





Three-Dimensional Soft-Tissue Facial Morphometry in Caucasian Obese Adults

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Abstract

Objective: To evaluate the facial morphology of Caucasian obese adults in relation to normal weight peers, and to study the association between three-dimensional soft-tissue facial measurements and cardiometabolic risk factors. **Material and Methods:** Nineteen Caucasian obese subjects aged 25 to 73 years underwent anthropometric measurements, blood samples and a stereophotogrammetric facial scan. Soft-tissue facial linear distances, angles, and volumes were obtained and compared to those collected on normal weight subjects by computing z-scores. Spearman correlation was used to assess the associations between facial measurements and metabolic parameters. Logistic regression analysis adjusted for sex and age was used to assess the risk of metabolic syndrome associated to the facial measurements. **Results:** Overall, when compared to normal weight persons, obese adults had a wider face in the horizontal dimension, with a middle face (maxilla) that was larger both in absolute value and relatively to the lower face (mandible), and a larger right side gonial angle (Wilcoxon test, $p < 0.01$). Only the mean (left and right) gonial angle was positively associated to serum triglycerides level, while the other facial measurements were associated with none of the cardiometabolic parameters. Moreover, none of the facial measurements was associated with the risk of metabolic syndrome. **Conclusion:** Despite larger facial dimensions and altered mandible/maxilla volume ratio, three-dimensional soft-tissue facial morphometry in Caucasian obese adults is not related to cardiometabolic risk factors. The actual association between morphological facial characteristics and clinical information on the health conditions of patients is still to be investigated.

Keywords: Anthropometry; Metabolic Syndrome; Obesity.

Introduction

Obesity is constantly increasing worldwide, becoming one of the major health issues. A recent investigation reports that 2.1 billion of people in 2013 were overweight or obese [1]. Over consumption of food, low physical activity and environmental and genetic factors are considered the main reasons of the epidemic development of obesity. This health issue is particularly relevant because general and abdominal obesity are the main risk factors for metabolic syndrome (MS), a cluster of risk factors including abdominal obesity, impaired fasting glucose, raised blood pressure, elevated triglyceride levels and low HDL levels, type 2 diabetes, cardiovascular disease and other causes of death [2,3].

Numerous studies on human face suggest that morphological facial characteristics can provide clinical information on the present and future health conditions of patients [4-9]. One of them reports that cheeks status, neck circumference and craniofacial morphology are associated with type 2 diabetes and hypertension [6]. Another study, using computed tomography, reveals that buccal fat is related to visceral abdominal fat, suggesting that plump cheeks could be a potential risk factor for the metabolic allies of obesity [4]. Similarly, further studies, using non-invasive methods, report that facial adiposity is related to Body Mass Index (BMI) and to cardiometabolic risk factors [5]. Nevertheless, the association between soft-tissue facial characteristics and MS is not thoroughly investigated. Moreover, limited investigations assessed the differences in facial dimensions between obese and normal weight subjects, despite the availability of novel non-invasive and convenient methods.

Indeed, quantitative soft-tissue facial data in the three dimensions can currently be obtained by digital, computerized anthropometry [10-21]. Current technology allows fast and non-invasive optical scans of facial surface, providing a global assessment of patients. Selected three-dimensional anthropometric measurements can be obtained without actual physical contact with the instruments, thus abolishing any kind of compression of cutaneous and subcutaneous tissues.

A previous photographic study on Korean adults reported that frontal plane measurements (mandibular width and the distance between the inferior most points on the ear lobes) are important indicators for discriminating between normal and visceral obese subjects [8]. However, this study is limited by interethnic variability in facial dimensions [22], and the relevant findings cannot be extrapolated to Caucasian adults.

In children and adolescents previous studies reported bimaxillary prognathism and relatively greater horizontal and anteroposterior facial measurements in obese subjects compared to normal-weighted peers [23-26]. Nevertheless, no evidence that facial morphology is importantly related to cardiometabolic outcomes was found in a large cohort of adolescents [17]. Studies on obese adults mostly focused on patients with obstructive sleep apnea (OSA) [26], while investigations on the relationships among obesity, facial morphometry and MS have not been conducted so far.

In the current investigation, the three-dimensional characteristics of the facial soft tissues have been assessed in a group of adult Caucasian obese patients. The subjects were measured by a

non-invasive, stereophotogrammetric instrument, and facial volumes, angles and distances were computed, and compared to those obtained in healthy subjects of the same age, sex and ethnic group. Finally, we studied the association between such facial morphological measurements and MS and its components.

Material and Methods

Subjects

Nineteen Caucasian (Southern Europe) obese subjects (nine men, ten women) aged 25 to 73 years (48 ± 15 years) were recruited at the International Center for the Assessment of Nutritional Status (ICANS, Università degli Studi di Milano). Subjects with previous history of craniofacial surgery, trauma or congenital anomalies were excluded. None reported respiratory problems, or had symptoms/ signs compatible with obstructive sleep apnoea. All subjects underwent anthropometric measurements by a trained dietitian and their faces were scanned using a stereophotogrammetric instrument. Blood samples were obtained in fasting state in order to measure biochemical markers.

Morphological facial data of 355 normal weight subjects obtained in a previous study [27] were used as standard reference. Reference subjects were divided for sex and age as follows: 18-30 years (80 men and 58 women); 31-40 years (66 men and 28 women); 41-50 years (27 men and 26 women); 51-64 years (19 men and 18 women); 65-80 years (18 men and 15 women).

Based on our previous experience in assessing three-dimensional soft-tissue facial morphometry in normal weight and obese children [24], we found that the sample enrolled in the present study ensured for many measurements a statistical power larger than 80% (in some cases, 100%).

Anthropometric Measurements

Anthropometric measurements were performed following international guidelines [28]. Body weight was measured to the nearest 100 g using a Seca 700 scale and height was measured to the nearest 0.1 cm using a Seca 217 vertical stadiometer (Seca Corporation, Hanover, MD, USA). BMI was calculated as weight (kg)/ height (m²) and classified according to the World Health Organization. Waist circumference was measured midway between the lower rib margin and the superior anterior iliac spine. Skinfolds (triceps, biceps, subscapular and suprailiac) were measured using a Tanner-Whitehouse caliper (Holtain Ltd, Crymych, UK). The skinfolds were then summed to obtain the sum of four skinfolds (SF4). In our Center, the intra-observer coefficient of variation for repeated measurements of these skinfolds is $\leq 2.9\%$. The sum of the four skinfolds was used to estimate body density using Durnin and Womersley's formula [29]. Later, body density was used to estimate fat mass using Siri's Formula [30].

Facial Measurements

The data collection procedure for facial measurements took place in two separate steps, and it was followed by off-line calculations [11,12]. At first, for each patient, a single experienced operator

located a set of 50 soft-tissue landmarks by inspection and/or palpation, and marked them on the cutaneous surface using an eye-liner. During landmarking, the patients sat relaxed in a position suitable for a correct identification of facial features.

In the second step, soft-tissue facial morphology was acquired by a three-dimensional stereophotogrammetry imaging system (Vectra-3D; Canfield Scientific Inc., Fairfield, NJ, USA). This imaging system is a modular 3D image capturing system constructed to capture and process stereo images; it consists of two pods, each including three cameras (two black and white, one colour) and a projector. The projector projects a random light pattern onto the face, and the cameras record synchronized pairs of two-dimensional images of the subjects with 2 ms. Using dedicated software, the information is employed to work out a three-dimensional reconstruction that subsequently can be processed, analyzed, manipulated and measured. The colour camera provides a live texture that is added to the three-dimensional data.

The reproducibility of stereophotogrammetric technology was well documented [16,18,19,31-33]. In our laboratory, no systematic errors between operators, calibrations and acquisitions were found; random errors in landmark identification were always lower than 1.2 mm [10], and the repeatability of most linear measurements and angles ranged from 82.2 to 98.7% [18].

The three-dimensional images obtained from the subjects were analyzed, and a subset of facial landmarks, 10 on the midline and 10 paired, were identified and digitized for the current study (Figure 1). The x, y, and z coordinates of the landmarks were used to calculate a set of facial linear distances, angles, and volumes [12,14,24]:

- Distances (unit: mm): upper (n-sn) and lower anterior facial heights (sn-pg); middle (zy-zy), and lower facial widths (go-go); landmark-to-line: middle [sn-(tr-tl)], and lower facial depths [pg-(tr-tl)];
- Angles (unit: degrees): naso-labial angle (prn-sn-ls); interlabial angle ($[\text{sn-ls}]^{\wedge}[\text{li-sl}]$); mentolabial angle (li-sl-pg); right and left gonial angles (t-go-pg);
- Volumes (unit: mm³): volumes of all facial structures from the external cutaneous surface up to a quasi-frontal plane passing through trichion, tragi and gonion; in particular, facial middle (maxilla), and lower third volumes (mandible) were considered; upper and lower lip volumes;
 - a) Facial middle third volume (maxilla): comprised between a quasi-horizontal plane passing through the tragi and the exocanthia, and a plane connecting the cheilion landmarks and the tragi, approximately corresponding to the maxillary and cheek regions;
 - b) Facial lower third volume (mandible): comprised between the cheilion-tragi plane and a plane drawn between pogonion and the gonion, approximately corresponding to the mandibular region;
 - c) Lip volumes: upper lip volume (approximated from the volumes of two tetrahedra: the first tetrahedron has the plane chr, chl, ls as its base and vertex in sn, the second has the plane chr, chl, ls as its base and vertex in sto); lower lip volume (as above, first tetrahedron with the plane chr, chl, li as its base and vertex in sl, the second with the plane chr, chl, li as its base and vertex in sto);
- Ratio (unit: %): mandibular to maxillary volume.

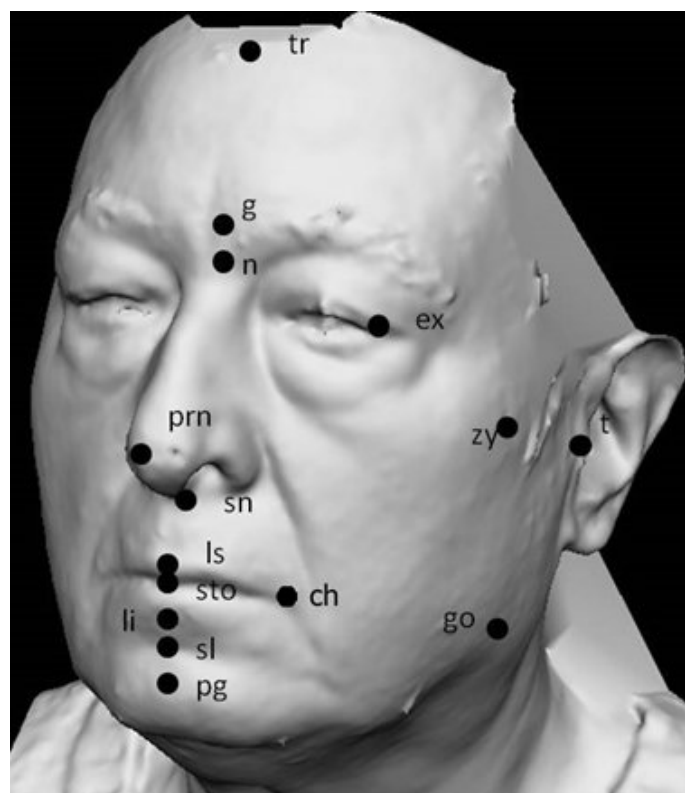


Figure 1. Soft tissue facial landmarks used in the current study: tr, trichion; g, glabella; n, nasion; prn, pronasale; sn, subnasale; ls, labiale superius; sto, stomion; li, labiale inferius; sl, sublabiale; pg, pogonion; ex, exocanthion; zy, zygion; t, tragion; ch, cheilion; go, gonion.

Metabolic Measurements

Fasting HDL cholesterol, triglycerides and glucose were measured using an enzymatic method (Cobas Integra 400 Plus, Roche Diagnostics, Rotkreuz, Switzerland). Blood pressure was measured by a physician using a random-zero mercury sphygmomanometer following JNC 7 guidelines [34].

Metabolic syndrome was diagnosed using the harmonized international definition [35]. Large waist was defined as waist circumference larger than 102 cm in men and 88 cm in women, low HDL-cholesterol as HDL-cholesterol <40 mg/dl in men and <50 mg/dl in women, high triglycerides as triglycerides ≥150 mg/dl, high blood pressure as systolic blood pressure ≥130 mm Hg or diastolic blood pressure ≥85 mm Hg, and high glucose as glucose ≥100 mg/dl. MS was defined when patients had 3 or more of the above components.

Data Analysis

Anthropometric facial data of the patients were compared to those collected in reference subjects by computing z-scores. In the 355 reference, control individuals, descriptive statistics were calculated for each variable separately for each age group and sex. The individual measurements obtained in the 19 patients were transformed to z-scores. The z-score measures the distance between a patient datum and the reference mean expressed in standard deviation units: $z\text{-score} = (\text{patient}$

value – mean value of the reference group)/ standard deviation of the reference group [11,14,20,21,24]. For each patient, calculations were performed using values of the reference group of the same sex and corresponding age [11,20,21].

Z-scores were used because the reduced number of patients impeded separate sex- and age-related analyses. Overall, this procedure permits to partially control for the mixed composition of the patient group. The procedure has already been used in previous investigations on the craniofacial characteristics of individuals with genetic or acquired alterations [14,20,21,24].

Descriptive statistics (50° percentile and interquartile range) were computed for the values of the soft-tissue facial z-scores, as well as for the anthropometric and metabolic variables. Males and female data were compared by Mann-Whitney test. Significance of the z-scores was assessed by Wilcoxon test (if the patient value is equal to the mean value of the reference group, the z-score is zero; the null hypothesis of the test is that the z-scores are null). Spearman correlation was used to assess the associations between three-dimensional soft-tissue facial distances, angles and volumes of obese subjects and metabolic parameters. Finally, logistic regression analysis was used to assess the risk of metabolic syndrome associated to the higher/lower values of the z-scores of the three-dimensional soft-tissue facial distances, angles and volumes of obese subjects. Several of the analyzed variables were interrelated, and the level of significance was set at 1% ($p < 0.01$), with two-sided tests used for all calculations.

Ethical Aspects

The study was carried out according to the Declaration of Helsinki and all subjects gave written informed consent. The institutional review board approved the study procedures (Ethics Committee of Università degli Studi di Milano, Protocol no. 230 92/2014).

Results

The anthropometric measurements, the metabolic characteristics and the three-dimensional soft-tissue facial distances, angles and volumes (expressed as z-scores) of obese subjects recruited in the current study are reported in Table 1.

Metabolic syndrome was identified in nine patients. Significant and expected sex differences were found only for standing height and for percentage fat mass. The discrepancy of soft-tissue facial characteristics from control subjects of the same sex and age (as assessed by z-scores) had no sex-related differences. Therefore, pooled z-scores were used in all subsequent analyses. Overall (Figure 2), the faces of obese patients were significantly larger in the horizontal dimension than those of control subjects (lower facial width, go-go), with a larger middle facial third (maxillary volume), and had a larger right side gonial angle (t-go-pg, Wilcoxon test, $p < 0.01$). The mandible-to-maxilla volume ratio was significantly reduced in obese patients.

Table 1. Anthropometric measurements, metabolic characteristics and three-dimensional soft-tissue facial distances, angles and volumes of obese patients.

Variables		Women			Men			Total			p-value
		P50	P25	P75	P50	P25	P75	P50	P25	P75	
Age	Years	49.5	29.0	55.0	52.0	41.0	61.0	52.0	30.0	58.0	ns
Nutritional Status											
Body Weight	kg	91.3	81.1	96.0	100.8	98.5	111.8	96.0	85.5	105.8	NS
Standing Height	m	1.6	1.6	1.7	1.8	1.7	1.8	1.7	1.6	1.8	0.004
Bmi	kg/m ²	33.4	33.0	37.0	31.3	30.8	34.8	33.0	31.2	36.3	ns
Σ Skinfolds	mm	122.2	111.1	139.4	111.8	110	124	114.6	110	129.8	ns
Fat Mass	%	43.8	41.5	45.8	37.0	35.6	37.3	39.5	36.6	45.0	0.001
Waist Circumference	cm	104.8	102.4	106.9	111.4	106.3	114.9	106.3	103.2	114	ns
Metabolic Parameters											
Triglycerides	mg/dl	97.6	85.0	122.0	99.0	88.0	116.0	99.0	85.0	122.0	ns
HDL-Cholesterol	mg/dl	53.5	50.0	60.0	52.0	37.0	60.0	52.0	43.1	60.0	ns
Fasting Glucose	mg/dl	94.0	81.0	110.0	94.0	89.0	99.0	94.0	87.0	101.0	ns
Systolic Blood Pressure	mm Hg	130.0	120.0	140.0	135.0	125.0	140.0	135.0	120.0	140.0	ns
Diastolic Blood Pressure	mm Hg	83.0	80.0	90.0	88.0	80.0	90.0	85.0	80.0	90.0	ns
Three-Dimensional Soft-Tissue Measurements (z-scores)											
n-sn		1.03	0.07	1.91	0.46	-1.18	1.10	0.76	-0.99	1.72	ns
sn-pg		-0.25	-0.47	0.15	-0.56	-1.50	0.03	-0.43	-1.30	0.15	ns
zy-zy		0.15	-0.51	2.58	0.76	0.36	1.51	0.52	-0.09	1.70	ns
go-go		2.79	2.60	3.04	1.62	1.12	2.22	2.60	1.32	2.93	ns
sn-(t-t)		-0.14	-0.65	0.61	0.68	0.56	0.95	0.56	-0.32	0.95	ns
pg-(t-t)		0.54	-0.10	0.95	0.41	-0.41	1.53	0.41	-0.41	1.06	ns
li-sl-pg		0.35	-0.43	0.64	0.32	-0.14	0.79	0.33	-0.43	0.79	ns
(sn-sl)^(li-sl)		0.21	-0.19	0.89	-0.03	-0.28	1.14	0.11	-0.28	1.14	ns
prn-sn-ls		0.35	-0.09	1.32	0.49	-0.39	1.38	0.49	-0.38	1.38	ns
t-go-pg R		0.43	0.11	1.23	0.33	-0.06	0.52	0.33	-0.06	0.69	ns
t-go-pg L		-0.14	-0.46	0.00	0.15	-0.08	0.89	-0.07	-0.33	0.31	ns
Maxilla Volume		1.55	1.18	2.01	1.77	0.60	2.30	1.77	0.60	2.30	ns
Mandible Volume		-0.14	-0.84	0.99	0.83	-0.52	1.07	0.16	-0.76	1.07	ns
Mandible/ Maxilla Volume Ratio		-1.16	-1.51	-0.63	-0.88	-1.26	0.02	-1.03	-1.35	-0.50	ns
Upper Lip Volume		-0.16	-1.17	0.25	-0.12	-0.5	0.16	-0.12	-1.17	0.25	ns
Lower Lip Volume		0.01	-1.34	1.29	-0.22	-0.88	0.34	-0.07	-1.06	1.09	ns

Probability values of Mann-Whitney test women *versus* men; ns: not significant (p>0.01).

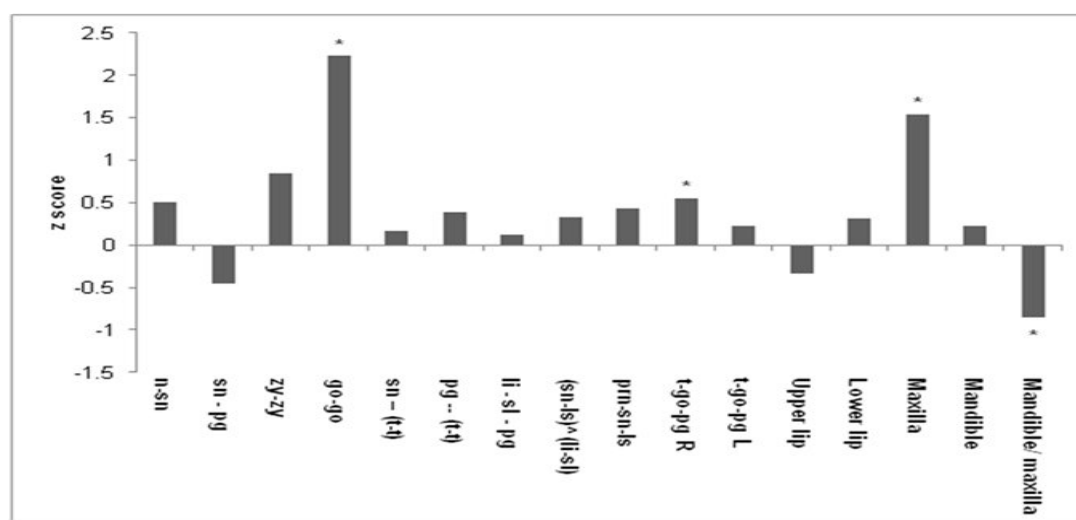


Figure 2. Facial soft tissues in obese patients (male and female data pooled). All values are z-scores obtained using sex- and age-related reference data. *The z-score is significantly different from zero (p<0.01, Wilcoxon test).

The associations between soft-tissue facial characteristics and cardiometabolic risk factors are reported in Table 2. The mean (left and right) gonial angle was positively associated to serum triglycerides level. However, the other three-dimensional soft-tissue facial measurements were associated with none of the cardiometabolic parameters considered in the present study. Moreover, the logistic regression adjusted for sex and age showed no associations between the three-dimensional soft-tissue facial distances, angles and volumes with the risk of metabolic syndrome (Table 3). All confidence intervals comprised 1, thus showing no significant increment or decrement of risk.

Table 2. Association between facial anthropometric characteristics and cardiometabolic risk factors.

Facial Landmarks	Waist	Triglycerides	HDL	Glucose	Systolic	Diastolic
	Circumference				Blood Pressure	Blood Pressure
n-sn	-0.239	0.088	-0.267	0.001	0.02	-0.041
zy-zy	0.046	0.437	-0.226	0.015	0.259	0.222
go-go	0.156	-0.427	0.099	0.319	0.101	-0.161
sn-pg	0.039	0.118	0.283	-0.126	-0.4	-0.1
sn-(t-t)	-0.032	0.239	-0.285	0.139	0.207	0.179
pg-(t-t)	-0.15	0.386	0.006	0.114	-0.13	-0.173
li-sl-pg	0.437	0.254	-0.313	-0.437	0.068	0.156
(sn-ls)^(li-sl)	-0.379	0.271	0.023	-0.107	-0.081	-0.115
prn-sn-ls	-0.381	0.191	-0.245	0.167	0.293	0.304
t-go-pg	0.294	0.499*	0.123	-0.238	0.175	0.166
Upper Lip	0.147	-0.06	0.258	0.189	-0.144	0.016
Lower Lip	-0.333	0	-0.018	-0.024	-0.228	-0.249
Maxilla	-0.279	0.2	0.04	0.333	0.045	-0.006
Mandible	-0.273	-0.047	-0.026	0.077	-0.252	-0.261
Mandible/Maxilla	-0.041	-0.32	-0.069	-0.495	-0.294	-0.188

Values are Spearman coefficients; *p<0.01.

Table 3. Association between three-dimensional soft-tissue facial distances, angles and volumes and risk of metabolic syndrome.

Three-Dimensional Soft-Tissue Facial Distances	Metabolic Syndrome OR (95% CI)
n-sn	1.270 (0.578 - 2.792)
zy-zy	4.730 (0.923 - 24.248)
go-go	1.155 (0.258 - 5.171)
sn-pg	1.228 (0.355 - 4.244)
sn-(t-t)	1.858 (0.624 - 5.539)
pg-(t-t)	1.777 (0.459 - 6.887)
li-sl-pg	0.681 (0.180 - 2.573)
(sn-ls)^(li-sl)	0.794 (0.187 - 3.363)
prn-sn-ls	2.090 (0.722 - 6.046)
t-go-pg	1.177 (0.332 - 4.172)
Upper Lip	1.054 (0.244 - 4.552)
Lower Lip	1.568 (0.748 - 3.289)
Maxilla	3.680 (0.646 - 20.985)
Mandible	1.695 (0.399 - 7.193)
Mandible/ Maxilla	0.140 (0.009 - 2.101)

Values are odd ratios (OR) and 95% confidence intervals (95% CI) of the risk for MS obtained using a logistic regression adjusted for sex and age. All p values were not significant (p>0.01).

Discussion

In the current study, we firstly compared the facial characteristics of Southern Europe Caucasian normal weight and obese adults, and, subsequently, we studied the association between such facial morphological measurements and the metabolic syndrome and its risk factors. We found that the faces of obese patients were significantly larger in the horizontal dimension than those of control subjects, with a larger middle facial third, and a larger gonial angle. A reduced mandible-to-maxilla volume ratio was also observed in obese patients. In addition, we found that only the mean gonial angle was positively associated to serum triglycerides level. Nevertheless, none of the facial morphological measurements were associated to the risk of MS. To the best of our knowledge, this is the first study that analyzed the three-dimensional soft-tissue facial characteristics of adult obese Southern Europe Caucasian patients without OSA or other respiratory problems, thus focusing on the problems associated only with an increased body weight. Previous investigations made on adults assessed other ethnic groups [8,26], used two-dimensional methods [8], or measured patients with OSA [26].

In a previous investigation [24], a group of obese adolescents aged 13 to 17 years was evaluated (mean BMI 31.67 kg·m⁻², SD 1.58, range from 30.03 to 36.69 kg·m⁻²). Obese adolescents appeared to possess faces that were significantly wider transversally (skull base width, mandibular width), deeper sagittally (mid and lower face depth, mandibular corpus length), and shorter vertically (upper facial height) than those of the reference group. A cephalometric investigation in 39 obese adolescents aged 14 to 16 years, showed that there was a general increment in facial dimensions, with an increase in mandibular length and a reduction in upper anterior facial height [26]. Previous authors found significantly larger mandibular and maxillary dimensions in 50 obese adolescents than in age- and sex-matched controls [25]. The increments were both in the anterior-posterior (maxilla and mandible) and in the vertical plane (lower anterior and posterior facial heights). Additionally, obesity was associated with bimaxillary prognathism. Similar findings were reported for female adolescents where a higher body fat proportion was associated with a relatively larger mid and lower face [36].

Our study shows that obese adults present a different facial morphology compared to normal weight persons. The increment in facial width observed here is in good accord with previous reports performed in individuals of comparable age but of other ethnic groups [8,9,37]. Overall, the larger maxillary volume may derive from both an increment in adipose (soft tissue), as well as from a larger skeleton, as found in obese adolescents [23-25]. However, despite the differences in facial morphology observed between normal weight and obese patients, such facial measurements were not associated to MS and its components with the single exception of serum triglycerides, substantially confirming findings obtained on children [17].

The principal limitation of the present investigation is in the reduced number of patients, spanning a large age range. The analysis was made using z-scores, a method that can partially control for the mixed composition of the group [20,21,24]. Nonetheless, the biological significance

of age and sex differences cannot be fully taken into account. A further limitation is the lack of a history about weight gain. Indeed, a lifelong history of obesity may change several characteristics of the craniofacial hard and soft tissues, as shown by previous investigations [23-25]. Furthermore, the metabolic and anthropometric characteristics taken into account were not longitudinally assessed, and we only measured them on a single occasion: we cannot control for their time-related variations.

Conclusion

This study reveals that Caucasian normal weight and obese adults present a different facial morphology. Particularly, most of the differences were observed in the middle and lower parts of the face: when compared to normal weight individuals, obese adults had a wider face in the horizontal dimension, with a middle face that was larger both in absolute value and relatively to the lower face. However, facial morphology does not seem to be importantly related to cardiometabolic outcomes, and the actual association between morphological facial characteristics and clinical information on the health conditions of patients is still to be investigated.

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Conflict of Interest: The authors declare no conflicts of interest.

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