Journal of Electromyography and Kinesiology 21 (2011) 298–310

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Relation between facial morphology on lateral skull radiographs and sEMG activity of head, neck, and trunk muscles in Caucasian adult females

Simona Tecco [a,*], Vito Crincoli [b], Beatrice Di Bisceglie [b], Sergio Caputi [a], Felice Festa [a]

[a] University G. D'Annunzio, Department of Oral Science, Chieti/Pescara, Italy
[b] University of Bari, Department of Oral Science, Italy

ARTICLE INFO

Article history:
Received 14 December 2009
Received in revised form 12 October 2010
Accepted 28 October 2010

Keywords:
Facial morphology
sEMG
Masticatory muscles
Neck muscles
Trunk muscles
Mandible
Maxilla
Cephalometry

ABSTRACT

This study aimed to evaluate whether there is an association between facial morphology on cephalometrics and surface electromyographic (sEMG) recordings of the head, neck, and trunk muscles.

Forty-seven Caucasian adult females, 18–29 years of age (average: 24), underwent lateral skull radiographs in "natural head position", obtained by having the subject look at a small mirror at eye level, and sEMG recordings for the following muscles: masseter, anterior temporal, digastric, posterior cervicals, sternocleidomastoid, and upper and lower trapezius. All muscles were monitored bilaterally at mandibular rest position and during maximal voluntary clenching (MVC). The maximal bite force was also measured to check MVC.

Pearson's correlation coefficient revealed significant correlations ($p < 0.01$): (i) between the variables concerning mandibular position and size and the sEMG activity of upper trapezius at mandibular rest position; (ii) between the topographic correlation between the maxillary and mandibular bases (called skeletal class) and the sEMG activity of upper trapezius at MVC; (iii) between the sEMG activity of sternocleidomastoid and the Frankfort to mandibular plane angle; and (iv) between the sEMG activity of masseter and the anterior cranial base to mandibular plane angle.

Some associations between the cephalometric variables and the sEMG activity of the head, neck, and trunk muscles were observed. No certain conclusion, however, was possible on the mechanism concerning these results. Future longitudinal studies are required.

1. Introduction

According to Moss and Salentijn (1969) human facial growth occurs as a response to functional needs and is mediated by the soft tissue. Consequently, the adult facial shape seems to be determined by both genetic influences and local environmental factors, among which masticatory muscle activity seems to play a considerable role.

Consequently, the existence of correlations between craniofacial morphology and masticatory muscle activity has often been investigated (Lowe et al., 1983; Miralles et al., 1991; Ueda et al., 1998; Nakakawaji et al., 2002), including in patients with anterior open bite and with symptoms and signs of craniomandibular disorders (Bakke and Michler, 1991). For example, the biting force and the resulting masticatory muscle basal activity have been correlated with jaw size and morphology (mandibular body length, ramus height, and gonial angle) Morimitsu et al. (1989) and Møller (1966) found the same correlation during masticatory muscular functions (chewing, swallowing, and maximal voluntary contraction).

In these studies, however, only the masticatory muscles were investigated. Therefore, the present study was undertaken to examine whether there is a relationship between the craniofacial morphology and not only the activity of the masticatory muscles but also that of the sternocleidomastoid, posterior cervicals, upper trapezius, lower trapezius, and digastric in adult subjects.

The rationale for this evaluation comes from various observations, as, for example, the association between cervical posture and facial morphology (Solow and Tallgren, 1977; Solow and Siersbaek-Nielsen, 1986; Hellsing et al., 1987; Huggare and Cooke, 1994), the correlations between the surface electromyographic (sEMG) activity of the jaw muscles and that of the neck and trunk muscles (Huggare and Raustia, 1992; Holmegren et al., 1985), and the changes in sEMG activity of the sternocleidomastoid and upper trapezius (tonic and swallowing) soon after the wearing of an intra-oral bite (an acrylic removable intra-oral device to reduce masticatory muscular spasm) by subjects with spasms in the mentioned muscles (Santander et al., 1994; Moya et al., 1994).

* Corresponding author. Address: University G. D'Annunzio, Department of Oral Science, Unit of Orthodontics, Via dei Vestini 31, 66013 Chieti, Italy. Tel.: +39 0871 3554343, +39 0871 3554123, +39 0871 3554149, +39 349 0751200, +39 329 7838023.

E-mail address: simtecc@unich.it (S. Tecco).

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doi:10.1016/j.jelekin.2010.10.014

Given this background, this study aimed to evaluate whether there is a correlation between the sEMG bilateral recordings of the head, neck, and trunk muscles and the facial morphology in a homogeneous sample for ethnic origin, sex, and age (Caucasian adult females from 18 to 29 years of age, average: 24). If a significant correlation could be found, the complex relationship between head morphology and body muscles could be better understood.

2. Methods

2.1. Sample

The sample comprised 47 Caucasian females, 18–29 years of age (average: 24), admitted to the Department of Orthodontics and Gnatology, University of Chieti, for orthodontic evaluation.

2.2. Inclusion criteria

The criteria for selection were gender, European ethnic origin, and age between 18 and 30 years. In addition, subjects were selected only if they did not play any sport for more than once a week, if their work did not require any particular muscular activity, if they were not receiving or had undergone orthodontic treatment and/or orthognathic surgery in the past, and if no temporomandibular joint disk displacement was assessed on the basis of a clinical evaluation (Tanaka, 1999). In addition, subjects were selected only if their muscle palpation revealed no tenderness and pain to palpation of jaw closure muscles bilaterally, if no bruxism was assessed, if no cervical muscle pain at palpation was found in the sample (Travell and Simons, 1983), and finally, if no skeletal asymmetry was found in the sample, as assessed through routinary frontal skull radiographs taken for orthodontic evaluation.

2.3. Cephalometric tracings

Lateral skull radiographs were taken using Instrumentarium Imaging®, Orthopantomograph OP100. Exposure data were 70 kV and 20 mA/s. The distance between the head and the radiological tube was 1.5 m. High-speed intensifying screens were used. The radiographs were exposed with the subjects in "natural head position", which is a standardized orientation employed for studying facial morphology; in this study, "natural head position" was obtained by asking the subject to look at a small mirror at eye level (this position is also called "mirror position") (Solow and Tallgren, 1971).

Table 1 describes the reference points (Riolo et al., 1974) individuated on lateral skull radiographs. Table 2 describes the references lines, and Table 3 describes the craniofacial morphological variables, which are depicted in Fig. 1.

The cephalometric tracing indicates the existence of abnormalities in the skeletal relationship between maxillary and mandibular bases (called skeletal classes). There are three main categories, called skeletal Class I, skeletal Class II, and skeletal Class III (Fig. 2a–c). This differentiation is important in orthodontics because each condition calls for a different type of orthodontic treatment. Class I (Fig. 2a) occurs when the two jaws line up with each other but the teeth do not mesh together properly. In these cases, the teeth could be either too large or too small for the dimension of the two jaws, making it hard for the subject to chew properly. Class II (Fig. 2b) occurs when the upper jaw grows too much and sticks out, or when the lower jaw does not grow enough and recedes. Class III (Fig. 2c) occurs when the lower jaw has outgrown the upper one.

In the cephalometric tracing, the position of the maxilla (on the sagittal mid plane) is defined by the SNA angle, while the position of the mandible is defined by the SNB and the SNPog angles (Fig. 1). The skeletal class is defined by the ANB angle (Fig. 2a–c) and by the Wits appraisal (Fig. 1).

2.4. Electromyography measurements

This study was performed using a Key-Win 2.0 surface electromyography (Biotronic s.r.l., S. Benedetto Tronto, Ascoli Piceno, Italy) with disposable electrodes (DUO F3010 bipolar – 10 mm, Ag–AgCl, lithium chloride gel, unit distance 22 mm, LTT FIAB Vicchio, Firenze, Italy). The Key-Win 2.0 is a 16-channel surface-electromyograph with simultaneous acquisition, common grounding to all channels, and low-pass filters of 15 Hz.

The muscles recorded were the right masseter (RMM), left masseter (LMM), right anterior temporal (RTA), left anterior temporal (LTA), right digastric (RDA), and left digastric (LDA) as masticatory muscles; and the right sternocleidomastoid (RSCM), left sternocleidomastoid (LSCM), right posterior cervicals (RPC), left posterior cervicals (LPC), right upper trapezius (RUTR), left upper trapezius (LUTR), right lower trapezius (RLTR), and left lower trapezius (LLTR) as postural muscles. The sEMG recordings were averaged over 25 ms, with muscle activity expressed as the root mean square (rms) of the amplitude (unit: μV) (Van der Bilt et al., 2001).

2.4.1. The electrodes' positioning and the general repeatability of the entire recording protocol

The electrodes, which determine to a large extent the quality of the recordings, were placed according to the electrode atlas of Cram and Kasman (1997). For each tested muscle, bipolar surface electrodes were placed on both sides of the muscles parallel to their muscle fibers. The ground electrode, which was rather larger, thus ensuring very good contact with the skin, was positioned on the subject's forehead to ensure a common reference to the amplifier's differential input.

Before the electrodes were applied, the skin was thoroughly cleaned with alcohol. The electrode positioning was kept as consistent as possible for all subjects. All recordings were performed with the patients in a "natural head position". As mentioned earlier, this is a standardized orientation for studying facial morphology, which was obtained in this study by having the subjects look at a small mirror at eye level, as described above (Riolo et al., 1974). The subjects were asked to make themselves comfortable, to relax their arms by their sides, and to look straight ahead and make no head or body movements during the test. With this arrangement, unintentional movements from other parts of the body were eliminated or reduced. The sEMG activity of the eight muscles was studied bilaterally (i) with the mandible at the rest position and (ii) in maximal voluntary clenching (MVC) (isometric contraction) (5 s).

Repeatability of positioning, as well as of the entire recording protocol, was investigated by asking 10 arbitrarily selected subjects to repeat the experiment 60 min after the recording was completed. We asked these 10 subjects to stay relaxed during this 60-min break once the electrodes were removed from their muscles, and to walk around the laboratory if they needed to. During this 60-min interval, they were allowed to drink only water but were restricted from smoking or drinking anything else. The results of the first and the second set of experiments showed a repeatability of measurements. These criteria were strictly followed to ensure consistent positioning for all the subjects. This repetition of the main experiment confirmed the repeatability of electrode positioning, as well as of the entire protocol, particularly with regard to the positioning the subjects in "natural head position" without any inclination of the body column which could have created an adaptation of the cervical column and consequently a different electric activity of the SCM and trapezius between the two recordings.

Table 1
Reference points on the cephalometric films.

Cephalometric reference points	Description	Characterization of reference points
Cranium		
S	Sella turcica	The midpoint of sella turcica, determined by inspection
Se	The midpoint of Sella opening	The midpoint of sella turcica opening (Schwarz)
N	Nasion	The intersection of the internasal suture with the nasofrontal suture in the midsagittal plane
N′	Cutaneous nasion point	Vertex of soft tissues between forehead and nose
Pn/2		The midpoint of Pn line (Schwarz)
Po	Porion	The midpoint on the upper edge of the porus acusticus externus (Björk)
Or	Orbitale	The lowest point on the lower margin of the bony orbit, midpoint between right and left images
Mandibular base		
B	Supramentale	The most posterior point in the concavity between infradentale and pogonion (Downs)
BO		The point of intersection between perpendicular line dropped from point B onto the occlusal plane and the occlusal plane
Pog	Pogonion	The most anterior point in the contour of the chin in median plane
Me	Menton	The lowermost point on the symphysial shadow as seen in norma lateralis
Gn	Gnathion	The most inferior point in the contour of the chin
vpUk		The point of intersection between perpendicular line dropped from pogonion onto the mandibular line and the mandibular line
Go	Gonion	The point which on the jaw angle is the most inferiorly, posteriorly, and outwardly directed
Rasc		The point of intersection between Ramus line and H line (Schwarz)
Ar	Articulare	The point of intersection of the dorsal contours of process articularis mandibulae and os temporale (Björk)
TG_i	The inferior tangent point at the angle of the mandible	The point of contact of the tangent to the angle of the mandible that passes through menton
TG_p	The posterior tangent point at the angle of the mandible	The point of contact of the tangent to the angle of the mandible that passes through articulare
TG_o (Go)	The intersection of the lines Me–TG_i and Ar–TG_p	It is a constructed point that can be used as Gonion
Maxillary base		
vpOK		The point of intersection between perpendicular line dropped from point A onto the palatal plane and the palatal plane (Schwarz)
A	Subspinale	The deepest midline point on the premaxilla between the anterior nasal spine and prosthion (Downs)
AO		The point of intersection between perpendicular line dropped from point A onto the occlusal plane and the occlusal plane
ANS	Anterior nasal spine	This point is the tip of the anterior nasal spine seen on the X-ray film from norma lateralis
PNS	Posterior nasal spine	The tip of the posterior spine of the palatine bone in the hard palate
Alveolar region		
Is	Incision superius	The incisal tip of the most anterior maxillary central incisor
U1apex	Apex of maxillary central incisor	The tip of the root of the most anterior maxillary central incisor
Ii	Incision inferius	The incisal tip of the most labial mandibular central incisor
L1apex	Apex of mandibular central incisor	The tip of the root of the most labial mandibular central incisor
I+	Coronal point of maxillary central incisor	The most coronal point of the crown of the most labial maxillary central incisor
I−	Coronal point of mandibular central incisor	The most coronal point of the crown of the most labial mandibular central incisor

2.4.2. The MVC recordings

The assessment of MVC was controlled by feedback and was standardized: the MVC was performed in the intercuspidal position for 5 s, while the patients were instructed to have their jaws closed in centric occlusion as forcefully as possible.

2.4.3. The assessment of bite force during MVC

To assess whether this isometric contraction corresponded to the maximal voluntary clenching, a bite force recording was conducted. Bite force recordings were taken with a digital dynamometer particle (model 500QD, single point) (DS, Europe, Milan, Italy) with a 100 kgf capacity, adapted to the mouth. The apparatus had an indicator in kgf and N, and a "set-zero" key, which allowed the control of the values obtained, as well as "peak" registers, which facilitated the record of the maximal force during measures. The dynamometer was connected to an oscilloscope placed at eye level for visual feedback, enabling the subject to keep the MVC constant. Before the actual recording took place, the subjects were asked to experiment with their MVC, and get accustomed with the process. For the latter, the subjects were asked to pull at MVC two times (5 s each time) with an interval of 2 min in between. A mark of the maximum MVC was made on the oscilloscope with a red tape. It was stressed to the subjects that they had to keep the MVC each time as constant as possible for the 5 s duration. Then, the subjects had some minutes to relax before the actual recording started.

2.4.4. The actual recording with normalization of EMG values: (i) MVC on cotton rolls and (ii) MVC on occlusal surfaces

During the actual recording, the subjects were asked to observe the oscilloscope's line, which had to reach the bottom part of the red tape during their MVC. Once this was reached, their sEMG signal was recorded for 5 s, during the MVC on cotton rolls, and afterwards the same procedure was performed again, on occlusal surfaces of teeth.

Recordings during MVC on cotton rolls provide reference EMG values for the subsequent normalization, as recently proved (Ferrario et al., 2006). Two 10-mm-thick cotton rolls were positioned on the mandibular first molars of each patient, and a 5-s MVC was recorded. For each of the analyzed muscles, the obtained mean EMG potential (rms of the amplitude) was set at 100%. Then, after obtaining the EMG recordings on occlusal surfaces (5 s), all the EMG potentials obtained during MVC on the occlusal surfaces were expressed in relation to the values obtained on cotton rolls [μV (on occlusal surfaces)/μV (on cotton rolls) $\times$ 100].

Table 2
Reference lines on the cephalometric films.

Cephalometric reference lines	Description	Characterization of reference lines
Cranium		
SN	Cranial base	The line extending between sella and nasion
SeN	Anterior cranial base (Schwarz)	The line extending between nasion and Se (Schwarz)
FH	Frankfort horizontal plane	Horizontal plane running through porion and orbitale
NA		The line extending between nasion and point A
NB		The line extending between nasion and point B
NPog		The line extending between nasion and pogonion
Mc Namara line	Nasion perpendicular	Perpendicular line dropped from nasion onto the Frankfort horizontal plane
Pn line (Schwarz)		Perpendicular line dropped from N′ onto SeN′ running until PNS–ANS line (Schwarz)
H Line (Schwarz)	Ideal Frankfort horizontal plane	Parallel line to SeN′ line through Pn/2 (Schwarz)
Mandibular base		
GoGn	Mandibular plane	Line extending between Gonion and Gnathion
ML	Mandibular line	Line parallel to axis of corpus, tangent to the lowermost border in TG_i (Schwarz)
Go-vpUK	Mandibular corpus length	The line extending between Gonion (TG_o) and vpUK (Schwarz)
RL	Ramus line	The tangent to the posterior border of the mandible in TG_p (Schwarz)
Go-Rasc	Ramus height	The line extending between Rasc point and Gonion (TG_o) (Schwarz)
Maxillary base		
ANS–PNS	Palatal plane	The line extending between ANS and PNS
PNS–vpOK	Maxillary corpus length	The line extending between PNS and vpOK (Schwarz)
Alveolar region		
FOP	Functional occlusal plane	A line overaging the points of posterior occlusal contact from the first permanent molars to the primary molars or bicuspids. It makes no reference to incisor and cuspid landmarks
Is–U1apex	Long axis of the upper incisor	The line drawn along long axis of the upper incisor (from the tip of the root to the incisal edge)
Ii–L1apex	Long axis of the lower incisor	The line drawn along long axis of the lower incisor (from the tip of the root to the incisal edge)

Table 3
List of variables.

Maxillary base		
SNA (°)	Prognatism of the maxillary apical base to cranial base	Sella–nasion–point A angle
PNS–vpOK (mm)	Maxillary corpus length	The distance between PNS and vpOK
Mandibular base		
SNB (°)	Prognatism of the mandibular apical base to cranial base	Sella–nasion–point B angle
SNPog (°)	Chin to cranial base	Sella–nasion–pogonion angle
Go-vpUK (mm)	Mandibular corpus length	Length of distance between Gonion (TG_o) and vpUK (Schwarz)
Go-Rasc (mm)	Ramus height	Length of distance between Rasc and Gonion (TG_o) (Schwarz)
Skeletal class (Class I, Class II or Class III)		
Wits (mm)	Wits appraisal (UniversityWitwatersrand)	Length of distance AO–BO
ANB (°)	The antero-posterior apical base relationship (skeletal pattern)	Point A–nasion–point B angle
Anterior cranial base		
SeN (mm)	Anterior cranial base length	Length of distance between Se and N
Vertical dimensions		
GoGn/SN (°)	Divergence of mandibular plane relative to anterior cranial base	The angle between S–N line and GoGn line
FM (°)	Frankfort–mandibular planes angle	The angle between Frankfort horizontal plane and GoGn line
MM (°)	Palatal to mandibular plane angle	The angle between GoGn line and PNS–ANS line
Dental variables		
Ii–L1apex/GoGn (°)	Axis of mandibular incisor to mandibular plane	The inclination of the long axis of the lower incisors with GoGn line
Is–U1apex/PNS–ANS (°)	Axis of maxillary incisor to palatal plane	The inclination of the long axis of the upper incisors with PNS–ANS line
Incisive angle (°)	Interincisal angle	Angle between axis of maxillary and mandibular incisors
I+ APog (mm)		Length of distance between APog line and the crown of the most labial maxillary central incisor
I− APog (mm)		Length of distance between Apog line and the crown of the most labial mandibular central incisor

2.5. Statistics

To assess the errors due to landmark identification on lateral skull radiographs, duplicate measurements were made of 10 randomly selected radiographs. These 10 radiographs were retraced by the same operator at a distance of 1 week. Cephalometric variables were compared, and the error variance was calculated (Glantz, 2002) and compared with the variance observed in the whole sample.

For the sEMG data, the paired-samples *T* test was first employed to assess the existence of significant differences between the sEMG activities of the right and left muscles. Then, a Pearson's correlation

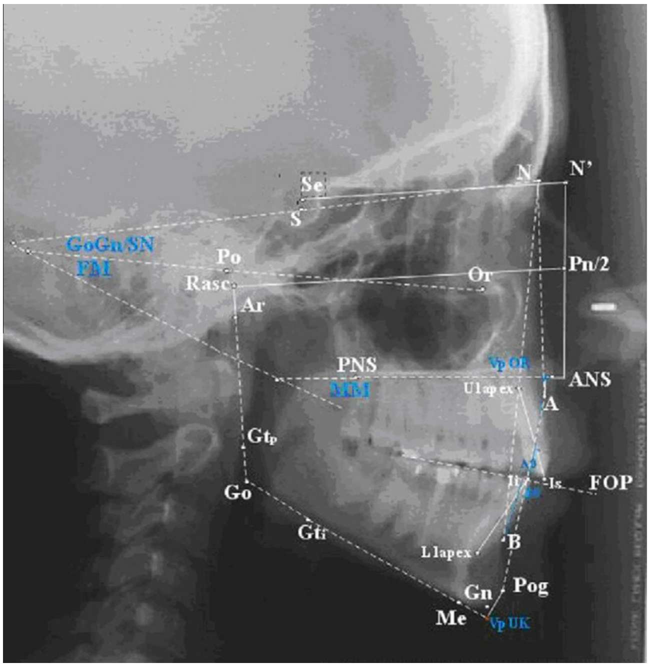

Fig. 1. Reference points and lines. See Tables 1–3 for details.

coefficient was performed to evaluate the associations between cephalometric variables and sEMG recordings. The limit $p < 0.05$ was considered as statistically significant.

3. Results

The variance of the intra-observer method error for all cephalometric variables was found to be less than 5% of the biological variance for the whole sample, as shown in Table 4.

Tables 4 and 5 show the descriptive statistics (mean, standard deviation – SD, range, minimum, maximum, and variances) for the cephalometric variables describing facial morphology (Table 4) and for the rms values of the sEMG activities of the analyzed muscles under the two different clinical conditions (Table 5). No significant difference was observed between the sEMG activities of the right and the left muscles.

Table 5 also shows the results of maximal bite force.

Fig. 3 shows the sEMG data of a patient.

3.1. Correlations

Table 6 and Fig. 4(a–e) describe the results of the correlation analysis for the variables studied in the whole sample. Significant correlations were observed between the sEMG activity of the upper trapezius at mandibular rest position and the morphological variables (see Table 6), concerning the position of the mandible in relation to the cranial base (SNB; $p < 0.01$, Fig. 4b) and its millimetric size (Go-vpUK; $p < 0.01$, Fig. 4c).

Furthermore, the sEMG activity of the upper trapezius during MVC strongly correlated with the variable indicating skeletal class, i.e., the WITS appraisal, or the University Witwatersrand appraisal, which indicates the relationship between maxillary length and mandibular length on the sagittal plane, calculated as the distance

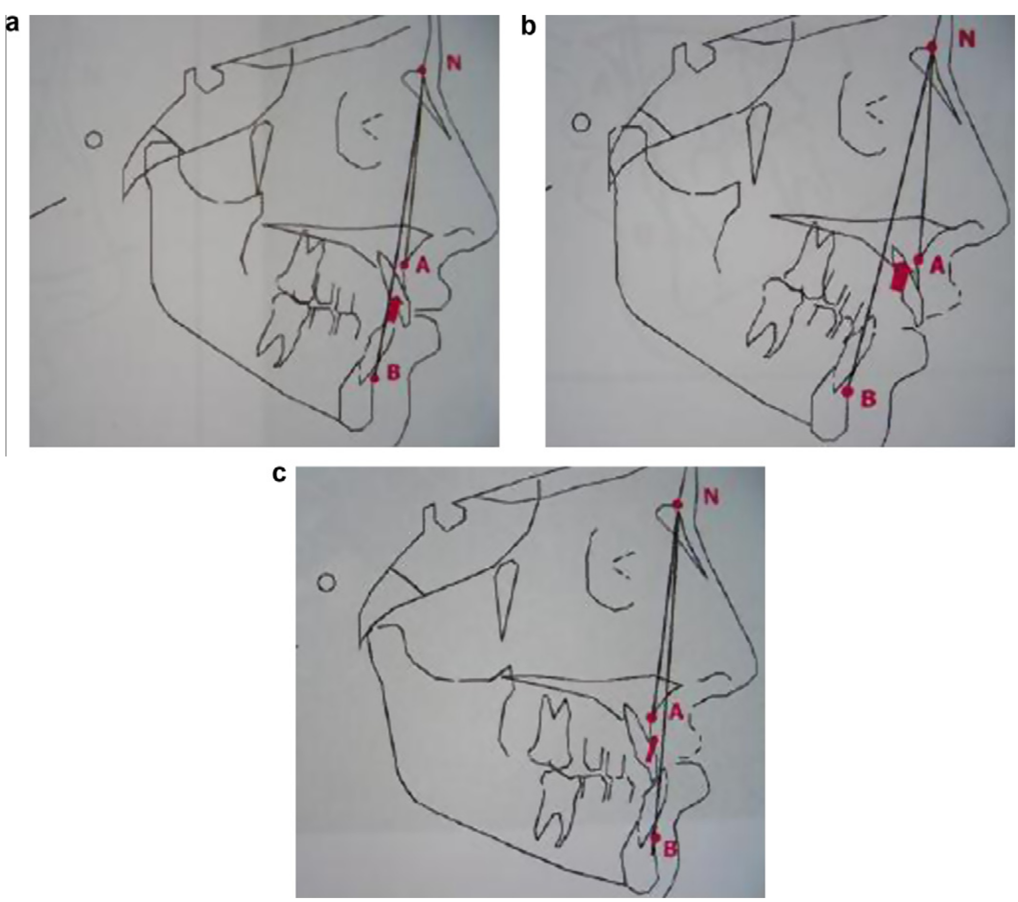

Fig. 2. The ANB angle defines the skeletal class. See Tables 1–3 for the definitions of the points; (a) Class I relationship between mandible and maxilla: ANB angle is 2 ± 2°; (b) Class II relationship between mandible and maxilla: ANB angle is >4°; and (c) Class III relationship between the mandible and the maxilla: ANB angle is <0°.

Table 4
Descriptive statistic of morphological variables on lateral skull radiographs.

Morphological variables on lateral skull radiographs	*N*	Range	Minimum	Maximum	Mean	SD	Variance	Variance of the intra-observer method error calculated on 10 radiographs (δ)
SNA (°)	47	16.5	75.5	92	81.4	3.9	15.5	0.7
SNB (°)	47	17	74	91	79.5	4	16.05	0.8
ANB (°)	47	14	−5	9	3.5	4.9	24.8	1.23
SNPog (°)	47	15	73	88	79.5	4.05	16.4	0.8
GoGn/SN (°)	47	15	24	39	32.5	6.9	47.7	2.2
FM (°)	47	19	15	34	24.6	6.8	46.8	2.3
MM (°)	47	16.5	22	38.5	22.9	5.9	34.6	1.7
Is–U1apex/PNS–ANS (°)	47	23	100	123	108.6	9.4	88.6	4.3
Ii–L1apex/GoGn (°)	47	19	87	106	92.5	7.5	56.7	2.6
Incisive angle (°)	47	16.5	122	138.5	131.7	13.3	178.3	8.2
I− Apog (mm)	47	10	−1	9	4.7	2.9	8.2	0.3
I+ Apog (mm)	47	10	−2	8	2.7	3.9	15.2	0.6
WITS (mm)	47	8	−4	4	−1	4.8	23.2	0.9
Go-vpUK (mm)	47	19	65	84	76.5	6.1	36.8	1.6
Go-Rasc (mm)	47	15	49	64	56.5	7.6	57.3	2.6
PNS–vpOK (mm)	47	18	46	64	52	5.4	29.2	1.3
Se–N (mm)	47	17	60	77	68	3.7	13.6	0.5

SD, standard deviation.

Table 5
Normalized root mean square for the different monitored muscles at mandibular rest position and in maximal voluntary clenching (MVC). Maximal bite force (*N*) and standard error in the molar regions. Results of the Kolmogorov–Smirnov *Z* test to assess the normality of data distribution.

Muscles	*N*	Mean (μV/μV s × 100)	SD	Kolmogorov–Smirnov *Z* (*p*)
Maximal voluntary clenching				
Anterior temporal (right)	47	1.78	0.19	0.79 (0.55)
Anterior temporal (left)	47	1.90	0.25	1.14 (0.15)
Masseter (right)	47	1.81	0.15	1.35 (0.053)
Masseter (left)	47	1.75	0.13	1.35 (0.053)
Digastric (right)	47	0.11	0.02	1.07 (0.02)
Digastric (left)	47	0.15	0.04	1.12 (0.16)
Sternocleidomastoid (right)	47	0.19	0.09	1.22 (0.1)
Sternocleidomastoid (left)	47	0.16	0.06	1.18 (0.12)
Upper trapezius (right)	47	0.27	0.07	1.1 (0.18)
Upper trapezius (left)	47	0.25	0.09	1.12 (0.16)
Lower trapezius (right)	47	0.24	0.07	0.94 (0.34)
Lower trapezius (left)	47	0.21	0.06	1.35 (0.053)
Cervicals (right)	47	0.14	0.02	1 (0.26)
Cervicals (left)	47	0.16	0.04	0.92 (0.36)
Mandibular rest position				
Anterior temporal (right)	47	0.15	0.04	1.17 (0.13)
Anterior temporal (left)	47	0.19	0.06	0.94 (0.34)
Masseter (right)	47	0.11	0.03	0.63 (0.83)
Masseter (left)	47	0.10	0.04	0.80 (0.55)
Digastric (right)	47	0.08	0.02	1.27 (0.08)
Digastric (left)	47	0.10	0.05	1.24 (0.09)
Sternocleidomastoid (right)	47	0.12	0.04	0.78 (0.58)
Sternocleidomastoid (left)	47	0.09	0.03	0.90 (0.40)
Upper trapezius (right)	47	0.17	0.04	0.1 (0.27)
Upper trapezius (left)	47	0.21	0.06	0.95 (0.32)
Lower trapezius (right)	47	0.18	0.06	0.72 (0.68)
Lower trapezius (left)	47	0.21	0.07	0.63 (0.82)
Cervicals (right)	47	0.15	0.06	1.09 (0.19)
Cervicals (left)	47	0.13	0.05	0.65 (0.8)
Maximal bite force (N)				
Right molar	47	220	20	0.75 (0.64)
Left molar	47	247	25	0.65 (0.78)

between the AO point and the BO point on the occlusal plane, as described in Fig. 1 and Table 3 ($p < 0.01$, Fig. 4a): the smaller this was, the lower the sEMG activity of the muscle, as shown in Table 6. Another finding was that the sEMG activity of sternocleidomastoid muscle at mandibular rest position correlated with the Frankfort to mandibular plane angle (FM angle) (Fig. 4e): the greater the angle, the lower the sEMG activity of the sternocleidomastoid. Another significant correlation was that found between the sEMG activity of masseter at mandibular rest position and the variables indicating the anterior cranial base to mandibular plane angle (GoGn/SN) (Fig. 4d): the greater the angle, the lower the sEMG activity of the masseter.

4. Discussion

4.1. Employed methods

Our study aimed to evaluate the existence of significant correlations between morphological variables of face on lateral skull radiographs and sEMG recordings of the head (anterior temporal, digastric, and masseter muscles), neck (sternocleidomastoid and cervical muscles), and trunk muscles (upper and lower trapezius muscles). To our knowledge, this study is the first to do so. We did not include in our sample subjects >29 years of age, because it was noted that the older the subject, the greater are the adaptations of the muscles due to life activity (working, movement, sport, and other factors).

In this study, the lateral skull radiographs were obtained with the subjects standing in the “natural head position” (Solow and Tallgren, 1977; Solow and Siersbaek-Nielsen, 1986), which is a standardized orientation for studying facial morphology. The “natural head position” in this study was clinically obtained by asking the patients to look at a small mirror at eye level (called the “mirror position”), as described above (Moorrees, 1994). The “natural head position” is a craniofacial reference system used for cephalometric analysis to study head posture (Lundström and Lundström, 1995), which has been advocated mainly because of its good intra-individual reproducibility to a true horizontal, confirmed in the literature (Moorrees and Kean, 1958; Madsen et al., 2008). In this study the intraindividual reproducibility to a true horizontal was good with a difference of 1.5° between the first and the second measurements. The typical method of registering “natural head position” (and used in this study) is based on the works of Solow and Tallgren (1977) and Solow and Siersbaek-Nielsen (1986), in which subjects were asked to stand looking into their own eyes in a mirror. It was observed more recently that subjects, while standing in “mirror position” to obtain lateral skull radiographs in “natural head position”, tended to hold their head in what seemed an unnaturally extended or flexed position, which would give grossly erroneous data if used for diagnosis, or, as in this study, for the evaluation of sEMG activity of the neck and trunk muscles. To avoid such problems Lundström and co-workers (1995) and Lundström and Lundström (1995) proposed using the

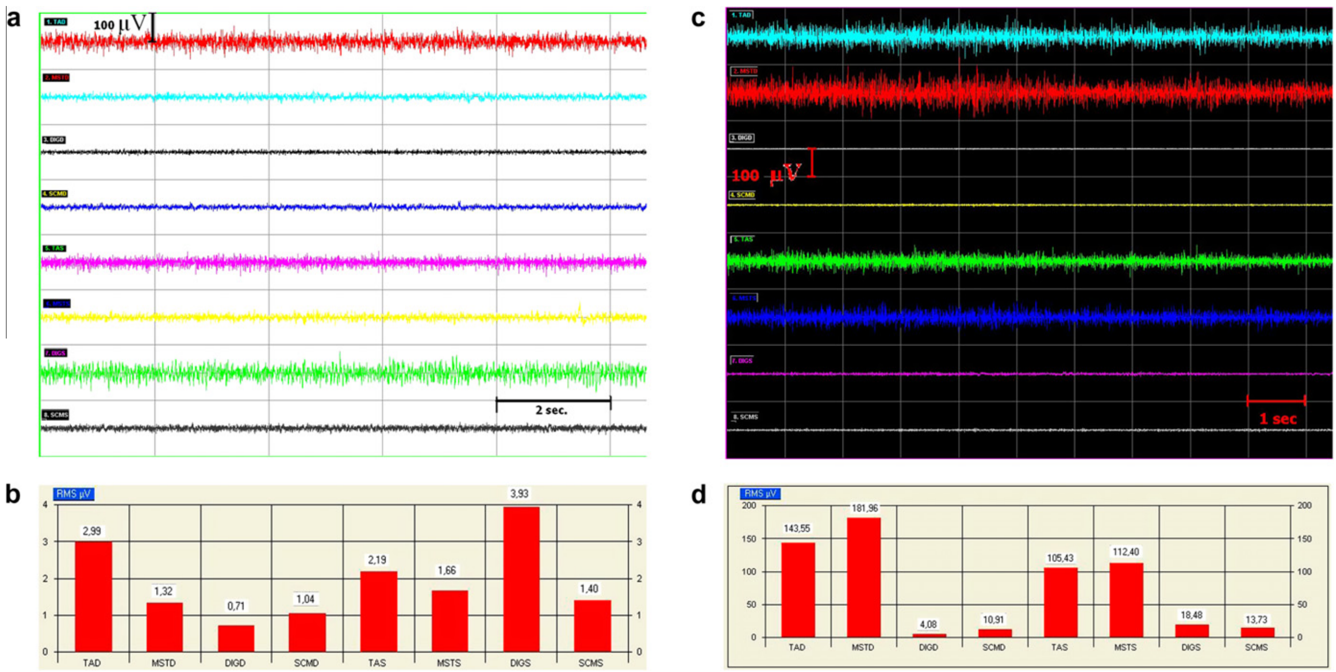

Fig. 3. sEMG tracings of a patient; (a) tracings at mandibular rest position; (b) plots of the rms values of the tested muscles; (c) tracings during maximal voluntary clenching; and (d) plots of the rms values of the tested muscles.

Table 6
Results of the correlation analyses performed between cephalometric variables and sEMG variables (normalized root mean square).

Variable 1 (normalized root mean square)	Variable 2	*N*	Pearson's correlation	Sig. (2-tailed)
Maximal voluntary clenching (MVC)				
Upper trapezius (right)	WITS (mm)	47	0.46	$p = 0.005$
Upper trapezius (left)	WITS (mm)	47	0.45	$p = 0.005$
Mandibular rest position				
Masseter (right)	GoGn/SN (°)	47	−0.40	$p = 0.004$
Masseter (left)	GoGn/SN (°)	47	−0.46	$p = 0.004$
Sternocleidomastoid (right)	FM (°)	47	−0.41	$p = 0.007$
Sternocleidomastoid (left)	FM (°)	47	−0.40	$p = 0.007$
Upper trapezius (right)	SNB (°)	47	−0.34	$p = 0.006$
Upper trapezius (left)	SNB (°)	47	−0.31	$p = 0.006$
Upper trapezius (right)	Go-vpUK (mm)	47	−0.39	$p = 0.002$
Upper trapezius (left)	Go-vpUK (mm)	47	−0.48	$p = 0.002$

"natural head orientation" as a better alternative. This is the position the orthodontist believes the patient's head would have if the patient were looking straight ahead to a distant point at eye level. It was shown, however, that "natural head orientation" depended mainly on chin position (Halazonetis, 2002), because images with protrusive chins were positioned with the head rotated more downwards, than were images with retrusive chins, calling into question its validity for diagnosis of both facial morphology and muscular activity, because it seems to depend on the same factor it aims to assess. For this reason, we decided, once and for all, to standardize the "natural head position" in this study by using the classic technique of the "mirror position", both to take lateral skull radiographs and to record sEMG activity, in order to obtain the more natural values possible in the analysis of lateral skull radiographs, as well as sEMG recordings. In our cephalometric tracings, we also calculated the Frankfurt to mandibular plane angle, but not to verify the postural position of the mandible, because the Frankfurt line has been demonstrated not to be an appropriate plane to individuate the gravity horizontal plane in lateral view (Petricevic et al., 2006), mostly if traced using the top of ear rods (Tremont, 1980). In our study, this variable was only intended to measure the vertical dimension from the middle to the lower third of face. In addition, in this investigation, the repetition of the main experiment in 10 subjects demonstrated the repeatability of positioning the subjects in "natural head position", without any inclination of the body column that was shown to create an adaptation of the cervical column (through a change in the atlanto-cervical angle) (Zepa et al., 2000) that could result in a different electric activity of the SCM and trapezius between the two recordings. In this study we did not observe any electrical activity of SCM muscle that was more than the noise level. Nowadays, correct sEMG assessment should be performed with standardized (normalized) potentials, thus removing most of the technical errors (De Luca, 1997). In particular, the current standardization was demonstrated to assess the role of MVC of teeth in muscle activity (Ferrario et al., 2006). This standardized protocol, as well as the assessed repeatability of the entire protocol, assured the affidability of our results with regard to the sEMG activity of the muscles, as well as to the morphological variables of face.

As to the positioning of the electrodes, attention was given to the problem of crosstalk, which was minimized by selecting compact electrodes (DUO F3010 bipolar) with an interelectrode spacing of 10 mm, in accordance with previous research (Cram and Kasman, 1988).

The crosstalk phenomenon consists in recording the volume-conducted electromyographic activity of muscles other than that under study. This interference may impair the correct interpretation of the results in a variety of experiments. Crosstalk depends on selectivity of electrodes and conductivity of the skin (also changing subcutaneous layer thickness, skin conductivity, and fiber length). During sEMG testing, a certain amount of impedance noise arises directly from the resistance of the electrodes' connection to the skin, which reduces the conductivity of the skin. This makes skin resistance a significant factor, mostly when working with the low-level sEMG signals typical of the small muscles involved in swallowing, mostly in the SUB mental area (including the anterior belly of the digastric).

In this area, the electrical impedance at the sites of electrode contact was reduced since the areas were lightly scrubbed with alcohol gauze pads. The alcohol removes the dead skin and surface oils, and the water moistens the skin and provides improved ion flow. In this study, we used DUO F3010 bipolar electrodes, located halfway between the innervation zone and the tendon region.

Considering that in the region of digastric muscle there is a higher subcutaneous layer thickness with respect to the other analyzed zones, we considered that for a subcutaneous layer thickness of 5 mm, these electrodes show a good selective property over all the detection points, as demonstrated by Mesin et al. (2009). In the method employed in this investigation, attention was given to the positioning of electrodes considering the position of the innervation zone (IZ). Many of the early EMG studies placed the electrodes over the motor point of the muscle (i.e., the location where the peripheral nerve enters the muscle) in an attempt to maximize the amplitude of the surface EMG signal (Basmajian and De Luca, 1985). Recently, however, increased attention has been focused on avoiding the IZ of the muscle during electrode placement (Rainoldi et al., 2000, 2004).

Generally speaking, the results of these studies show that bipolar electrode arrangements in single differential configuration placed over the IZ demonstrate lower absolute EMG amplitude, compared with the same arrangement positioned between the IZ and the tendon. Thus, it has been suggested that electrodes should not be placed over the IZ when recording sEMG signals (Rainoldi et al., 2000, 2004).

The results from a recent study (Beck et al., 2009) on the influence of IZs on EMG amplitude confirmed (a) that bipolar recording with high interelectrode distance (greater than 10 mm) reduces spatial selectivity and (b) that amplitude estimations when electrodes are placed over the innervation zone are wrong due to a geometrical artefact caused by the action potential travelling in opposite directions. Since the amplitude is calculated as the difference between the potentials under the two electrodes, it will be underestimated.

From a clinical point of view, however, it is important to note that for some muscles there is a great deal of variability among subjects for the location of the IZs (Rainoldi et al., 2004). For other muscles, such as small hand muscles, it may not be possible to avoid the IZ when recording EMG signals, as with multipennate muscles that could have several IZs (Rainoldi et al., 2004).

Collectively, therefore, these findings (Rainoldi et al., 2004) indicate that for some muscles, it may be very difficult to place electrodes such that they are not over or near the IZ. In these situations, the experimenter must use techniques that reduce/eliminate the potential influence of the IZ. Very little is known regarding techniques that may account for the potential effects of the IZ on EMG amplitude.

Some previous studies have shown that normalization is a useful technique for reducing the influence of factors that can affect EMG amplitude and center frequency data, such as skinfold thickness, muscle mass, skin impedance, amplification, interelectrode distance, and the signal processing technique used (Beck et al., 2004, 2006; Soderberg and Knutson, 2000). Theoretically, if normalization could also account for the effects of the IZ, then it may allow EMG data to be collected in situations where the IZ cannot be avoided.

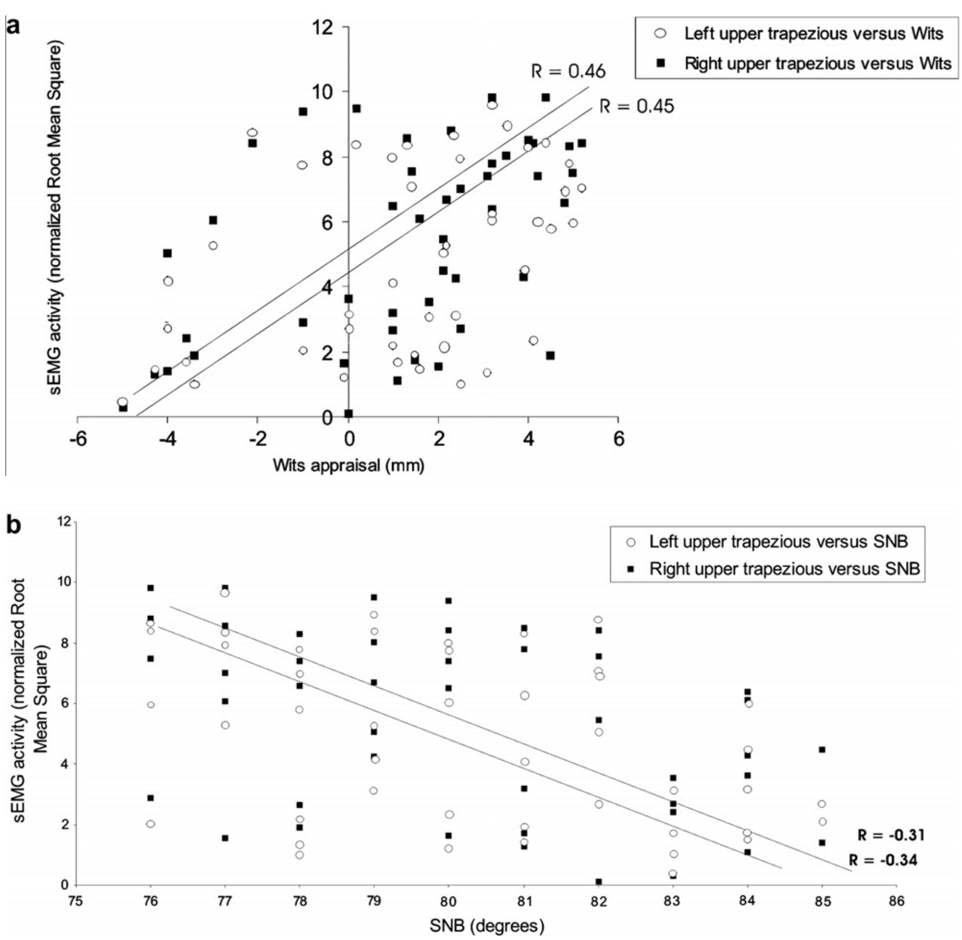

Fig. 4. Plots of the statistical significant correlations between morphological variables and sEMG activities: (a) upper trapezius versus Wits appraisal; (b) upper trapezius versus SNB angle; (c) upper trapezius versus Go-vpUK; (d) masseter versus GoGn/SN angle; and (e) sternocleidomastoid versus Frankfurt to mandibular plane angle.

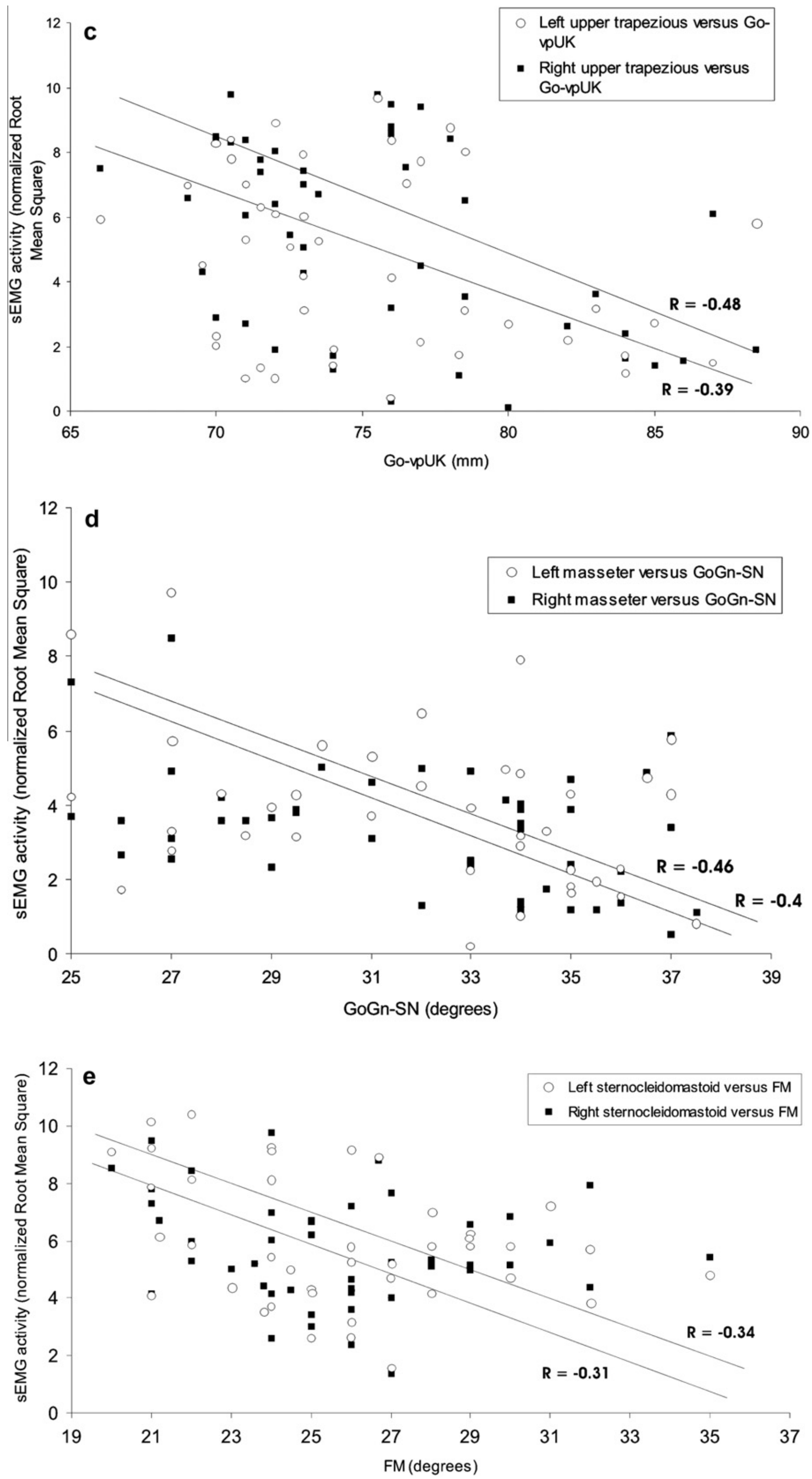

Fig. 4 (*continued*)

Thus, a recent study (Beck et al., 2009) examined the influence of interelectrode distance positioned over the estimated IZ for the vastus lateralis (Rainoldi et al., 2004) on the normalization of the EMG amplitude during isometric muscle actions of the leg extensors. The study concluded that the placement of bipolar electrode arrangements (20 and 40 mm of interelectrode distances) over the estimated IZ for the vastus lateralis had no effect on the normalized EMG amplitude of the leg extensors. The conclusion was that it may not be necessary to avoid the IZ when using 20 or 40 mm interelectrode distances to examine the patterns of responses for normalized EMG amplitude, almost for the vastus lateralis. The finding that there were no significant mean differences in the normalized EMG amplitude among the 20 IZ and 40 IZ, during isometric muscle actions, provided support for the practice of normalizing EMG amplitude to avoid the influences of the IZ position.

Thus, in our study, we did not estimate the exact location of the IZs, although very recently a method useful for the exact location of the IZ was introduced (Nishihara et al., 2010).

In a recent study, in fact, it was clearly demonstrated that normalization of data can reduce the influence of the IZ on EMG amplitude and that in situations where it is difficult to identify the precise location and/or avoid the IZ, the EMG signals can provide useful information regarding the normalized EMG amplitude (Beck et al., 2008).

Although an example of crosstalk is seen in frontal sEMG recordings when the patient clenches the teeth (Cram and Kasman, 1988), we positioned the ground electrode on the forehead because we used a similar protocol to other researchers (Tartaglia et al., 2009; Siéssere et al., 2009; Ferla et al., 2008; Tecco et al., 2008).

We examined the correlations between any two variables. We discuss the findings in the following section and compare them with the findings of other studies.

4.2. The observed correlations between facial morphology and neck and trunk muscles

The primary finding of this investigation was that the sEMG activity of some muscles of the neck and the trunk correlated with some morphological variables of the face, mostly concerning the morphology and the position of the mandible (Table 6).

First, the sEMG activity of the upper trapezius at mandibular rest position was correlated with the position of the mandible with respect to the anterior cranial base: the more anterior its position, the lower the activity of the muscle (Table 6). This finding seems to suggest that the position of the mandible with respect to the anterior cranial base is associated with the muscular activity of the trunk. Second, as the activity of the same muscle was also indirectly correlated with mandibular corpus length, the activity of trunk muscles also seems to be associated with the size of the mandible. Finally, during MVC, the resulting sEMG activity of the upper trapezius directly correlated with the orthodontic skeletal class, confirming the existence of a functional association between the trunk and the stomatognathic area.

As can be noted, the sagittal position of the maxilla did not show any correlation with the sEMG parameters achieved in this study. It can be concluded that the sagittal position of the maxilla and the maxillary corpus length do not seem to be correlated with the functional activity of the analyzed muscles. Only the mandible seems to play a role.

Considering that the skeletal class is determined by the reciprocal relationship between the mandible and the maxilla, and that no significant correlation was observed with the maxillary morphology or position, the correlation observed between the Wits appraisal (a variable describing the reciprocal topographic relationship between the maxilla and the mandible) and the sEMG activity of the upper trapezius can also be explained taking into account the role of mandible. As to the comparison of our results with the literature, unfortunately, to the best of our knowledge, no studies have investigated the relationship between trunk muscle sEMG activities and facial morphology.

Jiang and co-workers (2002) limited their investigation to assess the existence of correlations between the functional activity of the neck and upper trunk muscles and the mandibular movements in 10 normal adults, reporting that the activity of the upper trapezius increased during mandibular opening movements and tended to stop during MVC. No information was given on mandibular morphology, size, or position; only functional links between the two areas were reported. Comparison with other previous studies on the correlations between the facial morphology and the neck and trunk muscles is not possible because all other studies tested the correlations among the sEMG data (functional data). We are the first, to our knowledge, to present data regarding a comparison between functional and anatomical data.

The interesting point of our results is that the correlation was observed with the mandible at rest position, which suggests that the maintenance of a mandibular position could involve the activity of muscles also very far away from the mouth.

Furthermore, it must be noted that among the various morphological variables investigated in this study, all the observed correlations involved the mandible (mandibular size, mandibular position, or inclination of mandibular plane with respect to the planes of the head), suggesting an important role of the mandible in the determination of the subject's posture.

We also found an indirect correlation between the activity of the sternocleidomastoid, that counteracts the extensor muscles of the neck to stabilize the head (Tartaglia et al., 2008), at mandibular rest position, and the Frankfurt to mandibular plane angle, which indicates the mandibular divergence (FM angle, as shown in Table 6), resulting in correlation with the lumbar lordosis and with the pelvic inclination, on lateral body radiographs (Lippold et al., 2006); however, as digastric and SCM muscles were never active or no more than noise levels in this study (Fig. 3b and d), this correlation seems not to have a clinical significance, and we cannot confirm that cervical isometric strength can be affected by the bite position, as previously suggested (al-Abbasi et al., 1999).

4.3. The symmetry in the muscular activity

Concerning the symmetry of muscular activity, we always observed in this study that the same muscle was correlated with the same morphological variable, when analyzed both in the right and in the left sides, suggesting that the muscular function did not express the existence of any asymmetry between the two sides in our sample; this finding can be associated with the fact that our subjects did not show any asymmetry in skeletal dimensions, as assessed on frontal skull radiographs during the selection of the subjects. These observations seem to suggest that when there is skeletal symmetry, the same appears in the skeletal morphology as well as in the functional activity of muscles. Consequently, these findings indirectly confirm the correlation between the facial morphology and the functional activity of trunk muscles.

When our data are compared with the literature, it must be noted that in a previous study the subjects with mandibular asymmetry showed sEMG activity of the trapezius 1.8 times greater than that of the subjects with no mandibular asymmetry, also suggesting a relationship between the mandibular shape and the sEMG activity of that muscle (Jiang et al., 2002).

4.4. The observed correlations between facial morphology and masticatory muscles

We investigated the sEMG activity of the digastric muscle. Where this muscular area is concerned, a notation must be made on the method used in this study. The digastric muscle is part of the submental muscle group (SUB) that includes the anterior belly of the digastric, the mylohyoid, and the geniohyoid, all covered by the platysma; consequently, it must be underlined that the data recorded for this muscle must be considered indicative of the entire group. The function of the digastric muscle is to draw the hyoid bone up and forward; in addition, if the hyoid bone is fixed, the anterior belly of the digastric can serve to lower the jaw in conjunction with the geniohyoid, mylohyoid, and lateral pterygoid muscles. Submental (SUB) sEMG is acceptable when the investigators are not interested in differentiating geniohyoid activity from that of the mylohyoid or digastric muscles, as we intended in this investigation.

However, particular attention must be given to the placement of the electrodes, taking into account the direction of the fibers. Considering that the electrodes placed in this area had to record in particular the sEMG activity of the digastric, great attention was given to place them on the base of the direction of its fibers. In this study, the skin under the chin was cleansed with alcohol swabs prior to electrode placement. Electrode patch placement was determined by having participants press their tongues with force to the top of their mouths, during which palpation by the investigator helped to identify the submental muscle group. The patch was then placed at midline in the submental region to record the SUB myoelectrical activity from the common group of muscles of the submental area, over the platysma (SUB-location) approximately 1.27 cm posterior from the anterior, inferior midline of the mandible, with adjustments made for anatomical variability among the participants. The two recording electrodes were placed to the left and right of midline, along the direction of the fibers of the anterior belly of the digastric, attached to the skin beneath the chin, with long axes of the electrodes at a transversal angle in the range 0–10° with respect to the muscle (parallel to the fibers) (Mesin et al., 2009).

The electrode positions for each muscle group have been reported (Erb, 1886; Remak, 1909) and, in addition, can also be clarified following anatomical correlates (Goodgold, 1975).

As to the sEMG activity of the digastric muscle, there is also the problem of filtering effect due to the platysma. In the SUB area, there is the problem of the "volume conduction" by the platysma, as assessed by Cram and Kasman (1997). The "volume conduction" (or farfield potentials) refers to the source of the sEMG signal residing at some distance from the surface EMG sensors. Some sites are more easily contaminated by crosstalk and volume conduction, but they are more problematic for dynamic recordings than for static sEMG recordings.

However, the muscle scanning technique emphasized sampling from a variety of muscle sets. The "within" patient analysis of the multiple sites suggests the correct interpretation to the practitioner, considering the volume conduction data. In this case the submental area resides underneath the platysma.

In our cases the muscles were in synergy, which made it very difficult to select the proper activity of the digastric muscle. Therefore, we must underline that electrodes recorded the sEMG activity of the entire submental area.

We found a significant indirect correlation between the activity of the masseter at mandibular rest position and the anterior cranial base to mandibular plane angle (GoGn/SN) (Table 6), suggesting a correlation between masticatory muscle activity and vertical dimension of face. These findings are supported by previous studies (Morimitsu et al., 1989; Møller, 1966; Huggare and Cooke, 1994; Huggare and Raustia, 1992; Ahlgren, 1966), which demonstrated an indirect correlation between the anterior cranial base to mandibular plane angle and the sEMG activity of the masseter at MVC.

5. Conclusion

In a group of Caucasian adult females with particular criteria of inclusion, surface EMG data from the upper trapezius during mandibular rest position revealed a significant correlation with the position of the mandible with respect to the anterior cranial base, and with its size; the sEMG activity of the same muscle during maximal voluntary clenching of teeth revealed a significant correlation with the skeletal class of subject.

In the same group, the sEMG activity of the masseter muscles, at mandibular rest position, revealed a significant correlation with the angles indicating the vertical dimension of face. This study concludes that sEMG data can be considered to give indirect information on the facial morphology of the subject and vice-versa, mostly in a Caucasian adult female who fits the inclusion criteria used in this study.

Notwithstanding the originality of our results, certain conclusions on the mechanism of influence and on "what influences what" at this time are not possible. The type of study we have undertaken here cannot clarify this point, because the situation before the time of the study is not known. Longitudinal, controlled studies are required to analyze the detailed nature of the mechanism at work. Such studies will be directed to investigate the extent of environmental and genotype influences on growth. A clearer appreciation of these determinants will clarify the complex interrelationship between form and function in craniofacial morphogenesis.

Acknowledgement

Dr Beatrice Di Bisceglie helped Dr Simona Tecco, the principal investigator, in the collection of the data.

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Simona Tecco received her degree in 1999 at the University of Chieti, Italy, where she had also held Ph.D. degree in Oral Science with Prof. Felice Festa. She studied at the School in Orthodontics, at the Catholic University of Rome with Prof. Roberto Deli, and a second Ph.D. degree at the University of Turin with Prof. Pietro Bracco. She is now a Fellowship researcher at the University G. D'Annunzio of Chieti, tutor Prof. Felice Festa. She is author of many research articles and actually an expert of surface electromyography of masticatory muscles.

Vito Crincoli is a researcher at the University of Bari, Italy. He is an author of many research articles on oral pathology and an expert of oral prostheses.

Beatrice Di Bisceglie born in Rivoli (To, Italy) in 1977. In 2003 she graduated as a doctor in Dental Sciences (cum laude) at University of Bari. In 2008 she's got the degree of specialist in Orthodontics (cum laude) at the University of Chieti (Italy). She is author of papers published in Italian and in international journals.

Sergio Caputi is the Director of the Department of Oral Science, University G. D'Annunzio, Chieti/Pescara, Italy. He is also the chairman in Prosthodontics and Director of many courses for dental practitioners. He is actually an expert in prostheses and is author of many research articles on prostheses, oral pathology, oral science, orthodontics.

Felice Festa is the Director of the Post-graduated School in Orthodontics, University G. D'Annunzio, Chieti/Pescara. He is also the chairman in Orthodontics at the same University. He is actually an expert in orthodontics and is author of many research articles on gnathology, oral science and orthodontics.