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# Large-scale in-vivo Caucasian facial soft tissue thickness database for craniofacial reconstruction

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**Abstract**

A large-scale study of facial soft tissue depths of Caucasian adults was conducted. Over a 2-years period, 967 Caucasian subjects of both sexes, varying age and varying body mass index (BMI) were studied. A user-friendly and mobile ultrasound-based system was used to measure, in about 20 min per subject, the soft tissue thickness at 52 facial landmarks including most of the landmarks used in previous studies. This system was previously validated on repeatability and accuracy [S. De Greef, P. Claes, W. Mollemans, M. Loubele, D. Vandermeulen, P. Suetens, G. Willems, Semi-automated ultrasound facial soft tissue depth registration: method and validation. J. Forensic Sci. 50 (2005)]. The data of 510 women and 457 men were analyzed in order to update facial soft tissue depth charts of the contemporary Caucasian adult. Tables with the average thickness values for each landmark as well as the standard deviation and range, tabulated according to gender, age and BMI are reported. In addition, for each landmark and for both sexes separately, a multiple linear regression of thickness versus age and BMI is calculated. The lateral asymmetry of the face was analysed on an initial subset of 588 subjects showing negligible differences and thus warranting the unilateral measurements of the remaining subjects. The new dataset was statistically compared to three datasets for the Caucasian adults: the traditional datasets of Rhine and Moore [J.S. Rhine, C.E. Moore, Tables of facial tissue thickness of American Caucasoids in forensic anthropology. Maxwell Museum Technical series 1 (1984)] and Helmer [R. Helmer, Schädelidentifizierung durch elektronische bildmischung, Kriminalistik Verlag GmbH, Heidelberg, 1984] together with the most recent in vivo study by Manhein et al. [M.H. Manhein, G.A. Listi, R.E. Barsley, R. Musselman, N.E. Barrow, D.H. Ubelbaker, In vivo facial tissue depth measurements for children and adults. J. Forensic Sci. 45 (2000) 48–60]. The large-scale database presented in this paper offers a denser sampling of the facial soft tissue depths of a more representative subset of the actual Caucasian population over the different age and body posture subcategories. This database can be used as an updated chart for manual and computer-based craniofacial approximation and allows more refined analyses of the possible factors affecting facial soft tissue depth.


*Keywords:* Anthropology; Human identification; Cranio-facial approximation; Facial soft tissue depth data

## 1. Introduction

The main purpose of any forensic facial approximation is to recreate the face of a deceased at the time of death based on his/her skull. Although a corpse represents a tremendous source of information to the forensic pathologist, odontologist and anthropologist, even a multidisciplinary forensic analysis cannot always guarantee a final positive identification. Indeed, the most extended and detailed post-mortem data are useless without any link to the ante-mortem data. In these cases, forensic facial approximation can be considered as a last resort to trigger the identification process. Publication of the reconstructed face will hopefully stimulate recognition by relatives and allow further comparative analysis to be carried out for establishing the identity.

Since the first attempts in the late 19th century, different two- and three-dimensional, manual or computer-aided reconstruction techniques have been developed [5–9]. The majority of them are based on two components. Besides the various rules of thumb for a correct positioning of eyes, ears,

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nose and mouth, tissue depth tables are used to obtain a best estimate of the facial outline.

Over the past years some studies were performed to critically re-evaluate the rules of thumb and to propose new ones [10–17]. Research on facial tissue depths mainly focussed on children and adolescents [18–22], while studies on adults were rather ''small scale'' [4,23]. Some new measurement methods were proposed [24–26] and ideas developed within the computer graphics area were applied to expand the tissue depth landmarks to the complete head [27,28]. Two databases are currently used for the Caucasian model: the American cadaver study of Rhine and Moore [2] and the German in vivo study of Helmer [3]. Both were performed on a rather small number of subjects ($N = 73$ (Rhine and Moore) and $N = 123$ (Helmer)). The measurements are tabulated based on gender and further subdivided according to body build (Rhine and Moore) and age (Helmer), but not both simultaneously. Numerous authors have questioned the use of cadaver populations for tissue depth studies as well as the limited number of subjects in the existing studies in order to be representative for a specific population. The aim of the present study was to improve the representative quality of the sampling over different subcategories, such as gender, age and BMI by performing a large scale in vivo study. Furthermore, this extensive sampling will also allow a more refined analysis of the possible factors affecting soft tissue depth and could provide the necessary data to develop a

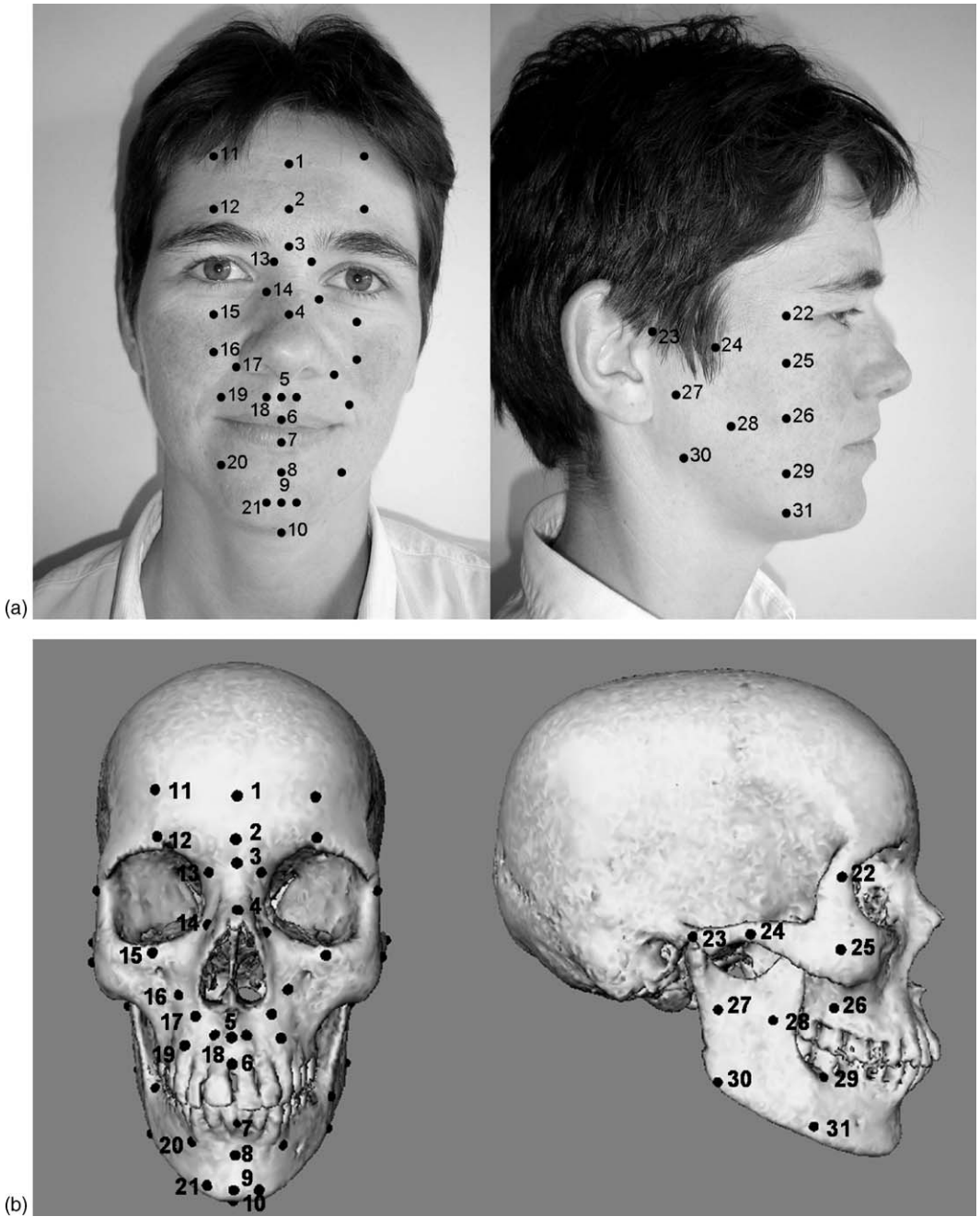


Fig. 1. (a) Facial landmarks and (b) skull landmarks.

statistical model that can be used in computer-based craniofacial approximation methods [29].

## 2. Materials and methods

### 2.1. Measurement protocol

Different state-of-the-art measurement technologies have been used in former studies to accurately measure facial soft tissue depths. The low cost and accessibility of ultrasound systems, free of radiation exposure and allowing measurements in an upright position appeared to be most appropriate. For the present study, we used a system composed of a portable computer connected to an Epoch 4b® ultrasound A-mode scanner (Panametrics, Waltham, USA). The selection of a very small (6 mm diameter) cylindrical, 10 MHz transducer, allowed sub-millimetre precise measurements with minimal indentation of the surrounding tissue. An interface program (Matlab, The Mathworks Inc., Natick, MA, USA) was developed to shorten the measurement procedure by partially automating the tissue depth acquisition, data transfer and storage.

Ten bilateral landmarks were added to the traditional facial landmarks of Rhine and Moore, bringing the total number of landmarks to 52, 10 located on the midline and 21 located bilaterally. The selection of these landmarks was based on their presence in former ultrasound studies, but also on the ability to reliably locate them in a standardised way on the face (Table 1; Fig. 1a and b).

Every landmark was measured three times, taking care not to indent the facial soft tissues. The transducer orientation was interactively determined such that the highest peak, corresponding to the most perpendicular position of the transducer to the bone, was obtained. Of the three thickness measurements, the largest one, corresponding to minimal soft tissue compression,

Table 1
Landmark number, name and description

| | Midline | |
|---|---|---|
| 1 | Supraglabella | Most anterior point on midline |
| 2 | Glabella | Crosspoint between midline and supraorbital line |
| 3 | Nasion | Midpoint of the fronto-nasal suture |
| 4 | End of nasal | Passage between bone and cartrilage of the nose |
| 5 | Mid-philtrum | Centered between nose and mouth on midline |
| 6 | Upper lip | Midline on the upperlip |
| 7 | Lower lip | Midline on the lower lip |
| 8 | Chin–lip fold | Midline centered in fold chin, below lips |
| 9 | Mental eminence | Centered on forward most projecting point of chin |
| 10 | Beneath chin | The vertical measure of the soft tissue on the lower edge of the chin |
| **Left/Right** | **Bilateral** | |
| 32/11 | Frontal eminence | Centered on eyepupil, most anterior point of the forehead |
| 33/12 | Supraorbital | Centered on eyepupil, just above eyebrow |
| 34/13 | Lateral glabella | Junction of the frontal, maxillary, and lacrimal bones on the medial bone of the orbit |
| 35/14 | Lateral nasal | Side of the bridge of the nose, horizontal just above the end of nasal on a vertical line with the inner canthus of the eye |
| 36/15 | Suborbital | Centered on eyepupil, just under inferior orbita margin |
| 37/16 | Inferior malar | Centered on the eyepupil, just under the zygomatic process |
| 38/17 | Lateral nostril | Next to the most lateral point of the ala nasi |
| 39/18 | Naso-labial ridge | The prominence next to the Mid-philtrum |
| 40/19 | Supra canina | Vertically lined up with the cheilion, on the horizontal level of the Mid-philtrum |
| 41/20 | Sub canina | Vertically lined up with the cheilion, on the horizontal level of the Chin-lip fold |
| 42/21 | Mental tubercle anterior | Most prominent point on the lateral bulge of the chin mound |
| 43/22 | Mid lateral orbit | Vertically centered on the orbit, next to the lateral orbit border |
| 44/23 | Supraglenoid | Root of the zygomatic arch just before the ear |
| 45/24 | Zygomatic arch | Maximum, most lateral curvature of the zygomatic bone |
| 46/25 | Lateral orbit | Lined up with the lateral border of the eye on the center of the zygomatic process |
| 47/26 | Supra M2 | Cheek region, lateral: lined up with bottom of nose; vertical: lined up beneath lateral border of the eye |
| 48/27 | Mid masseter | Middle of the masseter, the halfway point between the supraglenoid and the gonion |
| 49/28 | Occlusal line | Border of the masseter,on vertical level of the cheilion |
| 50/29 | Sub M2 | Below the second molar on horizontally lined up with Supra M2 |
| 51/30 | Gonion | At the angle of the mandible |
| 52/31 | Mid mandibular | Inferior border of the mandible, vertically lined up with Supra M2 |

was retained. Landmarks in the area of dental prostheses, moustaches or beards, which could interfere with the measurements, were skipped for these subjects. The lateral nasal landmark was skipped for subjects wearing spectacles, because of the possible permanent deformation of the soft tissues at that point. The measurements were obtained with the subject in a seated position with a neutral, relaxed, facial expression. The measurement protocol was evaluated for repeatability and, in contrast to the older studies, also for accuracy compared to a gold standard (X-ray Computed Tomography). A detailed description of the complete acquisition protocol and its validation are part of a previous publication [1].

Exactly 1000 volunteers were recruited on an arbitrary basis and measured using the procedure described above. After we excluded the non-Caucasians and minors, the studied population consisted of 457 males and 510 females. An initial subset of 588 subjects was measured bilaterally, the remaining subjects were measured unilaterally on the right side of the face.

### 2.2. Statistical analysis

Several statistical analyses were carried out on the facial soft tissue depth data obtained. Similar to the traditional databases of facial soft tissue depths for the adult Caucasian model, we report standard summary statistics such as average, standard deviation and ranges of soft tissue thickness for each landmark per chosen subcategory. In contrast to previous studies, we extend the hypothesized important subcategories to gender, age and body mass index (BMI). Indeed, the tables of Helmer are subdivided according to gender and age, but not according to body posture whereas the tables of Rhine and Moore are subdivided according to gender and body posture but not according to age. Furthermore, in the latter study, body posture is based on visual assessment of the subjects which is subjective and, hence, not reproducible.

Besides reporting the measurements per subcategory, we also calculate for each landmark a gender-specific robust multiple linear regression [30] of soft tissue thickness versus age and BMI. For the bilateral landmarks the averages of left and right measurements were used in the regression.

Several statistical hypothesis tests were carried out to test for bilateral symmetry. Contralateral soft tissue measurements were compared using a paired *t*-test (assuming normal distributions), a Wilcoxon paired signed rank test (relaxing the normality assumption of the underlying distribution as well as being more robust to outliers) and by comparing the median

Table 2a
Tissue depth means (mm) for Caucasian adult females between 18 and 29 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (56) | | | | | 20–25 (149) | | | | | >25 (29) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.9 | 0.6 | 2.8 | 5.3 | 56 | 4.1 | 0.6 | 2.9 | 6.0 | 127 | 4.5 | 0.7 | 3.4 | 6.2 | 29 |
| 2 | Glabella | 4.9 | 0.7 | 3.3 | 6.5 | 56 | 5.1 | 0.8 | 3.4 | 7.5 | 127 | 5.5 | 0.8 | 4.3 | 7.7 | 29 |
| 3 | Nasion | 5.9 | 1.3 | 2.4 | 8.7 | 56 | 6.3 | 1.2 | 4.0 | 9.4 | 127 | 6.4 | 1.2 | 4.6 | 8.3 | 29 |
| 4 | End of nasal | 2.5 | 0.6 | 1.7 | 6.1 | 56 | 2.6 | 0.8 | 1.6 | 9.2 | 127 | 3.0 | 0.7 | 2.2 | 4.7 | 29 |
| 5 | Mid-philtrum | 10.0 | 1.6 | 5.8 | 13.7 | 56 | 9.8 | 1.6 | 2.6 | 13.6 | 126 | 9.8 | 2.0 | 6.8 | 16.5 | 28 |
| 6 | Upper lip margin | 9.8 | 2.1 | 5.9 | 18.6 | 56 | 10.0 | 1.7 | 5.6 | 13.8 | 126 | 9.8 | 2.0 | 4.6 | 13.7 | 28 |
| 7 | Lower lip margin | 10.9 | 1.9 | 7.4 | 15.0 | 56 | 11.0 | 2.0 | 6.9 | 15.5 | 127 | 10.8 | 2.2 | 5.8 | 15.0 | 28 |
| 8 | Chin–lip fold | 9.5 | 1.0 | 7.4 | 11.9 | 55 | 9.6 | 1.0 | 7.2 | 12.2 | 127 | 9.7 | 1.3 | 7.1 | 12.2 | 29 |
| 9 | Mental eminence | 9.1 | 1.5 | 6.2 | 12.4 | 56 | 9.6 | 1.7 | 6.7 | 14.3 | 127 | 11.0 | 1.9 | 6.4 | 15.0 | 29 |
| 10 | Beneath chin | 5.6 | 1.1 | 3.7 | 8.9 | 56 | 5.6 | 1.3 | 3.3 | 10.2 | 126 | 7.1 | 1.5 | 5.0 | 12.0 | 28 |
| 32/11 | Frontal eminence | 3.8 | 0.5 | 2.7 | 5.2 | 56 | 3.9 | 0.6 | 2.7 | 6.1 | 127 | 4.5 | 0.6 | 3.6 | 5.9 | 29 |
| 33/12 | Supraorbital | 5.1 | 0.8 | 3.7 | 7.0 | 56 | 5.4 | 1.0 | 3.8 | 10.9 | 127 | 6.1 | 0.7 | 5.2 | 8.5 | 29 |
| 34/13 | Lateral glabella | 5.7 | 1.0 | 3.7 | 8.6 | 56 | 5.7 | 1.1 | 2.8 | 9.0 | 127 | 5.7 | 1.4 | 3.6 | 10.1 | 28 |
| 35/14 | Lateral nasal | 3.9 | 0.6 | 2.7 | 5.6 | 49 | 3.7 | 0.6 | 2.1 | 5.2 | 110 | 3.7 | 0.8 | 2.4 | 5.7 | 21 |
| 36/15 | Suborbital | 9.3 | 2.2 | 3.6 | 15.1 | 56 | 9.4 | 2.1 | 3.3 | 14.2 | 127 | 10.3 | 2.4 | 4.4 | 14.9 | 29 |
| 37/16 | Inferior malar | 16.2 | 2.9 | 10.8 | 23.2 | 56 | 17.9 | 2.7 | 10.6 | 25.1 | 127 | 20.3 | 2.0 | 17.2 | 23.6 | 28 |
| 38/17 | Lateral nostril | 9.6 | 1.1 | 7.2 | 12.8 | 56 | 9.5 | 1.3 | 5.8 | 12.6 | 127 | 9.4 | 1.8 | 4.9 | 13.1 | 29 |
| 39/18 | Naso-labial ridge | 10.1 | 1.7 | 5.9 | 14.0 | 55 | 9.5 | 1.6 | 3.5 | 12.9 | 126 | 10.0 | 2.1 | 6.1 | 16.6 | 29 |
| 40/19 | Supra canina | 9.6 | 1.9 | 5.5 | 14.9 | 56 | 9.5 | 1.9 | 5.3 | 15.2 | 127 | 9.2 | 1.9 | 6.2 | 12.7 | 29 |
| 41/20 | Sub canina | 10.3 | 1.6 | 6.5 | 13.9 | 56 | 10.3 | 1.5 | 6.7 | 14.8 | 127 | 10.9 | 1.8 | 8.0 | 14.4 | 29 |
| 42/21 | Mental tubercle ant. | 9.3 | 1.4 | 6.1 | 12.5 | 56 | 9.6 | 1.6 | 5.5 | 13.4 | 127 | 10.7 | 1.7 | 7.5 | 14.0 | 29 |
| 43/22 | Mid lateral orbit | 4.8 | 0.7 | 3.6 | 6.2 | 56 | 5.0 | 1.1 | 3.5 | 10.3 | 126 | 5.0 | 1.0 | 3.8 | 7.4 | 29 |
| 44/23 | Supraglenoid | 9.3 | 2.1 | 3.4 | 13.4 | 56 | 9.6 | 2.2 | 3.4 | 13.9 | 126 | 10.3 | 1.9 | 7.4 | 14.3 | 29 |
| 45/24 | Zygomatic arch | 6.1 | 1.4 | 3.9 | 8.8 | 56 | 6.9 | 1.5 | 3.6 | 11.3 | 126 | 8.7 | 1.9 | 4.9 | 12.2 | 29 |
| 46/25 | Lateral orbit | 9.4 | 1.5 | 6.3 | 12.4 | 56 | 10.0 | 1.7 | 6.4 | 15.4 | 126 | 12.6 | 2.2 | 8.7 | 16.9 | 29 |
| 47/26 | Supra-M2 | 25.8 | 3.9 | 6.4 | 32.2 | 56 | 26.6 | 3.8 | 10.1 | 33.6 | 126 | 29.2 | 3.6 | 20.2 | 37.8 | 29 |
| 48/27 | Mid-masseter muscle | 16.5 | 3.0 | 8.0 | 21.1 | 56 | 17.2 | 3.5 | 4.5 | 24.0 | 126 | 17.7 | 3.9 | 8.6 | 23.6 | 29 |
| 49/28 | Occlusal line | 18.8 | 2.4 | 8.3 | 25.2 | 56 | 19.4 | 2.0 | 15.1 | 24.4 | 126 | 22.0 | 2.7 | 16.9 | 28.6 | 29 |
| 50/29 | Sub-M2 | 18.5 | 2.7 | 12.0 | 24.9 | 56 | 19.0 | 3.1 | 10.4 | 27.1 | 126 | 21.5 | 3.3 | 15.8 | 28.5 | 29 |
| 51/30 | Gonion | 13.8 | 2.3 | 9.4 | 19.4 | 56 | 14.4 | 2.6 | 7.0 | 21.4 | 126 | 16.7 | 2.7 | 11.8 | 24.4 | 29 |
| 52/31 | Mid mandibular angle | 10.7 | 2.2 | 6.6 | 15.3 | 56 | 11.4 | 2.4 | 4.3 | 17.6 | 126 | 14.2 | 2.0 | 11.0 | 18.8 | 29 |

of the differences for each landmark to the confidence interval for the medians calculated using a resampling-with-replacement bootstrapping technique [31].

We also compared the new database with the traditional datasets of Rhine and Moore [2], Helmer [3] and the more recently performed Manhein et al. study [4]. Since the raw data of these studies were not available, we restricted the analysis to a comparison of our measurements to the mean and median values reported. More specifically, for the Helmer study, a Wilcoxon signed rank test was performed. It tests the hypothesis that our data originates from distributions with medians equal to the corresponding medians reported in the Helmer study. Alternatively we also test if the median values of our study fall within the 95% confidence intervals for the median as reported by Helmer. For the Rhine and Moore and Manhein studies, a *t*-test was performed to test the hypothesis that our data originates from distributions with means equal to the means reported in these studies. Corresponding age categories between the current study and the former studies were compared and Body Mass Index ranges (BMI $< 20$, $20 <$ BMI $< 25$, $25 <$ BMI) were defined to correspond to the slender, normal and obese subcategories, respectively, used as body build criteria in the Rhine and Moore study. For each of the comparative studies we performed a two-way ANOVA test to verify the influence of the different subcategories (gender and age or body posture).

For some of the comparative analyses we also provide a graphical representation of the results. We first define a facial template by averaging 3D facial surfaces of 118 subjects using the procedure proposed by Claes et al. [32]. We define the average skeletal landmark positions by setting out the average (over all subjects in our database) tissue depth per landmark inwards and perpendicular to the surface at the associated skin landmark. This represents a gender-, age- and BMI-unspecific baseline of skeletal landmark positions. The effect on the facial outlook of a certain choice of tissue depths can then be visualized by reconstructing the skin landmarks from the reference skeletal landmarks at a distance equal to the soft tissue depths along the same normal but now in the direction of the facial surface. The average facial template is then deformed to interpolate these new skin landmark positions. This gives us an overall impression of the facial outlook for that particular choice of landmarks. Two such outlooks for two different sets of tissue depths can then be compared by showing the signed distance between the two reconstructed surfaces as a color scale coded texture on the average of the two surfaces.

Table 2b
Tissue depth means (mm) for Caucasian adult females between 30 and 39 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (12) | | | | | 20–25 (40) | | | | | >25 (20) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.7 | 0.5 | 3.0 | 4.9 | 12 | 4.1 | 0.5 | 3.2 | 5.3 | 40 | 4.5 | 0.5 | 3.4 | 5.9 | 20 |
| 2 | Glabella | 4.2 | 0.6 | 3.1 | 4.9 | 12 | 4.9 | 0.7 | 3.5 | 6.5 | 40 | 5.4 | 0.7 | 4.4 | 7.0 | 20 |
| 3 | Nasion | 5.4 | 0.9 | 4.0 | 7.1 | 12 | 6.2 | 1.4 | 3.8 | 11.0 | 40 | 6.6 | 1.4 | 4.2 | 8.8 | 20 |
| 4 | End of nasal | 2.7 | 0.7 | 1.9 | 4.2 | 12 | 2.5 | 0.6 | 1.6 | 4.7 | 40 | 3.0 | 0.8 | 1.8 | 4.8 | 20 |
| 5 | Mid-philtrum | 8.7 | 1.0 | 7.0 | 10.1 | 12 | 9.2 | 1.6 | 6.2 | 13.3 | 40 | 8.8 | 1.3 | 6.6 | 11.6 | 20 |
| 6 | Upper lip margin | 9.2 | 1.4 | 7.3 | 11.8 | 12 | 9.4 | 1.7 | 6.5 | 14.0 | 39 | 9.5 | 1.3 | 7.0 | 11.5 | 18 |
| 7 | Lower lip margin | 10.1 | 1.3 | 7.9 | 11.6 | 12 | 10.7 | 1.9 | 6.8 | 16.3 | 39 | 11.1 | 2.1 | 6.5 | 16.2 | 19 |
| 8 | Chin–lip fold | 8.7 | 1.2 | 7.1 | 10.9 | 12 | 10.2 | 1.7 | 7.2 | 17.5 | 40 | 10.4 | 0.9 | 8.6 | 12.0 | 20 |
| 9 | Mental eminence | 8.9 | 1.4 | 6.5 | 10.7 | 12 | 9.7 | 1.7 | 7.2 | 14.4 | 40 | 11.5 | 1.7 | 9.6 | 15.9 | 20 |
| 10 | Beneath chin | 5.9 | 1.8 | 4.6 | 10.9 | 12 | 5.7 | 1.4 | 3.7 | 9.4 | 38 | 7.6 | 2.1 | 4.1 | 12.1 | 20 |
| 32/11 | Frontal eminence | 3.7 | 0.7 | 3.0 | 5.2 | 12 | 4.0 | 0.5 | 3.0 | 5.2 | 40 | 4.6 | 0.5 | 3.6 | 5.8 | 20 |
| 33/12 | Supraorbital | 4.7 | 0.7 | 3.6 | 6.1 | 12 | 5.2 | 0.6 | 3.8 | 6.7 | 40 | 6.3 | 0.8 | 5.5 | 8.5 | 20 |
| 34/13 | Lateral glabella | 4.9 | 0.9 | 3.2 | 6.3 | 12 | 5.5 | 1.4 | 3.2 | 9.4 | 40 | 6.6 | 1.0 | 4.1 | 8.3 | 20 |
| 35/14 | Lateral nasal | 3.7 | 0.7 | 2.7 | 5.0 | 11 | 3.6 | 0.7 | 2.0 | 5.4 | 36 | 3.8 | 0.7 | 3.0 | 5.8 | 16 |
| 36/15 | Suborbital | 7.9 | 1.8 | 3.8 | 10.6 | 12 | 9.3 | 2.9 | 3.1 | 16.1 | 40 | 10.5 | 2.0 | 7.7 | 15.0 | 20 |
| 37/16 | Inferior malar | 15.0 | 2.1 | 11.2 | 19.3 | 12 | 17.4 | 3.4 | 10.4 | 24.8 | 40 | 21.0 | 3.6 | 14.0 | 27.8 | 20 |
| 38/17 | Lateral nostril | 8.3 | 1.6 | 5.9 | 11.0 | 12 | 8.8 | 1.2 | 6.0 | 11.2 | 40 | 9.0 | 1.2 | 7.6 | 11.6 | 20 |
| 39/18 | Naso-labial ridge | 8.5 | 1.3 | 6.7 | 11.2 | 12 | 9.4 | 1.6 | 6.5 | 14.7 | 38 | 9.3 | 1.2 | 6.1 | 11.6 | 20 |
| 40/19 | Supra canina | 8.5 | 1.7 | 5.0 | 11.7 | 12 | 8.4 | 1.9 | 3.7 | 12.7 | 39 | 8.7 | 1.6 | 6.4 | 13.3 | 20 |
| 41/20 | Sub canina | 8.7 | 1.6 | 6.4 | 11.9 | 12 | 9.9 | 1.6 | 6.7 | 13.4 | 39 | 10.8 | 1.6 | 7.8 | 13.7 | 20 |
| 42/21 | Mental tubercle ant. | 9.1 | 1.4 | 6.7 | 11.7 | 12 | 9.9 | 1.3 | 7.5 | 13.1 | 40 | 11.0 | 1.6 | 8.3 | 14.4 | 20 |
| 43/22 | Mid lateral orbit | 4.6 | 0.8 | 3.8 | 6.1 | 12 | 4.7 | 0.9 | 3.6 | 7.6 | 40 | 5.4 | 1.1 | 3.8 | 7.9 | 20 |
| 44/23 | Supraglenoid | 7.7 | 2.6 | 3.8 | 12.3 | 12 | 8.8 | 2.1 | 4.5 | 13.2 | 40 | 9.9 | 2.9 | 5.2 | 16.0 | 20 |
| 45/24 | Zygomatic arch | 5.6 | 1.2 | 3.8 | 7.6 | 12 | 6.8 | 1.8 | 3.8 | 11.0 | 40 | 8.7 | 2.4 | 5.6 | 15.8 | 20 |
| 46/25 | Lateral orbit | 7.9 | 1.3 | 6.4 | 10.3 | 12 | 9.7 | 2.2 | 5.8 | 13.9 | 40 | 12.5 | 1.7 | 10.0 | 16.3 | 20 |
| 47/26 | Supra-M2 | 23.1 | 3.1 | 18.2 | 29.3 | 12 | 25.6 | 3.5 | 17.8 | 36.7 | 38 | 28.7 | 2.8 | 25.3 | 35.4 | 19 |
| 48/27 | Mid-masseter muscle | 14.1 | 2.8 | 8.6 | 17.5 | 12 | 16.8 | 2.5 | 10.3 | 21.8 | 40 | 19.8 | 3.1 | 12.7 | 26.2 | 20 |
| 49/28 | Occlusal line | 17.5 | 1.1 | 15.4 | 19.1 | 12 | 18.8 | 2.0 | 15.0 | 24.9 | 40 | 21.5 | 2.6 | 17.8 | 26.6 | 20 |
| 50/29 | Sub-M2 | 15.7 | 1.7 | 12.8 | 18.8 | 11 | 18.1 | 3.0 | 12.9 | 26.5 | 38 | 20.2 | 2.7 | 15.8 | 25.6 | 19 |
| 51/30 | Gonion | 13.4 | 1.8 | 10.9 | 16.2 | 12 | 14.2 | 2.6 | 10.3 | 22.2 | 40 | 17.6 | 2.5 | 13.8 | 24.1 | 20 |
| 52/31 | Mid mandibular angle | 10.0 | 1.9 | 7.9 | 14.5 | 12 | 11.0 | 2.1 | 7.8 | 17.0 | 39 | 14.8 | 2.7 | 11.0 | 23.3 | 20 |

All tests were implemented using the Matlab7R14 (The Mathworks Inc., Natick, MA, USA) data analysis software.

## 3. Results

Tables 2(a–e) and 3(a–e) report the soft tissue depth results of the right side of the face for females and males. The measurements are presented in millimetres and rounded to one fractional digit. They provide the soft tissue depth means, standard deviations and range as well as the number of involved subjects in the analysis of the 31 landmarks. The two gender-specific populations are further subdivided according to age and BMI. The distribution of the 967 subjects over the different subpopulations and the average BMI and age per subcategory is shown in Table 4. Note that the subpopulations with a BMI less than 20 are relatively small, especially the male subcategory, this effect being even more pronounced for the older subcategories.

Some initial observations can be made without any formal statistical analysis. The largest averages, standard deviations as well as measurement ranges can be observed at the landmarks supra-M2, mid-masseter, sub-M2, inferior malar, occlusal line and mid-mandibular angle. These landmarks are all located in the cheek region, which is known from previous studies to be highly variable in soft tissue thickness. The maximum within-subpopulation standard deviation in the female population is 4.06 mm at the sub-M2 point whereas it is 5.28 mm at the mid-masseter point in the male population. In general, the standard deviations in the male population are higher than in the female population. Within each age subpopulation, the averages per landmark seem to increase with an increase in BMI. No such pronounced singular effect can be observed for changes in age for fixed BMI categories.

The age and BMI related effects are corroborated by the per landmark and gender-specific robust, multiple, linear regression equations of the tissue depths versus age and BMI as tabulated in Table 5, showing the partial regression coefficients for the individual landmarks, the root mean square (RMS) errors and the significance levels for the null-hypothesis of the partial regression coefficients to be zero. The RMS error represents 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. RMS errors correlate well with the standard deviations in Tables 2(a–e) and 3(a–e). Figs. 2 and 3 show the age and BMI partial regression

Table 2c
Tissue depth means (mm) for Caucasian adult females between 40 and 49 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (12) | | | | | 20–25 (32) | | | | | >25 (21) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.9 | 0.7 | 2.6 | 5.4 | 11 | 4.3 | 0.6 | 3.4 | 6.4 | 32 | 5.1 | 1.2 | 3.4 | 9.4 | 21 |
| 2 | Glabella | 4.3 | 0.6 | 3.1 | 5.6 | 11 | 4.8 | 0.8 | 2.0 | 6.8 | 32 | 5.7 | 0.8 | 4.4 | 7.8 | 20 |
| 3 | Nasion | 5.4 | 1.0 | 3.6 | 7.4 | 12 | 6.3 | 1.1 | 3.9 | 8.1 | 32 | 6.7 | 0.7 | 5.5 | 8.4 | 21 |
| 4 | End of nasal | 2.6 | 0.9 | 2.0 | 5.0 | 12 | 2.5 | 0.6 | 1.7 | 4.9 | 32 | 2.8 | 0.5 | 2.2 | 3.8 | 21 |
| 5 | Mid-philtrum | 8.2 | 1.7 | 5.6 | 11.5 | 12 | 8.5 | 1.9 | 5.6 | 14.4 | 31 | 9.3 | 1.3 | 7.6 | 11.5 | 20 |
| 6 | Upper lip margin | 7.4 | 1.6 | 6.0 | 10.7 | 11 | 9.2 | 1.8 | 5.1 | 12.8 | 31 | 8.6 | 1.3 | 6.7 | 11.5 | 20 |
| 7 | Lower lip margin | 9.4 | 1.2 | 7.7 | 12.1 | 11 | 10.3 | 2.1 | 7.0 | 15.6 | 32 | 10.5 | 2.0 | 6.3 | 14.8 | 21 |
| 8 | Chin-lip fold | 9.0 | 1.2 | 6.8 | 10.4 | 12 | 10.3 | 1.1 | 7.7 | 11.9 | 32 | 10.7 | 1.0 | 8.9 | 12.4 | 21 |
| 9 | Mental eminence | 8.7 | 1.0 | 7.1 | 10.2 | 12 | 9.9 | 1.9 | 5.9 | 13.6 | 32 | 12.0 | 1.7 | 8.6 | 15.6 | 21 |
| 10 | Beneath chin | 4.8 | 0.8 | 3.6 | 6.2 | 12 | 5.7 | 1.4 | 3.7 | 8.7 | 32 | 6.9 | 1.8 | 4.0 | 10.2 | 21 |
| 32/11 | Frontal eminence | 3.8 | 0.6 | 2.7 | 5.1 | 12 | 4.1 | 0.6 | 3.0 | 5.9 | 31 | 5.0 | 0.9 | 3.4 | 6.8 | 21 |
| 33/12 | Supraorbital | 5.0 | 1.6 | 3.4 | 9.6 | 12 | 5.3 | 0.6 | 4.3 | 6.8 | 32 | 6.3 | 0.8 | 5.0 | 8.4 | 21 |
| 34/13 | Lateral glabella | 4.9 | 1.3 | 2.5 | 7.0 | 12 | 5.6 | 0.8 | 4.4 | 7.2 | 32 | 5.9 | 0.9 | 4.0 | 7.3 | 21 |
| 35/14 | Lateral nasal | 3.3 | 0.6 | 2.0 | 4.2 | 10 | 3.4 | 0.5 | 2.3 | 4.3 | 22 | 3.9 | 0.7 | 2.9 | 5.7 | 14 |
| 36/15 | Suborbital | 9.5 | 4.0 | 4.0 | 18.4 | 11 | 10.0 | 2.5 | 6.3 | 15.6 | 32 | 10.9 | 2.9 | 7.5 | 18.6 | 21 |
| 37/16 | Inferior malar | 16.5 | 2.9 | 10.5 | 19.7 | 12 | 18.1 | 3.1 | 8.5 | 23.7 | 32 | 20.2 | 3.3 | 13.3 | 26.5 | 21 |
| 38/17 | Lateral nostril | 7.6 | 1.0 | 6.0 | 8.9 | 11 | 9.2 | 1.5 | 5.6 | 12.3 | 32 | 9.4 | 1.1 | 7.2 | 11.8 | 21 |
| 39/18 | Naso-labial ridge | 8.0 | 1.8 | 5.5 | 11.7 | 12 | 8.7 | 1.3 | 6.4 | 11.7 | 31 | 9.4 | 1.7 | 5.8 | 12.9 | 20 |
| 40/19 | Supra canina | 7.4 | 1.1 | 5.8 | 9.2 | 12 | 8.3 | 1.2 | 6.4 | 10.3 | 31 | 9.1 | 2.2 | 5.9 | 14.1 | 20 |
| 41/20 | Sub canina | 9.1 | 1.9 | 5.9 | 12.1 | 12 | 10.5 | 1.5 | 8.1 | 13.7 | 32 | 11.0 | 1.6 | 8.0 | 13.5 | 21 |
| 42/21 | Mental tubercle ant. | 8.7 | 1.0 | 7.3 | 10.2 | 12 | 10.1 | 1.5 | 7.5 | 12.8 | 32 | 11.8 | 1.5 | 7.7 | 14.6 | 21 |
| 43/22 | Mid lateral orbit | 4.2 | 0.9 | 3.1 | 6.1 | 12 | 4.8 | 1.0 | 3.4 | 6.8 | 32 | 5.5 | 1.7 | 3.5 | 9.8 | 21 |
| 44/23 | Supraglenoid | 7.4 | 1.9 | 4.2 | 10.7 | 12 | 9.2 | 2.3 | 5.4 | 14.7 | 30 | 10.2 | 2.3 | 6.2 | 14.5 | 21 |
| 45/24 | Zygomatic arch | 5.7 | 1.3 | 3.9 | 7.8 | 12 | 7.0 | 1.8 | 4.1 | 12.2 | 32 | 8.9 | 2.1 | 3.8 | 13.2 | 21 |
| 46/25 | Lateral orbit | 7.5 | 1.3 | 5.1 | 9.3 | 12 | 9.5 | 1.8 | 4.3 | 13.0 | 32 | 12.4 | 1.7 | 9.5 | 15.2 | 21 |
| 47/26 | Supra-M2 | 22.7 | 1.7 | 19.9 | 25.6 | 9 | 26.0 | 2.7 | 20.0 | 32.0 | 31 | 29.7 | 3.0 | 25.6 | 35.0 | 21 |
| 48/27 | Mid-masseter muscle | 13.3 | 3.4 | 8.4 | 18.1 | 12 | 16.4 | 2.5 | 12.2 | 21.0 | 32 | 19.7 | 3.3 | 9.7 | 24.0 | 21 |
| 49/28 | Occlusal line | 15.9 | 2.1 | 13.1 | 19.4 | 12 | 17.7 | 2.2 | 13.8 | 23.0 | 32 | 21.8 | 2.2 | 17.1 | 25.6 | 21 |
| 50/29 | Sub-M2 | 16.7 | 3.1 | 11.4 | 21.1 | 10 | 18.7 | 3.2 | 10.6 | 25.2 | 29 | 21.5 | 2.5 | 17.0 | 26.2 | 20 |
| 51/30 | Gonion | 11.5 | 2.3 | 9.1 | 15.9 | 12 | 13.9 | 2.7 | 7.9 | 19.0 | 32 | 18.1 | 2.6 | 14.6 | 22.9 | 20 |
| 52/31 | Mid mandibular angle | 10.1 | 2.3 | 6.8 | 13.9 | 12 | 11.3 | 2.3 | 6.8 | 15.9 | 32 | 14.9 | 2.2 | 12.1 | 19.3 | 20 |

Table 2d
Tissue depth means (mm) for Caucasian adult females between 50 and 59 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (4) | | | | | 20–25 (29) | | | | | >25 (41) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.7 | 0.2 | 3.5 | 3.8 | 3 | 4.3 | 0.5 | 3.4 | 5.4 | 29 | 4.9 | 0.7 | 3.5 | 6.6 | 41 |
| 2 | Glabella | 4.4 | 0.4 | 4.1 | 4.9 | 3 | 4.8 | 0.7 | 3.6 | 6.6 | 28 | 5.8 | 0.9 | 4.2 | 8.5 | 41 |
| 3 | Nasion | 5.9 | 2.0 | 4.6 | 8.2 | 3 | 6.2 | 1.2 | 4.4 | 9.2 | 29 | 7.2 | 1.6 | 4.4 | 11.0 | 41 |
| 4 | End of nasal | 2.7 | 0.6 | 2.2 | 3.5 | 4 | 2.6 | 0.6 | 1.6 | 3.7 | 29 | 2.9 | 0.7 | 1.8 | 5.0 | 41 |
| 5 | Mid-philtrum | 7.3 | 0.8 | 6.7 | 8.5 | 4 | 8.1 | 1.5 | 4.7 | 10.9 | 26 | 9.1 | 1.5 | 6.9 | 11.8 | 35 |
| 6 | Upper lip margin | 8.3 | 1.9 | 6.3 | 10.9 | 4 | 9.1 | 1.3 | 6.6 | 12.7 | 21 | 8.8 | 1.5 | 5.1 | 12.0 | 33 |
| 7 | Lower lip margin | 9.7 | 2.7 | 6.9 | 13.2 | 4 | 10.3 | 1.5 | 6.7 | 12.7 | 24 | 10.9 | 2.1 | 6.5 | 15.7 | 37 |
| 8 | Chin-lip fold | 9.7 | 1.3 | 8.2 | 11.4 | 4 | 10.1 | 1.4 | 7.3 | 13.2 | 28 | 10.9 | 1.2 | 8.1 | 14.2 | 40 |
| 9 | Mental eminence | 9.4 | 0.3 | 9.2 | 9.8 | 4 | 10.0 | 1.6 | 6.0 | 13.5 | 28 | 11.6 | 1.7 | 8.6 | 15.9 | 41 |
| 10 | Beneath chin | 5.5 | 2.3 | 3.9 | 8.2 | 3 | 5.9 | 1.4 | 4.0 | 9.6 | 28 | 6.9 | 1.7 | 4.3 | 11.7 | 41 |
| 32/11 | Frontal eminence | 3.9 | 0.4 | 3.5 | 4.3 | 3 | 4.3 | 0.5 | 3.2 | 5.3 | 29 | 5.0 | 0.5 | 3.9 | 6.3 | 41 |
| 33/12 | Supraorbital | 5.0 | 0.3 | 4.7 | 5.2 | 3 | 5.3 | 0.7 | 4.3 | 7.6 | 27 | 6.5 | 0.9 | 5.0 | 8.9 | 41 |
| 34/13 | Lateral glabella | 4.6 | 0.8 | 3.8 | 5.4 | 3 | 5.5 | 1.1 | 3.8 | 8.3 | 28 | 6.4 | 1.5 | 3.3 | 9.6 | 41 |
| 35/14 | Lateral nasal | – | – | – | – | 0 | 3.4 | 0.6 | 2.4 | 4.4 | 17 | 4.0 | 0.7 | 2.9 | 5.6 | 15 |
| 36/15 | Suborbital | 9.7 | 1.0 | 8.5 | 10.4 | 3 | 9.1 | 2.9 | 3.3 | 14.6 | 28 | 11.1 | 2.7 | 5.6 | 17.5 | 41 |
| 37/16 | Inferior malar | 13.8 | 2.0 | 11.6 | 16.3 | 4 | 19.2 | 3.0 | 12.6 | 25.7 | 28 | 21.0 | 3.1 | 13.9 | 28.0 | 41 |
| 38/17 | Lateral nostril | 8.8 | 2.2 | 6.9 | 11.3 | 4 | 8.4 | 1.4 | 5.9 | 10.7 | 27 | 9.4 | 1.4 | 6.7 | 12.2 | 41 |
| 39/18 | Naso-labial ridge | 7.6 | 0.8 | 6.5 | 8.3 | 4 | 8.4 | 1.1 | 6.2 | 10.3 | 25 | 9.3 | 1.1 | 7.3 | 11.5 | 33 |
| 40/19 | Supra canina | 7.4 | 1.5 | 5.7 | 9.4 | 4 | 8.1 | 1.6 | 5.8 | 12.1 | 21 | 8.4 | 1.9 | 3.9 | 12.2 | 33 |
| 41/20 | Sub canina | 9.7 | 1.1 | 8.7 | 11.2 | 4 | 9.9 | 1.1 | 7.6 | 12.4 | 26 | 10.8 | 1.9 | 5.9 | 16.7 | 38 |
| 42/21 | Mental tubercle ant. | 8.9 | 1.8 | 6.8 | 10.8 | 4 | 10.4 | 1.3 | 8.3 | 13.4 | 27 | 11.5 | 1.4 | 6.6 | 13.9 | 40 |
| 43/22 | Mid lateral orbit | 4.5 | 0.8 | 3.8 | 5.3 | 3 | 5.0 | 1.4 | 3.4 | 10.6 | 27 | 5.6 | 1.3 | 3.9 | 8.7 | 41 |
| 44/23 | Supraglenoid | 9.0 | 2.6 | 7.4 | 12.0 | 3 | 8.6 | 2.7 | 4.8 | 15.9 | 25 | 10.4 | 2.6 | 5.6 | 19.0 | 41 |
| 45/24 | Zygomatic arch | 4.6 | 0.6 | 4.2 | 5.3 | 3 | 6.8 | 1.4 | 5.5 | 10.3 | 27 | 8.4 | 1.7 | 6.1 | 12.8 | 41 |
| 46/25 | Lateral orbit | 8.0 | 1.0 | 6.8 | 9.2 | 4 | 9.9 | 2.5 | 5.9 | 16.2 | 27 | 12.4 | 2.3 | 7.4 | 18.0 | 41 |
| 47/26 | Supra-M2 | 25.1 | 2.9 | 21.8 | 27.2 | 3 | 27.2 | 3.0 | 21.8 | 32.4 | 23 | 29.2 | 3.2 | 22.1 | 37.8 | 31 |
| 48/27 | Mid-masseter muscle | 14.3 | 3.2 | 10.8 | 17.2 | 3 | 16.4 | 2.8 | 9.1 | 20.5 | 27 | 19.0 | 3.7 | 7.2 | 25.7 | 41 |
| 49/28 | Occlusal line | 15.7 | 1.4 | 14.6 | 17.2 | 3 | 18.0 | 2.4 | 12.6 | 25.1 | 27 | 21.0 | 2.3 | 16.6 | 26.5 | 41 |
| 50/29 | Sub-M2 | 17.6 | 0.6 | 17.2 | 18.1 | 2 | 17.9 | 2.3 | 11.3 | 21.6 | 22 | 22.3 | 3.6 | 15.5 | 29.1 | 34 |
| 51/30 | Gonion | 11.8 | 1.9 | 9.6 | 13.0 | 3 | 14.0 | 2.0 | 11.0 | 18.5 | 27 | 17.6 | 3.0 | 12.7 | 24.6 | 41 |
| 52/31 | Mid mandibular angle | 9.7 | 1.6 | 7.5 | 11.0 | 4 | 11.4 | 1.9 | 8.5 | 14.6 | 27 | 15.5 | 2.2 | 9.6 | 19.4 | 41 |

Table 2e
Tissue depth means (mm) for Caucasian adult females between 60+ years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (7) | | | | | 20–25 (37) | | | | | >25 (43) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.7 | 0.5 | 3.1 | 4.6 | 7 | 4.4 | 0.7 | 3.2 | 5.9 | 37 | 4.6 | 0.8 | 3.4 | 7.4 | 43 |
| 2 | Glabella | 4.4 | 0.6 | 3.4 | 4.8 | 7 | 5.3 | 0.9 | 3.2 | 7.6 | 37 | 5.6 | 1.0 | 3.8 | 7.7 | 43 |
| 3 | Nasion | 6.7 | 1.2 | 5.2 | 8.5 | 7 | 7.2 | 1.2 | 4.8 | 9.9 | 37 | 7.3 | 1.7 | 4.4 | 11.6 | 42 |
| 4 | End of nasal | 2.4 | 0.5 | 2.0 | 3.5 | 7 | 2.5 | 0.5 | 2.0 | 4.0 | 37 | 2.8 | 0.7 | 2.0 | 5.3 | 43 |
| 5 | Mid-philtrum | 7.0 | 0.9 | 6.1 | 8.4 | 5 | 8.0 | 1.2 | 6.1 | 10.6 | 23 | 8.7 | 1.4 | 6.2 | 11.8 | 33 |
| 6 | Upper lip margin | 9.0 | 3.4 | 4.5 | 13.0 | 5 | 9.9 | 2.1 | 6.2 | 17.3 | 21 | 9.0 | 1.6 | 5.2 | 11.5 | 26 |
| 7 | Lower lip margin | 9.7 | 2.0 | 7.2 | 11.9 | 5 | 10.7 | 1.8 | 7.3 | 15.3 | 23 | 10.9 | 1.5 | 8.5 | 14.5 | 34 |
| 8 | Chin-lip fold | 11.1 | 0.6 | 10.1 | 11.6 | 6 | 10.8 | 1.7 | 7.0 | 14.2 | 34 | 11.2 | 1.6 | 6.7 | 13.8 | 37 |
| 9 | Mental eminence | 9.7 | 2.0 | 8.2 | 13.8 | 7 | 10.5 | 2.0 | 5.6 | 16.5 | 37 | 11.6 | 1.7 | 8.5 | 16.1 | 43 |
| 10 | Beneath chin | 6.5 | 2.6 | 3.6 | 10.1 | 7 | 7.0 | 2.1 | 3.8 | 11.6 | 37 | 7.3 | 2.0 | 4.4 | 13.0 | 43 |
| 32/11 | Frontal eminence | 3.7 | 0.4 | 3.3 | 4.3 | 6 | 4.6 | 0.8 | 3.4 | 7.5 | 37 | 4.8 | 0.9 | 3.0 | 7.1 | 43 |
| 33/12 | Supraorbital | 4.8 | 0.4 | 4.2 | 5.4 | 7 | 5.5 | 0.7 | 4.5 | 7.4 | 37 | 6.5 | 1.0 | 5.1 | 9.3 | 43 |
| 34/13 | Lateral glabella | 5.8 | 1.5 | 3.9 | 8.2 | 7 | 6.1 | 1.2 | 4.8 | 10.1 | 37 | 6.4 | 1.5 | 3.9 | 10.2 | 43 |
| 35/14 | Lateral nasal | – | – | – | – | 0 | 3.7 | 0.5 | 3.1 | 4.1 | 5 | 3.8 | 0.6 | 3.1 | 4.6 | 4 |
| 36/15 | Suborbital | 9.6 | 1.9 | 6.8 | 12.3 | 6 | 10.4 | 1.9 | 7.5 | 13.6 | 36 | 10.4 | 2.5 | 4.9 | 16.2 | 43 |
| 37/16 | Inferior malar | 17.6 | 2.6 | 13.7 | 20.9 | 7 | 19.8 | 3.4 | 13.7 | 27.5 | 36 | 21.3 | 3.6 | 12.0 | 27.5 | 43 |
| 38/17 | Lateral nostril | 9.2 | 0.8 | 8.4 | 10.3 | 7 | 9.6 | 1.1 | 6.7 | 11.7 | 35 | 9.5 | 1.1 | 7.1 | 11.9 | 43 |
| 39/18 | Naso-labial ridge | 8.0 | 1.3 | 6.6 | 10.1 | 5 | 8.4 | 1.0 | 6.3 | 11.0 | 22 | 8.9 | 1.5 | 6.5 | 12.9 | 29 |
| 40/19 | Supra canina | 7.6 | 1.3 | 5.6 | 8.5 | 4 | 8.1 | 2.2 | 3.8 | 13.0 | 22 | 9.5 | 2.4 | 5.9 | 15.7 | 26 |

Table 2e (*Continued*)

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (7) | | | | | 20–25 (37) | | | | | >25 (43) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 41/20 | Sub canina | 10.8 | 2.1 | 7.9 | 13.8 | 6 | 11.1 | 1.3 | 9.2 | 13.9 | 27 | 11.1 | 1.8 | 7.1 | 15.0 | 32 |
| 42/21 | Mental tubercle ant. | 10.6 | 2.0 | 8.4 | 14.6 | 7 | 10.9 | 1.7 | 5.7 | 15.0 | 37 | 11.4 | 1.6 | 8.4 | 14.8 | 43 |
| 43/22 | Mid lateral orbit | 4.6 | 0.6 | 3.7 | 5.7 | 7 | 5.0 | 1.3 | 3.3 | 10.3 | 37 | 5.9 | 1.0 | 4.0 | 8.7 | 43 |
| 44/23 | Supraglenoid | 8.8 | 2.1 | 6.6 | 11.7 | 7 | 9.6 | 2.4 | 4.8 | 16.5 | 36 | 10.9 | 3.0 | 5.3 | 20.2 | 43 |
| 45/24 | Zygomatic arch | 5.4 | 1.7 | 2.8 | 7.6 | 7 | 6.5 | 1.6 | 3.8 | 11.1 | 37 | 8.7 | 1.9 | 5.4 | 12.7 | 42 |
| 46/25 | Lateral orbit | 8.8 | 1.1 | 7.4 | 10.1 | 7 | 9.7 | 1.5 | 6.8 | 12.4 | 36 | 12.1 | 2.0 | 8.9 | 16.2 | 43 |
| 47/26 | Supra-M2 | 24.5 | 0.8 | 24.0 | 25.5 | 3 | 27.1 | 3.4 | 18.8 | 32.8 | 19 | 29.0 | 3.3 | 23.6 | 34.2 | 18 |
| 48/27 | Mid-masseter muscle | 14.1 | 1.8 | 12.5 | 17.1 | 7 | 15.7 | 2.6 | 9.6 | 19.5 | 37 | 17.2 | 3.6 | 8.3 | 23.2 | 43 |
| 49/28 | Occlusal line | 18.2 | 2.7 | 16.0 | 24.0 | 7 | 18.0 | 3.3 | 12.0 | 33.3 | 36 | 20.8 | 2.2 | 16.8 | 25.0 | 43 |
| 50/29 | Sub-M2 | 21.5 | 4.1 | 18.8 | 26.2 | 3 | 21.2 | 2.6 | 15.1 | 27.4 | 23 | 22.4 | 4.0 | 16.0 | 29.2 | 21 |
| 51/30 | Gonion | 12.9 | 2.5 | 9.1 | 15.4 | 7 | 13.6 | 1.9 | 9.4 | 18.7 | 37 | 17.2 | 2.5 | 12.5 | 23.6 | 43 |
| 52/31 | Mid mandibular angle | 13.7 | 3.0 | 9.5 | 19.2 | 7 | 14.0 | 2.4 | 10.8 | 21.3 | 37 | 17.2 | 3.4 | 10.3 | 24.7 | 43 |

coefficients ($b_1$ and $b_2$, respectively, in Table 5) for each landmark. The regression of soft tissue depth on age is of different signs for different landmarks, indicating no systematic unidirectional change of soft tissue depth with age, if any. The age-related regression coefficient is also systematically smaller than the BMI-related regression coefficient, even after normalization for the relative differences in standard deviation of BMI and age (the standard deviation of age being about 4 times larger than the standard deviation of BMI). The BMI partial regression coefficients are systematically positive, with the exception of the very small negative partial regression coefficients for the upper lip in women and the naso-labial

Table 3a
Tissue depth means (mm) for Caucasian adult males between 18 and 29 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (28) | | | | | 20–25 (149) | | | | | >25 (34) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.9 | 0.39 | 3.2 | 4.8 | 27 | 4.1 | 0.55 | 2.8 | 7.0 | 148 | 4.8 | 0.85 | 3.7 | 7.6 | 34 |
| 2 | Glabella | 4.6 | 0.54 | 3.7 | 5.6 | 27 | 5.0 | 0.69 | 3.2 | 7.9 | 149 | 5.8 | 1.30 | 4.5 | 10.6 | 34 |
| 3 | Nasion | 5.6 | 0.85 | 4.0 | 8.4 | 27 | 5.9 | 1.10 | 3.6 | 9.7 | 149 | 6.3 | 1.32 | 4.2 | 10.0 | 34 |
| 4 | End of nasal | 2.7 | 0.67 | 2.0 | 4.5 | 27 | 2.8 | 0.69 | 1.6 | 6.5 | 148 | 3.2 | 0.73 | 2.1 | 5.5 | 34 |
| 5 | Mid-philtrum | 11.6 | 1.71 | 8.2 | 14.0 | 27 | 11.2 | 1.78 | 7.1 | 16.6 | 146 | 10.8 | 1.66 | 7.4 | 13.9 | 33 |
| 6 | Upper lip margin | 11.1 | 2.14 | 7.2 | 17.7 | 26 | 11.0 | 2.15 | 6.4 | 15.9 | 147 | 10.4 | 1.71 | 6.1 | 14.2 | 34 |
| 7 | Lower lip margin | 12.1 | 1.70 | 8.3 | 16.0 | 25 | 12.5 | 2.05 | 8.0 | 17.6 | 147 | 12.2 | 2.17 | 8.3 | 15.8 | 34 |
| 8 | Chin-lip fold | 10.1 | 1.41 | 7.5 | 12.6 | 25 | 10.1 | 1.31 | 6.5 | 13.8 | 139 | 10.1 | 0.97 | 8.8 | 12.2 | 33 |
| 9 | Mental eminence | 8.7 | 1.57 | 5.3 | 12.5 | 25 | 9.5 | 1.66 | 4.6 | 15.0 | 144 | 10.3 | 1.91 | 5.0 | 13.5 | 33 |
| 10 | Beneath chin | 5.5 | 1.02 | 3.8 | 7.6 | 25 | 6.1 | 1.20 | 3.9 | 9.9 | 142 | 7.2 | 1.73 | 4.7 | 11.0 | 32 |
| 32/11 | Frontal eminence | 3.8 | 0.47 | 3.1 | 4.7 | 27 | 4.1 | 0.64 | 2.0 | 5.9 | 149 | 5.0 | 0.96 | 3.6 | 8.6 | 34 |
| 33/12 | Supraorbital | 4.7 | 0.52 | 3.6 | 5.6 | 27 | 5.1 | 0.65 | 3.6 | 7.4 | 149 | 6.1 | 0.66 | 5.0 | 8.1 | 33 |
| 34/13 | Lateral glabella | 5.9 | 1.12 | 3.4 | 7.7 | 27 | 6.0 | 1.29 | 2.8 | 9.7 | 148 | 6.2 | 1.31 | 3.7 | 9.0 | 34 |
| 35/14 | Lateral nasal | 3.7 | 0.59 | 2.7 | 4.8 | 23 | 3.7 | 0.64 | 2.4 | 6.0 | 120 | 4.1 | 0.68 | 3.1 | 5.4 | 21 |
| 36/15 | Suborbital | 7.7 | 1.35 | 5.1 | 10.7 | 27 | 8.3 | 2.07 | 4.0 | 14.5 | 148 | 9.8 | 2.18 | 4.6 | 13.8 | 34 |
| 37/16 | Inferior malar | 14.7 | 2.44 | 9.8 | 20.7 | 27 | 16.2 | 2.80 | 10.6 | 24.6 | 148 | 18.9 | 3.23 | 12.4 | 24.7 | 34 |
| 38/17 | Lateral nostril | 10.4 | 1.37 | 6.9 | 13.1 | 26 | 10.1 | 1.48 | 6.8 | 14.2 | 146 | 10.3 | 1.27 | 8.1 | 12.8 | 34 |
| 39/18 | Naso-labial ridge | 11.4 | 1.67 | 8.3 | 15.3 | 26 | 11.1 | 1.93 | 6.4 | 17.2 | 143 | 11.0 | 1.57 | 8.1 | 14.1 | 33 |
| 40/19 | Supra canina | 10.0 | 1.74 | 7.0 | 13.4 | 25 | 10.4 | 1.93 | 6.4 | 16.3 | 147 | 10.5 | 1.96 | 8.2 | 18.1 | 33 |
| 41/20 | Sub canina | 9.5 | 1.19 | 6.7 | 11.4 | 25 | 10.5 | 1.65 | 6.5 | 16.4 | 147 | 11.1 | 1.95 | 7.7 | 16.0 | 33 |
| 42/21 | Mental tubercle ant. | 9.2 | 1.21 | 7.0 | 12.5 | 24 | 9.6 | 1.42 | 6.3 | 13.3 | 142 | 10.8 | 1.57 | 7.3 | 14.6 | 33 |
| 43/22 | Mid lateral orbit | 4.8 | 1.34 | 3.7 | 8.8 | 25 | 4.6 | 0.82 | 3.4 | 10.3 | 148 | 5.4 | 1.67 | 3.8 | 13.5 | 34 |
| 44/23 | Supraglenoid | 9.1 | 3.11 | 4.0 | 15.0 | 25 | 9.8 | 2.92 | 3.8 | 18.0 | 147 | 10.7 | 3.26 | 5.1 | 17.5 | 34 |
| 45/24 | Zygomatic arch | 4.8 | 1.05 | 3.1 | 7.0 | 25 | 5.7 | 1.15 | 3.4 | 9.1 | 148 | 8.4 | 1.66 | 5.8 | 12.2 | 34 |
| 46/25 | Lateral orbit | 6.7 | 1.15 | 4.7 | 9.8 | 25 | 7.4 | 1.37 | 4.0 | 12.4 | 148 | 10.3 | 1.68 | 5.4 | 14.1 | 34 |
| 47/26 | Supra-M2 | 23.6 | 4.29 | 15.8 | 35.3 | 25 | 25.0 | 3.48 | 16.4 | 33.4 | 148 | 29.4 | 3.48 | 20.8 | 37.3 | 33 |
| 48/27 | Mid-masseter muscle | 16.2 | 3.29 | 7.0 | 20.8 | 25 | 16.8 | 3.98 | 6.5 | 27.5 | 141 | 19.0 | 4.06 | 10.3 | 26.9 | 34 |
| 49/28 | Occlusal line | 17.8 | 1.83 | 15.0 | 21.5 | 25 | 19.4 | 2.38 | 12.4 | 28.4 | 148 | 22.8 | 2.37 | 18.5 | 27.8 | 34 |
| 50/29 | Sub-M2 | 16.1 | 3.50 | 10.0 | 23.9 | 25 | 17.2 | 2.82 | 10.5 | 25.5 | 148 | 21.0 | 4.35 | 7.7 | 30.8 | 33 |
| 51/30 | Gonion | 13.6 | 2.16 | 9.9 | 17.2 | 25 | 14.4 | 2.42 | 7.0 | 22.3 | 146 | 17.8 | 3.64 | 8.0 | 25.2 | 34 |
| 52/31 | Mid mandibular angle | 8.9 | 1.88 | 5.4 | 13.1 | 25 | 9.8 | 2.30 | 5.0 | 16.9 | 144 | 13.7 | 2.49 | 9.6 | 18.7 | 34 |

Table 3b
Tissue depth means (mm) for Caucasian adult males between 30–39 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (3) | | | | | 20–25 (37) | | | | | >25 (31) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 3.6 | 0.24 | 3.4 | 3.8 | 3 | 4.1 | 0.54 | 3.2 | 5.6 | 37 | 4.8 | 0.84 | 3.2 | 6.8 | 31 |
| 2 | Glabella | 4.7 | 0.55 | 4.1 | 5.1 | 3 | 4.7 | 0.44 | 3.8 | 5.7 | 37 | 5.4 | 0.88 | 4.1 | 7.9 | 31 |
| 3 | Nasion | 5.3 | 0.34 | 4.9 | 5.6 | 3 | 5.6 | 1.00 | 3.7 | 7.4 | 37 | 6.8 | 1.54 | 4.0 | 10.2 | 31 |
| 4 | End of nasal | 3.1 | 0.94 | 2.4 | 4.2 | 3 | 2.7 | 0.68 | 1.9 | 4.8 | 37 | 3.0 | 0.78 | 1.7 | 5.0 | 31 |
| 5 | Mid-philtrum | 9.5 | 1.48 | 7.8 | 10.6 | 3 | 10.6 | 1.63 | 6.7 | 13.9 | 36 | 10.7 | 1.72 | 7.4 | 15.6 | 27 |
| 6 | Upper lip margin | 10.1 | 1.84 | 8.0 | 11.6 | 3 | 9.8 | 1.65 | 6.5 | 14.0 | 35 | 10.8 | 1.78 | 8.6 | 16.5 | 31 |
| 7 | Lower lip margin | 9.3 | 1.65 | 7.8 | 11.1 | 3 | 11.8 | 2.04 | 7.9 | 17.5 | 36 | 13.1 | 2.43 | 9.1 | 20.8 | 31 |
| 8 | Chin-lip fold | 10.3 | 0.96 | 9.2 | 11.0 | 3 | 9.6 | 1.21 | 6.9 | 11.8 | 34 | 10.7 | 0.93 | 9.2 | 13.4 | 27 |
| 9 | Mental eminence | 9.6 | 0.50 | 9.2 | 10.1 | 3 | 9.4 | 1.60 | 6.0 | 13.0 | 37 | 11.3 | 1.26 | 7.9 | 13.7 | 28 |
| 10 | Beneath chin | 5.3 | 0.67 | 4.8 | 6.1 | 3 | 6.2 | 1.43 | 3.9 | 10.8 | 37 | 7.1 | 1.46 | 4.9 | 10.8 | 25 |
| 32/11 | Frontal eminence | 3.7 | 0.56 | 3.1 | 4.2 | 3 | 4.1 | 0.65 | 3.1 | 6.0 | 37 | 4.8 | 0.77 | 3.6 | 6.5 | 31 |
| 33/12 | Supraorbital | 4.9 | 0.64 | 4.2 | 5.3 | 3 | 5.0 | 0.53 | 4.1 | 6.0 | 37 | 6.3 | 0.89 | 4.9 | 8.0 | 31 |
| 34/13 | Lateral glabella | 5.9 | 0.70 | 5.1 | 6.3 | 3 | 5.5 | 1.40 | 3.2 | 8.5 | 36 | 5.9 | 1.32 | 3.8 | 9.2 | 31 |
| 35/14 | Lateral nasal | 4.8 | 0.20 | 4.7 | 5.0 | 2 | 3.6 | 0.50 | 2.8 | 5.2 | 24 | 3.8 | 0.84 | 2.4 | 5.8 | 26 |
| 36/15 | Suborbital | 6.1 | 2.50 | 4.6 | 9.0 | 3 | 8.4 | 2.31 | 4.5 | 13.3 | 36 | 10.0 | 2.25 | 6.5 | 14.0 | 31 |
| 37/16 | Inferior malar | 13.7 | 2.29 | 11.8 | 16.2 | 3 | 16.5 | 3.19 | 8.6 | 23.0 | 37 | 20.2 | 3.50 | 14.2 | 27.2 | 31 |
| 38/17 | Lateral nostril | 9.7 | 1.34 | 8.7 | 11.2 | 3 | 9.2 | 1.13 | 7.3 | 12.1 | 37 | 10.0 | 1.29 | 6.7 | 12.3 | 31 |
| 39/18 | Naso-labial ridge | 10.8 | 1.35 | 9.2 | 11.6 | 3 | 10.8 | 1.66 | 8.5 | 15.3 | 35 | 11.0 | 1.57 | 8.7 | 14.4 | 25 |
| 40/19 | Supra canina | 10.2 | 2.46 | 8.4 | 13.0 | 3 | 9.7 | 1.87 | 6.5 | 14.5 | 37 | 10.0 | 2.02 | 7.2 | 15.7 | 26 |
| 41/20 | Sub canina | 9.3 | 0.70 | 8.9 | 10.1 | 3 | 9.7 | 1.42 | 6.0 | 12.1 | 37 | 11.2 | 1.81 | 7.5 | 14.5 | 30 |
| 42/21 | Mental tubercle ant. | 9.2 | 1.15 | 8.0 | 10.3 | 3 | 9.5 | 1.34 | 6.1 | 12.3 | 35 | 11.4 | 1.70 | 8.3 | 15.0 | 27 |
| 43/22 | Mid lateral orbit | 4.7 | 0.44 | 4.2 | 5.1 | 3 | 4.4 | 0.68 | 3.5 | 6.0 | 36 | 5.2 | 1.23 | 3.4 | 9.8 | 31 |
| 44/23 | Supraglenoid | 8.1 | 1.20 | 6.8 | 9.2 | 3 | 8.8 | 2.71 | 4.8 | 14.8 | 36 | 10.5 | 2.63 | 6.4 | 15.6 | 31 |
| 45/24 | Zygomatic arch | 4.9 | 0.73 | 4.4 | 5.7 | 3 | 5.8 | 1.23 | 4.3 | 10.0 | 37 | 7.9 | 1.48 | 5.5 | 11.1 | 31 |
| 46/25 | Lateral orbit | 6.8 | 0.87 | 6.3 | 7.8 | 3 | 7.3 | 1.55 | 4.3 | 11.9 | 37 | 10.6 | 1.17 | 8.4 | 12.7 | 31 |
| 47/26 | Supra-M2 | 22.9 | 0.58 | 22.2 | 23.3 | 3 | 24.1 | 3.83 | 15.1 | 31.0 | 37 | 28.7 | 3.86 | 19.1 | 36.1 | 30 |
| 48/27 | Mid-masseter muscle | 16.7 | 1.03 | 15.8 | 17.8 | 3 | 16.9 | 3.45 | 9.0 | 23.5 | 37 | 21.7 | 4.58 | 10.7 | 29.6 | 31 |
| 49/28 | Occlusal line | 16.4 | 0.52 | 15.8 | 16.9 | 3 | 18.8 | 2.36 | 14.2 | 24.6 | 36 | 22.3 | 3.01 | 16.1 | 27.0 | 31 |
| 50/29 | Sub-M2 | 17.0 | 1.63 | 15.9 | 18.9 | 3 | 16.5 | 2.86 | 10.0 | 22.7 | 36 | 21.3 | 3.35 | 14.8 | 27.4 | 31 |
| 51/30 | Gonion | 12.9 | 0.57 | 12.6 | 13.6 | 3 | 14.2 | 2.21 | 9.4 | 19.0 | 37 | 19.1 | 2.91 | 11.8 | 24.4 | 31 |
| 52/31 | Mid mandibular angle | 9.5 | 1.08 | 8.6 | 10.7 | 3 | 9.9 | 2.13 | 5.2 | 16.1 | 37 | 15.1 | 3.32 | 9.0 | 20.8 | 31 |

Table 3c
Tissue depth means (mm) for Caucasian adult males between 40 and 49 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (1) | | | | | 20–25 (24) | | | | | >25 (35) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 4.3 | – | – | – | 1 | 4.5 | 0.66 | 3.0 | 5.6 | 23 | 5.3 | 0.95 | 3.9 | 8.5 | 35 |
| 2 | Glabella | 6.7 | – | – | – | 1 | 5.1 | 0.60 | 3.9 | 6.2 | 24 | 5.9 | 1.06 | 3.8 | 9.0 | 35 |
| 3 | Nasion | 8.8 | – | – | – | 1 | 6.4 | 1.15 | 4.6 | 9.3 | 24 | 6.8 | 1.53 | 4.9 | 11.3 | 35 |
| 4 | End of nasal | 3.1 | – | – | – | 1 | 3.1 | 0.81 | 2.2 | 4.8 | 24 | 3.2 | 0.89 | 2.0 | 6.5 | 34 |
| 5 | Mid-philtrum | 13.1 | – | – | – | 1 | 9.7 | 1.88 | 7.7 | 14.4 | 22 | 10.6 | 1.58 | 7.3 | 13.9 | 27 |
| 6 | Upper lip margin | 11.9 | – | – | – | 1 | 10.6 | 2.52 | 6.2 | 16.0 | 22 | 10.6 | 2.47 | 6.9 | 17.4 | 34 |
| 7 | Lower lip margin | 11.2 | – | – | – | 1 | 11.7 | 2.23 | 7.1 | 14.8 | 23 | 12.5 | 2.16 | 9.1 | 17.3 | 35 |
| 8 | Chin-lip fold | 8.7 | – | – | – | 1 | 10.9 | 1.59 | 8.8 | 14.7 | 24 | 11.5 | 1.37 | 8.5 | 13.9 | 32 |
| 9 | Mental eminence | 14.0 | – | – | – | 1 | 10.8 | 1.45 | 7.9 | 14.6 | 24 | 12.1 | 2.16 | 8.4 | 16.3 | 32 |
| 10 | Beneath chin | 5.9 | – | – | – | 1 | 6.4 | 1.27 | 4.7 | 9.2 | 24 | 7.5 | 1.98 | 4.3 | 11.8 | 33 |
| 32/11 | Frontal eminence | 4.5 | – | – | – | 1 | 4.7 | 0.70 | 3.1 | 5.8 | 24 | 5.3 | 1.15 | 3.8 | 9.1 | 35 |
| 33/12 | Supraorbital | 5.0 | – | – | – | 1 | 5.3 | 0.72 | 4.2 | 6.8 | 24 | 6.6 | 1.30 | 3.8 | 10.0 | 35 |
| 34/13 | Lateral glabella | 3.0 | – | – | – | 1 | 6.6 | 1.25 | 4.0 | 8.3 | 24 | 6.8 | 1.61 | 4.6 | 10.9 | 35 |
| 35/14 | Lateral nasal | - | – | – | – | 0 | 4.0 | 0.69 | 2.8 | 5.5 | 14 | 3.9 | 0.60 | 3.1 | 5.1 | 19 |
| 36/15 | Suborbital | 6.3 | – | – | – | 1 | 9.7 | 2.01 | 6.8 | 14.5 | 24 | 10.4 | 2.60 | 5.0 | 17.2 | 35 |
| 37/16 | Inferior malar | 15.4 | – | – | – | 1 | 17.9 | 3.43 | 10.0 | 24.2 | 24 | 21.8 | 3.88 | 11.6 | 31.6 | 35 |
| 38/17 | Lateral nostril | 9.4 | – | – | – | 1 | 9.6 | 1.69 | 7.0 | 12.7 | 24 | 10.2 | 1.74 | 6.8 | 14.6 | 35 |
| 39/18 | Naso-labial ridge | 14.1 | – | – | – | 1 | 10.4 | 2.15 | 7.5 | 15.5 | 21 | 10.9 | 1.55 | 8.5 | 13.9 | 27 |
| 40/19 | Supra canina | 8.7 | – | – | – | 1 | 9.9 | 2.01 | 7.3 | 14.9 | 20 | 10.2 | 2.07 | 7.1 | 15.0 | 27 |
| 41/20 | Sub canina | 11.6 | – | – | – | 1 | 10.9 | 1.35 | 7.9 | 13.3 | 23 | 12.0 | 2.33 | 7.0 | 16.3 | 34 |

Table 3c (*Continued*)

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (1) | | | | | 20–25 (24) | | | | | >25 (35) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 42/21 | Mental tubercle ant. | 13.9 | – | – | – | 1 | 10.8 | 1.45 | 8.6 | 14.6 | 24 | 11.8 | 1.99 | 7.7 | 17.1 | 32 |
| 43/22 | Mid lateral orbit | 4.4 | – | – | – | 1 | 5.0 | 1.32 | 3.6 | 10.0 | 24 | 5.3 | 1.04 | 3.7 | 7.4 | 34 |
| 44/23 | Supraglenoid | 6.8 | – | – | – | 1 | 10.8 | 3.88 | 5.4 | 18.7 | 24 | 10.2 | 3.41 | 5.2 | 19.4 | 35 |
| 45/24 | Zygomatic arch | 3.8 | – | – | – | 1 | 6.1 | 1.26 | 4.0 | 9.0 | 24 | 8.1 | 2.22 | 4.4 | 14.1 | 35 |
| 46/25 | Lateral orbit | 5.2 | – | – | – | 1 | 8.1 | 1.46 | 5.6 | 11.6 | 24 | 10.8 | 2.18 | 6.2 | 15.9 | 35 |
| 47/26 | Supra-M2 | 26.8 | – | – | – | 1 | 24.9 | 3.84 | 10.2 | 29.2 | 23 | 30.8 | 3.96 | 23.8 | 39.8 | 34 |
| 48/27 | Mid-masseter muscle | 20.0 | – | – | – | 1 | 18.2 | 3.88 | 6.1 | 24.8 | 24 | 23.0 | 3.61 | 14.9 | 32.2 | 34 |
| 49/28 | Occlusal line | 21.8 | – | – | – | 1 | 19.5 | 1.62 | 16.2 | 23.8 | 24 | 23.1 | 3.66 | 14.3 | 31.4 | 34 |
| 50/29 | Sub-M2 | 19.0 | – | – | – | 1 | 18.7 | 2.91 | 11.1 | 22.7 | 22 | 22.4 | 4.20 | 15.2 | 32.3 | 32 |
| 51/30 | Gonion | 14.6 | – | – | – | 1 | 15.6 | 2.39 | 10.5 | 19.6 | 24 | 19.1 | 3.71 | 10.3 | 30.5 | 34 |
| 52/31 | Mid mandibular angle | 12.1 | – | – | – | 1 | 11.9 | 2.52 | 7.9 | 16.9 | 24 | 15.0 | 3.15 | 9.2 | 24.6 | 32 |

ridge in men. Based on these partial regression coefficients, BMI seems to have a bigger impact, in general, on the tissue depths for men as compared to women. The *p*-values listed in Table 5 also indicate that not all coefficients have a significant impact on tissue depth. For example, the same small negative partial regression coefficients for BMI, mentioned above, are indeed not statistically significant in the depth determination. In females, the soft tissue depth at the lower lip is even statistically unrelated to age and BMI.

Table 6 reports the statistical differences between the left and right side of the face. The median values of the left and right side of the face, the median values of the ''paired'' differences, the confidence intervals for the median differences for every landmark at a significance level of 99% and the relative median

Table 3d
Tissue depth means (mm) for Caucasian adult males between 50 and 59 years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (2) | | | | | 20–25 (18) | | | | | >25 (45) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | 2.9 | 0.08 | 2.9 | 3.0 | 2 | 4.6 | 0.53 | 3.9 | 5.8 | 18 | 5.1 | 0.78 | 3.1 | 7.7 | 45 |
| 2 | Glabella | 3.8 | 0.48 | 3.5 | 4.2 | 2 | 5.5 | 1.05 | 4.1 | 8.0 | 17 | 5.9 | 0.91 | 4.1 | 7.9 | 43 |
| 3 | Nasion | 4.3 | 0.71 | 3.8 | 4.8 | 2 | 6.8 | 1.48 | 4.2 | 9.1 | 18 | 7.2 | 1.66 | 3.0 | 11.5 | 45 |
| 4 | End of nasal | 2.3 | 0.04 | 2.3 | 2.4 | 2 | 2.7 | 0.35 | 2.2 | 3.2 | 18 | 3.2 | 0.74 | 2.1 | 5.5 | 44 |
| 5 | Mid-philtrum | 10.3 | – | – | – | 1 | 10.4 | 1.87 | 7.9 | 14.7 | 14 | 10.4 | 2.01 | 7.9 | 15.7 | 34 |
| 6 | Upper lip margin | 6.6 | 2.46 | 4.9 | 8.3 | 2 | 9.8 | 2.28 | 6.4 | 14.6 | 17 | 10.1 | 1.88 | 6.4 | 14.5 | 40 |
| 7 | Lower lip margin | 11.8 | 2.63 | 10.0 | 13.7 | 2 | 12.8 | 2.41 | 8.8 | 16.8 | 16 | 11.8 | 2.67 | 7.3 | 24.6 | 43 |
| 8 | Chin-lip fold | 9.3 | 0.83 | 8.8 | 9.9 | 2 | 10.5 | 1.22 | 7.7 | 12.7 | 16 | 11.3 | 1.37 | 7.7 | 15.0 | 42 |
| 9 | Mental eminence | 8.9 | 2.76 | 6.9 | 10.8 | 2 | 10.2 | 1.48 | 8.5 | 13.6 | 16 | 12.2 | 2.23 | 8.0 | 18.8 | 41 |
| 10 | Beneath chin | 5.0 | 1.15 | 4.2 | 5.8 | 2 | 6.2 | 0.84 | 4.9 | 8.0 | 15 | 7.8 | 1.82 | 5.2 | 13.0 | 39 |
| 32/11 | Frontal eminence | 3.1 | 0.31 | 2.9 | 3.4 | 2 | 4.6 | 0.62 | 3.6 | 5.8 | 18 | 5.2 | 0.87 | 3.9 | 8.3 | 45 |
| 33/12 | Supraorbital | 4.1 | 0.31 | 3.9 | 4.3 | 2 | 5.8 | 1.06 | 4.6 | 8.5 | 18 | 6.5 | 0.73 | 4.7 | 8.4 | 44 |
| 34/13 | Lateral glabella | 4.3 | 0.14 | 4.2 | 4.4 | 2 | 6.0 | 1.56 | 3.5 | 8.9 | 18 | 6.5 | 1.39 | 3.9 | 10.8 | 45 |
| 35/14 | Lateral nasal | 3.9 | 1.90 | 2.6 | 5.2 | 2 | 4.0 | 0.59 | 3.0 | 4.5 | 8 | 3.7 | 0.35 | 3.2 | 4.7 | 17 |
| 36/15 | Suborbital | 7.8 | 1.53 | 6.7 | 8.9 | 2 | 9.0 | 3.36 | 3.7 | 14.8 | 18 | 11.6 | 3.24 | 4.2 | 18.8 | 45 |
| 37/16 | Inferior malar | 15.0 | 0.28 | 14.8 | 15.2 | 2 | 18.2 | 3.77 | 10.7 | 25.4 | 18 | 20.7 | 4.39 | 9.7 | 28.8 | 45 |
| 38/17 | Lateral nostril | 7.7 | 2.06 | 6.2 | 9.2 | 2 | 9.7 | 1.91 | 6.0 | 13.8 | 18 | 10.2 | 1.76 | 6.8 | 13.8 | 43 |
| 39/18 | Naso-labial ridge | 8.6 | – | – | – | 1 | 10.4 | 1.50 | 8.2 | 12.8 | 12 | 10.3 | 1.60 | 8.3 | 14.2 | 33 |
| 40/19 | Supra canina | 11.5 | – | – | – | 1 | 9.4 | 1.58 | 7.1 | 13.2 | 13 | 10.4 | 1.85 | 6.8 | 13.7 | 36 |
| 41/20 | Sub canina | 9.1 | 1.32 | 8.2 | 10.0 | 2 | 10.5 | 1.82 | 8.5 | 15.1 | 16 | 11.8 | 1.70 | 8.8 | 15.6 | 43 |
| 42/21 | Mental tubercle ant. | 7.4 | 0.42 | 7.1 | 7.7 | 2 | 10.9 | 1.26 | 8.5 | 13.6 | 16 | 12.3 | 1.78 | 9.6 | 18.3 | 40 |
| 43/22 | Mid lateral orbit | 4.0 | 0.45 | 3.6 | 4.3 | 2 | 4.8 | 0.84 | 3.8 | 6.7 | 18 | 5.7 | 1.40 | 3.9 | 10.7 | 45 |
| 44/23 | Supraglenoid | 8.9 | – | – | – | 1 | 9.5 | 1.77 | 7.1 | 12.2 | 18 | 11.0 | 3.16 | 6.5 | 20.9 | 45 |
| 45/24 | Zygomatic arch | 4.8 | – | – | – | 1 | 6.3 | 1.78 | 3.6 | 11.4 | 18 | 8.1 | 1.90 | 4.2 | 14.4 | 45 |
| 46/25 | Lateral orbit | 7.4 | – | – | – | 1 | 8.0 | 1.46 | 5.8 | 10.7 | 18 | 10.7 | 2.15 | 7.2 | 16.3 | 45 |
| 47/26 | Supra-M2 | 19.1 | – | – | – | 1 | 23.7 | 4.29 | 14.5 | 31.4 | 14 | 29.2 | 3.80 | 19.8 | 34.9 | 32 |
| 48/27 | Mid-masseter muscle | 14.0 | – | – | – | 1 | 18.0 | 2.85 | 12.6 | 24.2 | 18 | 21.5 | 4.02 | 12.7 | 31.2 | 45 |
| 49/28 | Occlusal line | 16.8 | – | – | – | 1 | 19.1 | 2.24 | 14.3 | 23.8 | 17 | 21.8 | 3.14 | 14.2 | 29.4 | 44 |
| 50/29 | Sub-M2 | 14.7 | – | – | – | 1 | 17.3 | 2.79 | 12.4 | 22.1 | 13 | 21.4 | 3.24 | 15.5 | 27.7 | 35 |
| 51/30 | Gonion | 14.5 | – | – | – | 1 | 13.1 | 2.65 | 8.5 | 18.6 | 17 | 18.7 | 3.39 | 9.0 | 26.4 | 42 |
| 52/31 | Mid mandibular angle | 10.2 | – | – | – | 1 | 11.4 | 1.84 | 7.1 | 14.5 | 17 | 15.1 | 3.08 | 8.2 | 20.8 | 41 |

Table 3e
Tissue depth means (mm) for Caucasian adult males between 60+ years

| Point numbers and descriptions | | BMI | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | <20 (0) | | | | | 20–25 (13) | | | | | >25 (37) | | | | |
| | | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # | Mean | S.D. | Range | | # |
| 1 | Supraglabella | – | – | – | – | 0 | 4.3 | 0.54 | 2.9 | 4.8 | 13 | 5.0 | 0.94 | 3.4 | 7.4 | 37 |
| 2 | Glabella | – | – | – | – | 0 | 5.2 | 0.68 | 4.2 | 7.0 | 13 | 5.9 | 1.12 | 4.2 | 8.6 | 37 |
| 3 | Nasion | – | – | – | – | 0 | 6.3 | 1.46 | 3.8 | 9.1 | 13 | 7.0 | 1.24 | 3.8 | 9.7 | 37 |
| 4 | End of nasal | – | – | – | – | 0 | 3.2 | 1.26 | 2.1 | 6.8 | 13 | 3.4 | 1.06 | 2.0 | 6.9 | 37 |
| 5 | Mid-philtrum | – | – | – | – | 0 | 9.0 | 1.07 | 7.1 | 10.3 | 8 | 9.9 | 1.42 | 8.0 | 13.4 | 30 |
| 6 | Upper lip margin | – | – | – | – | 0 | 9.4 | 1.53 | 7.4 | 11.3 | 8 | 9.6 | 1.67 | 4.9 | 12.6 | 25 |
| 7 | Lower lip margin | – | – | – | – | 0 | 10.1 | 1.85 | 7.2 | 12.2 | 8 | 12.9 | 2.76 | 9.5 | 18.5 | 27 |
| 8 | Chin-lip fold | – | – | – | – | 0 | 10.1 | 1.29 | 8.3 | 12.6 | 13 | 11.5 | 1.95 | 7.4 | 17.0 | 34 |
| 9 | Mental eminence | – | – | – | – | 0 | 10.5 | 2.12 | 7.0 | 14.5 | 13 | 12.6 | 2.15 | 8.8 | 16.9 | 35 |
| 10 | Beneath chin | – | – | – | – | 0 | 6.8 | 1.63 | 4.6 | 9.5 | 13 | 7.8 | 1.77 | 4.7 | 12.3 | 35 |
| 32/11 | Frontal eminence | – | – | – | – | 0 | 4.5 | 0.72 | 3.0 | 5.8 | 13 | 5.2 | 1.14 | 3.5 | 8.3 | 37 |
| 33/12 | Supraorbital | – | – | – | – | 0 | 5.5 | 0.78 | 4.3 | 7.0 | 13 | 6.8 | 1.11 | 5.3 | 10.6 | 37 |
| 34/13 | Lateral glabella | – | – | – | – | 0 | 6.6 | 1.55 | 4.7 | 9.8 | 13 | 6.2 | 1.59 | 3.4 | 11.2 | 37 |
| 35/14 | Lateral nasal | – | – | – | – | 0 | 4.7 | 1.29 | 3.2 | 5.6 | 3 | 4.0 | 0.78 | 2.5 | 4.8 | 6 |
| 36/15 | Suborbital | – | – | – | – | 0 | 10.5 | 2.93 | 5.9 | 16.0 | 13 | 10.6 | 3.51 | 4.8 | 19.7 | 37 |
| 37/16 | Inferior malar | – | – | – | – | 0 | 18.3 | 3.83 | 10.9 | 25.1 | 13 | 22.3 | 3.98 | 13.8 | 30.8 | 37 |
| 38/17 | Lateral nostril | – | – | – | – | 0 | 10.2 | 1.86 | 7.9 | 15.0 | 13 | 9.6 | 1.52 | 6.6 | 13.5 | 37 |
| 39/18 | Naso-labial ridge | – | – | – | – | 0 | 9.0 | 1.18 | 6.9 | 10.1 | 8 | 9.9 | 1.58 | 7.7 | 13.5 | 27 |
| 40/19 | Supra canina | – | – | – | – | 0 | 9.2 | 1.22 | 7.7 | 11.6 | 8 | 9.6 | 1.86 | 7.2 | 13.6 | 24 |
| 41/20 | Sub canina | – | – | – | – | 0 | 10.5 | 1.16 | 8.7 | 12.2 | 8 | 11.3 | 1.60 | 8.7 | 15.3 | 29 |
| 42/21 | Mental tubercle ant. | – | – | – | – | 0 | 10.8 | 1.09 | 9.4 | 12.4 | 13 | 12.3 | 1.90 | 8.7 | 15.8 | 35 |
| 43/22 | Mid lateral orbit | – | – | – | – | 0 | 4.5 | 0.45 | 3.9 | 5.3 | 13 | 5.4 | 1.08 | 3.6 | 7.6 | 37 |
| 44/23 | Supraglenoid | – | – | – | – | 0 | 9.1 | 2.90 | 5.8 | 14.2 | 13 | 10.3 | 3.61 | 5.6 | 21.1 | 37 |
| 45/24 | Zygomatic arch | – | – | – | – | 0 | 5.9 | 1.13 | 4.5 | 8.2 | 13 | 8.3 | 1.63 | 5.9 | 12.6 | 37 |
| 46/25 | Lateral orbit | – | – | – | – | 0 | 7.8 | 1.13 | 6.1 | 10.1 | 13 | 10.4 | 1.57 | 7.7 | 13.8 | 37 |
| 47/26 | Supra-M2 | – | – | – | – | 0 | 28.0 | 4.30 | 23.1 | 34.0 | 6 | 29.6 | 5.04 | 18.2 | 38.2 | 21 |
| 48/27 | Mid-masseter muscle | – | – | – | – | 0 | 17.3 | 3.54 | 12.0 | 22.6 | 13 | 19.8 | 5.28 | 8.5 | 31.8 | 37 |
| 49/28 | Occlusal line | – | – | – | – | 0 | 18.6 | 1.92 | 14.9 | 21.2 | 13 | 21.8 | 3.41 | 17.1 | 35.2 | 37 |
| 50/29 | Sub-M2 | – | – | – | – | 0 | 19.8 | 2.07 | 17.8 | 23.1 | 6 | 22.0 | 3.66 | 16.4 | 28.6 | 16 |
| 51/30 | Gonion | – | – | – | – | 0 | 14.0 | 3.11 | 8.0 | 19.4 | 12 | 19.3 | 3.65 | 13.9 | 29.1 | 37 |
| 52/31 | Mid mandibular angle | – | – | – | – | 0 | 13.0 | 2.72 | 10.0 | 20.4 | 12 | 16.7 | 3.58 | 11.4 | 29.8 | 35 |

differences are reported. Twelve of the 21 bilateral points show a statistically significant difference at a significance level of $p < 0.01$. The relative bilateral median differences however never exceed 6%, with the maximal absolute median difference being 1.04 mm (for the mid-masseter muscle) compared to an associated average of 17 mm.

Tables 7–9 and Figs. 4–6 report on the differences between the new database and the databases of former studies. For the common points between these studies and our study, the medians [3]or means [2,4] of the traditional and the new database, the difference between the corresponding medians or means, as well as the significance level of the hypothetical tests of equality of medians or means and the involved number of subjects are reported. The percentage of landmarks showing a significant difference at a level of $p < 0.01$ vary between 91% for the Rhine and Moore study, 78% for the Helmer study and 61% for the Manhein study. Figs. 4–6 show for each of the comparative studies the typical facial outlook, per subcategory, for the reference study and our study, as well as the colorscale-coded surfaces representing the corresponding differences. Since two-way ANOVA tests showed these differences to be much less related to gender than to any of the two other attributes (age and body posture), we show the renderings for both sexes merged.

In the Rhine and Moore study, with the exception of the supra-orbital landmark, all the landmarks in the slender group are thinner than in our study. This is also statistically confirmed by a one-sided *t*-test showing that for both male and female 19 out of 21 landmarks in the slender subcategory are significantly ($p < 0.01$) smaller in the Rhine and Moore study. This difference, in number and in magnitude, diminishes and even reverses for some of the landmarks, especially the lateral orbit and zygomatic arch, with increase in body build as is pictorially demonstrated in Fig. 4. The inferior malar, suborbital, supra-M2 and sub-M2, however, remain systematically thinner in the Rhine and Moore study over all body posture categories. The supra-orbital landmark, on the other hand, is systematically thicker compared to the new dataset in all three categories. A two-way ANOVA analysis shows, for all landmarks, a much larger dependence of inter-study soft tissue thickness differences on body posture as compared to gender.

Compared to our dataset, in the Helmer study 3 of the 24 common landmarks (supra-M2, gonion and suborbital) were reported systematically thinner. In contrast, the lateral nasal and

Table 4
Overview composition population De Greef et al. study

| | 18–29 years | | | | | | 30–39 years | | | | | | 40–49 years | | | | | | 50–59 years | | | | | | 60+ years | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BMI | <20 | | 20–25 | | >25 | | <20 | | 20–25 | | >25 | | <20 | | 20–25 | | >25 | | <20 | | 20–25 | | >25 | | <20 | | 20–25 | | >25 | |
| Gender | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F | M | F |
| Number | 28 | 56 | 149 | 127 | 34 | 29 | 3 | 12 | 37 | 40 | 31 | 20 | 1 | 12 | 24 | 32 | 35 | 21 | 2 | 4 | 18 | 29 | 45 | 41 | 0 | 7 | 13 | 37 | 37 | 43 |
| Mean BMI | 19.68 | 18.55 | 22.38 | 21.99 | 28.44 | 28.18 | 19.03 | 18.92 | 22.77 | 22.29 | 28.62 | 28.49 | 19.92 | 18.99 | 23.13 | 22.78 | 29.10 | 32.02 | 19.25 | 18.97 | 24.13 | 23.03 | 28.15 | 29.78 | – | 19.32 | 23.80 | 22.68 | 29.64 | 28.87 |
| Mean age | 22.00 | 21.75 | 22.96 | 22.55 | 23.64 | 23.27 | 34.00 | 33.07 | 33.86 | 33.87 | 34.12 | 34.45 | 43.00 | 44.33 | 43.95 | 44.40 | 44.34 | 45.23 | 50.50 | 54.50 | 54.50 | 54.06 | 55.20 | 54.36 | – | 69.71 | 69.90 | 74.43 | 68.10 | 71.44 |

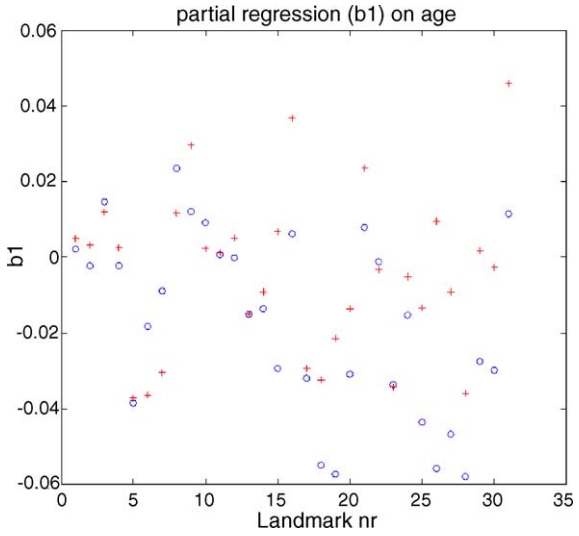


Fig. 2. Partial regression coefficients $b_1$ (female: circle, male: cross) of soft tissue depths (mm) on age (year). Bilateral measurements are merged before regression.

mid-philtrum landmarks are systematically thicker in the Helmer study. The difference in the supra-M2 results could be explained by the slight difference in landmark positioning between the two studies since Helmer measured at the first molar whereas we measured at the second molar. A two-way ANOVA analysis shows, for most of the landmarks, a slightly larger dependence of inter-study soft tissue thickness differences on age as compared to gender.

The differences between the Manhein study and our study are overall smaller than between our study and any of the two other studies as can be seen by comparing Figs. 4–6. The landmarks supra-M2, sub-M2, gonion and mid-mandibular angle are systematically higher in the Manhein et al. tables. Again, as in the former comparisons, the suborbital landmark is systematically higher in our dataset. The most probable

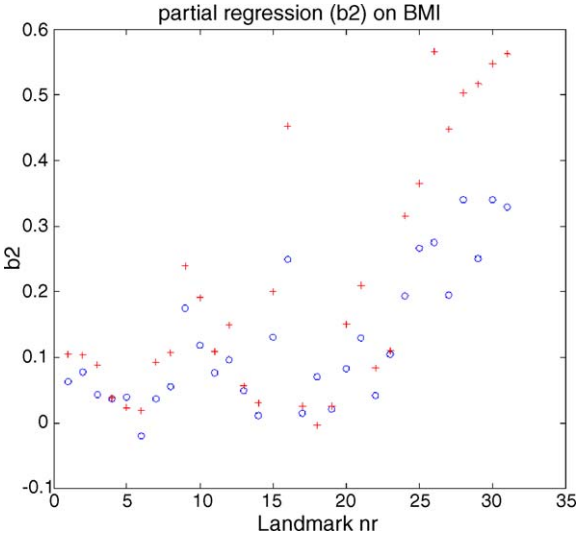


Fig. 3. Partial regression coefficients $b_2$ (female: circle, male: cross) of soft tissue depths (mm) on BMI (kg/m$^2$). Bilateral measurements are merged before regression.

Table 5
Linear regression equation: partial regression coefficients, the root mean square (RMS) errors and the significance levels

| Point numbers and descriptions | | Males | | | | | | Females | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $b_0$ | $b_1$ | $p$ | $b_2$ | $p$ | RMSE | $b_0$ | $b_1$ | $p$ | $b_2$ | $p$ | RMSE |
| 1 | Supraglabella | 1.7 | 5.0 | * | 104.5 | ** | 0.6 | 2.7 | 2 | | 62 | ** | 0.6 |
| 2 | Glabella | 2.5 | 3.2 | | 103.1 | ** | 0.7 | 3.4 | −2 | | 77 | ** | 0.8 |
| 3 | Nasion | 3.6 | 11.9 | ** | 87.9 | ** | 1.2 | 4.8 | 15 | ** | 42 | ** | 1.3 |
| 4 | End of nasal | 1.8 | 2.4 | | 37.6 | ** | 0.6 | 1.7 | −2 | * | 36 | ** | 0.5 |
| 5 | Mid-philtrum | 11.4 | −37.2 | ** | 22.8 | | 1.7 | 9.7 | −39 | ** | 39 | * | 1.6 |
| 6 | Upper lip margin | 11.3 | −36.5 | ** | 17.7 | | 2.0 | 10.6 | −18 | ** | −21 | | 1.7 |
| 7 | Lower lip margin | 11.0 | −30.5 | ** | 92.0 | ** | 2.1 | 10.1 | −9 | | 37 | | 2.0 |
| 8 | Chin-lip fold | 7.4 | 11.7 | * | 107.0 | ** | 1.3 | 7.9 | 23 | ** | 54 | ** | 1.2 |
| 9 | Mental eminence | 3.4 | 29.7 | ** | 238.3 | ** | 1.7 | 5.5 | 12 | ** | 174 | ** | 1.7 |
| 10 | Beneath chin | 1.7 | 2.4 | | 190.8 | ** | 1.3 | 2.9 | 9 | * | 118 | ** | 1.5 |
| 32/11 | Frontal eminence | 1.7 | 1.0 | | 108.4 | ** | 0.7 | 2.3 | 1 | | 76 | ** | 0.6 |
| 33/12 | Supraorbital | 1.8 | 5.1 | | 148.8 | ** | 0.9 | 3.3 | 0 | | 95 | ** | 0.8 |
| 34/13 | Lateral glabella | 5.0 | −15.0 | ** | 55.6 | ** | 1.3 | 4.9 | −15 | ** | 48 | ** | 1.1 |
| 35/14 | Lateral nasal | 3.4 | −9.1 | * | 30.6 | * | 0.6 | 3.9 | −14 | ** | 10 | | 0.6 |
| 36/15 | Suborbital | 4.0 | 6.9 | | 199.1 | ** | 2.3 | 7.7 | −29 | ** | 130 | ** | 2.2 |
| 37/16 | Inferior malar | 5.2 | 36.9 | ** | 452.6 | ** | 3.3 | 12.3 | 6 | | 249 | ** | 2.8 |
| 38/17 | Lateral nostril | 10.2 | −29.5 | ** | 25.7 | | 1.5 | 9.9 | −32 | ** | 14 | | 1.3 |
| 39/18 | Naso-labial ridge | 12.0 | −32.3 | ** | −4.2 | | 2.0 | 9.6 | −55 | ** | 70 | ** | 1.6 |
| 40/19 | Supra canina | 10.5 | −21.3 | * | 25.8 | | 2.0 | 10.6 | −57 | ** | 20 | | 1.7 |
| 41/20 | Sub canina | 7.2 | −13.6 | | 149.9 | ** | 1.7 | 9.2 | −31 | ** | 82 | ** | 1.5 |
| 42/21 | Mental tubercle ant. | 4.2 | 23.4 | ** | 208.9 | ** | 1.4 | 6.6 | 8 | | 129 | ** | 1.5 |
| 43/22 | Mid lateral orbit | 2.8 | −3.5 | | 83.9 | ** | 0.7 | 4.1 | −1 | | 42 | ** | 0.9 |
| 44/23 | Supraglenoid | 8.3 | −34.2 | ** | 109.7 | * | 2.8 | 8.2 | −34 | ** | 104 | ** | 1.9 |
| 45/24 | Zygomatic arch | −1.2 | −5.1 | | 315.4 | ** | 1.2 | 3.0 | −15 | * | 194 | ** | 1.4 |
| 46/25 | Lateral orbit | −0.3 | −13.4 | * | 364.9 | ** | 1.4 | 5.2 | −44 | ** | 266 | ** | 1.7 |
| 47/26 | Supra-M2 | 12.4 | 9.6 | | 565.5 | ** | 3.4 | 22.5 | −56 | ** | 275 | ** | 2.9 |
| 48/27 | Mid-masseter muscle | 6.7 | −9.1 | | 447.0 | ** | 4.5 | 13.4 | −47 | ** | 194 | ** | 3.3 |
| 49/28 | Occlusal line | 8.8 | −36.0 | ** | 503.4 | ** | 2.4 | 13.1 | −58 | ** | 340 | ** | 2.0 |
| 50/29 | Sub-M2 | 5.4 | 1.8 | | 516.5 | ** | 3.2 | 14.2 | −27 | | 250 | ** | 3.2 |
| 51/30 | Gonion | 2.0 | −2.8 | | 547.0 | ** | 3.0 | 7.5 | −30 | ** | 340 | ** | 2.4 |
| 52/31 | Mid mandibular angle | −4.1 | 45.9 | ** | 562.0 | ** | 2.5 | 3.8 | 12 | | 329 | ** | 2.3 |

$Y = b_0 + b_1 \times \text{age} + b_2 \times \text{BMI}$; b0 (mm), $b_1$ (mm/YR) (‰); $b_2$ (mm/BMI) (‰); RMSE (mm).
* $p < 0.05$.
** $p < 0.01$.

Table 6
Statistical analysis between the left and right side of the face

| | | Left | Right | Diff. | Conf. int. | | Rel. diff. (%) |
|---|---|---|---|---|---|---|---|
| 32/11 | Frontal eminence | 4.1 | 4.3 | 0.00 | −0.08 | 0.04 | 0 |
| 33/12 | Supraorbital | 5.6 | 5.4 | 0.12 | 0.04 | 0.24 | 2 |
| 34/13 | Lateral glabella | 5.7 | 5.9 | 0.12 | 0.00 | 0.20 | 2 |
| 35/14 | Lateral nasal | 3.8 | 3.7 | 0.14 | 0.08 | 0.22 | 4 |
| 36/15 | Suborbital | 9.5 | 9.4 | 0.24 | 0.00 | 0.46 | 3 |
| 37/16 | Inferior malar | 17.5 | 18.2 | 0.10 | −0.19 | 0.36 | 1 |
| 38/17 | Lateral nostril | 9.7 | 9.5 | 0.01 | −0.12 | 0.14 | 0 |
| 39/18 | Naso-labial ridge | 10.1 | 9.8 | 0.18 | 0.04 | 0.39 | 2 |
| 40/19 | Supra canina | 9.9 | 9.3 | 0.22 | 0.03 | 0.42 | 2 |
| 41/20 | Sub canina | 10.0 | 10.5 | −0.03 | −0.24 | 0.07 | 0 |
| 42/21 | Mental tubercle ant. | 9.7 | 10.3 | −0.21 | −0.30 | −0.07 | −2 |
| 43/22 | Mid lateral orbit | 4.8 | 4.8 | 0.04 | −0.04 | 0.16 | 1 |
| 44/23 | Supraglenoid | 9.9 | 9.5 | −0.04 | −0.21 | 0.26 | 0 |
| 45/24 | Zygomatic arch | 6.5 | 6.7 | 0.04 | −0.12 | 0.16 | 1 |
| 46/25 | Lateral orbit | 8.9 | 9.4 | 0.00 | −0.12 | 0.13 | 0 |
| 47/26 | Supra-M2 | 26.6 | 26.8 | 0.24 | 0.00 | 0.60 | 1 |
| 48/27 | Mid-masseter muscle | 16.2 | 17.8 | −1.04 | −1.40 | −0.56 | −6 |
| 49/28 | Occlusal line | 19.0 | 19.5 | −0.32 | −0.52 | −0.12 | −2 |
| 50/29 | Sub-M2 | 17.9 | 18.8 | −0.50 | −0.84 | −0.24 | −3 |
| 51/30 | Gonion | 14.2 | 15.1 | −0.40 | −0.64 | −0.18 | −3 |
| 52/31 | Mid mandibular angle | 10.6 | 12.1 | −0.72 | −0.96 | −0.42 | −6 |

Grey shaded landmarks show a statistically significant difference at a significance level of $p < 0.01$.

Table 7
Comparison of the De Greef et al. (KUL) soft tissue depth measurements with the Rhine and Moore (RHI) study (1984)

Males

| Point numbers and description | | | Slender | | | | Normal | | | | Obese | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUL | RHI | | RHI, 3 | KUL, 36 | DIFF | $p$ | RHI, 37 | KUL, 241 | DIFF | $p$ | RHI, 8 | KUL, 182 | DIFF | $p$ |
| 1 | 1 | Supraglabella | 2.3 | 3.8 | −1.5 | ** | 4.3 | 4.2 | 0.1 | | 5.5 | 5.0 | 0.5 | ** |
| 2 | 2 | Glabella | 2.5 | 4.6 | −2.1 | ** | 5.3 | 5.0 | 0.2 | ** | 7.5 | 5.8 | 1.7 | ** |
| 3 | 3 | Nasion | 4.3 | 5.6 | −1.4 | ** | 6.5 | 6.0 | 0.5 | ** | 7.5 | 6.8 | 0.7 | ** |
| 4 | 4 | End of nasals | 2.5 | 2.7 | −0.2 | * | 3.0 | 2.8 | 0.2 | ** | 3.5 | 3.2 | 0.3 | ** |
| 5 | 5 | Mid-philtrum | 6.3 | 11.4 | −5.1 | ** | 10.0 | 10.9 | −0.9 | ** | 11.0 | 10.5 | 0.5 | ** |
| 6 | 6 | Upper lip margin | 9.8 | 10.8 | −1.1 | ** | 9.8 | 10.7 | −0.9 | ** | 11.0 | 10.3 | 0.7 | ** |
| 7 | 7 | Lower lip margin | 9.5 | 11.9 | −2.4 | ** | 11.0 | 12.2 | −1.2 | ** | 12.8 | 12.4 | 0.3 | |
| 8 | 8 | Chin–lip fold | 8.8 | 10.0 | −1.3 | ** | 10.8 | 10.1 | 0.6 | ** | 12.3 | 11.1 | 1.2 | ** |
| 9 | 9 | Mental eminence | 7.0 | 9.0 | −2.0 | ** | 11.3 | 9.7 | 1.5 | ** | 14.0 | 11.7 | 2.3 | ** |
| 10 | 10 | Beneath chin | 4.5 | 5.4 | −0.9 | ** | 7.3 | 6.2 | 1.0 | ** | 10.8 | 7.5 | 3.2 | ** |
| 11 | 11 | Frontal eminence | 3.0 | 3.8 | −0.8 | ** | 4.3 | 4.2 | 0.0 | | 5.5 | 5.1 | 0.4 | ** |
| 12 | 12 | Supraorbital | 6.3 | 4.7 | 1.5 | ** | 8.3 | 5.2 | 3.1 | ** | 10.3 | 6.5 | 3.8 | ** |
| 15 | 13 | Suborbital | 2.8 | 7.7 | −5.0 | ** | 5.8 | 8.6 | −2.9 | ** | 8.3 | 10.6 | −2.3 | ** |
| 16 | 14 | Inferior malar | 8.5 | 14.8 | −6.3 | ** | 13.3 | 16.6 | −3.4 | ** | 15.3 | 20.8 | −5.6 | ** |
| 23 | 17 | Supraglenoid | 4.3 | 9.0 | −4.8 | ** | 8.5 | 9.7 | −1.2 | ** | 11.3 | 10.6 | 0.7 | ** |
| 24 | 16 | Zygomatic arch | 3.0 | 4.9 | −1.9 | ** | 7.3 | 5.8 | 1.5 | ** | 11.8 | 8.1 | 3.6 | ** |
| 25 | 15 | lateral orbit | 5.0 | 6.7 | −1.7 | ** | 10.0 | 7.5 | 2.5 | ** | 13.8 | 10.6 | 3.2 | ** |
| 26 | 19 | Supra-M2 | 12.0 | 23.7 | −11.7 | ** | 19.5 | 24.9 | −5.4 | ** | 25.0 | 29.6 | −4.6 | ** |
| 28 | 20 | Occlusal line | 12.0 | 17.9 | −5.9 | ** | 18.3 | 19.3 | −1.0 | ** | 23.5 | 22.3 | 1.2 | ** |
| 29 | 21 | Sub-M2 | 10.0 | 16.5 | −6.5 | ** | 16.0 | 17.3 | −1.3 | ** | 19.8 | 21.6 | −1.8 | ** |
| 30 | 18 | Gonion | 4.5 | 13.7 | −9.2 | ** | 11.5 | 14.4 | −2.9 | ** | 17.5 | 18.8 | −1.3 | ** |

Females

| Point numbers and description | | | Slender | | | | Normal | | | | Obese | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUL | RHI | | RHI, 3 | KUL, 93 | DIFF | $p$ | RHI, 19 | KUL, 268 | DIFF | $p$ | RHI, 3 | KUL, 154 | DIFF | $p$ |
| 1 | 1 | Supraglabella | 2.5 | 3.9 | −1.4 | ** | 3.5 | 4.2 | −0.7 | ** | 4.3 | 4.7 | −0.5 | ** |
| 2 | 2 | Glabella | 4.0 | 4.7 | −0.7 | ** | 4.8 | 5.1 | −0.3 | ** | 7.5 | 5.6 | 1.9 | ** |
| 3 | 3 | Nasion | 5.3 | 5.8 | −0.6 | ** | 5.5 | 6.4 | −0.9 | ** | 7.0 | 6.9 | 0.1 | |
| 4 | 4 | End of nasals | 2.3 | 2.5 | −0.3 | ** | 2.8 | 2.5 | 0.2 | ** | 4.3 | 2.9 | 1.4 | ** |
| 5 | 5 | Mid-philtrum | 5.0 | 9.3 | −4.3 | ** | 8.5 | 9.2 | −0.7 | ** | 9.0 | 9.1 | −0.1 | |
| 6 | 6 | Upper lip margin | 6.3 | 9.3 | −3.1 | ** | 9.0 | 9.7 | −0.7 | ** | 11.0 | 9.1 | 1.9 | ** |
| 7 | 7 | Lower lip margin | 8.5 | 10.5 | −2.0 | ** | 10.0 | 10.8 | −0.8 | ** | 12.3 | 10.8 | 1.4 | ** |
| 8 | 8 | Chin–lip fold | 9.3 | 9.4 | −0.2 | | 9.5 | 10.0 | −0.5 | ** | 13.8 | 10.6 | 3.1 | ** |
| 9 | 9 | Mental eminence | 8.5 | 9.1 | −0.6 | ** | 10.0 | 9.8 | 0.2 | | 14.3 | 11.5 | 2.7 | ** |
| 10 | 10 | Beneath chin | 3.8 | 5.6 | −1.9 | ** | 5.8 | 5.9 | −0.1 | | 9.0 | 7.1 | 1.9 | ** |
| 11 | 11 | Frontal eminence | 2.8 | 3.8 | −1.0 | ** | 3.5 | 4.1 | −0.6 | ** | 5.0 | 4.8 | 0.2 | ** |
| 12 | 12 | Supraorbital | 5.3 | 5.0 | 0.3 | ** | 7.0 | 5.4 | 1.6 | ** | 10.0 | 6.4 | 3.6 | ** |
| 15 | 13 | Suborbital | 4.0 | 9.2 | −5.2 | ** | 6.0 | 9.6 | −3.6 | ** | 8.5 | 10.6 | −2.1 | ** |
| 16 | 14 | Inferior malar | 7.0 | 16.1 | −9.1 | ** | 12.8 | 18.2 | −5.5 | ** | 14.0 | 20.8 | −6.8 | ** |
| 23 | 17 | Supraglenoid | 4.3 | 8.7 | −4.5 | ** | 8.0 | 9.3 | −1.3 | ** | 10.5 | 10.4 | 0.1 | |
| 24 | 16 | Zygomatic arch | 3.5 | 5.9 | −2.4 | ** | 7.5 | 6.9 | 0.6 | ** | 13.0 | 8.7 | 4.3 | ** |
| 25 | 15 | lateral orbit | 6.0 | 8.9 | −2.9 | ** | 10.8 | 9.9 | 0.9 | ** | 14.8 | 12.4 | 2.4 | ** |
| 26 | 19 | Supra-M2 | 12.0 | 25.1 | −13.1 | ** | 19.3 | 26.5 | −7.2 | ** | 23.8 | 29.2 | −5.4 | ** |
| 28 | 20 | Occlusal line | 11.0 | 18.1 | −7.1 | ** | 17.0 | 18.8 | −1.8 | ** | 20.3 | 21.3 | −1.1 | ** |
| 29 | 21 | Sub-M2 | 9.5 | 18.0 | −8.5 | ** | 15.5 | 18.9 | −3.4 | ** | 18.8 | 21.7 | −2.9 | ** |
| 30 | 18 | Gonion | 5.0 | 13.3 | −8.3 | ** | 12.0 | 14.1 | −2.1 | ** | 17.5 | 17.4 | 0.1 | |

$p$ = significance level of the $t$-test.
* $p < 0.05$.
** $p < 0.01$.

explanation for the suborbital landmark to be systematically higher in our study compared to all other studies is that in our study design this landmark is positioned just below the orbital rim, and not on the orbit as in the other studies, because of the difficulty of obtaining a strong enough reflected ultrasound signal otherwise. As a result, the tissue depths at this slightly shifted landmark position are systematically larger. A two-way ANOVA analysis now shows, for all the landmarks, a modestly larger dependence of inter-study soft tissue thickness differences on age as compared to gender.

Table 8a
Comparison of the De Greef et al. (KUL) tissue depth measurements with the Helmer (HEL) study (1984) for women

| Point numbers and description | | | 20–29 years | | | | | 30–39 years | | | | | 40–49 years | | | | | 50–59 years | | | | | 60+ years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUL | HEL | | HEL, 12 | KUL, 172 | DIFF | P1 | P2 | HEL, 13 | KUL, 72 | DIFF | P1 | P2 | HEL, 11 | KUL, 64 | DIFF | P1 | P2 | HEL, 15 | KUL, 74 | DIFF | P1 | P2 | HEL, 11 | KUL, 87 | DIFF | P1 | P2 |
| 1 | 3 | Supraglabella | 4.5 | 4.0 | 0.5 | ** | | 4.5 | 4.1 | 0.4 | ** | * | 4.6 | 4.3 | 0.3 | * | | 4.7 | 4.5 | 0.2 | | | 5.2 | 4.3 | 0.9 | ** | * |
| 2 | 5 | Glabella | 5.5 | 5.0 | 0.5 | ** | | 5.7 | 4.9 | 0.8 | ** | * | 5.9 | 4.9 | 1.0 | ** | | 6.0 | 5.3 | 0.7 | ** | * | 6.5 | 5.4 | 1.1 | ** | * |
| 3 | 6 | Nasion | 6.9 | 6.1 | 0.8 | ** | | 6.5 | 5.9 | 0.6 | * | * | 6.2 | 6.4 | −0.2 | | | 6.5 | 6.6 | −0.1 | | | 6.5 | 7.0 | −0.5 | ** | |
| 4 | 8 | End of nasal | 2.3 | 2.4 | −0.1 | ** | | 2.5 | 2.4 | 0.1 | | | 2.4 | 2.4 | 0.0 | | | 2.3 | 2.6 | −0.3 | ** | * | 2.5 | 2.4 | 0.1 | | |
| 5 | 11 | Mid-philtrum | 13.8 | 9.6 | 4.2 | ** | * | 12.8 | 8.9 | 3.9 | ** | * | 12.6 | 8.5 | 4.1 | ** | * | 13.2 | 8.2 | 5.0 | ** | * | 12.2 | 8.4 | 3.8 | ** | * |
| 6 | 12 | Upper lip margin | 11.8 | 9.8 | 2.0 | ** | * | 10.7 | 9.2 | 1.5 | ** | * | 10.5 | 8.7 | 1.8 | ** | * | 10.0 | 9.0 | 1.0 | ** | | 9.8 | 9.3 | 0.5 | | |
| 7 | 13 | Lower lip margin | 12.0 | 10.6 | 1.4 | ** | * | 12.0 | 10.5 | 1.5 | ** | * | 12.5 | 10.2 | 2.3 | ** | * | 11.8 | 10.4 | 1.4 | ** | * | 11.5 | 10.8 | 0.7 | ** | |
| 8 | 14 | Chin–lip fold | 10.4 | 9.7 | 0.7 | ** | * | 10.8 | 9.9 | 0.9 | ** | * | 12.3 | 10.2 | 2.1 | ** | * | 12.8 | 10.6 | 2.2 | ** | * | 11.5 | 11.0 | 0.5 | * | |
| 9 | 15 | Mental eminence | 9.6 | 9.5 | 0.1 | | | 10.0 | 10.0 | 0.0 | | | 9.6 | 10.1 | −0.5 | * | | 11.3 | 10.6 | 0.7 | * | | 12 | 10.9 | 1.1 | ** | |
| 10 | 16 | Beneath chin | 7.1 | 5.6 | 1.5 | ** | * | 7.2 | 5.9 | 1.3 | ** | * | 6.9 | 5.6 | 1.3 | ** | | 8.0 | 6.2 | 1.8 | ** | * | 8.7 | 7.0 | 1.7 | ** | * |
| 11 | 17 | Frontal eminence | 5.2 | 3.9 | 1.3 | ** | * | 5.0 | 4.2 | 0.8 | ** | * | 5.3 | 4.2 | 1.1 | ** | | 5.0 | 4.7 | 0.3 | ** | * | 5.3 | 4.5 | 0.8 | ** | * |
| 12 | 18 | Supraorbital | 6.6 | 5.2 | 1.4 | ** | * | 6.5 | 5.4 | 1.1 | ** | * | 7.4 | 5.5 | 1.9 | ** | * | 6.7 | 5.8 | 0.9 | ** | * | 6.8 | 5.8 | 1.0 | ** | * |
| 14 | 9 | Lateral nasal[a] | 7.0 | 3.7 | 3.3 | ** | * | 6.3 | 3.6 | 2.7 | ** | * | 6.7 | 3.6 | 3.1 | ** | * | 6.5 | 3.7 | 2.8 | ** | * | 7.3 | 3.8 | 3.5 | ** | * |
| 15 | 19 | Suborbital | 5.5 | 9.5 | −4.0 | ** | * | 5.5 | 9.4 | −3.9 | ** | * | 5.4 | 9.4 | −4.0 | ** | * | 6.0 | 10.4 | −4.4 | ** | * | 6.3 | 10.2 | −3.9 | ** | * |
| 16 | 20 | Inferior malar[a] | 18.8 | 17.7 | 1.1 | ** | * | 20.2 | 17.5 | 2.7 | ** | * | 19.1 | 18.8 | 0.3 | | | 20.7 | 20.1 | 0.6 | | | 22.3 | 20.6 | 1.7 | ** | |
| 17 | 10 | Lateral nostril | 11.6 | 9.4 | 2.2 | ** | * | 11.0 | 8.8 | 2.2 | ** | * | 11 | 8.9 | 2.1 | ** | * | 11.5 | 9.1 | 2.4 | ** | * | 11.5 | 9.4 | 2.1 | ** | * |
| 22 | 25 | Mid lateral orbit | 5.2 | 4.8 | 0.4 | ** | | 5.0 | 4.7 | 0.3 | | | 5.1 | 4.7 | 0.4 | | | 5.3 | 5.1 | 0.2 | | | 5.5 | 5.3 | 0.2 | | |
| 24 | 31 | Zygomatic arch | 4.8 | 6.8 | −2.0 | ** | * | 5.2 | 7.0 | −1.8 | ** | * | 5.4 | 6.9 | −1.5 | ** | * | 5.3 | 7.2 | −1.9 | ** | * | 5.2 | 7.5 | −2.3 | ** | ** |
| 25 | 26 | Lateral orbit[a] | 8.9 | 10.0 | −1.1 | ** | * | 9.0 | 10.3 | −1.3 | ** | * | 9.1 | 9.5 | −0.4 | ** | | 9.0 | 11.5 | −2.5 | ** | * | 10.3 | 10.5 | −0.2 | | |
| 26 | 21 | Supra-M2[a] | 19.2 | 27.2 | −8.0 | ** | * | 21.5 | 25.9 | −4.4 | ** | * | 20.5 | 26.3 | −5.8 | ** | * | 19.3 | 28.6 | −9.3 | ** | * | 20.5 | 27.8 | −7.3 | ** | ** |
| 27 | 32 | Mid-mas. muscle[a] | 17.2 | 17.3 | −0.1 | | | 18.3 | 17.1 | 1.2 | ** | | 17.8 | 16.9 | 0.9 | | | 17.3 | 18.0 | −0.7 | | | 19.2 | 16.6 | 2.6 | ** | |
| 29 | 22 | Sub-M2[a] | 16.6 | 18.6 | −2.0 | ** | | 19.0 | 18.0 | 1.0 | * | | 18 | 19.2 | −1.2 | ** | | 17.7 | 19.6 | −1.9 | ** | * | 19 | 21.3 | −2.3 | ** | ** |
| 30 | 33 | Gonion | 9.2 | 14.3 | −5.1 | ** | * | 9.0 | 14.6 | −5.6 | ** | * | 9.1 | 15.6 | −6.5 | ** | * | 9.0 | 15.5 | −6.5 | ** | * | 10.3 | 15.0 | −4.7 | ** | |
| 31 | 28 | Mid mand. angle | 10.7 | 11.6 | −0.9 | ** | | 11.5 | 11.5 | 0.0 | | | 11.8 | 12.3 | −0.5 | * | | 12.0 | 13.9 | −1.9 | ** | * | 13.7 | 15.3 | −1.6 | ** | |

P1 = significance level of the Wilcoxon rank test; P2 = significance level of the alternative test, testing if the median values of our study fall within the 95% confidence intervals for the median as reported by Helmer.

[a] Landmark with a slight different localisation between the two studies.

* $p < 0.05$.

** $p < 0.01$.

Table 8b
Comparison of the De Greef et al. (KUL) tissue depth measurements with the Helmer (HEL) study (1984) for men

| Point numbers and description | | | 20–29 years | | | | | 30–39 years | | | | | 40–49 years | | | | | 50–59 years | | | | | 60+ years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUL | HEL | | HEL, 13 | KUL, 188 | DIFF | P1 | P2 | HEL, 14 | KUL, 71 | DIFF | P1 | P2 | HEL, 13 | KUL, 60 | DIFF | P1 | P2 | HEL, 11 | KUL, 63 | DIFF | P1 | P2 | HEL, 10 | KUL, 50 | DIFF | P1 | P2 |
| 1 | 3 | Supraglabella | 5.0 | 4.1 | 0.9 | ** | * | 5.0 | 4.2 | 0.8 | ** | * | 5.0 | 4.9 | 0.1 | | | 5.0 | 5.0 | 0.0 | | | 4.8 | 4.6 | 0.2 | | |
| 2 | 5 | Glabella | 5.7 | 4.9 | 0.8 | ** | * | 6.2 | 4.8 | 1.4 | ** | * | 6.0 | 5.5 | 0.5 | ** | | 6.0 | 5.7 | 0.3 | * | | 6.3 | 5.4 | 0.9 | ** | |
| 3 | 6 | Nasion | 8.2 | 5.8 | 2.4 | ** | * | 7.3 | 6.1 | 1.2 | ** | * | 6.8 | 6.5 | 0.3 | | | 7.3 | 7.1 | 0.2 | | | 7.1 | 6.9 | 0.2 | | |
| 4 | 8 | End of nasal | 2.3 | 2.7 | −0.4 | ** | | 2.5 | 2.7 | −0.2 | ** | | 2.7 | 3.0 | −0.3 | ** | | 2.8 | 3.0 | −0.2 | * | | 2.6 | 3.2 | −0.6 | ** | |
| 5 | 11 | Mid-philtrum | 15.5 | 10.9 | 4.6 | ** | * | 14.6 | 10.3 | 4.3 | ** | * | 15.6 | 10.1 | 5.5 | ** | * | 14.3 | 10.2 | 4.1 | ** | * | 12.9 | 9.6 | 3.3 | ** | * |
| 6 | 12 | Upper lip margin | 14.0 | 10.7 | 3.3 | ** | * | 12.3 | 10.0 | 2.3 | ** | * | 12.6 | 10.2 | 2.4 | ** | * | 11.8 | 9.7 | 2.1 | ** | * | 9.9 | 9.2 | 0.7 | | |
| 7 | 13 | Lower lip margin | 14.2 | 12.2 | 2.0 | ** | * | 14.9 | 12.3 | 2.6 | ** | * | 14.2 | 12.3 | 1.9 | ** | | 13.0 | 11.7 | 1.3 | ** | * | 12.7 | 11.7 | 1.0 | | |
| 8 | 14 | Chin–lip fold | 12.0 | 10.1 | 1.9 | ** | * | 12.1 | 10.1 | 2.0 | ** | * | 13.3 | 11.1 | 2.2 | ** | * | 13.0 | 11.1 | 1.9 | ** | * | 12.7 | 10.9 | 1.8 | ** | * |
| 9 | 15 | Mental eminence | 9.7 | 9.5 | 0.2 | | | 10.3 | 10.2 | 0.1 | | | 11.7 | 11.4 | 0.3 | | | 13.7 | 11.5 | 2.2 | ** | | 12.3 | 11.8 | 0.5 | | |
| 10 | 16 | Beneath chin | 7.5 | 6.1 | 1.4 | ** | * | 8.3 | 6.3 | 2.0 | ** | * | 9.5 | 6.6 | 2.9 | ** | * | 9.8 | 6.8 | 3.0 | ** | * | 8.9 | 7.4 | 1.5 | ** | * |
| 11 | 17 | Frontal eminence | 5.5 | 4.2 | 1.3 | ** | * | 6.0 | 4.2 | 1.8 | ** | * | 5.5 | 4.9 | 0.6 | ** | * | 6.0 | 4.8 | 1.2 | ** | * | 6.2 | 4.7 | 1.5 | ** | * |
| 12 | 18 | Supraorbital | 7.3 | 5.1 | 2.2 | ** | * | 7.3 | 5.4 | 1.9 | ** | * | 7.2 | 5.9 | 1.3 | ** | * | 7.5 | 6.3 | 1.2 | ** | | 6.7 | 6.2 | 0.5 | * | |
| 14 | 9 | Lateral nasal[a] | 7.5 | 3.7 | 3.8 | ** | * | 7.4 | 3.6 | 3.8 | ** | * | 7.3 | 3.9 | 3.4 | ** | * | 8.2 | 3.8 | 4.4 | ** | * | 6.7 | 4.2 | 2.5 | ** | * |
| 15 | 19 | Suborbital | 5.2 | 8.4 | −3.2 | ** | * | 5.0 | 8.9 | −3.9 | ** | * | 5.8 | 9.7 | −3.9 | ** | * | 5.5 | 10.7 | −5.2 | ** | * | 5.8 | 10.6 | −4.8 | ** | * |
| 16 | 20 | Inferior malar[a] | 18.8 | 15.8 | 3.0 | ** | * | 19.7 | 17.8 | 1.9 | ** | | 21.5 | 20.2 | 1.3 | * | | 21.8 | 19.9 | 1.9 | ** | | 21.5 | 21.8 | −0.3 | | |
| 17 | 10 | Lateral nostril | 13.3 | 10.1 | 3.2 | ** | * | 11.7 | 9.5 | 2.2 | ** | * | 12.2 | 9.8 | 2.4 | ** | * | 12.5 | 9.7 | 2.8 | ** | ** | 11.9 | 9.6 | 2.3 | ** | * |
| 22 | 25 | Mid lateral orbit | 5.3 | 4.6 | 0.7 | ** | * | 5.2 | 4.7 | 0.5 | ** | * | 5.8 | 5.1 | 0.7 | ** | | 5.7 | 5.0 | 0.7 | ** | * | 5.6 | 4.9 | 0.7 | ** | |
| 24 | 31 | Zygomatic arch | 5.3 | 5.7 | −0.4 | ** | * | 5.3 | 6.2 | −0.9 | ** | | 5.5 | 6.9 | −1.4 | ** | ** | 5.5 | 7.5 | −2.0 | ** | * | 5.0 | 7.6 | −2.6 | ** | |
| 25 | 26 | Lateral orbit[a] | 7.5 | 7.3 | 0.2 | | | 7.6 | 9.0 | −1.4 | ** | * | 6.8 | 9.1 | −2.3 | ** | * | 8.0 | 9.4 | −1.4 | ** | * | 7.5 | 9.9 | −2.4 | ** | * |
| 26 | 21 | Supra-M2[a] | 20.2 | 25.4 | −5.2 | ** | * | 22.0 | 26.4 | −4.4 | ** | * | 21.7 | 28.1 | −6.4 | ** | * | 22.3 | 28.1 | −5.8 | ** | * | 18.8 | 30.4 | −11.6 | ** | * |
| 27 | 32 | Mid-mas. muscle[a] | 19.2 | 17.4 | 1.8 | ** | | 21.3 | 19.2 | 2.1 | ** | | 20.4 | 20.9 | −0.5 | | | 20.5 | 20.2 | 0.3 | | | 20.6 | 19.3 | 1.3 | * | |
| 29 | 22 | Sub-M2[a] | 19.0 | 17.2 | 1.8 | ** | | 18.5 | 18.2 | 0.3 | | | 18.3 | 20.5 | −2.2 | ** | | 18.3 | 20.1 | −1.8 | ** | * | 17.2 | 21.3 | −4.1 | ** | * |
| 30 | 33 | Gonion | 9.2 | 14.4 | −5.2 | ** | * | 10.1 | 15.7 | −5.6 | ** | * | 10.2 | 17.0 | −6.8 | ** | * | 12.0 | 17.5 | −5.5 | ** | * | 10.3 | 17.6 | −7.3 | ** | * |
| 31 | 28 | Mid mand. angle | 12.0 | 9.9 | 2.1 | ** | * | 11.9 | 11.3 | 0.6 | | | 12.8 | 13.7 | −0.9 | | | 14.2 | 13.8 | 0.4 | | | 13.4 | 15.5 | −2.1 | ** | * |

P1 = significance level of the Wilcoxon rank test; P2 = significance level of the alternative test, testing if the median values of our study fall within the 95% confidence intervals for the median as reported by Helmer.

[a] Landmark with a slight different localisation between the two studies.

* $p < 0.05$.

** $p < 0.01$.

Table 9
Comparison of the De Greef et al. (KUL) tissue depth measurements with the Manhein (MAN) study (2000)

Males

| Point numbers and description | | | 19–34 Years | | | | 35–45 Years | | | | 46–55 Years | | | | >56 Years | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUL | MAN | | MAN, 28 | KUL, 163 | DIFF | P | MAN, 10 | KUL, 32 | DIFF | P | MAN, 5 | KUL, 21 | DIFF | P | MAN, 5 | KUL, 19 | DIFF | P |
| 2 | 1 | Glabella | 5.0 | 4.9 | 0.1 | | 5.5 | 4.9 | 0.6 | ** | 6.0 | 5.3 | 0.7 | ** | 5.6 | 5.4 | 0.2 | |
| 3 | 2 | Nasion | 6.0 | 5.9 | 0.1 | | 6.4 | 6.0 | 0.4 | * | 7.2 | 6.4 | 0.8 | * | 6.6 | 6.7 | −0.1 | |
| 4 | 3 | End of nasal | 1.9 | 2.8 | −0.9 | ** | 2.4 | 2.8 | −0.4 | ** | 1.8 | 3.0 | −1.2 | ** | 2.0 | 3.1 | −1.1 | ** |
| 5 | 5 | Mid-philtrum | 11.9 | 11.2 | 0.7 | ** | 10.6 | 10.2 | 0.4 | | 8.0 | 9.7 | −1.7 | ** | 9.4 | 9.7 | −0.3 | |
| 8 | 6 | Chin–lip fold | 11.1 | 10.0 | 1.1 | ** | 13.1 | 10.6 | 2.5 | ** | 11.6 | 10.6 | 1.0 | * | 12.2 | 10.3 | 1.9 | ** |
| 9 | 7 | Mental eminence | 10.0 | 9.4 | 0.6 | ** | 12.0 | 10.5 | 1.5 | ** | 11.0 | 10.6 | 0.4 | | 11.8 | 10.4 | 1.4 | |
| 10 | 8 | Beneath chin | 7.2 | 6.1 | 1.1 | ** | 8.0 | 6.2 | 1.8 | ** | 7.2 | 6.4 | 0.8 | * | 5.6 | 6.6 | −1.0 | * |
| 33 | 9 | Supraorbital | 5.3 | 5.0 | 0.3 | ** | 5.9 | 5.1 | 0.8 | ** | 7.7 | 5.6 | 2.1 | ** | 5.6 | 5.8 | −0.2 | |
| 36 | 10 | Suborbital | 5.8 | 8.2 | −2.4 | ** | 6.2 | 9.4 | −3.2 | ** | 6.8 | 9.9 | −3.1 | ** | 5.0 | 9.3 | −4.3 | ** |
| 38 | 4 | Lateral nostril | 7.5 | 9.9 | −2.4 | ** | 9.8 | 9.7 | 0.1 | | 10.4 | 9.3 | 1.1 | * | 10.8 | 10.1 | 0.7 | |
| 40 | 11* | Supra canina[a] | 11.9 | 10.3 | 1.6 | ** | 10.1 | 10.2 | −0.1 | | 10.0 | 9.4 | 0.6 | | 9.2 | 9.0 | 0.2 | |
| 41 | 12* | Sub canina[a] | 11.5 | 10.3 | 1.2 | ** | 10.2 | 10.7 | −0.5 | * | 10.0 | 10.6 | −0.6 | | 11.8 | 10.1 | 1.7 | ** |
| 43 | 16 | Mid lateral orbit | 4.2 | 4.6 | −0.4 | ** | 4.3 | 4.9 | −0.6 | * | 5.4 | 4.9 | 0.5 | * | 5.2 | 4.5 | 0.7 | ** |
| 45 | 19 | Zygomatic arch | 7.8 | 5.6 | 2.2 | ** | 6.6 | 6.0 | 0.6 | * | 5.4 | 6.2 | −0.8 | ** | 5.2 | 6.1 | −0.9 | * |
| 46 | 17 | Lateral orbit | 7.8 | 7.3 | 0.5 | ** | 8.2 | 8.0 | 0.2 | | 8.2 | 8.3 | −0.1 | | 6.4 | 7.6 | −1.2 | ** |
| 47 | 13 | Supra-M2 | 28.5 | 24.7 | 3.8 | ** | 24.6 | 25.3 | −0.7 | | 28.2 | 25.6 | 2.6 | ** | 23.6 | 24.3 | −0.7 | |
| 50 | 14 | Sub-M2 | 25.1 | 17.0 | 8.1 | ** | 21.1 | 17.8 | 3.3 | ** | 21.4 | 18.0 | 3.4 | ** | 20.6 | 19.2 | 1.4 | |
| 51 | 18 | Gonion | 20.0 | 14.4 | 5.6 | ** | 19.6 | 15.2 | 4.4 | ** | 19.0 | 14.2 | 4.8 | ** | 14.0 | 13.6 | 0.4 | |
| 52 | 15 | Mid mand. angle | 14.8 | 9.8 | 5.0 | ** | 15.6 | 11.1 | 4.5 | ** | 15.4 | 11.9 | 3.5 | ** | 11.4 | 12.3 | −0.9 | |

Females

| Point numbers and description | | | 19–34 Years | | | | 35–45 Years | | | | 46–55 Years | | | | >56 Years | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KUL | MAN | | MAN, 52 | KUL, 141 | DIFF | *p* | MAN, 15 | KUL, 34 | DIFF | *p* | MAN, 6 | KUL, 31 | DIFF | *p* | MAN, 9 | KUL, 47 | DIFF | *p* |
| 2 | 1 | Glabella | 4.8 | 5.1 | −0.3 | ** | 4.7 | 4.9 | −0.2 | * | 4.8 | 4.7 | 0.1 | | 5.2 | 5.3 | −0.1 | |
| 3 | 2 | Nasion | 5.5 | 6.2 | −0.7 | ** | 5.3 | 6.3 | −1.0 | ** | 6.2 | 6.2 | 0.0 | | 6.0 | 7.1 | −1.1 | ** |
| 4 | 3 | End of nasal | 1.8 | 2.6 | −0.8 | ** | 1.6 | 2.5 | −0.9 | ** | 1.8 | 2.6 | −0.8 | ** | 1.8 | 2.5 | −0.7 | ** |
| 5 | 5 | Mid-philtrum | 9.1 | 9.7 | −0.6 | ** | 7.4 | 8.9 | −1.5 | ** | 8.0 | 7.9 | 0.1 | | 8.0 | 8.2 | −0.2 | |
| 8 | 6 | Chin–lip fold | 10.3 | 9.7 | 0.6 | ** | 9.6 | 10.6 | −1.0 | ** | 9.8 | 10.1 | −0.3 | | 11.4 | 10.6 | 0.8 | ** |
| 9 | 7 | Mental eminence | 9.2 | 9.6 | −0.4 | * | 9.2 | 10.4 | −1.2 | ** | 10.7 | 9.4 | 1.3 | ** | 12.3 | 10.5 | 1.8 | ** |
| 10 | 8 | Beneath chin | 6.0 | 5.6 | 0.4 | ** | 5.4 | 6.1 | −0.7 | * | 6.7 | 5.3 | 1.4 | ** | 8.0 | 6.9 | 1.1 | ** |
| 33 | 9 | Supraorbital | 5.7 | 5.4 | 0.3 | ** | 5.5 | 5.3 | 0.2 | | 6.5 | 5.2 | 1.3 | ** | 6.3 | 5.5 | 0.8 | ** |
| 36 | 10 | Suborbital | 6.1 | 9.3 | −3.2 | ** | 5.7 | 10.3 | −4.6 | ** | 7.3 | 9.1 | −1.8 | ** | 7.0 | 10.3 | −3.3 | ** |
| 38 | 4 | Lateral nostril | 8.6 | 9.2 | −0.6 | ** | 8.0 | 9.4 | −1.4 | ** | 10.8 | 8.7 | 2.1 | ** | 9.8 | 9.3 | 0.5 | * |
| 40 | 11* | Supra canina[a] | 9.3 | 9.3 | 0.0 | | 7.8 | 8.6 | −0.8 | * | 7.7 | 8.1 | −0.4 | | 8.0 | 8.1 | −0.1 | |
| 41 | 12* | Sub canina[a] | 9.4 | 10.1 | −0.7 | ** | 8.7 | 10.8 | −2.1 | ** | 9.0 | 9.9 | −0.9 | ** | 9.7 | 10.9 | −1.2 | ** |
| 43 | 16 | Mid lateral orbit | 4.7 | 4.9 | −0.2 | * | 4.3 | 4.8 | −0.5 | * | 4.5 | 5.0 | −0.5 | * | 4.9 | 5.0 | −0.1 | |
| 45 | 19 | Zygomatic arch | 7.4 | 6.9 | 0.5 | ** | 4.9 | 6.7 | −1.8 | ** | 6.0 | 7.4 | −1.4 | ** | 7.4 | 6.5 | 0.9 | ** |
| 46 | 17 | Lateral orbit | 9.3 | 9.8 | −0.5 | ** | 8.7 | 10.0 | −1.3 | ** | 10.2 | 9.6 | 0.6 | | 11.0 | 9.8 | 1.2 | ** |
| 47 | 13 | Supra-M2 | 26.3 | 26.2 | 0.1 | | 25.1 | 26.6 | −1.5 | * | 27.2 | 26.8 | 0.4 | | 29.4 | 27.1 | 2.3 | ** |
| 50 | 14 | Sub-M2 | 23.4 | 18.6 | 4.8 | ** | 20.1 | 18.4 | 1.7 | * | 21.7 | 18.4 | 3.3 | ** | 27.2 | 20.6 | 6.6 | ** |
| 51 | 18 | Gonion | 17.4 | 14.4 | 3.0 | ** | 15.3 | 14.3 | 1.0 | | 14.7 | 14.0 | 0.7 | | 16.9 | 13.6 | 3.3 | ** |
| 52 | 15 | Mid mand. angle | 13.7 | 11.3 | 2.4 | ** | 12.6 | 11.4 | 1.2 | ** | 13.0 | 11.3 | 1.7 | ** | 17.4 | 13.6 | 3.8 | ** |

*p* = significance level of the *t*-test.
[a] Landmark with a slight different localisation between the two studies.
* $p < 0.05$.
** $p < 0.01$.

## 4. Discussion

The present study has produced a set of facial soft tissue depth measurements for the contemporary adult Caucasian population. This new dataset is an upgrade of the traditional datasets in the number of landmarks and in the finer subdivision of the tested population according to age and BMI.

Statistical tests, comparing the traditional studies with the present study, showed a majority of the measurements being significantly different. Due to the lack of raw data of the traditional studies, we were forced to use fairly weak tests based on comparison of our measurements to the reported means and medians. Furthermore, these tests do not take into account the variation of the measurements in the traditional studies since

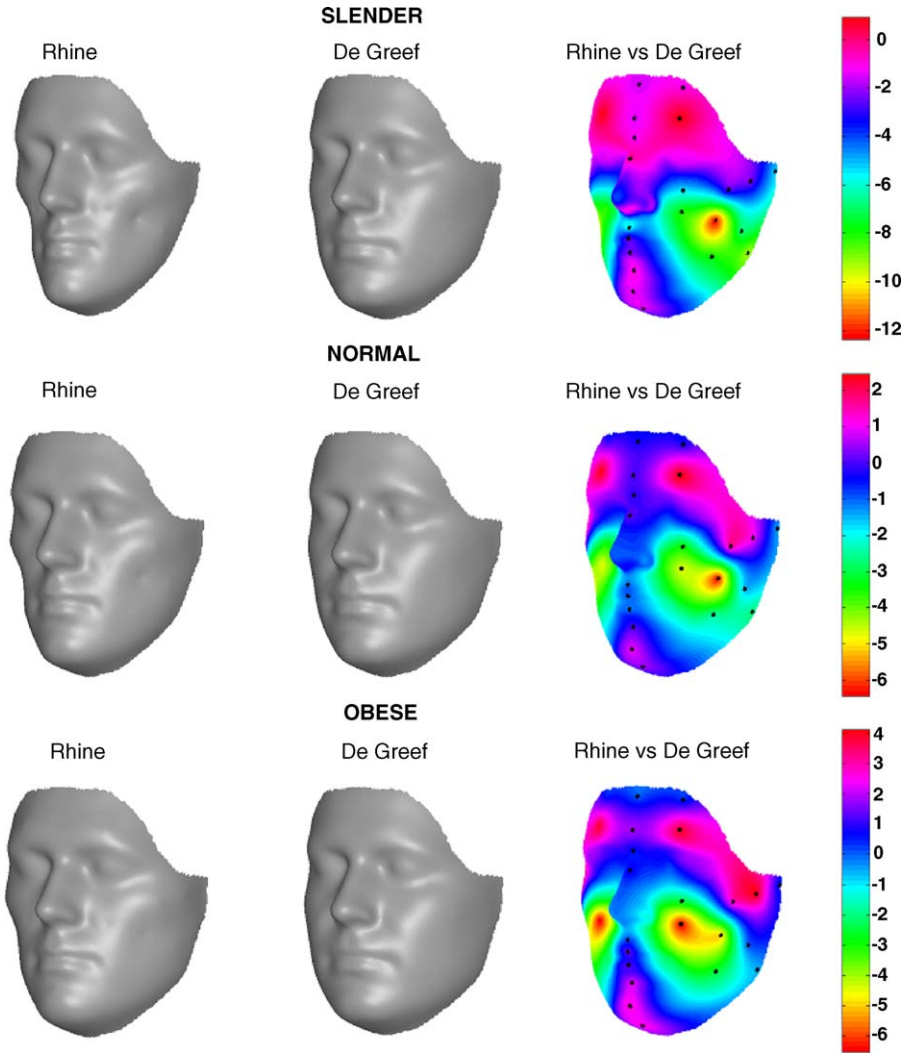


Fig. 4. Facial outlook of the Rhine and Moore subcategories based on the original results (left), the results of De Greef et al. (middle) and the difference between them color-coded (right) based on the common landmarks (black).

this was either not available [2] or only reported as ranges and confidence intervals on the median [3]. However, the relatively high number of observations per subcategory in our study makes the tests very sensitive such that even very small differences become statistically significant. Notwithstanding this, the lack of coherence between the older datasets and ours can be attributed to a number of factors. First, as mentioned before, the small amount of subjects in most of the subpopulations in the traditional studies. Second, in ex-vivo studies post-mortem alterations such as dehydration and putrification have an impact on the soft tissue depths, despite the freshness of the cadavers. Third, post-mortem measurements correspond to supine subject positioning coding also for gravity-related influences, which was also shown during the validation study [1] revealing discrepancies in those regions that are influenced the most by gravitational differences between the supine (CT) and upright (our protocol) measurement positioning. Finally, the criteria to define the subpopulations in our dataset, to compare with the corresponding subpopulation in the older data, play an important role in the differences observed. This is especially true in the comparison with the Rhine and Moore study where body posture definitions (slender, normal, obese) are based on visual assessment and are not perfectly matched to the three BMI categories (<20, 20<>25, >25) defined in our study. The Manhein study appeared to correspond better to our study than the Helmer study, although both divided their subpopulation based on gender and age. However, in the selection of the Manhein population, an extra BMI criterion (20–25) was used, since they reported on White adults of ‘‘normal’’ weight. Such a body posture selection was not performed in the Helmer study.

From the craniofacial approximation point of view these last observations indicate that narrowing down the scope of the selected subpopulation will probably approximate more the correct tissue depth necessary to produce a more accurate approximation.

Although the tests on bilateral symmetry indicated about half of the lateral landmarks to be statistically different left

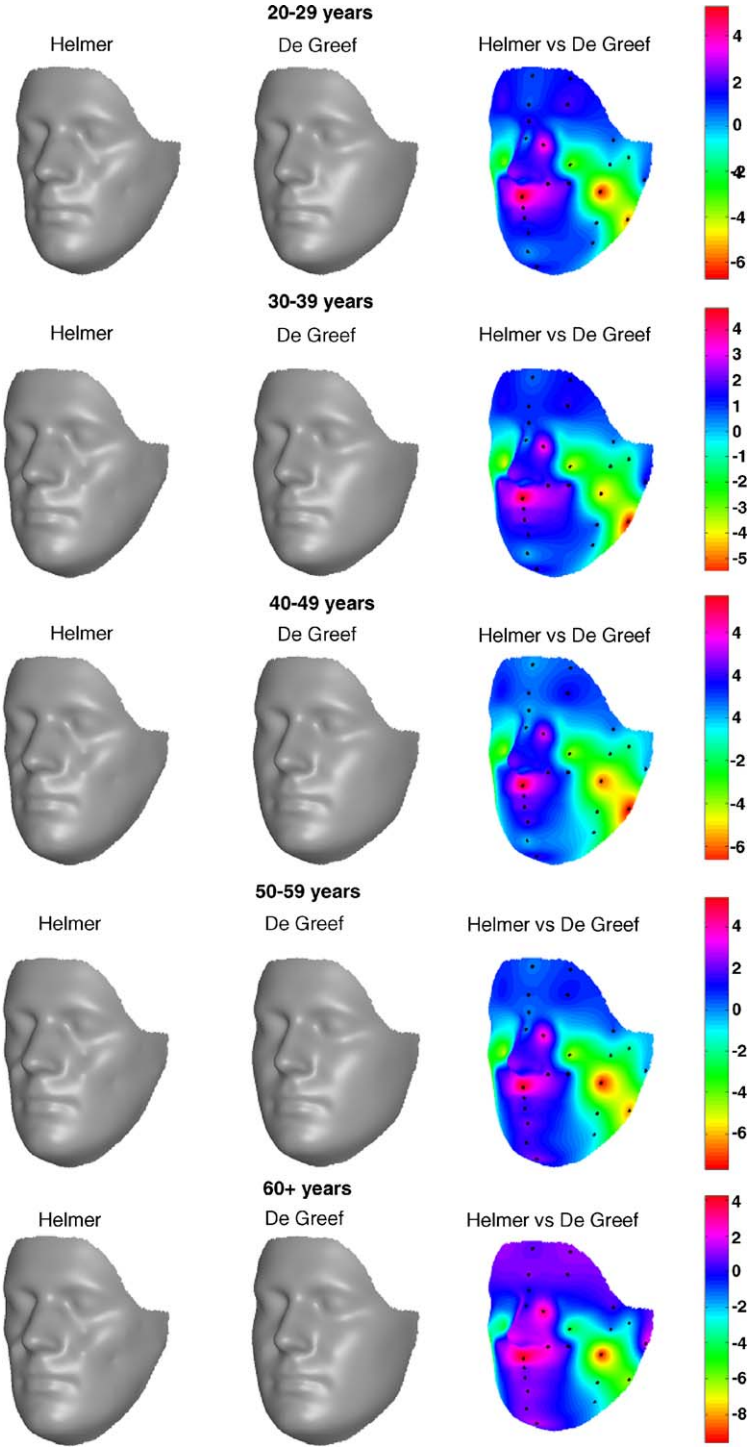


Fig. 5. Facial outlook of the Helmer subcategories based on the original results (left), the results of De Greef et al. (middle) and the difference between them color-coded (right) based on the common landmarks (black).

versus right, the values are so small both in absolute (<1 mm) and relative (<6%) values to be most probably not significant from a cranio-facial approximation point of view. As a result, in the final tables we report only the lateral values measured on the right side of the face of all individuals ($N = 967$). The regression equations showed that the influence of the BMI as coded by the partial regression coefficient ($b_2$) is typically, but not systematically, higher than the influence of age ($b_1$), even when corrected for the relative differences in standard deviation of BMI and age (a factor of about 4). This also confirms the importance to dissociate the individual properties of the subjects, especially when studying the impact of gender, age or BMI on the facial soft tissue depth measurements. However, although some initial observations have been formulated on

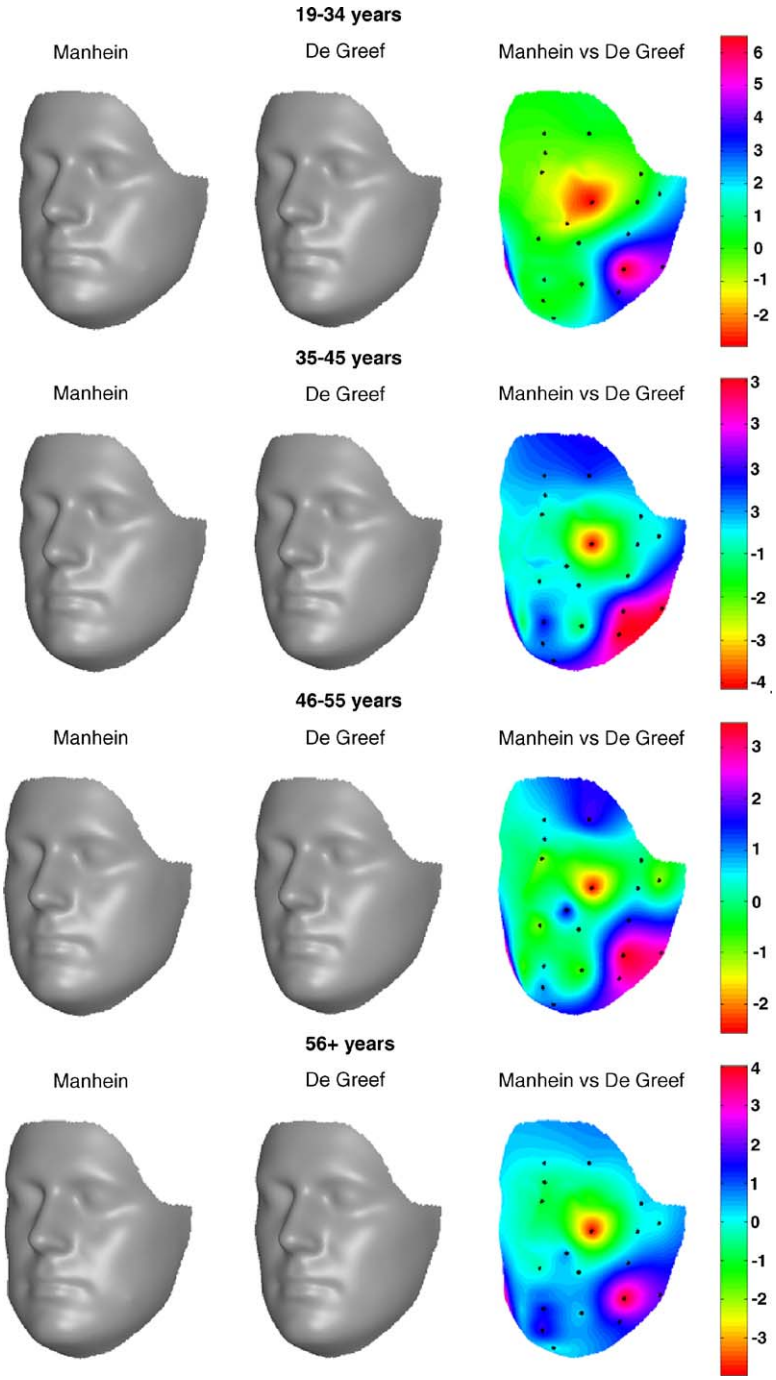


Fig. 6. Facial outlook of the Manhein subcategories based on the original results (left), the results of De Greef et al. (middle) and the difference between them color-coded (right) based on the common landmarks (black).

such possible effects, any formal statistical analysis, substantiating these observations in conjunction with a multivariate statistical analysis of the data, exploring statistically significant covariations of soft tissue depths at different landmarks, e.g., is beyond the scope of this paper.

## 5. Conclusions

In order to increase the degree of accuracy of cranio-facial approximations, a validated dataset with an increased number of landmarks, coding for more refined subject-specific attributes is provided. Not only will this allow a better determination of the facial contours, it opens new perspectives in understanding the relation between the physical properties of the subject and his facial soft tissue depths.

Forensic facial approximation is a discipline that traditionally combines art and science. A correct soft tissue envelope with individual variations will never be accurately determined using average tissue depth data [9]. By providing the forensic artist with more refined tissue depth data as presented in this

paper, we conjecture that more subject-specific cranio-facial reconstructions can be obtained on a more scientific basis.

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