Forensic Sci Med Pathol (2009) 5:60–65
DOI 10.1007/s12024-009-9085-9

ORIGINAL ARTICLE

The influence of sex, age and body mass index on facial soft tissue depths

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Accepted: 12 March 2009 / Published online: 13 May 2009

Abstract Facial soft tissue depth charts are used in the majority of forensic facial approximation methods. In the past, based on the multitude of available soft tissue depth charts, a number of hypotheses were advanced concerning the impact of sex, BMI and age on the depth of tissues. In this study, for the first time, a multivariate analysis was performed on a large-scale study on Caucasian adults to determine the "real" impact of these attributes. The calculation of a robust multiple linear regression of soft tissue thickness versus BMI, age and sex for each landmark separately, allowed us to study the impact from a statistical as well as practical point of view. Former findings were re-evaluated. Additionally, the results confirm the dominant role of BMI in the alterations of facial soft tissue thickness. However, excluding age and sex from the equation should be considered with care and can certainly not be applied to all landmarks. Finally, the regression equation allows increase in the specificity of tissue depths used in real cases by offering practitioners the possibility of calculating individual tissue depths.

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Keywords Facial soft tissue depths · Influences age · BMI · Sex · Forensic craniofacial identification · Facial approximation · Facial reconstruction

Introduction

When no link can be found between the post-mortem file of unidentified human remains and the available ante-mortem files of reported missing people, dissemination of information concerning the victim to the public can be considered in order to redirect the investigation toward a potential identity. Different forensic facial imaging techniques are available to attempt to depict the facial appearance of the individual [14]. One of these techniques is cranio-facial approximation, which consists of (re-) creating the face of the individual based on its skull. Recently, this method gained popularity through the media, as well as scientific recognition as indicated by the number of peer-reviewed papers published in the scientific literature. Cranio-facial approximation is based on a correct application of rules of thumb in combination with facial soft tissue depth data, two components that allow quantification and thus repeatability. Rules of thumb define the correct position of eyes, nose, mouth and ears, and soft tissue depths determine the shape of the facial tissue envelope. The impact of the facial soft tissue depths has been repeatedly questioned for two main reasons. Firstly, only tissue depths averaged over a subcategory of the population are used for all the skulls. Secondly, anthropological assessment of age, sex or ethnic origin of the skull is imperfect, not to mention the difficulty of accurately determining the corpulence from skeletal remains. Studies on the use of inappropriate tissue depths are rather limited. Two studies were performed on the effect of using datasets of a non-matching ethnical group. Aulsebrook and Van Rensburg [1] showed that strict adherence to the traditional tissue depths for White Europeans and Black Africans in the reconstruction of a skull of mixed racial origin compromised the accuracy of the facial approximation. Wilkinson et al. [16] applied the Manchester method to produce six different approximations of the same skull based on data of different ethnic groups and used resemblance ratings and photographic superimposition to score them. The tissue depth data of the proper ethnic group of the skull gave the best results, but reasonable resemblance was also obtained even with the tissue depths of other ethnicities. They suggested that strict adherence to the exact tissue depths should be avoided and that the morphology of the skull and the anatomy should be followed with tissue depth measurements being used only as guides. A view on which apparently even pioneers such as Gerasimov, whose morphologic method was claimed to be based only on the anatomical structures, and Krogman, whose morphometric method rested only on tissue depths, could have agreed on according to Stephan [10]. Starbuck and Ward [8] chose to examine the facial variations associated with body weight within the same ethnic group as well as its effect on facial recognition. They manually created an emaciated, normal and obese face on three casts of the same skull by using the American method and applying different tissue depth data. Morphological variation was measured quantitatively, using the anthropometric craniofacial variability index [15], as well as qualitatively using survey data that assessed the subjective appearance of similarity among photographs of the three faces. The qualitative data appeared in opposition with the quantitative data. They concluded that, although the use of different tissue depths with regard to body composition has minimal effect on the overall pattern of facial form, it significantly affects the subjective assessment, which suggests that variation in weight may be an important contributor to the ability to achieve correct recognition of a reconstructed face. To cope with this issue the authors proposed to generate multiple versions of the face, bringing us back to the role of the soft tissue depth data in the approximation process. Indeed, apart from the wrinkling and texturing in the final stage of the process, alterations of the properties such as corpulence, age and sex, further referred to as attributes, are based on facial soft tissue depth tables.

A number of facial soft tissue depth studies have been performed since the end of the 19th century, providing the forensic artists with many charts reporting classic statistics of means, medians, standard deviations or ranges for different ethnic groups, subdivided into different categories based on body build, age and sex [17]. Maat [6] and Stephan et al. [9] questioned this sex separation because the variation within each sex was large while the variation between the sexes was small. Just recently, Stephan and Simpson [11] studied trends and differences across 55 adult studies published between 1883 and 2007 in a univariate way. They suggested that subcategorization of the soft tissue depth data according to variables such as publication year, method of measurement, race and sex is of little practical benefit given the totality of data uncertainty that exists. Uncertainty caused not only by measurement errors but also by the choice of the measurement method as well as erroneous physical placement and representation of the soft tissue depths on skulls in caseworks. They proposed to pool all the soft tissue depth data available in the literature in order to provide a statistically more powerful and simplified data set involving 25 commonly measured landmarks.

Prior to this last study, in the wake of their studies on facial soft tissue depths, researchers reported on the impact of the attributes. Some researchers based their observations on statistical significance tests for establishing differences between the different subcategories present in their studies, others on univariate correlation coefficients between the tissue depths and certain attributes.

None of these studies, however, performed any multivariate analysis, probably because of the limited number of volunteers involved in these studies. This paper therefore reports on the results of a multivariate analysis of the data of a large scale in vivo study on facial soft tissue depths of Caucasian adults performed in 2006. It allows a better apprehension of the influence of age, sex and body build (represented by the Body-Mass-Index (BMI)) on facial soft tissue depths from a statistical as well as practical point of view.

Materials and methods

The raw data of a large-scale in vivo Caucasian facial soft tissue thickness database were used for the analysis [3]. The database contained the soft tissue depths at 52 different facial landmarks (lm's) of a randomly selected extensive sample ($n = 967$, 457 males, 510 females, age range: [18–91 years]) of the Belgian adult population (Fig. 1). Every subject in this study was scanned with an ultrasound device (Epoch 4b®, Panametrics, Waltham, USA) using an acquisition protocol that was validated for repeatability and accuracy [2].

In the analysis of very large datasets, multivariate data reduction and analysis techniques such as factor analysis and principal component analysis are considered in order to extract the relevant information. These different techniques enable hypothesis testing on large datasets by reducing the available data and revealing the correlated structure of the dataset. In our specific case, the goal was to investigate the

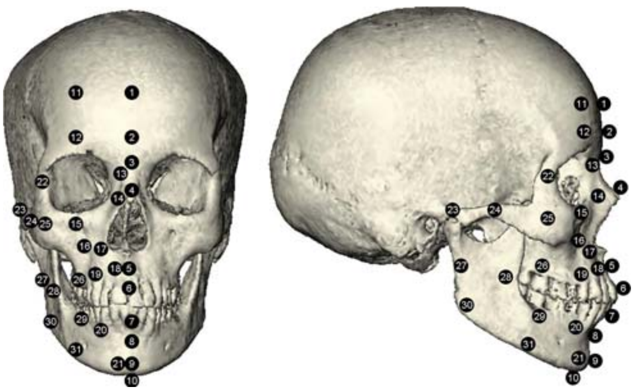

Fig. 1 Landmarks in frontal and lateral view

influence of age, BMI and sex on the facial soft tissue depths at the different lm's. We considered the three attributes as the independent variables (sex was coded as −1 for females and +1 for males) and the soft tissue depth measurement as the dependent variable and calculated a robust (Holland and Welsch [5]) multiple linear regression of soft tissue thickness versus BMI, age and sex for each landmark separately. This allowed us to evaluate the impact of the attributes, from a statistical point of view, by reporting the significance levels for the null-hypothesis of the partial regression coefficients to be zero, and, from a practical point of view, by reporting the differences in tissue depths in millimetres as well as the root mean square errors (RMSE) representing an estimate of the standard deviation of the residual error, i.e. the difference between the measured tissue depths and the values predicted by the regression equations. The number of involved volunteers in the computation varied between 840 and 960 with an exception for the lateral nasal ($n = 624$). The presence of beards and moustaches but also the tissue deformations due to the presence of dentures and spectacles, were reasons to skip some lm's during acquisition. The measurements of the right side of the volunteers' faces were used in the regression and the test was implemented using the Matlab R2006b (The Mathworks Inc., Natick, MA) data analysis software.

Results

The attribute related effects are represented by the per landmark linear regression and are tabulated in Table 1.

From a statistical point of view, based on the significance levels, it appears that 14 of the 31 lm's are influenced by the three attributes, 3 lm's are influenced by just one attribute and 1 lm, the lateral nasal, is not influenced at all by any of the attributes. In addition, all BMI related regression coefficients are positive, indicating a strictly positive change of soft tissue depth with BMI, while the regression coefficients of soft tissue depth on age and sex are of different signs for different landmarks. Indeed, half of the age related regression coefficients are negative, as are approximately one in three sex related regression coefficients, indicating no systematic unidirectional change of soft tissue depth with age and sex.

When assessing the impact of the different attributes on the tissue depths from a practical point of view, based on the regression coefficients, the different magnitudes and ranges of age, sex and BMI have to be taken into consideration. Indeed, sex ranges between −1 for females and +1 for males, age ranges approximately between 20 and 70 years old and BMI ranges approximately between 20 and 30. Note that, although the last two attributes start from the same value, they have a different range.

BMI-related observations

The upper lip and nose region appear to be independent from the BMI from a statistical and practical point of view. The p-values for the upper lip margin (6), lateral nasal (13), lateral nostril (17), mid philtrum (5) and supra canina (19) indicate no impact of the BMI on the tissue depths. The end of nasal (4) and nasio-labial ridge (18), although statistically significantly influenced by BMI, practically don't change with BMI alterations. Indeed, a change of 10 on the BMI-scale, representing a weight difference of 30 kg in a 175 cm tall individual, would change the total soft tissue depth with not even half a millimetre.

The mandible (gonion (30), mid mandibular angle (31), sub M2 (29), mid masseter muscle (27)) and the cheek region (supra M2 (26), occlusal line (28), inferior malar (15)) are most influenced by the BMI. A change, as in the example above, of 10 on the BMI-scale would have an impact around 4–5 mm on the tissue depths.

Age-related observations

The magnitude of the age-related partial regression coefficients is remarkably small. Even when considering the fact that the age-range is the largest of all the attributes and more than 50 years separate the youngest and oldest individuals, a majority of the tissue depth differences between these groups do not exceed 1 mm. The inferior malar (15) and the mid mandibular angle (31) increase about 2 mm with ageing of 50 years whereas the upper lip zone (Mid-philtrum (5), nasio-labial ridge (18), upperlip margin (6) and the supracanina (19)) decrease approximately between 1 and 2 mm, as do the occlusal line (28) and midmasseter muscle (27).

Sex-related observations

Since the sex attribute ranges between −1 for females and +1 for males, it is sufficient to multiply the

Table 1 Linear regression equation: partial regression coefficients, the significance levels; the root mean square (RMS) errors and number of involved volunteers per landmark. Y = b0 + b1 × bmi + b2 × age + b3 × sex; b0 (mm), b1 (mm/bmi); b2 (mm/yr); b3 (mm/sex) female = −1, male = +1; RMSE (mm)

Landmark		b0	b1	p	b2	p	b3	p	RMSE	*n*
1	Supraglabella	2.1592	0.085	**	0.003	**	0.042	*	0.675	957
2	Glabella	2.8781	0.095	**	0.000		−0.016		0.816	955
3	Nasion	4.09	0.073	**	0.012	**	−0.105	*	1.298	959
4	End of nasal	1.7282	0.040	**	0.000		0.123	**	0.733	958
5	Mid-philtrum	10.686	0.024		−0.037	**	0.695	**	1.668	877
6	Upper lip margin	10.842	0.003		−0.027	**	0.476	**	1.904	872
7	Lower lip margin	10.624	0.060	**	−0.017	**	0.702	**	2.064	899
8	Chin-lip fold	7.5046	0.086	**	0.018	**	0.160	**	1.305	918
9	Mental eminence	4.2648	0.219	**	0.018	**	0.016		1.718	939
10	Beneath chin	2.2939	0.157	**	0.005		0.167	**	1.495	927
11	Frontal eminence	2.0161	0.086	**	0.006	**	0.090	**	0.702	958
12	Supraorbital	2.0892	0.134	**	0.005	**	−0.023		0.845	956
13	Lateral glabella	4.4951	0.057	**	0.002		0.150	**	1.294	956
14	Lateral nasal	3.5428	0.010		−0.002		0.039		0.721	624
15	Suborbital	5.2747	0.153	**	0.013	**	−0.378	**	2.478	954
16	Inferior malar	6.706	0.419	**	0.038	**	−0.447	**	3.159	957
17	Lateral nostril	9.3928	0.021		−0.007	*	0.302	**	1.434	950
18	Naso-labial ridge	10.137	0.042	**	−0.033	**	0.679	**	1.627	853
19	Supra canina	9.5965	0.031		−0.026	**	0.572	**	1.913	853
20	Sub canina	7.7428	0.114	**	0.002		0.078		1.656	908
21	Mental tubercle ant.	4.9142	0.194	**	0.020	**	0.047		1.52	930
22	Mid lateral orbit	3.2258	0.066	**	0.002		−0.107	**	1.102	952
23	Supraglenoid	7.0091	0.123	**	−0.009		0.023		2.742	946
24	Zygomatic arch	0.18809	0.287	**	−0.007	*	−0.492	**	1.575	952
25	Lateral orbit	1.3923	0.343	**	−0.006		−1.104	**	1.783	953
26	Supra-M2	15.505	0.487	**	−0.010		−0.512	**	3.642	841
27	Mid-masseter muscle	8.9584	0.409	**	−0.022	**	0.471	**	3.69	945
28	Occlusal line	10.886	0.420	**	−0.033	**	0.157	*	2.407	949
29	Sub-M2	9.1014	0.390	**	0.018	*	−0.537	**	3.226	841
30	GonioN	4.0415	0.488	**	−0.010		0.280	**	2.681	945
31	Mid mandibular angle	0.025481	0.440	**	0.042	**	−0.480	**	2.539	938

* $p < 0.05$

** $p < 0.01$

regression coefficient with a factor of two to obtain the difference in tissue depth between the sexes. The lateral orbit (25) is the only lm where the difference between males and females exceeds 2 mm. The upper lip zone (Mid-philtrum (5), nasio-labial ridge (18), upperlip margin (6) and the supracanina (19)) and the lower lip are between 1 and 1.5 mm thicker in males than females, the cheek zone (sub-M2 (29) and supra-M2 (26)) are 1 mm thicker in females than males. In the rest of the landmarks the difference never exceeds 1 mm.

Discussion

Since the beginning of research on facial soft tissue depths, researchers have reported on the influences of the attributes on the tissue depths.

Concerning the impact of the body composition, the results of the earlier studies are congruent with each other and can roughly be summarized as follows: (a) all tissues are thinner for emaciated compared to well-nourished people with the exception of the nasal bridge (cfr. end of nasal (4)), and (b) the landmarks differing most are the chin, mandible and cheek region. No negative correlation coefficient has been found in this study either, and the cheek and mandible zone are most influenced by the BMI. However, next to the end of nasal (4), the upper lip zone appears from a statistical as well as a practical point of view not to be influenced by the BMI and the effect of the BMI on the chin region, although present, is less obvious than the cheek and mandible zone. Suzuki [12], who noted that the tissues around the eyes did not decrease or increase, and Sutton [13], who limited his study to the zygomatic arch, concluded that the effects of nutritional state could be linked to the presence of hypodermic fat or well-developed muscles. Hypodermic fat has indeed a protective and metabolic function. It is partitioned into multiple independent anatomical compartments although the volume of these different compartments are proportionally related [4]. Cadaver dissections show that the thickest zone is the “malar fat pad” followed by the “premental fat pad”, whereas in the forehead and lip zones, the fat layer is almost non-existent, which is congruent with our findings.

Wilkinson [17], based on a review of former studies, stated that the age-related changes in tissues are very variable. Tissues at the mouth and lower cheek tend to decrease with age, and tissues at the chin and eyebrow may increase with age. Concerning the changes in the oral, chin and brow zones, these findings are in agreement with our results, although the last two zones are influenced more from a statistical than from a practical point of view. Comparing our observations in the cheek and jaw region with former studies is less obvious. We observe an increase at the inferior malar (lm 16) and the mid mandibular angle (lm 31) but two adjacent lm’s, the occlusal line (lm 28) and mid masseter muscle (lm 27) appear to decrease. An explanation for these local differences could be found in the study of Rohrich and Pessa [7] on the role of fat on the ageing face. Indeed, the authors concluded that the ageing face can be analysed as a change in volume and position of the different fat compartments, both superficial and deep.

A majority of facial soft tissue depth studies subdivided their population into male and female categories, resulting in numerous hypotheses on the differences in facial soft tissue depths related to sex. Generally and considering all the different racial groups, researchers concluded that men have thicker tissues over most of the face than women, especially at the brow, mouth and jaw while women have thicker tissues at the cheeks. Our results show indeed thicker soft tissues around the mouth in men and larger cheeks in women but the differences in tissue depths at the brow (supraorbital (lm 12), and glabella (lm 2)) appears from a statistical and practical point of view negligible and women even tend to be slightly bigger than men at the brow.

Based on the significance levels and regression coefficients, it is obvious that the BMI is the major contributor to the differences in facial soft tissue depths between individuals. The age and sex factor, although significant in 2/3 of the landmarks, have from a practical point a view less impact on the tissue depths. In fifty percent of the lm’s a change of sex or a BMI increase of ten would not even influence the tissue depths by more than half a millimetre. Concluding that these attributes could be excluded out of the equation would however be overstated. For example, in the mouth region, where the BMI appears to have no impact, a combination of the sex and age factor would account for 2.1 mm of the difference between an old man and a young woman at the mid-philtrum (lm 5).

Conclusion

The purpose of this study was to investigate the age, sex and BMI-related changes of the adult facial soft tissue depths used in different facial approximation techniques. By using a multiple regression equation, integrating the three attributes, we were able for the first time to dissociate the impacts of the BMI, age and sex on the facial soft tissue depths in the different lm’s. This allowed re-evaluation of the results of former studies. Our results also show that, although the BMI plays a dominant role in the alterations of the facial soft tissue depths, negation of the age- and sex factors should be considered with care and can certainly not be applied to all lm’s. Additionally, the presented regression equations contribute to an increase of the specificity of the tissue depths used in real cases by allowing the practitioners to calculate individual tissue depths. Finally, it is worth nothing that these conclusions only apply to adults. There may well be significant age and sex related differences for juveniles.

Future research in the field should focus on linking anatomical structures, such as fat compartments and muscles, to the tissue depth variations by using medical imaging technology in order to acquire a better understanding in the changes reported in this study. Most importantly, a true multivariate statistical analysis including the influence of attributes on all the lm’s together, could reveal important remaining relationships.

Key points

Facial soft tissue depth charts are used in a majority of the forensic facial approximation methods. In this study a multivariate analysis was performed on a large-scale study on Caucasian adults to determine the ‘real’ impact of sex, BMI and age on the tissue depths. The results confirm the dominant role of the BMI in the alterations of the facial soft tissue depths. However excluding age and sex out of the equation should be considered with care and can certainly not be applied to all lm’s. Additionally a regression equation offers the practitioners the possibility to calculate individual tissue depths in order to increase the specificity of the tissue depths used in real cases.

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