

Article

Relationship Between Vertical Facial Patterns and Palatal Morphology in Class I and Class II Malocclusion

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Abstract: (1) The purpose of this study is to relate the bidimensional and tridimensional measures of the palate to the vertical facial pattern defined by the angle “SN-MP” between the mandibular plane and the anterior cranial base (Sella–Nasion/mandibular plane angle) in skeletal Class II untreated patients. Furthermore, the same palatal measures were used to compare Class II with Class I subjects. (2) A sample of 197 Class II Caucasian subjects (112 females and 85 males) with untreated skeletal Class II was collected retrospectively (from a private dental clinic specialized in orthodontics) and divided into two main groups according to the ANB angle: 74 Class I patients ($0^\circ \leq \text{ANB} \leq 4^\circ$) and 123 Class II patients ($\text{ANB} > 4^\circ$). Class II subjects were furthermore divided into three groups depending on the angle SN-MP. Lateral cephalograms and digital 3D maxillary dental scans were available. Bidimensional and tridimensional measures were taken on each maxillary dental scan. The differences among the groups were analyzed for significance using a variance analysis. (3) A decrease in the posterior palatal height and an increase in the palatal surface area in Class I subjects were reported. The results showed a change in upper arch form, with a greater intermolar width in patients with a low SN-MP angle and a smaller one in high-angle patients. The more a Class II subject tended towards high-angle divergence, the narrower the palate was. (4) A greater posterior palatal height was found in Class II malocclusion, while greater surface area was noted in Class I malocclusion. In addition to this result, another statistical significance was detected in Class II malocclusion: the intermolar distance was greater in hypodivergent than in hyperdivergent patients. Similar volume values were noted across different malocclusions and vertical divergence groups. Palatal width seemed to be related to vertical facial pattern, while palatal height and area seemed to be related to sagittal malocclusions. These findings underscore the importance of considering palatal morphology variations in designing individualized orthodontic treatments, thereby improving patient-specific outcomes and broadening our understanding of skeletal Class II malocclusion.

Keywords: palatal morphology; class I malocclusion; class II malocclusion; vertical facial pattern; 3D analysis

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1. Introduction

Multiple factors are involved in the development of malocclusion, which can involve not only genetic [1,2] but also environmental factors [3,4].

Among the causes that lead to the development of Class II malocclusion, there are genetic factors. The reduced growth of the jaw and/or a greater sagittal expansion of the maxilla may contribute to the establishment of a Class II malocclusion. Environmental factors are also important in the genesis of this type of malocclusion. Swallowing occurs by coordinating the movement of the tongue and orofacial muscles, which overall create a stable occlusion. In swallowing, the tongue pushes on the palate; several studies have stated that there is a correlation between the pressure exerted by the tongue in swallowing and the morphology of the palate [5,6]. Yu M. and Gao X. [7], in their article, aimed to measure the pressure of the tongue against the hard palate and relate it to the forms of dental arch at different times, both in the supine and sitting positions and while swallowing. At rest, the pressure of the tongue increased from front to back, both in the supine and sitting positions. During saliva swallowing, lingual pressure was positively correlated with Body Mass Index (BMI) and weight in the posterior region and palate length in the anterior region of the palate. As a result, as the width of the dental arch increases, the pressure of swallowing in the anterior and lateral regions of the palate decreases. Other authors [8] analyzed the different pressure exerted by the resting tongue and during swallowing by dividing the subjects of the study into two groups: a group in which the tongue touches the teeth while swallowing (atypical) and another group in which the tongue does not touch the teeth while swallowing. At rest, there were no differences between the two groups. While swallowing, participants with atypical swallowing showed greater force than the group in which the tongue did not touch the teeth.

Kurabeish H. et al. [9], in their article, related the pressure of the tongue with the type of malocclusion and came to the conclusion that the pressure exerted by the tongue in swallowing and the maximum pressure of the tongue are of minor significance in Class II subjects, and that this would perhaps be caused by the mandibular retrusion often present in this type of malocclusion.

Palatal arch shape can influence the orthodontic treatment plan, since there could be a discrepancy between the available space and the necessary space for therapy and a difference in the stability of the treatment itself over time.

Several authors have studied the morphological variations in the palate and the different arch forms in subjects with Class II malocclusion.

Some studies have focused on the differences between arch forms in Class I and Class II, and the key findings can be summarized. Staley et al. [10] analyzed 36 patients with normal occlusion and 39 in Class II, Division 1, all untreated orthodontically, and found out that the maxillary transverse lengths (intermolar and intercanine) were greater in Class I subjects than in Class II ones. A similar intercanine mandibular width was noticed in the two groups. Overall, the maxillary dental arch was narrower in Class

II, Division 1 patients. The same result was obtained in the study of Sayin and Turkkahraman [11], in which the maxillary arch was confirmed to be greater overall in subjects with normocclusion than those in Class II, Division 1. As regards the posterior transverse interarch discrepancy (PTID) in Class II subjects, authors have shown that

Class II patients with PTID have a significantly smaller jaw arch when compared to Class II subjects with no PTID [12,13]. Therefore, the Class II group without PTID showed an “anatomic” mandibular retrusion, because of a migrognathic mandible, while the Class II group with PTID showed a “functional” mandibular retrusion, because of a normal size mandible, posteriorly displaced. Other studies focused on the analyses of palatal differences among vertical facial patterns. Grippaudo et al. [14] found a smaller intercanine diameter in the hyperdivergent facial type than in the hypodivergent ones.

Paoloni et al. [15] realized a study where the conclusion was that, as divergence increases in skeletal Class II subjects, the palate is narrower and deeper. Subjects with minor divergence (“low angle”) tend to have a wider and flatter palate.

The purpose of this study is to relate the bidimensional and tridimensional measurements of the palate to the vertical facial pattern defined by the angle “SN-MP” between the mandibular plane and the anterior cranial base (Sella–Nasion/mandibular plane angle) in skeletal Class II untreated patients. Furthermore, the same palatal measurements were used to compare Class II with Class I subjects.

2. Materials and Methods

2.1. Sample

A sample of 197 Class II Caucasian subjects (112 females and 85 males) with untreated skeletal Class II was included in this study, collecting their data from a private dental clinic specialized in orthodontics. The inclusion criteria were lateral cephalogram, dental 3D casts, full permanent dentition, skeletal Class I ($0^\circ \leq \text{ANB} \leq 4^\circ$), skeletal Class II ($\text{ANB} > 4^\circ$), no previous orthodontic treatments, cervical stage value ≥ 4 .

The exclusion criteria were skeletal Class III ($\text{ANB} < 0^\circ$), malformations, previous orthodontic treatments, deciduous or ectopic teeth, edentulous spaces, systemic diseases.

The sample was divided in two main groups according to the angle ANB (indicating the sagittal relationship between the maxilla and mandible):

- $0^\circ \leq \text{ANB} \leq 4^\circ$ (74 Class I patients);
- $\text{ANB} > 4^\circ$ (123 Class II patients).

Class II subjects were furthermore divided into 3 groups depending on the angle SN-MP:

- $\text{SN-MP} < 27.3^\circ$ (35 hypodivergent subjects);
- $\text{SN-MP} = 32.5^\circ \pm 5.2^\circ$ (58 normodivergent subjects);
- $\text{SN-MP} > 37.7^\circ$ (30 hyperdivergent subjects).

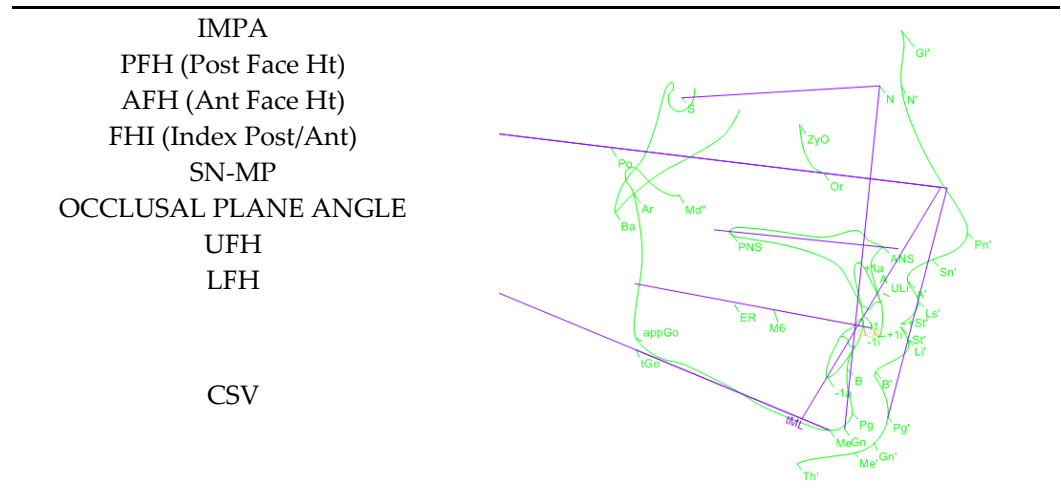
This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Università Cattolica del Sacro Cuore (2020).

2.2. Measurement

Lateral cephalograms and digital 3D maxillary dental scans were available for each subject. Lateral cephalograms were taken with Planmeca Romexis (Version 5.3) and cephalometric measures were taken in order to select the participants for the study with the Analysis Module (Planmeca Romexis), in order to select and analyze the sample. Cephalometric measures are shown in Table 1.

Table 1. Cephalometric measures. SNA (Sella–Nasion to A Point angle), SNB (Sella–Nasion to B Point angle), ANB (difference between SNA and SNB angles), FMA (Frankfort mandibular plane angle), FMIA (Frankfort mandibular incisor angle), IMPA (incisor mandibular plane angle), PFH (posterior facial height), AFH (anterior facial height), FHI (facial height index), SN-MP (Sella–Nasion to mandibular plane angle), OCCLUSAL PLANE ANGLE (Frankfurt plane–occlusal plane angle), UFH (upper facial height), LFH (lower facial height), CSV (cervical vertebral stage).

Measures	Cephalometric Visualization
SNA	
SNB	
ANB	
FMA	
FMIA	



Each maxillary scan was performed with the Trios 3 shape scanner and was available as an stl file. Bidimensional and tridimensional measures were taken on each maxillary dental scan using the software 3 shape Ortho Analyzer (Version 2023.1) and Autodesk Meshmixer (Version 3.5). Firstly, each maxillary dental scan has been cut with a plane collocated distally to the first molars. More specifically, the distal plane was collocated perpendicular to the plane, obtained by connecting the two most distal points of each upper first molar (Figure 1a). On the basis of the models thus obtained, the measurements shown in the table were taken (Table 2). All the measurements were repeated by the same operator after a month.

Table 2. Description of palatal measures performed on digital 3D dental cast.

Measures	Measurement Unit	Definition
Inter canine distance (U3)	mm	Distance between the most apical dental–gingival point of the upper canine to the same point of the contralateral canine.
Interpremolar distance (U4)	mm	Distance between the most apical dental–gingival point of the upper first premolar to the same point of the contralateral first premolar.
Intermolar distance (U6)	mm	Distance between the most apical dental–gingival point of the upper first molar to the same point of the contralateral first molar.
Palatal length	mm	Distance from the most anterior point along the median palatine suture of the palatal scan to the most posterior point along the palate.
Anterior palatal height	mm	Millimetric distance between the palate and the line that connects the most apical points of the dental–gingival junction of the upper canines in verticality.
Posterior palatal length	mm	Millimetric distance between the palate and the line that connects the most apical points of the dental–gingival junction of the upper first molars in verticality.
Palatal surface area	mm ²	Palatal area of the surface obtained by connecting the most apical points of the dental–gingival junction of all erupted teeth.
Palatal volume	mm ³	Volume that falls inside the palatine vault, placing the most distal part of the palate (previously cut) on the reference grid.

Therefore, regarding palatal widths, three transversal measures were taken by connecting the most apical point of the dental–gingival junction of each dental element to the same point of the controlateral tooth, which was also carried out for the upper canines, first premolars, and first molars (Figure 1b).

In order to investigate palatal depth, two measurements were taken (Figure 1c):

- Anterior palatal height, between the median palatine suture and the line that connects the most apical points of the dental–gingival junction of the upper canines in verticality.
- Posterior palatal height, equally measured but at the intermolar level.

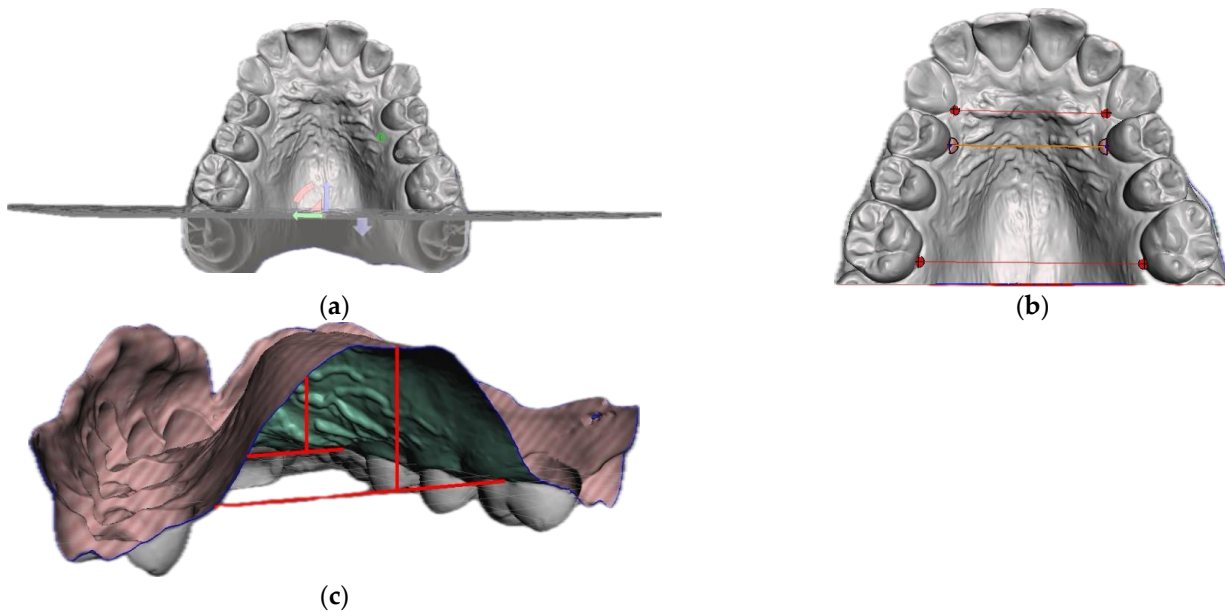
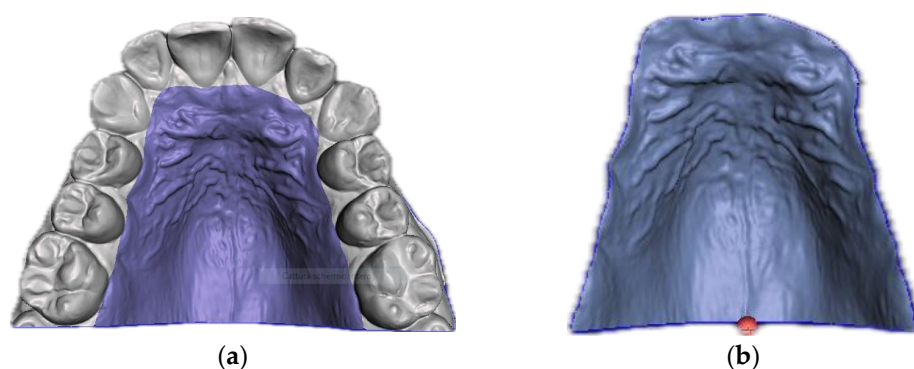


Figure 1. (a) The placement of the cutting plane distally to the upper first molars; (b) the palatal width measurement shown at the intercanine, interpremolar (U4), and intermolar levels; (c) the anterior and posterior palatal height measured at the intercanine and intermolar level.

In order to analyze the palate exclusively, without any interference from teeth, such as tipping and torquing, the palatal surface was selected by connecting the most apical point of the dental–gingival junction of all erupted teeth (Figure 2a). This area was subsequently separated from the rest of the model and used to measure area and volume (Figure 2b). The model was collocated on the reference grid with the most distal part coinciding with it, and the palatal area and volume were measured accordingly (Figure 2c). With the aim of investigate the antero-posterior whole length of the palatal vault, a sagittal plane cut was placed along the median palatine suture (Figure 2d) and measured (Figure 2e).



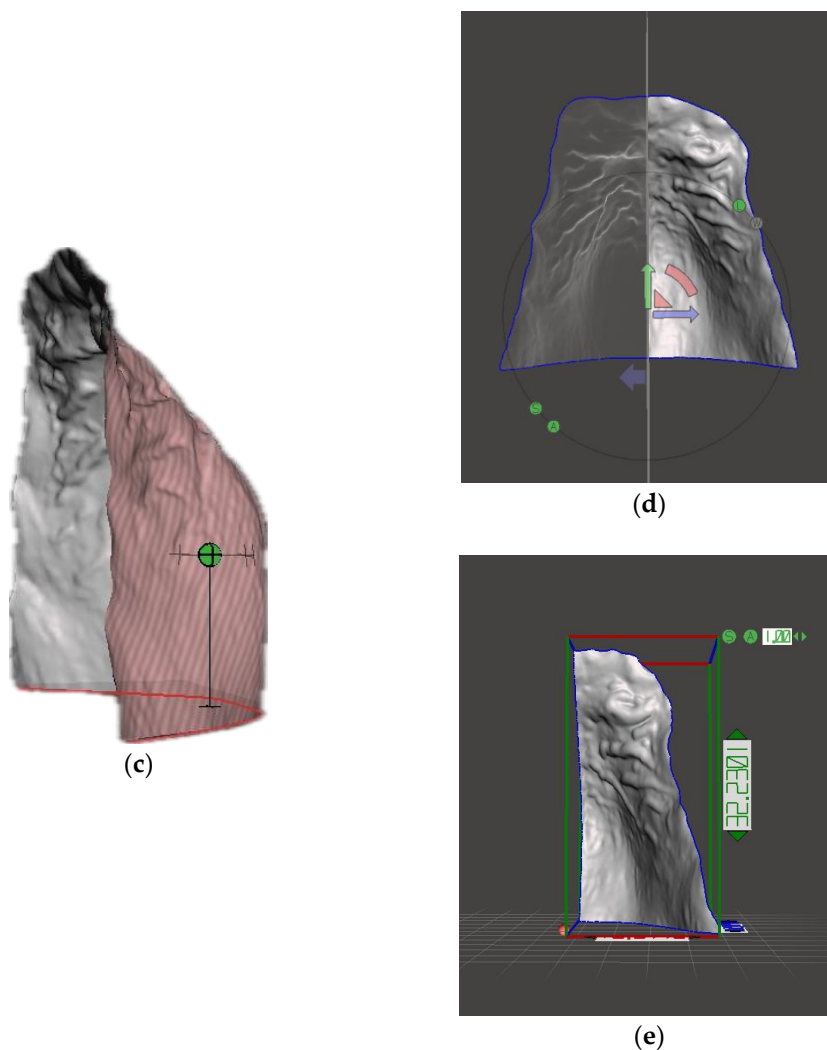


Figure 2. (a) The connection of the most apical points of the dental–gingival junction of all erupted teeth; (b) the isolation of the previously selected palatine vault; (c) an illustration of palatal vault placement on the reference grid for the measurement of palatal area and volume; (d) a palatal section, with the sagittal plane passing through the median palatine suture; (e) the palatal length measured on the divided scan obtained.

2.3. Statistical Analysis

The difference among the groups were analyzed for significance using a variance analysis. The Kolmogorov–Smirnov test was performed to determine the variable distribution. A statistical normal distribution was recorded for all measurements, apart from the variable area and volume, which showed a non-normal distribution. For the comparison between Class I and Class II, a t-student test was used for the parametric variables (Table 3) and a Mann–Whitney test for the non-parametric variables (Table 4).

Table 3. Descriptive statistics and statistical comparisons on bidimensional values between Class I and Class II subjects.

Variables	Class I		Class II		p
	Mean	SD	Mean	SD	
Inter canine distance (mm)	25.12	1.91	24.87	2.22	0.411 a
Inter premolar distance (mm)	26.93	1.85	27.19	2.34	0.384 b
Inter molar distance (mm)	33.34	2.82	33.48	2.67	0.742 a
Palatal depth (mm)	31.99	2.07	31.41	2.96	0.113 b

Anterior palatal height (mm)	4.65	1.82	5.05	1.88	0.143 a
Posterior palatal height (mm)	15.54	2.04	16.34	2.51	0.021 a

a: The p -values of the t -student test with equal variances assumed; b: The p -values of the t -student test with equal variances not assumed.

Table 4. Descriptive statistics and statistical comparisons of palatal area and volume between Class I and Class II.

Variables	Class I	Class II	p
	Median (min; max)	Median (min; max)	
Area (mm ²)	1290.09 (841.17;1561.94)	1235.44 (827.11;10,001.50)	0.026
Volume (mm ³)	5995.08 (3411.47;8999.72)	5865.62 (2416.07;59,844.61)	0.386

For the comparison between hypodivergent, normodivergent, and hyperdivergent subjects in Class II, an Anova test was used for the parametric variables (Table 5) and a Kruskal–Wallis test for the non-parametric values (Table 6).

Table 5. Descriptive statistics and statistical comparisons on bidimensional values between hypodivergent, normodivergent, and hyperdivergent Class II subjects.

Variables	Hypodivergent		Normodivergent		Hyperdivergent		p
	Mean	SD	Mean	SD	Mean	SD	
Inter canine distance (mm)	24.97	2.31	25.17	2.09	24.16	2.28	0.122
Interpre molar distance (mm)	27.56	2.31	27.33	2.13	26.48	2.67	0.142
Inter molar distance (mm)	34.36	2.34	33.39	2.72	32.59	2.71	0.026
Palatal depth (mm)	31.42	2.78	31.44	3.38	31.35	2.31	0.991
Palatal anterior height (mm)	4.67	1.62	5.27	1.98	5.06	1.96	0.336
Palatal posterior height (mm)	16.37	2.26	16.07	2.45	16.81	2.89	0.422

Table 6. Descriptive statistics and statistical comparisons on palatal area and volume between hypodivergent, normodivergent, and hyperdivergent Class II subjects.

Variables	Hypodivergent	Normodivergent	Hyperdivergent	p
	Median (min;max)	Median (min;max)	Median (min;max)	
Area (mm ²)	1235.44 (934.12;10,001.50)	1239.14 (827.11;1641.60)	1226.17 (879.64;1497.83)	0.896
Volume (mm ³)	5754.49 (3516.42;7741.19)	6070.57 (2416.07;59,844.61)	5592.83 (3492.51;8399.65)	0.544

3. Results

3.1. First Statistical Comparison

As regards the first statistical comparison between Class I and Class II subjects, two values were considered statistically significant:

- Posterior palatal height, greater in Class II subjects than in Class I ones ($p = 0.021$) (Figure 3);
- Palatal surface area, greater in Class I subjects than in Class II ones ($p = 0.026$) (Figure 4).

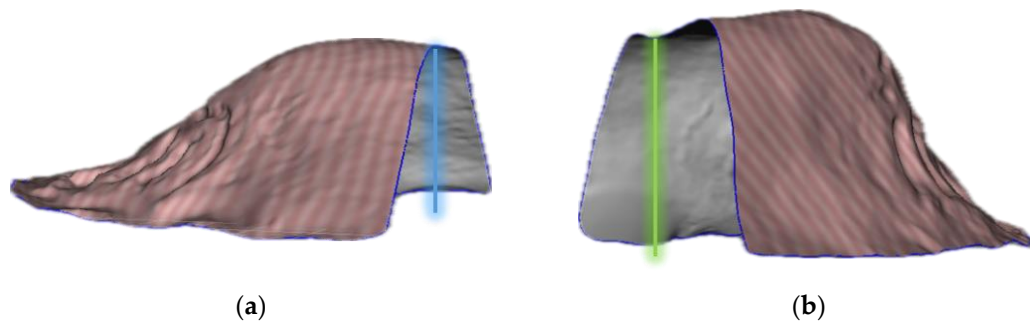


Figure 3. An illustration of an example of different palatal depths between Class I and Class II: (a) posterior palatal height in a Class I patient; (b) posterior palatal height in a Class II patient.



Figure 4. An illustration of the difference between the palatal area of Class I and Class II patients: (a) the surface palatal area of a Class I patient; (b) the surface palatal area of a Class II patient.

3.2. Second Statistical Comparison

Regarding the second statistical comparison between hypodivergent, normodivergent, and hyperdivergent subjects in Class II, the intermolar distance was found to be statistically significant ($p = 0.026$). Notably, the Anova test showed a progressively smaller value of this distance from the hypodivergent to the hyperdivergent Class II subjects. Hypodivergent ones showed a wider palatal arch when compared to normodivergent and hyperdivergent patients (Figure 5).

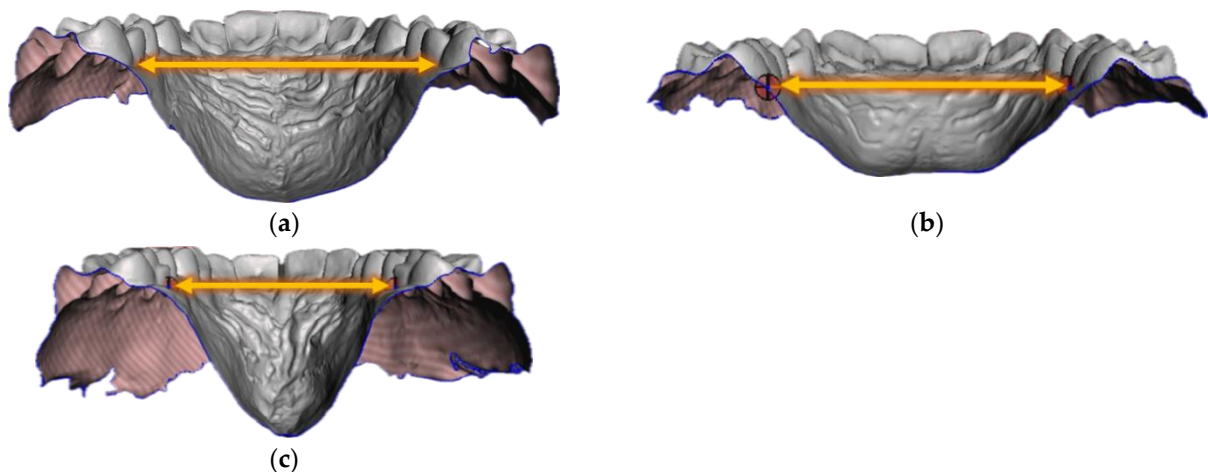


Figure 5. Examples of intermolar widths in different vertical facial patterns in the Class II sample: (a) hypodivergent patients; (b) normodivergent patients; (c) hyperdivergent patients.

4. Discussion

The statistically significant value of the posterior palatal height resulting from this study indicates that the Class II palatal morphology is characterized by a deeper palatine vault than Class I.

A similar result was obtained from the analysis conducted by Saadeh and Ghafari [16], which compared different types of sagittal malocclusions and vertical divergence patients. They also found a depth difference, but at the anterior level: the palatal depth at the canine depth was significantly greater in Class II, Division 2, than in Class I and Class III.

Comparing the results concerning the depth of the palate with the existing literature is complex, because of the different software or manual systems used, especially given that the reference points chosen for measuring the palate height are different from one study to another. Some studies, such as the one we carried out, use gingival margins [16] as reference points, while others measure height by including dental cusps [17,18].

From the comparison between the three subgroups analyzed in Class II, a statistically significant difference in the intermolar distance was found, confirming the fact that hypodivergent patients in Class II have a wider maxillary arch when compared to the normodivergent and hyperdivergent patients of the same class. Hypodivergent Class II subjects exhibit wider palatal dimensions compared to hyperdivergent subjects due to the interaction between craniofacial growth patterns and mechanical forces. Specifically, hypodivergent individuals, characterized by a lower mandibular plane angle, tend to have a more horizontally oriented growth trajectory. This promotes greater transverse development of the maxilla, resulting in a wider palatal arch. Conversely, in hyperdivergent subjects with a higher mandibular plane angle, vertical growth predominates, limiting the transverse expansion of the maxilla and leading to a narrower and deeper palate. Furthermore, the tongue's resting posture and its contact with the palate during functional activities such as swallowing might differ between these groups, amplifying the observed differences. Thus, the result obtained is consistent with the statements in the literature, listed below/as here reported. According to the article by Paoloni et al. [15], in fact, hyperdivergent subjects in Class II tend to have a narrower palate, but it is higher than the hypodivergent subjects in the same class, which instead have a lower and wider palate.

Grippaudo et al., in a further study [14], analyzed the differences between Class II patients with a high SN-MP angle and Class II patients with a lower SN-MP angle. In this case, a difference in transversality emerged in the intercanine distance: a smaller value was found in hyperdivergent subjects than in hypodivergent ones.

The study by Forster et al. [19] analyzed a sample of 185 subjects—not orthodontically treated—between 18 and 68 years with complete permanent dentition (except third molars), with the aim of identifying the differences between the dental arches according to the vertical pattern. The result was that as the SN-MP angle increased and the divergence increased, the arch width decreased.

According to the results of the study by Saadeh et al. [16], the molar and intermolar amplitude is greater in hypodivergent subjects than in hyperdivergent ones.

The conclusions of this study confirm the results of the above studies: the transverse maxillary dimensions are greater in hypodivergent subjects than in hyperdivergent ones.

An interesting result of this study is that the palate area is significantly greater in Class I than in Class II. Looking at the studies on this topic, there is no significant contribution in the analysis of the palate area in the different malocclusions and in the different facial verticalities, so this theme can be further explored in the literature. A notable contribution on this theme was given by the article by Saadeh and Ghafari [16], which, in addition to linear measures of the palate, aimed to analyze the area and the volume of the palate regarding the different types of malocclusion and divergence. Despite some significant differences in linear measurements, on average, the area and volume showed no major differences between the types of sagittal malocclusion and even between the different divergences.

The study by Lione et al. [20] also analyzed the area and volume of the palate, distinguishing these measures between a sample of mouth-breathing and a sample of nose-breathing subjects. Both area and volume were smaller in the mouth-breathing subjects.

Our result of a greater surface palatal area in Class I subjects could represent an initial step in considering the treatment of developing Class II patients. The aim of the therapy could be to increase this specific area in developing Class II patients in order to raise maxillary dimensions, considering that this type of malocclusion is frequently/most often characterized by mandibular retrusion [21–23]. Further investigations could analyze the differences in the palate area between the different vertical growth patterns and the various types of malocclusion that exist.

As regards the volume, there were no differences in any of the statistical comparisons. It is not easy to find articles that analyze volume differences in samples of untreated patients distinguished by the type of malocclusion. According to the authors, there are differences in the identification of reference plans when measuring samples. Among these, the work of Gracco et al. [24] aimed to evaluate the volumetric changes in the palate as a result of its rapid expansion in the early mixed dentition of 30 patients with an average age of 7 years, 6 months. Three-dimensional scanning of the upper arches was achieved by piezoelectric scanning of the models. The horizontal reference plane was obtained by joining the lowest point of the gum margin of a central incisor with the two lowest points of the gum margins of the first permanent molars. The posterior boundary is a plane tangent to the distal surface of the upper sixth, forming an angle of 90° with the horizontal plane. After treatment, the volume showed a significant increase. Saadeh and Ghafari [16] found no statistical differences in the palatal volume among types of malocclusions and facial divergence patterns. Differences emerge in choosing the position of the palatal surface in the 3D space: in the present study, the palate has been positioned to coincide distally with the previously cut surface and the upper first molars in the reference grid, in order to reduce errors in volumetric measurement.

The morphological differences in the palate found by the analysis carried out in this study can be explained by referring to the etiopathogenesis. Multiple factors are involved in the development of malocclusion, which, according to Profitt [25], can be not only genetic [1] but also environmental [3,4] or specific.

Identifying morphological palatal differences among vertical facial patterns and different malocclusions can be useful for clinical purposes: the palate is studied in orthodontics for the purpose of anchoring. In the orthodontic field of space analysis, the investigation of the palatal arch of patients, from a skeletal point of view, could help a lot to achieve a complete knowledge of the maxillary dimensions and to carry out individualized treatments. For orthodontists, understanding these morphological variations is essential for individualized treatment plans, optimizing appliance selection, and improving post-treatment stability, thereby enhancing both the efficiency and efficacy of clinical outcomes.

There are some limitations in this study that can be observed. The sample selected consisted of patients who spontaneously went to the orthodontic clinic and not of people randomly selected from the population. Moreover, just one ethnic group was included in this work, so it is not a multiethnic study. Furthermore, there could be some differences between males and females, but the whole sample was analyzed in this study without distinction between sex categories.

5. Conclusions

Palatal morphology plays a fundamental role in the choice of the orthodontic device to use for each case. In this study, the conclusions can be summarized as follows:

- Palatal posterior height was greater in Class II subjects than Class I ones;

- Palatal surface area was significantly greater in Class II participants than in Class II ones;
- Sagittal patterns are therefore related to differences in the morphology of the palate;
- Intermolar distance was greater in hypodivergent Class II subjects when compared to hypodivergent ones of the same class;
- Vertical growth patterns are therefore related to the transverse growth of the maxilla in skeletal Class II.
- Volume showed no statistical significance in either comparison;
- Class II hyperdivergent patients showed a narrower palate than Class II hypodivergent patients, deeper than Class I;
- Morphological differences should be considered for the design and use of orthodontic palatal devices.

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Informed Consent Statement: Patient consent was waived due to the fact that patients were identified by a number not attributable to any personal data.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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

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