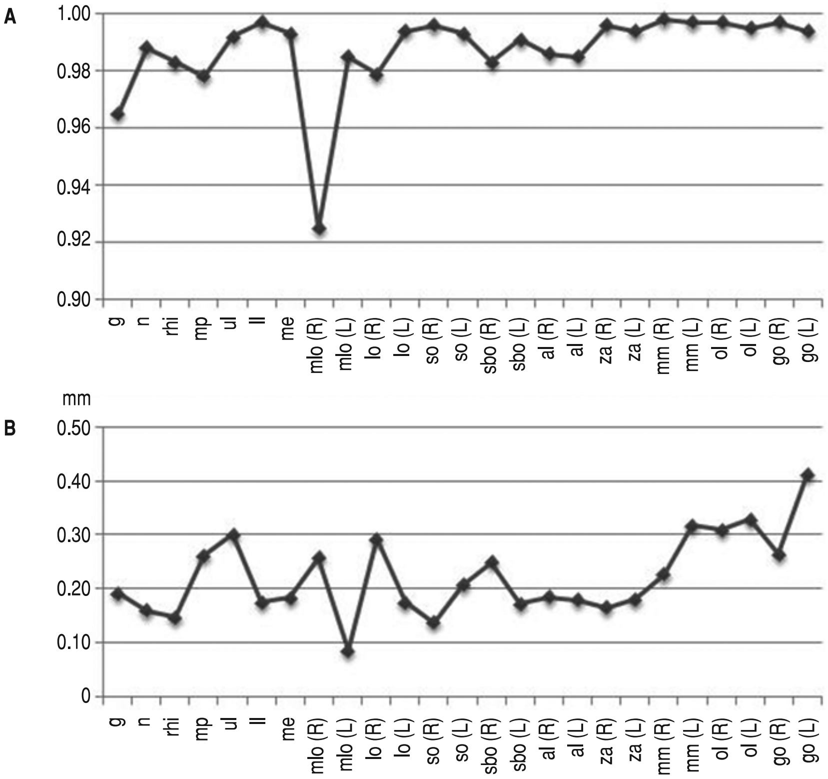

Figure 3. Intraobserver reliability of the soft tissue measurements; **A.** Intraclass correlation coefficient; **B.** Technical error of measurement; L — left; R — right; for the rest abbreviations — see Table 1.

(0.09 mm) and the highest one was observed for the STT measured at the left gonion (0.41 mm).

Descriptive statistics

The basic statistics of each STT, considering the gender and BMI categories, are presented in Tables 2 and 3. The thinnest soft tissues were observed in the nose and orbital area and the thickest ones in the mandible and cheek area. Based on the CV values, the STTs at suborbital, zygomatic arch and gonion were among the most variable metrics. From midline landmarks, rhinion appeared among the most variable ones.

BMI differences

None of the midline STTs in males showed BMI differences, unlike the bilateral ones, where significant differences were established for the most laterally located points i.e. landmarks identified on the mandible and cheeks. The greatest absolute differences were observed for the mid-masseter and occlusal line with values exceeding 4 mm and 3 mm, respectively (Table 4).

Unlike the males, significant BMI differences in females were found for few midline landmarks such as rhinion and lower lip. The mid-masseter, zygomatic arch and gonion were again among the mostly affected lateral landmarks, but the right supraorbital landmark and both alare differed significantly as well. One-half of the absolute differences were within 1 mm and only the right mid-masseter was thicker in the overweight females with more than 3 mm.

Sex differences

In the normal BMI category, the males had thicker soft tissues at most of the landmarks than females (Table 4). The only exceptions, which differed with more than 1 mm, were zygomatic arch and lateral orbit. Significant sex differences were observed in almost 1/3 of the STTs, as most of them were located in the midline. The greatest absolute differences were established for the upper and lower lips, which were thicker in males with more than 2 mm.

In the overweight BMI category, the males also had thicker soft tissues at almost all landmarks with the exception of the cheek measurements. However, significant differences were established at fewer measurements in comparison to the normal BMI category. The greatest differences between

Table 2. Descriptive statistics for soft tissue thicknesses in males and females from the normal body mass index category

Landmarks	Males							Females						
	N	Mean [mm]	SD [mm]	Min [mm]	Max [mm]	Median [mm]	CV [%]	N	Mean [mm]	SD [mm]	Min [mm]	Max [mm]	Median [mm]	CV [%]
Glabella	15	5.48	0.75	4.13	6.34	5.77	13.69	25	5.24	1.09	3.37	8.46	5.23	20.80
Nasion	15	7.89	1.19	4.54	9.64	8.04	15.08	25	6.59	1.40	3.28	9.43	6.42	21.24
Rhinion	15	2.97	0.91	1.66	5.18	2.85	30.64	25	2.36	0.59	1.19	3.23	2.32	25.00
Mid-philtrum	15	11.66	1.82	8.65	14.16	11.55	15.61	25	10.00	1.72	6.58	13.60	10.35	17.20
Upper lip	11	11.05	2.59	7.23	15.50	11.08	23.44	18	9.04	1.88	6.25	13.60	8.91	20.80
Lower lip	11	12.61	1.68	10.85	15.47	11.75	13.32	19	10.51	1.97	5.77	13.34	10.89	18.74
Mental eminence	15	12.10	1.89	7.77	15.08	12.41	15.62	25	10.30	1.74	7.03	14.81	10.47	16.89
Mid lateral orbit (R)	15	3.48	0.54	2.62	4.42	3.40	15.52	25	3.44	1.06	1.24	5.64	3.56	30.81
Mid lateral orbit (L)	15	3.18	0.63	1.90	4.34	2.98	19.81	25	3.26	0.78	1.24	4.78	3.24	23.93
Lateral orbit (R)	15	7.38	1.58	5.12	11.17	6.96	21.41	25	8.67	2.38	3.67	13.90	8.91	27.45
Lateral orbit (L)	15	7.10	1.51	4.79	10.20	6.57	21.27	25	8.75	1.86	4.14	12.80	8.60	21.26
Supraorbital (R)	15	7.79	1.79	5.32	11.25	7.45	22.98	25	6.96	1.99	2.42	11.07	7.37	28.59
Supraorbital (L)	15	7.59	1.66	5.19	11.54	7.59	21.87	25	6.73	1.65	3.69	9.61	6.95	24.52
Suborbital (R)	15	5.27	2.06	3.02	9.33	4.54	39.09	25	5.28	1.52	2.52	7.70	5.33	28.79
Suborbital (L)	15	5.40	1.96	2.64	9.10	4.77	36.30	25	5.11	1.40	2.02	7.39	5.13	27.40
Alare (R)	15	9.78	1.88	5.81	13.61	9.78	19.22	25	8.94	1.46	7.27	14.29	8.71	16.33
Alare (L)	15	9.54	1.42	6.33	12.59	9.45	14.88	25	8.69	1.40	6.42	13.00	8.42	16.11
Zygomatic arch (R)	15	6.98	2.36	3.36	12.18	7.16	33.81	25	8.07	2.49	3.55	14.78	7.65	30.86
Zygomatic arch (L)	15	7.29	2.38	4.14	11.36	6.58	32.65	25	8.33	2.50	4.34	15.13	8.10	30.01
Mid-masseter (R)	14	19.71	3.32	13.65	25.28	19.32	16.84	25	19.22	4.28	11.37	30.05	18.60	22.27
Mid-masseter (L)	14	20.21	3.16	13.94	26.59	20.54	15.64	25	18.71	4.17	12.06	28.76	17.76	22.29
Occlusal line (R)	14	22.55	3.75	15.86	30.01	21.35	16.63	25	21.33	2.82	16.40	28.20	21.19	13.22
Occlusal line (L)	14	22.27	3.45	17.62	29.64	21.63	15.49	25	21.30	2.31	16.28	25.46	21.54	10.85
Gonion (R)	14	13.28	3.68	7.66	20.36	12.94	27.71	25	13.10	4.64	6.76	28.83	12.04	35.42
Gonion (L)	14	14.27	3.50	9.43	20.10	13.81	24.53	25	13.29	4.56	5.61	27.30	12.81	34.31

CV — coefficient of variation; L — left; Max — maximum; Min — minimum; R — right; SD — standard deviation

overweight males and females were over 3 mm, demonstrated by measurements in the lateral jaw region.

Bilateral differences

Concerning the normal BMI category, significant bilateral differences were observed at the mid lateral orbit in males and at alare in females (Table 5). In the overweight BMI category, gonion was the single landmark differing significantly between the right and left side in males. However, the overweight females showed more significant bilateral differences, affecting supraorbital landmark, zygomatic arch, and mid-masseter.

Correlations

In males, the weight and BMI correlated strongly and moderately with 10 of the STTs, located especially in the cheek and jaw regions. However, in females, these two factors correlated moderately with only one measurement. The correlations of the STTs with body height were mostly “very weak” in both sexes (Table 6).

Considering the correlations between separate STTs, the “very strong” ones referred mainly to the homologous landmarks on the right and left side and the “strong” correlations affected closely located landmarks in the same facial regions (nasal, orbital, mandible). Strong correlations were also established between cheek and mandible STTs.

Table 3. Descriptive statistics for soft tissue thicknesses in males and females from the overweight body mass index category

Landmarks	Males							Females						
	N	Mean [mm]	SD [mm]	Min [mm]	Max [mm]	Median [mm]	CV [%]	N	Mean [mm]	SD [mm]	Min [mm]	Max [mm]	Median [mm]	CV [%]
Glabella	19	5.89	1.00	4.01	8.19	5.94	16.98	15	5.48	0.94	4.17	7.25	5.28	17.15
Nasion	19	8.03	1.42	5.50	10.25	7.92	17.68	15	6.94	1.30	5.10	9.40	6.78	18.73
Rhinion	19	3.22	0.85	1.78	4.79	3.26	26.40	15	2.74	0.50	1.79	3.52	2.81	18.25
Mid-philtrum	17	11.98	1.84	8.28	14.92	12.71	15.36	14	10.12	0.92	8.62	11.59	9.97	9.09
Upper lip	13	11.10	2.32	7.80	15.97	10.18	20.90	8	9.67	1.29	7.98	11.17	9.74	13.34
Lower lip	14	12.82	3.03	7.06	18.63	13.08	23.63	9	12.03	1.44	10.00	14.44	11.92	11.97
Mental eminence	19	12.27	1.82	9.71	17.09	12.42	14.83	15	10.81	1.75	7.18	14.62	10.55	16.19
Mid lateral orbit (R)	19	4.04	0.99	2.58	5.78	4.06	24.50	15	3.58	1.02	1.90	5.47	3.33	28.49
Mid lateral orbit (L)	19	4.02	0.98	2.77	6.01	4.00	24.38	15	3.45	0.82	2.15	5.38	3.37	23.77
Lateral orbit (R)	19	8.99	2.38	5.60	13.65	9.04	26.47	15	9.37	1.98	6.27	13.89	9.28	21.13
Lateral orbit (L)	19	9.28	2.58	4.55	13.75	9.19	27.80	15	9.78	2.10	6.10	14.02	9.65	21.47
Supraorbital (R)	19	8.86	1.63	6.11	12.25	8.72	18.40	15	8.16	1.39	5.88	10.17	8.73	17.03
Supraorbital (L)	19	8.55	1.55	5.97	11.50	8.58	18.13	15	7.62	1.65	4.91	10.07	7.62	21.65
Suborbital (R)	19	5.97	1.98	2.94	10.49	5.87	33.17	15	5.73	1.78	3.18	9.35	5.32	31.06
Suborbital (L)	19	6.14	2.15	3.30	9.96	5.57	35.02	15	5.61	1.70	2.83	8.28	5.32	30.30
Alare (R)	19	10.13	1.54	8.49	14.28	9.98	15.20	15	9.99	1.44	8.11	12.04	10.32	14.41
Alare (L)	19	9.85	1.69	6.22	13.86	9.72	17.16	15	9.85	1.31	7.99	12.12	9.65	13.30
Zygomatic arch (R)	19	9.37	2.67	3.17	15.45	9.29	28.50	15	9.88	2.40	5.25	14.45	9.33	24.29
Zygomatic arch (L)	19	9.17	2.64	3.72	15.26	9.36	28.79	15	9.35	2.13	5.43	13.12	8.90	22.78
Mid-masseter (R)	19	24.55	3.88	15.31	31.41	24.56	15.80	15	22.74	5.08	9.51	30.68	23.55	22.34
Mid-masseter (L)	19	24.47	4.90	16.24	33.53	24.97	20.02	15	21.13	4.18	10.73	29.30	21.75	19.78
Occlusal line (R)	19	26.04	4.02	18.39	32.09	26.74	15.44	15	22.87	4.12	14.32	31.36	21.94	18.01
Occlusal line (L)	19	26.11	3.34	18.67	30.41	26.60	12.79	15	22.15	3.64	15.18	28.87	21.27	16.43
Gonion (R)	19	16.14	4.21	7.14	24.89	16.17	26.08	15	15.78	4.77	5.24	23.40	15.96	30.23
Gonion (L)	19	17.73	4.48	8.04	25.30	18.24	25.27	15	15.13	4.58	6.21	23.28	15.57	30.37

CV — coefficient of variation; L — left; Max — maximum; Min — minimum; R — right; SD — standard deviation

The midline STTs correlated between each other of weak and moderate degrees. The moderate correlations referred to different interrelationships in both sexes. Furthermore, the midline STTs demonstrated weaker and moderate correlations with the lateral ones, since the latter correlations affected all lateral facial regions, mainly the orbital one in males and the orbital and mandible regions in females. Moderate correlations were also established between STTs in the lateral facial regions, in particular between STTs at the orbital region with those on the cheek and mandible in males and between STTs on the mandible with those at the cheek and orbital regions in females.

DISCUSSION

Recently, there has been a considerable increase in the research of facial STTs for the needs of the forensic facial approximation. We hereby report data about facial STTs in Bulgarians, not available so far.

There is a considerable variability in the facial STTs. Some authors established high variability at lateral landmarks in the maxillary and mandibular regions [6], while the other noted large individual variation in the areas around lips and chin [24]. However, our results show that the most variable STTs established through CV are in the cheek and orbital region, and only gonion from the mandible variables appears in the most front positions. It should be taken into account that the most variable measurements can lead to greater deviation in the facial approximation and dissimilarity to the original face. Bearing in mind that this refers to landmarks such as zygomatic arch and gonion, which determine the shape of the face, it could be supposed that in some cases the result

Table 4. Body mass index (BMI) and sex differences. The significant differences ($p < 0.05$) are denoted in bold. The absolute differences (AD) are given in mm

Landmarks	BMI differences				Sex differences			
	Males		Females		Normal BMI		Overweight BMI	
	AD	p	AD	p	AD	p	AD	p
Glabella	0.41	0.202	0.24	0.486	0.24	0.462	0.41	0.238
Nasion	0.14	0.765	0.35	0.432	1.30	**0.004**	1.09	**0.028**
Rhinion	0.25	0.400	0.38	**0.041**	0.61	**0.014**	0.48	0.093
Mid-philtrum	0.32	0.618	0.12	0.965	1.66	**0.006**	1.86	**0.005**
Upper lip	0.05	0.958	0.63	0.405	2.01	**0.023**	1.43	0.205
Lower lip	0.21	0.839	1.52	**0.049**	2.10	**0.006**	0.79	0.478
Mental eminence	0.17	0.799	0.51	0.376	1.80	**0.004**	1.46	**0.024**
Mid lateral orbit (R)	0.56	**0.045**	0.14	0.692	0.04	0.878	0.46	0.194
Mid lateral orbit (L)	0.84	**0.007**	0.19	0.466	–0.08	0.738	0.57	0.084
Lateral orbit (R)	1.60	**0.032**	0.70	0.341	–1.29	0.072	-0.38	0.617
Lateral orbit (L)	2.18	**0.007**	1.03	0.115	–1.65	**0.006**	-0.50	0.548
Supraorbital (R)	1.07	0.078	1.20	**0.048**	0.83	0.191	0.70	0.192
Supraorbital (L)	0.96	0.092	0.89	0.106	0.86	0.121	0.93	0.102
Suborbital (R)	0.70	0.199	0.45	0.393	–0.01	0.986	0.24	0.722
Suborbital (L)	0.74	0.349	0.50	0.320	0.29	0.583	0.53	0.444
Alare (R)	0.35	0.544	1.05	**0.034**	0.84	**0.041**	0.14	0.958
Alare (L)	0.31	0.570	1.16	**0.013**	0.85	0.073	0.00	0.998
Zygomatic arch (R)	2.39	**0.010**	1.81	**0.030**	–1.09	0.180	-0.51	0.565
Zygomatic arch (L)	1.88	**0.040**	1.02	0.191	–1.04	0.206	-0.18	0.829
Mid-masseter (R)	4.84	**< 0.001**	3.52	**0.024**	0.49	0.712	1.81	0.247
Mid-masseter (L)	4.26	**0.008**	2.42	**0.028**	1.50	0.252	3.34	**0.044**
Occlusal line (R)	3.49	**0.016**	1.54	0.258	1.22	0.256	3.17	**0.031**
Occlusal line (L)	3.84	**0.003**	0.85	0.369	0.97	0.304	3.96	**0.002**
Gonion (R)	2.86	**0.050**	2.68	**0.027**	0.18	0.608	0.36	0.815
Gonion (L)	3.46	**0.023**	1.84	0.078	0.98	0.299	2.60	0.106

L — left; R — right

from the facial approximation can be misleading in the face recognition process.

BMI differences

The most affected facial regions with respect to the nutritional status of the individuals are those with high content of hypodermic fat or well-developed muscles [28]. Thus, a decrease in nutrition leads to smaller STTs, except for the tissues around the eyes, which could be due to the lack of subcutaneous fat in this area [29]. It has been established that the "malar fat pad" is the thickest facial zone followed by the "premental fat pad", whereas the fat tissue in the forehead zone is almost non-existing [12]. The STTs located in the areas around the mandible and cheeks are the first to alter along with changes in body weight [3]. Furthermore, the STTs located in the facial region with highest fat concentration increase proportionally with the increasing BMI [30].

In different studies, nutritional status of the individuals has affected a different number of landmarks. Comparing the normal and obese BMI categories, Dong et al. [9] found statistically significant differences at all landmarks in both sexes, while Ruiz [22] established differences in less than one-half of the STTs. Accordingly, our findings reveal that the BMI affects significantly nearly half of the STTs in males and around 1/3 of the STTs in females.

Most of the recent studies have established BMI differences in the cheek and mandible region [7, 18, 31] as well as at the orbital area [18, 31] and glabella [18]. Concerning the size and location of the

Table 5. Bilateral differences for males and females from the normal and overweight body mass index (BMI) category. The significant differences ($p < 0.05$) are denoted in bold. The absolute differences (AD) are given in mm

	Males		Females	
	AD	p	AD	p
Normal BMI category				
Mid lateral orbit	0.30	**0.012**	0.18	0.141
Lateral orbit	0.28	0.073	–0.08	0.633
Supraorbital	0.20	0.646	0.23	0.171
Suborbital	–0.13	0.503	0.17	0.261
Alare	0.24	0.384	0.25	**0.042**
Zygomatic arch	–0.31	0.188	–0.26	0.156
Mid-masseter	–0.50	0.196	0.51	0.135
Occlusal line	0.28	0.761	0.03	0.931
Gonion	–0.99	0.126	–0.19	0.545
Overweight BMI category				
Mid lateral orbit	0.02	0.846	0.13	0.437
Lateral orbit	–0.29	0.385	–0.41	0.143
Supraorbital	0.31	0.078	0.54	**0.028**
Suborbital	–0.17	0.491	0.12	0.556
Alare	0.28	0.481	0.14	0.609
Zygomatic arch	0.20	0.206	0.53	**0.015**
Mid-masseter	0.09	0.859	1.61	**0.015**
Occlusal line	–0.07	0.872	0.72	0.094
Gonion	–1.59	**0.004**	0.65	0.288

BMI differences, our results confirm the majority of the previous studies. In addition, they demonstrate more significant differences due to the nutritional status than the sex of the individuals. Thus, our data confirmed the conclusions of previous studies that the BMI appears a major contributing factor to differences in facial STTs [7, 9].

It should be noted that the usage of a STT dataset designed for a definite BMI category could limit the possibility for recognition in the forensic practice. It is therefore highly recommended, whenever possible, the creation of different versions of facial approximation based on the datasets for different BMI categories as suggested by Starbuck and Ward [25]. Moreover, the growing percentage of the overweight people among different population groups nowadays is a strong indicator of the necessity for the performance of facial approximations using STT datasets for overweight individuals to increase the possibility for recognition.

Sex differences

Most studies show that men from different ethnic groups had thicker tissues at more facial regions than women. It has been established that gender has a significant effect on the facial STTs at glabella [10, 30], nasal region [10, 15, 19, 22, 31], lower part of the nose area [2], mouth [2, 5, 13, 22, 31], chin [5, 13], orbital region [13, 15, 31], cheek region [13, 19] as well as at the landmarks on the mandible [10, 13, 19, 22, 30] and maxilla [10, 15, 19, 30].

Although males have more tissue at the majority of facial landmarks than females, there are some facial regions which appear to be thicker in females. The thicker STTs in the cheek region in females have been observed in a number of studies [2, 5, 10, 16, 19, 20, 21, 28, 29, 30]. Besides, some of the authors have found greater STTs at the orbital region [20, 21], forehead [20], chin [22, 24] and skull vault [23]. Furthermore, El-Mehallawi and Soliman [13] revealed a notable

Table 6. Correlations between soft tissue thicknesses (STTs) and body height, weight and body mass index (BMI) and between separate STTs in males (upper right side of the table) and females (lower left side of the table). The significant differences ($p < 0.05$) are denoted in bold

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1. Height	1	**0.42**	−0.15	0.23	0.24	0.17	0.14	−0.07	−0.10	0.24	0.00	0.18	−0.02	0.19	−0.14	−0.06	0.23	0.29	0.20	0.10	0.13	0.07	0.00	0.04	**0.34**	**0.35**	−0.07	0.02
2. Weight	**0.58**	1	**0.83**	0.30	0.10	0.20	0.22	0.04	−0.05	0.02	**0.38**	**0.46**	**0.41**	**0.59**	0.26	0.26	0.28	**0.37**	0.28	0.26	**0.53**	**0.46**	**0.60**	**0.49**	**0.55**	**0.62**	0.30	**0.40**
3. BMI	0.17	**0.90**	1	0.19	−0.05	0.13	0.15	0.08	0.00	−0.12	**0.40**	**0.37**	**0.47**	**0.52**	**0.37**	**0.34**	0.16	0.22	0.20	0.23	**0.49**	**0.46**	**0.67**	**0.53**	**0.41**	**0.49**	**0.38**	**0.44**
4. g	−0.08	0.22	**0.31**	1	**0.61**	0.27	**0.48**	0.19	0.27	**0.48**	0.20	**0.39**	**0.46**	**0.44**	**0.42**	**0.59**	**0.42**	**0.40**	0.29	**0.39**	0.24	0.22	0.25	0.22	0.29	**0.45**	0.04	0.26
5. n	−0.01	0.21	0.26	**0.68**	1	0.00	**0.45**	0.20	0.23	0.23	0.27	**0.49**	0.05	0.15	0.02	0.28	0.13	0.21	0.04	0.28	0.01	0.05	−0.11	−0.11	−0.09	0.11	−0.17	−0.01
6. rhi	−0.21	0.18	**0.33**	**0.39**	**0.51**	1	0.22	−0.34	0.09	**0.38**	**0.35**	0.18	0.31	**0.36**	**0.59**	**0.41**	**0.47**	0.33	0.29	0.26	0.39	**0.42**	**0.45**	**0.43**	**0.49**	**0.53**	0.25	0.20
7. mp	0.10	−0.10	−0.16	0.16	0.10	0.01	1	**0.60**	**0.57**	0.24	0.31	0.31	0.35	**0.38**	0.22	0.22	**0.51**	**0.52**	**0.57**	**0.55**	0.14	0.11	0.14	0.14	0.35	**0.44**	−0.05	0.14
8. ul	0.13	0.08	0.02	0.28	0.07	0.30	**0.39**	1	**0.54**	−0.16	−0.25	−0.15	0.18	0.24	−0.17	−0.16	0.25	0.30	0.38	0.29	0.06	−0.11	−0.12	−0.12	0.10	0.10	−0.29	−0.14
9. ll	−0.35	−0.01	0.21	0.24	0.02	0.19	**0.44**	0.32	1	0.04	−0.24	−0.13	0.12	0.24	0.11	−0.06	0.27	0.32	0.18	0.35	0.06	0.03	0.08	−0.06	0.27	0.27	−0.02	0.14
10. me	0.24	0.14	0.04	0.28	**0.38**	0.26	0.14	**0.46**	−0.11	1	−0.20	−0.03	0.33	0.25	**0.45**	**0.36**	0.35	0.31	**0.36**	**0.38**	0.13	0.15	0.07	0.09	0.32	0.28	−0.07	−0.01
11. mlo (R)	−0.22	0.00	0.11	0.31	**0.34**	**0.39**	0.09	0.38	0.29	0.18	1	**0.84**	0.23	**0.35**	0.20	**0.35**	0.20	0.26	0.06	0.20	0.23	0.27	0.32	**0.42**	0.08	0.30	0.19	0.32
12. mlo (L)	−0.17	0.00	0.08	0.31	**0.32**	**0.38**	−0.03	**0.42**	0.10	0.28	**0.81**	1	0.23	**0.37**	0.09	0.31	0.20	**0.35**	−0.06	0.17	0.25	0.26	0.23	0.29	0.05	0.28	0.06	0.25
13. lo (R)	0.14	0.25	0.23	**0.48**	**0.32**	**0.49**	0.15	**0.57**	−0.09	**0.47**	**0.50**	**0.44**	1	**0.88**	**0.58**	**0.49**	**0.73**	**0.69**	**0.51**	**0.59**	**0.70**	**0.67**	**0.62**	**0.60**	**0.59**	**0.63**	**0.48**	**0.51**
14. lo (L)	0.07	0.26	0.28	**0.49**	0.31	**0.48**	0.14	**0.47**	−0.06	**0.41**	**0.37**	**0.36**	**0.91**	1	**0.39**	0.33	**0.68**	**0.71**	**0.46**	**0.52**	**0.74**	**0.68**	**0.62**	**0.62**	**0.65**	**0.72**	**0.46**	**0.49**
15. so (R)	0.15	**0.33**	**0.32**	**0.58**	**0.57**	**0.45**	0.18	**0.43**	0.03	**0.40**	**0.42**	**0.46**	**0.54**	**0.45**	1	**0.73**	**0.41**	0.30	**0.39**	**0.44**	**0.42**	**0.47**	**0.56**	**0.46**	**0.46**	**0.48**	**0.35**	**0.37**
16. so (L)	0.15	**0.34**	**0.33**	**0.57**	**0.63**	**0.41**	0.19	**0.41**	0.08	**0.42**	**0.48**	**0.48**	**0.55**	**0.44**	**0.90**	1	**0.36**	0.26	0.34	**0.38**	0.32	**0.41**	**0.48**	**0.47**	0.32	**0.38**	0.33	**0.39**
17. sbo (R)	−0.13	0.10	0.19	**0.43**	**0.36**	**0.46**	−0.07	0.27	−0.09	**0.32**	**0.45**	**0.48**	**0.62**	**0.64**	**0.34**	**0.39**	1	**0.90**	**0.56**	**0.61**	**0.52**	**0.50**	**0.44**	**0.42**	**0.60**	**0.64**	0.23	0.24
18. sbo (L)	−0.15	0.06	0.16	**0.43**	0.20	**0.34**	−0.05	**0.40**	0.09	**0.33**	**0.45**	**0.55**	**0.59**	**0.66**	0.29	0.31	**0.89**	1	**0.44**	**0.59**	**0.46**	**0.42**	0.33	0.28	**0.47**	**0.52**	0.09	0.12
19. al (R)	0.05	0.31	**0.34**	0.19	0.16	0.25	−0.02	0.18	0.30	0.29	0.12	0.17	0.26	0.26	0.23	0.28	0.19	0.25	1	**0.78**	0.21	0.19	0.17	0.20	**0.45**	**0.37**	0.00	0.15
20. al (L)	−0.08	0.25	**0.33**	0.23	0.20	0.26	−0.07	0.12	**0.40**	0.26	0.12	0.19	0.17	0.28	0.14	0.18	0.31	**0.39**	**0.88**	1	0.20	0.23	0.17	0.19	0.31	**0.38**	−0.06	0.13
21. za (R)	0.04	**0.32**	**0.38**	**0.52**	**0.41**	0.27	0.01	0.33	0.20	**0.37**	**0.34**	**0.37**	**0.50**	**0.54**	**0.45**	**0.50**	**0.34**	**0.34**	0.30	0.30	1	**0.96**	**0.78**	**0.70**	**0.75**	**0.72**	**0.66**	**0.60**
22. za (L)	−0.04	0.25	**0.33**	**0.53**	**0.39**	0.24	−0.05	0.22	0.09	0.23	**0.32**	**0.35**	**0.46**	**0.50**	**0.37**	**0.47**	**0.34**	0.31	0.24	0.22	**0.94**	1	**0.79**	**0.73**	**0.74**	**0.70**	**0.72**	**0.65**
23. mm (R)	0.11	**0.43**	**0.46**	**0.51**	**0.47**	**0.47**	−0.11	**0.45**	0.17	**0.48**	**0.34**	**0.39**	**0.54**	**0.51**	**0.46**	**0.51**	0.27	0.25	**0.34**	0.29	**0.83**	**0.78**	1	**0.91**	**0.80**	**0.83**	**0.82**	**0.80**
24. mm (L)	0.05	**0.33**	**0.38**	**0.56**	**0.41**	**0.42**	−0.13	**0.44**	0.07	**0.41**	**0.33**	**0.44**	**0.56**	**0.57**	**0.48**	**0.54**	**0.40**	**0.40**	0.26	0.26	**0.83**	**0.83**	**0.92**	1	**0.76**	**0.80**	**0.82**	**0.85**
25. ol (R)	0.03	0.26	0.29	**0.41**	**0.43**	**0.39**	0.06	0.28	0.19	**0.50**	**0.38**	0.29	**0.56**	**0.50**	0.29	**0.37**	**0.32**	0.29	0.26	0.24	**0.74**	**0.67**	**0.78**	**0.67**	1	**0.91**	**0.66**	**0.65**
26. ol (L)	0.03	0.25	0.28	**0.53**	**0.51**	0.28	0.00	0.13	0.20	**0.48**	**0.35**	0.26	**0.49**	**0.45**	**0.32**	**0.43**	0.27	0.26	0.20	0.18	**0.76**	**0.73**	**0.76**	**0.69**	**0.91**	1	**0.65**	**0.71**
27. go (R)	0.07	**0.33**	**0.36**	**0.47**	**0.49**	**0.40**	−0.05	**0.44**	0.00	**0.39**	**0.34**	**0.38**	**0.55**	**0.49**	**0.47**	**0.56**	**0.35**	0.27	**0.34**	0.29	**0.74**	**0.77**	**0.82**	**0.79**	**0.69**	**0.69**	1	**0.87**
28. go (L)	0.04	0.29	**0.33**	**0.43**	**0.42**	0.31	−0.08	0.36	−0.07	0.29	**0.40**	**0.44**	**0.51**	**0.45**	**0.46**	**0.60**	**0.44**	**0.36**	0.25	0.21	**0.67**	**0.75**	**0.70**	**0.79**	**0.60**	**0.63**	**0.90**	1

L — left; R — right; for the rest abbreviations — see Table 1 sexual dimorphism in facial soft tissues with significantly greater STTs in females in most of the facial regions, including eye, cheek, lip, chin and jaw. However, the females examined in our study have more tissue only at the cheeks in accordance with the most common model.

In our study, 1/3 of the differences between male and female STTs are statistically significant. Similar to our results, many authors [5, 9, 10, 22, 23, 24] have reported significant sex differences in the midline landmarks. Moreover, our data show that an increase in the BMI leads to a decrease in the number of the significant sex differences at these landmarks.

Stephan et al. [26] and de Greef et al. [7] stated that although STTs show some sexual dimorphism, it has little practical value for craniofacial identification. However, de Greef et al. [7] pointed out that the impact of the sex should not be negated or at least should be considered for certain landmarks. We agree with this statement and although the differences between males and females are not very large for certain landmarks, we presume that the use of specific sex STT data could give a shade in the facial approximation, more relevant to a particular sex.

Bilateral differences

A modest amount of facial asymmetry is normal and present in most individuals [31]. A high influence of asymmetry, affecting around 50% of the lateral landmarks, has been established in some of the studies reporting data for the right and left homologous STTs [6, 10, 31]. In our study, the statistically significant differences are less in number. However, in other studies, no significant bilateral differences have been found [15, 16, 24, 32].

The direction and size of the bilateral asymmetry differ among the studies. Thicker STTs on the right side of the face are established by Sutton [28], de Greef et al. [6] and Drgáčová et al. [10]. According to our results, such a tendency is observed to a greater degree for females, particularly for the overweight ones, while the differences in males are distributed in an equal number for both facial sides. On the other hand, other studies [22, 23] found greater STTs on the left side of the face. Concerning the size of bilateral differences, our data are commensurable with the previously reported ones [6, 31], since most of the differences in the normal and overweight males as well as in the normal females are within 0.5 mm, and only in the overweight females more than half of the differences exceed 0.5 mm.

The most differing soft tissues between both facial sides have been reported at the lower face, especially at the masseter muscle area [16, 22, 30], possibly related to the masticatory function [22]. The direction of the asymmetry observed for the mid-masseter varies in different studies. According to De Greef et al. [6] and Drgáčová et al. [10], it is thicker on the right side, while Hwang et al. [16] reported that it is thicker on the left one. Thus, our results are more in concordance with the studies for the European populations.

Most of the statistically significant bilateral differences obtained in our study are observed in other studies as well, which means that they probably are not accidental. Assuming that the observed significant bilateral differences in the overweight groups are mostly in region with high fat content, the asymmetry could possibly be related not only to the muscle activity, but also to an uneven accumulation of fat tissue. However, further research is needed to trace if there is a stable tendency in the manifestation of the facial asymmetry and its relation to the muscle development or fat contain.

Correlations

There exist few studies on the correlations between separate STTs [24] as well as between the STTs and weight [23], BMI [18, 23] and height [23]. The male STTs are more strongly related to the weight and BMI than the female ones, indicating that their soft tissues, especially those in the cheek and mandible regions, become thicker more proportionally with the increase of weight and BMI [23, present study]. On the other hand, the relationships between STTs and body height are rather weaker in both sexes [23, present study].

Strong correlations have been found within and between STTs in different parts of the face [24]. Our results show strong correlations especially in the cheek and jaw regions, but slighter relationships between the STTs in the midline zones. Hence, stronger correlations are observed between the STTs in the zone containing the highest amount of fat tissue. In addition, the correlations between the homologous bilateral landmarks are among the strongest ones.

The use of mean STT values in facial reconstructions has been criticised by Simpson and Henneberg [24]. In this regard, if a researcher decides in the process of facial reconstruction to use for definite landmarks other than the mean values from a given dataset (median, minimum, maximum values), it is desirable to include also the other landmarks, which correlate strongly with them, so as the face proportions to be maintained.

CONCLUSIONS

The present study focuses the attention on the presence of differences in soft tissues in relation to the sex, nutritional status and facial sides. It provides the first data set on facial STTs for the Bulgarian population. In Bulgarian adults, the facial soft tissues change in accordance with the nutritional status of the individuals and the STTs in both sexes increase with the increasing BMI. Male soft tissues are more influenced by the nutrition than females, since the cheek and mandible regions are the most strongly affected. For both BMI categories, males have more tissue than females at the majority of facial points and the only exceptions are identified in the cheek zone, where the soft tissues are thicker in females. Bilateral asymmetry in facial STTs is found in either sex and BMI category. Stronger correlations are established for the STTs in the jaw region and between the cheek and jaw soft tissues. It can be inferred that the BMI appears a leading factor for changes in facial soft tissues and thus the nutritional status of the individual should not be neglected in the facial approximation.

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