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Thoracic-lumbar-sacral spine sagittal alignment and cranio-mandibular morphology in adolescents

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ABSTRACT

Purpose: The relationship between thoracic-lumbar-sacral spine sagittal alignment and craniofacial morphology is still controversial. Evidence-based results are difficult to obtain and scientific studies are inhomogeneous. The aim of this study was to investigate the difference of thoracic-lumbar-sacral spine posture and cephalometric values comparing two groups of subjects with different cranial structure in the sagittal plane.
Methods: Eighty-one subjects were consecutively selected and divided into two groups, according to the orientation of the condyle-orbital plane (CoOr) with respect to the superior maxilla (SpP): Group1: 49 subjects 11.6 (2.1) years showing posterior-rotation of CoOr: SpPˆCoOr $\leq -2°$, $-4.1°(2.1°)$; Group2: 32 subjects 12.9 (2.3) years showing anterior-rotation of CoOr: SpPˆCoOr $\geq 2°$, 3.7°(1.9°). Each patient underwent in blinding, Spinal Mouse recording and cephalometry of the skull.
Results: Group1 showed a significant forward tilting of the spine 4.4°(1.8°) with respect to Group2 2.4°(1.3°) ($p < 0.0001$) and higher values related to the vertical dimension of the skull: higher maxillary divergency ($p < 0.0001$), steep occlusal plane ($p < 0.0007$), higher gonial angle ($p < 0.001$).
Discussion: The results of this study showed a difference in the thoracic-lumbar-sacral spine inclination between groups with different craniofacial morphology. The achievement of this outcome is important to improve our multidisciplinary evaluation and treatment planning.

1. Introduction

The relationship between craniofacial morphology and posture of spinal column is still a controversial issue and evidence-based results are difficult to obtain due to the complexity of the subject and to the number of districts involved (Gomes et al., 2014). Some recent scientific articles in literature studied the link between the entire spine, and the craniofacial morphology. Even though they are very dishomogeneous and consider cranial structures in different ways, a number of them showed a link between spinal column posture and craniofacial morphology (Huggare, 1998; Lippold et al., 2006; Lippold et al., 2010; Michelotti et al., 1999; Nobili and Adversi, 1996; Tingey et al., 2001).

Other studies focused on the cervical column only using teleradiographies and evaluated the correlation with ethnic origins (Cooke and Wei, 1988), sex (Cooke and Wei, 1988; Solow and Siersbaek-Nielsen, 1992), age (Hellsing et al., 1987; Sforza et al., 2002; Vieira et al., 2009), craniofacial morphology (Arntsen and Sonnesen., 2011; Gomes et al., 2014; Solow and Tallgren, 1976; Solow and Siersbaek-Nielsen, 1992; Sonnesen, 2010), maxillary divergency (Hellsing et al., 1987), mandibular size (Solow and Tallgren, 1976; Sonnesen, 2010), shape of the face (Festa et al., 2003, Naini et al., 2016), respiratory function (Sforza et al., 2004; Solow and Tallgren, 1976; Solow and

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Siersbaek-Nielsen, 1992) and temporomandibular dysfunctions (Matheus et al., 2009). Teleradiography is a valuable and repeatable imaging for the evaluation of the cephalometric parameters (Cassi et al., 2016). However, regarding the study of the cervical column during teleradiography, the cephalostat may force the position of the head and, consequently, of the cervical column.

It is known that the posture is a set of interactions between muscle-skeletal system with afferent and efferent pathways of the central nervous system and whose role is to keep the body in a state of muscle-skeletal balance, against gravity, protecting the supporting structures of the body against injury or progressive deformity. A deeper understanding of the link between craniofacial morphology and spinal posture is of importance to improve the balance of the standing station and the efficiency of the system avoiding compensatory reactions that may lead to failure and pain of both the spine column and the cranial district, during time (Carini et al., 2017).

To this end, our preliminary study showed a positive link between craniofacial morphology and spinal inclination in a limited sample of sportsmen (the Spearman correlation was significant for the sagittal inclination of the horizontal condylar-orbital plane [CoOr] and the sagittal inclination of the spinal column) (Piancino et al., 2009). Following the results of that preliminary research, in the current study, we evaluated a large orthodontic sample using the cephalometric analysis and the Spinal Mouse system (Idiag, Voletswil, Switzerland). The latter is a non-invasive and validated instrument able to detect the spinal column inclination in the sagittal plane by means of bony landmarks (Guermazi et al., 2006; Mannion et al., 2004; Post and Leferink, 2004; Ripani et al., 2008).

The aim of this research was to investigate the difference of the thoracic-lumbar-sacral spine sagittal alignment and the cephalometric values comparing two groups of subjects with different cranial structure in the sagittal plane. The hypothesis was that the thoracic-lumbar-sacral spine sagittal alignment is different when considering different cranial structure.

2. Methods

Eighty-one subjects with malocclusions, 38 males and 43 females, out of 200, referring to the Orthodontic Department of the University of Turin, Italy, for orthodontic diagnosis, from September 2016 through September 2017 were consecutively selected for the study, on the basis of their cephalometric craniofacial morphology described by the orientation of the condyle-orbital plane with respect to the upper maxilla – as reference bone – represented by SpP^CoOr angle (angle between condyle-orbital plane [CoOr] and upper maxilla [SpP]). Before entering the study, informed consent was obtained from all the patients' parents. The study was approved by the Institutional Review Board of the University Hospital Company – Turin - Italy" n° 0088896, 10th September 2014.

The patients met the following inclusion criteria: SpP^CoOr $\leq -2°$ or SpP^CoOr $\geq 2°$.

The exclusion criteria were: any previous orthodontic therapy, any prosthesis, any motor or neurological problems, any internal diseases, any orthopedic trauma or impairments, any spinal pathology, presence of congenital and hereditary pathologies and any signs or symptoms of cranio-mandibular disorders.

The flow chart of patient selection is illustrated in Fig. 1. Sample size, sex and age distribution of the subjects are given in Table 1.

The subjects were divided into two groups according to the cephalometric orientation of the condyle-orbital plane represented by SpP^CoOr angle:

Group 1: 49 subjects (27 male and 22 female, mean age (standard deviaton – SD) 11.6 (2.1) years showing posterior-rotation of the condyle-orbital plane: SpP^CoOr $\leq -2°$ mean value (SD), $-4.1°$ (2.1°);

Group 2: 32 subjects (11 male and 21 female, mean age (SD) 12.9 (2.3) years, showing anterior-rotation of the condyle-orbital-plane: SpP^CoOr $\geq 2°$ mean value (SD) 3.7° (1.9°).

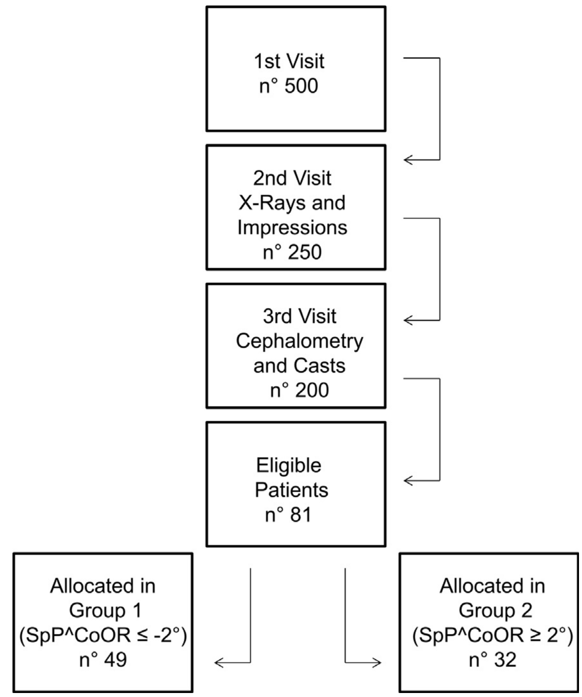


Fig. 1. Flow chart illustrating the study group selection.

Table 1
Sample size, sex and age distribution of the two groups.

	Sex	Mean Age ± SD	SpP^CoOr (°) mean value ± SD
Group 1 (SpP^CoOr ≤ -2°)	27 male (55%) 22 female (45%)	11.6 ± 2.1	−4.1° ± 2.1°
Group 2 (SpP^CoOr ≥ 2°)	11 male (34%) 21 female (66%)	12.9 ± 2.3	3.7° ± 1.9°

Each subject underwent the following sequence of investigations: 1. Clinical and orthodontic examination; 2. Model casts for occlusal diagnosis; 3. Latero-lateral teleradiography of the skull and subsequent cephalometric analysis to evaluate the craniofacial morphology; 4. Spinal Mouse recording to analyse the thoracic-lumbar-sacral spine sagittal alignment

Thoracic-lumbar-sacral spine analysis

The test to evaluate the thoracic-lumbar-sacral spine sagittal alignment was performed with the Spinal Mouse® system (Idiag, Volestwil, Switzerland), that is an electronic inclinometer. It consists of a hand-held computer-assisted electromechanical device that can be used upon spinal curvatures in various postures. This device uses accelerometers, which record distance and changes of inclination with regard to the vertical line as it is rolled along the length of the spine. The device is guided along the midline of the spine starting at the spinous process of C7 and finishing at the top of the anal crease (approximately S3). These landmarks are firstly determinated by palpation and marked on the skin surface with a cosmetic pencil. Two rolling wheels follow the contour of the spine; distance and angle measurements are transfered radio-graphically via an analog-digital converter from the device to a base station positioned approximately 1–2 m away and interfaced to a personal computer. Data is sampled every 1.3 mm as the mouse is rolling along the spine, giving a sampling frequency of approximately 150 Hz. This information is then used to calculate the relative positions of the sacrum and vertebral bodies of the underlying bony spinal column using an intelligent recursive algorithm.

For each testing position, the thoracic (T1-2 to T11-12), lumbar (T12-L1 to the sacrum) spine, the trunk inclination angle (angle formed by the vertical and a line joining C7 to the sacrum) and the position of the sacrum and the hips (difference between the sacral angle and the vertical) were recorded (Kellis et al., 2008).

The Spinal Mouse recording, in the sagittal plane, has been validated showing repeatability and reliability (Guermazi et al., 2006; Mannion et al., 2004; Post and Leferink, 2004; Ripani et al., 2008).

The measurements of the spine were performed by the same experienced operator, with more than 10 years' experience in the use of the Spinal Mouse®, blinded to the purpose of the study. All spinal motions and subsequent measurements were performed according to the manufacturer's specifications, in the morning, in a dedicated and quiet room.

The electromechanical device was then guided along the midline of the spine from the starting point until the end point. The measurements were recorded at a slow speed to avoid data transmission errors to the base station. The testing procedure was performed in 3 positions, according to the manufacturer's specification and the subjects were previously informed about the testing procedures (Fig. 2). First, the subject assumed a relaxed position, with the head looking forward, the arms hanging by the side, the knees normally extended, and the feet shoulder-width apart (standing upright position). Second, the subject was asked to slowly flex the trunk as far as possible, aiming to curl the head into the knees (maximal flexion). Third, from the same leg position, the subject had his hands on the sides of the body and extended the trunk as far as possible (head was kept at neutral position). The sequence of testing was the same for all measurements, that is, assessment in standing, maximal flexion, and maximal extension position.

Latero-lateral cephalometric analysis

The cephalometric values taken into consideration were (Fig. 3):

SpPˆCoOr, angle between superior maxilla (SpP) and condyle-orbital plane (CoOr), used to select the sample; the condyle-orbital plane is similar to the Frankfurt plane, but it considers the Condyle point (Co) instead of the Porion point (Pr). This choice is due to the fact that the condyle point is of high clinical significance for the dynamic characteristics of the mandible and it is easily detectable on the x-ray;

SpPˆGoGn, angle between superior maxilla (SpP) and the body of the mandible (GoGn) in order to evaluate the maxillary divergency, according to Schudy (Schudy, 1965);

SpPˆOc, angle between superior maxilla (SpP) and occlusal functional plane (Oc), in order to evaluate the orientation of the occlusal

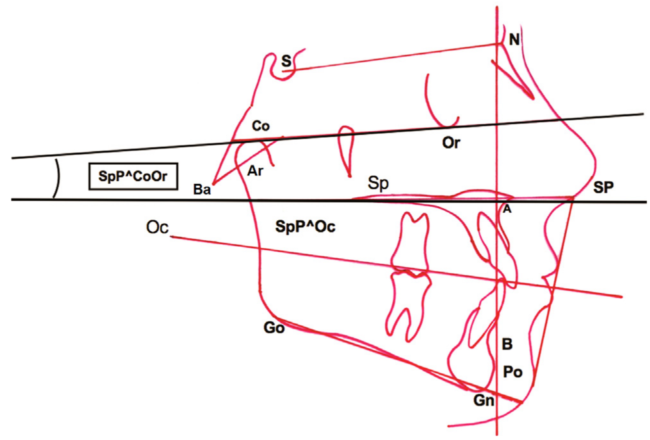


Fig. 3. Angle SpPˆCoOr: angle between the superior maxilla (SpP) and the condylar-orbital plane (CoOr). See the explanation in materials and methods section for the other cephalometric values.

plane;

CoGoˆGoGn, the gonial angle between the ramus (CoGo) and the body (GoGn) of the mandible;

ANˆB, sagittal cranial relationship (the relantioship in the sagittal plane between the upper maxilla and the mandible with respect to the cranial base as reference), according to Steiner (Steiner, 1959);

A:Po, sagittal maxillary relationship (the relantioship in the sagittal plane between the upper maxilla and the mandible, using the upper maxilla as reference bone), according to Schudy (Schudy, 1965);

NSˆBa, the cranial base angle;

NSˆAr, the sella turcica angle;

SArˆGo, the articular angle;

Landmarks were digitized on lateral teleradiography by the same skilled operator with more than 10 years' experience in the field, blinded to the purpose of the study; cephalograms were traced and values measured using a custom made software.

Statistical analysis

Data were expressed as mean (SD) or percentages. The statistical distribution of the quantitative measures was tested by Shapiro-Wilk test and maxillary divergency (SpPˆGoGn), steep occlusal plane (SpPˆOc), articular angle (SArGo) and the lumbar curvature showed non Gaussian distribution. Comparison between the 2 groups was then performed using two-samples *t*-test or the Mann-Whitney rank-sum

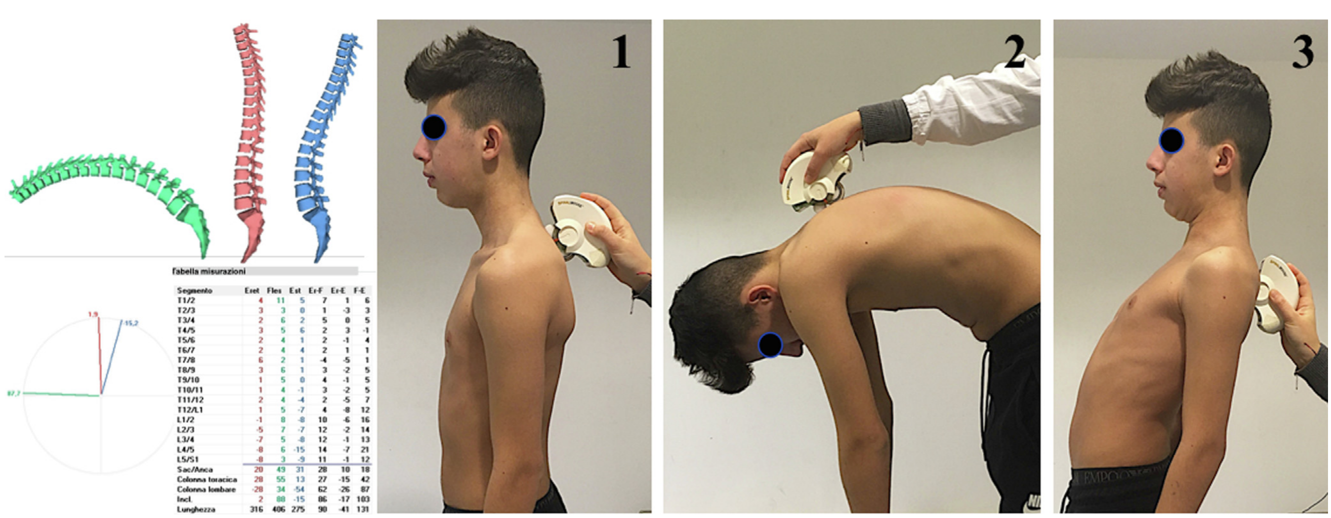


Fig. 2. Graphic and numerical outcome after the recording with Spinal Mouse: in standing (1), flexion (2) and extension (3) position.

Table 2
Mean values ± SD for each considered measures of Group 1 and Group 2 with statistical significance.

Cephalometric values	SpP^CoOr ≤ -2° Mean (SD)	SpP^CoOr ≥ 2° Mean (SD)	*p*
SpP^GoGn	29.2° (± 6.1)	22.0° (± 5.1)	*< 0.0001*
SpP^Oc	12.0° (± 5.9)	7.8° (± 3.7)	*0.0007*
A:Po	7.3 mm (± 4.7)	3.8 mm (± 5.0),	*0.002*
CoGo^GoGn	123.6° (± 6.2)	118.8° (± 6.1),	*0.001*
ANB	3.8° (± 2.7)	3.7° (± 2.1)	*0.89*
NSBa	131.4° (± 5.2)	131.2° (± 5.7).	*0.88*
SArGo	141.3° (± 6.5)	141.1° (± 5.1)	*0.74*
NSAr	124.8° (± 5.3)	123.2° (± 4.8)	*0.16*
Go:Gn	72.3 (± 2.9)	71.5 (± 3.0)	*0.23*
Spine values on the sagittal plane in standing position			
Inclination	4.4° (± 1.8)	2.4° (± 1.3)	*< 0.0001*
Thoracic curvature	40.9° (± 9.7).	40.2° (± 10.8)	*0.77*
Lumbar curvature	−29.8° (± 5.4)	−31.1° (± 6.9)	*0.22*
Sacral angle	17.9° (± 4.0)	18.1° (± 5.3)	*0.81*
Dental Occlusion	%	%	*0.46*
Class I	23.1	31.2	
Class II	73.1	68.7	
Class III	3.8	0	

tests, as appropriate. For categorical variables, between-group differences were assessed with the use of Fisher exact probability tests. Pearson or Spearman's rank correlation coefficients were used to evaluate the relationship between spine inclination and cephalometric measures. All the tests were two tailed and the level of significance was set at 5%.

3. Results

The results of spinal column recordings, cephalometric analysis, and dental occlusion are reported in Table 2. The results showed significant differences between Group 1 and Group 2 regarding the thoracic-lumbar-sacral spine sagittal alignment as well as the cephalometryc analysis.

Thoracic-lumbar-sacral spine sagittal alignment (Table 2)

The inclination of the spine in the sagittal plane in Group 1 (posterior-rotation of condyle-orbital plane) resulted significantly tilted forward 4.4° (1.8°) with respect to Group 2 (anterior-rotation of condyle-orbital plane) 2.4° (1.3°), ($P < 0.0001$). Any difference was shown for thoracic curvature, lumbar curvature and sacral angle values.

Cephalometric analysis (Table 2)

Group 1 (posterior-rotation of condyle-orbital-plane) showed higher values related to the vertical dimension of the skull than Group 2 (anterior-rotation of condyle-orbital-plane) represented by: higher maxillary divergency [SpP^GoGn] (Group 1: 29.2° (6.1°), Group 2: 22.0° (5.1°); $p < 0.0001$; steep occlusal plane [SpP^Oc] (Group 1: 12.0° (5.9°), Group 2: 7.8° (3.7°); $p = 0.0007$; higher gonial angle [CoGo^GoGn] (Group 1: 123.6° (6.2°), Group 2: 115.8° (20.2°); $p = 0.001$. Also the sagittal maxillary relationship [A:Po] showed higher values for Group 1 than Group 2 (Group 1: 7.3 mm (4.7 mm), Group 2: 3.8 mm (5.0 mm); $p = 0.002$, revealing a higher frequency of sagittal class II (superior maxilla advanced with respect to the mandible) in Group 1. Any difference was shown for the sagittal cranial relationship [AN^B], the cranial base angle [NS^Ba], the articular angle [SAr^Go], the sella turcica angle [NS^Ar] values.

The relationship between the spine inclination and SpP^CoOr (Table 3) was weak and not statistically significant but we could notice that at higher inclination of the thoracic-lumbar-sacral spine, the cephalometric parameter decreased in Group 1 (rho = -0.1) and increased in Group 2 (rho = 0.3).

4. Discussion

The purpose of the present study was to evaluate the difference of the thoracic-lumbar-sacral spine sagittal alignment and the cephalometric values comparing a group of adolescents with a posterior-rotation of the condyle-orbital plane (Group 1, SpP^CoOr ≤ −2°) versus a group with an anterior-rotation of the condyle-orbital plane (Group 2, SpP^CoOr ≥ 2°). Significant differences between the thoracic-lumbar-sacral spine sagittal alignment and some cephalometric values have been showed, resulting the spine significantly tilted forward in Group 1 (posterior-rotation of the condyle-orbital plane) compared with Group 2 (anterior-rotation of the condyle-orbital plane) and the angles SpP^GoGn (maxillary divergency), SpP^Oc (occlusal plane orientation), CoGo^GoGn (gonial angle) and the A:Po value (sagittal maxillary relationship) significantly higher in Group 1 with respect to Group 2 (Fig. 4).

The angle between the condyle-orbital plane and the superior maxilla (SpP^CoOr), was chosen to select the subjects because it refers to the postural and functional characteristics of the mandible related to the morphology of the skull (Fig. 2). The mean age of the two groups was around the pubertal spurt that has been shown to represent a reliable developmental stage of postural functions. Kellis showed the reliability of the spinal mouse in the sagittal plane in a group aged 10.6 (1.7) years. (Carini et al., 2017; Hsu et al., 2009; Kellis et al., 2008; Lippold et al., 2010).

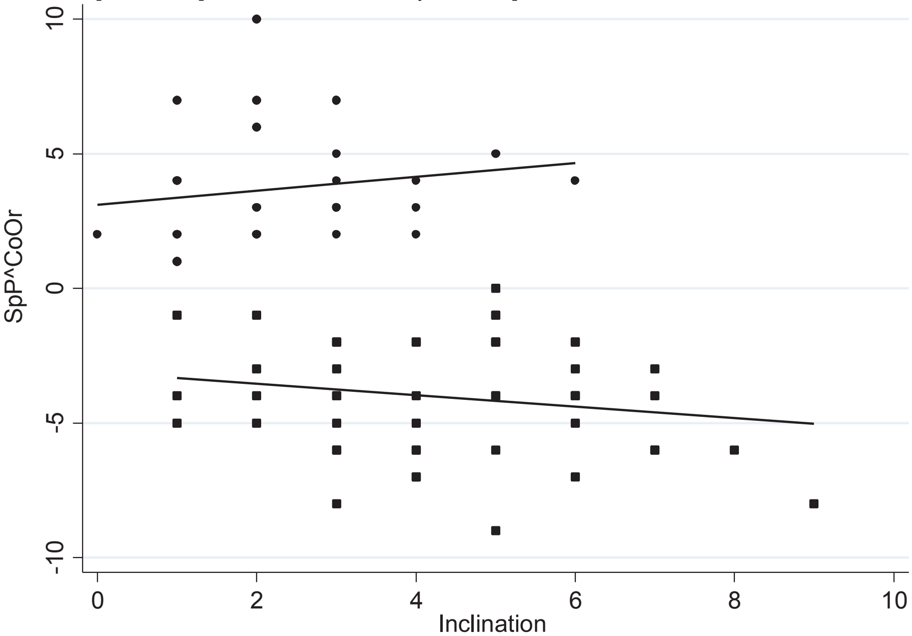
Group 1 was characterized by a posterior-rotation of the condyle-orbital plane with respect to the maxillary plane that is the reference bone; consequently, in this group, the glenoid fossa and the condyle are both located backward and upward with respect to the skull. As a consequence, the mandible slides backward and upward with respect to the maxilla and the skull: it is a "dynamic" or "functional" characteristic due to the postural position of the mandible. In this group, higher values related to the vertical dimension of the skull were found: higher maxillary divergency, steep occlusal plane and higher gonial angle. Moreover, for this group it was found more frequently a superior maxilla advanced with respect to the mandible (Sagittal Class II). All these are typical features of hyperdivergent patients.

Group 2 was characterized by an anterior-rotation of the condyle-orbital plane with respect to the maxillary plane that is the reference bone; consequently, in this group, the glenoid fossa and the condyle are both located forward and downward with respect to the skull. As a consequence, the mandible slides forward and downward with respect to the maxilla and the skull: it is a "dynamic" or "functional" characteristic due to the postural position of the mandible. In this group, lower values related to the vertical dimension of the skull were found: lower maxillary divergency, flat occlusal plane, lower gonial angle. Moreover, sagittal maxillary relationship values resulted significantly lower with respect to Group 1, showing no advancement of the superior maxilla with respect to the mandible. All these are typical features of hypodivergent patients.

No significant differences resulted for the following cephalometric values: sagittal cranial relationship, cranial base angle, sella turcica angle, articular angle, that are related to anatomical, not dynamic features of the human skull, and, as well, for the thoracic, lumbar and sacral angle of the spinal column, probably due to the individual variability and complexity of the system.

Other Authors evaluated the posture of the spine in relation to the craniofacial morphology, using different references with respect to our study such as skeletal classification (Festa et al., 2003; Hellsing et al., 1987) and dental class (Arntsen and Sonnesen., 2011; Michelotti et al., 1999). For this reason, the results are not comparable. Furthermore, in literature, the cephalometric characteristics have been often related to the cervical column only (Cooke and Wei, 1988; Gomes et al., 2014; Matheus et al., 2009; Sforza et al., 2004; Solow and Tallgren, 1976;

Table 3
Relationship between spine inclination and condyle-orbital plane.



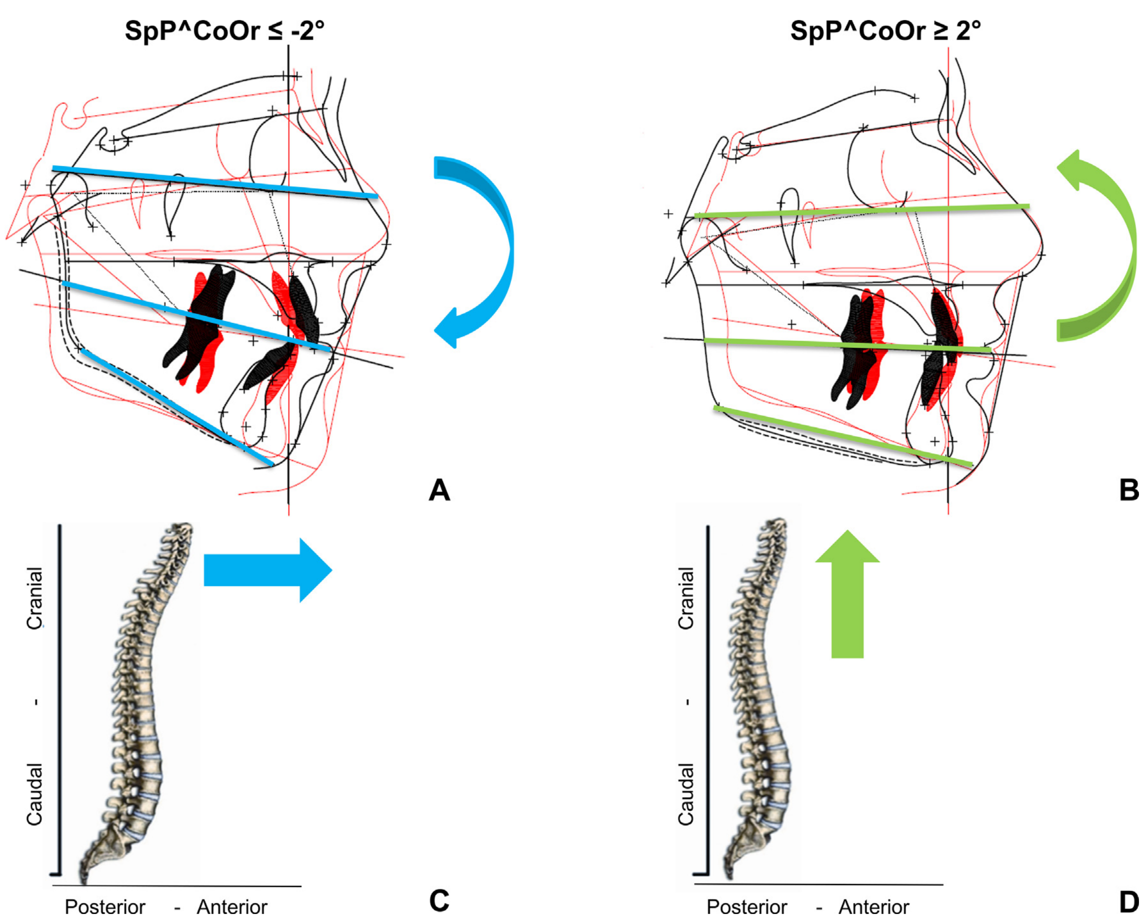


Fig. 4. (A) Cephalometric features of Group 1 (SpPˆCoOr ≤ −2°). (B) Cephalometric features of Group 2 (SpPˆCoOr ≥ 2°). (C) The spine column tilting of Group 1. (D) the spine column titling of Group 2.

Sonnesen et al., 2010). This is due to the fact that orthodontists are used to consider the latero-lateral teleradiography that includes the cervical column. However, the trunk is more representative of the total body posture of the subject, while the cervical tract may be influenced by the cephalostat, eventual trauma and variable compensations (Hellsing et al., 1987).

The interaction between the features of the cranial structure and the thoracic-lumbar-sacral spine sagittal alignment to obtain a better body balance, is of clinical interest. Vertical skull features in the sagittal plane and posterior-rotation of the mandible should be considered from a dynamic and multidisciplinary point of view. In fact, the forward tilting of the spine might be a predisposing factor to a further and easier deterioration of the sagittal balance during ageing. Even though the results in literature regarding the relationship between posture and symptoms of musculoskeletal disorders are still not in agreement (Michelotti et al., 1999; Perinetti et al., 2011), othopedic studies recently highlighted the congruence between alteration of the sagittal balance (due to loss of lumbar lordosis secondary to disc degeneration) and the low back pain (Boucher et al., 2018; Diebo et al., 2015; Lamartina and Berjano, 2014; Viggiani et al., 2017). To this end, a deeper understanding of the link between the craniofacial morphology and the thoracic-lumbar-sacral spine sagittal alignment is of importance to prevent postural discomforts sometimes disabling and not easy to control (Lima et al., 2018).

The limitations of the present study is the lack of information regarding the cervical column due to the anatomy and the technical features of the Spinal Mouse® that is not able to record the cervical spine in a reliable way (Cooke and Wei, 1988; Gomes et al., 2014; Matheus et al., 2009; Sforza et al., 2004; Solow and Tallgren, 1976; Sonnesen et al., 2010). The future directions of this research will be the evaluation of the entire spine by means of teleradiography of the column that could add informations regarding the cervical column, the orientation of the vertebral bodies in the three spatial planes and the pelvix index that is related to the individual lordosis, improving the differences and the clinical relevance observed in this study. In fact the relationship between the spine inclination and SpPˆCoOr (Table 3) was weak but we could notice that at higher inclination of the thoracic-lumbar-sacral spine, the cephalometric parameter decreased in Group 1 (rho = −0.1) and increased in Group 2 (rho = 0.3).

The interaction between the craniofacial morphology and the spinal column inclination can improve our understanding of the human body as a whole, to the aim to avoid side effects and to improve therapeutical results of all districts with a multidisciplinary approach.

5. Conclusions

The hypothesis that the thoracic-lumbar-sacral spine sagittal alignment is different when considering different cranial structure has been confirmed and it was noticed that the group with a posterior-rotation of the condyle-orbital plane showed a higher anterior inclination of the spine. The orientation of the condyle-orbital plane with respect to the upper maxilla may be considered a reliable cranial reference in the sagittal plane. This could be a diagnostic data useful to improve our knowledge for multidisciplinary evaluation.

Acknowledgments

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Compliance with ethical standards

The Committee on Ethics and the Institutional Review Board of Turin University approved the study protocol (Approved Number: 0088896).

Declaration of Competing Interest

None of the authors has any potential conflict of interest.

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