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Incisor Inclination and Its Association with the Sagittal and Vertical Skeletal Pattern in a Sample of Romanian Orthodontic Adult Patients: A Cephalometric Study

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Abstract

Background: The main objective of this study was to investigate the associations between maxillary and mandibular incisor inclinations, and sagittal and vertical skeletal parameters in Romanian adults using multivariable regression analysis adjusted for age and sex. Secondly, the aim was to determine differences in incisor inclination among skeletal Classes I, II, and III, providing population-specific data to complement existing international research. **Methods:** In this retrospective cephalometric study, 187 adult patients (aged 18 years and older; 49.7% female) were selected. Multiple linear regression models were built for Max1-FH (SNA, ANB, S-N/Go-Gn, Ar-Go-Me, age, sex) and IMPA (SNA, ANB, age, sex). Skeletal classes were compared with ANOVA or Kruskal–Wallis tests. Correlations were exploratory. Reliability was excellent (ICC ≥ 0.967). **Results:** Class II was the most frequent skeletal pattern (48.13%), followed by Class I (36.36%) and Class III (15.51%). In the multivariable models, Max1-FH was independently associated with SNA (B = 0.732, $p < 0.001$), ANB (B = −0.577, $p = 0.001$) and Ar-Go-Me (B = −0.279, $p = 0.011$) (R^2 =0.323), whereas IMPA was independently associated with SNA (B = 0.638, $p < 0.001$) and ANB (B = 1.241, $p < 0.001$) ($R^2 = 0.273$). Age and sex were not significant in either model. Max1-FH was higher in Class III (120.71° ± 7.24°) than in Class I (114.45° ± 7.81°, $p = 0.002$) and Class II (114.22° ± 8.70°, $p < 0.001$). IMPA was higher in Class II (median 97.00°) than in Class I (86.00°) and Class III (87.00°), with no difference between Classes I and III ($p = 1.000$). **Conclusions:** In this Romanian orthodontic adult sample, incisor inclinations were independently associated with sagittal skeletal parameters (SNA and ANB), and maxillary incisor inclination was also associated with the gonial angle (Ar-Go-Me), whereas age and sex showed no significant association. Incisor inclination differed among skeletal classes, with greater maxillary incisor proclination in Class III and greater mandibular incisor proclination in Class II.

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1. Introduction

Accurate diagnosis and individualized treatment planning require a comprehensive assessment of facial morphology, soft tissue features, and underlying dental and skeletal relationships, with cephalometric analysis serving as an essential diagnostic tool [1,2]. Among the parameters evaluated through this analysis, the antero-posterior position of the maxillary and mandibular incisors occupies a central role, as it directly influences occlusal function, periodontal support, and the stability of the final treatment outcome [3,4].

Upper and lower incisors position plays an important role in achieving facial harmony and maintaining an aesthetically balanced profile. Therefore, establishing optimal interincisal relationships is crucial for the long-term stability of an orthodontic treatment, especially in cases involving the camouflage of underlying skeletal discrepancies through dentoalveolar compensation [5,6].

Cephalometric analysis allows clinicians to quantify incisor inclination through several angular measurements, most commonly the angle between the maxillary central incisor long axis and the Frankfort horizontal plane (FH), Max1-FH, for the maxillary incisor and the incisor–mandibular plane angle (IMPA) for the mandibular incisor, together with the interincisal angle (II), which reflects the combined inclination of both incisors. These measurements are not independent of the surrounding skeletal architecture: the Frankfort–mandibular plane angle (FMA) and the sagittal relationship between the jaws (expressed through the Sellae-Nasion-point A angle (SNA), Sellae-Nasion-point B angle (SNB), and the sagittal skeletal classification) are known to influence how the dentoalveolar complex compensates for underlying skeletal discrepancies [7].

Previous studies have established that incisor inclination is influenced by the underlying sagittal and vertical skeletal pattern [7–10]. Alhammadi (2019) reported differences in dentoalveolar compensation across sagittal and vertical skeletal malocclusions [7], while Jain et al. (2020) focused primarily on mandibular incisor angulation and symphyseal morphology [11]. Kirschneck et al. (2013) also investigated related dentoskeletal associations in Class II patients, accounting for age [12]. However, the simultaneous evaluation of maxillary and mandibular incisor inclinations across all three sagittal skeletal classes, while accounting for the independent contributions of sagittal and vertical skeletal parameters and adjusting for age and sex, remains an important analytical question. In particular, it is relevant to determine whether the associations between skeletal parameters and incisor inclination persist when these variables are considered simultaneously rather than examined only through separate group comparisons or unadjusted correlations.

Therefore, the present study aimed to investigate the relationships between maxillary and mandibular incisor inclinations and sagittal and vertical skeletal parameters in a Romanian orthodontic adult sample, using multivariable regression analysis to assess their independent associations after adjustments for age and sex. Additionally, differences in incisor inclination among skeletal Classes I, II, and III were examined. Because craniofacial and dentoalveolar characteristics may vary across populations, these data also complement the existing international literature with population-specific evidence from Romania.

The null hypotheses were that incisor inclinations do not differ among skeletal classes and that after adjustment for the other model variables, no regression coefficient differs from zero.

2. Materials and Methods

2.1. Ethical Considerations

This study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments and was approved by the Research Ethics Committee of the University of Oradea (Approval no. 35/10 February 2026). Informed consent for the use of medical records was obtained from all participants before enrolment. Participation was voluntary and anonymous, with no financial or other incentives provided.

2.2. Sample Selection

This retrospective observational study was conducted between February and July 2026. Patients with complete orthodontic records, including good-quality initial orthopantomograms, lateral cephalometric radiographs, intraoral and extraoral photographs, study casts, and a complete dental history were eligible for inclusion. Panoramic radiographs were not directly used in the quantitative analysis; however, their availability was included in the complete-record eligibility criterion to ensure standardized and comprehensive orthodontic documentation.

Eligible patients were aged 18 and older, with various dental and skeletal anomalies, and willing to undergo orthodontic treatment. Exclusion criteria included age under 18, a history of trauma, cleft lip and/or palate, syndromic conditions, craniofacial deformities, endocrine or metabolic disorders, incomplete orthodontic records and previous orthodontic treatment. The final sample consisted of 187 patients.

2.3. Skeletal Classification, Growth Pattern Assessment and Workflow

Lateral cephalometric radiographs were obtained for all patients prior to orthodontic treatment, with the head oriented in natural position and the posterior teeth in maximum intercuspation at the same radiology center located in Oradea, Romania by the same radiologic technologist.

Several cephalometric parameters were digitally measured by the investigators using OnyxCeph^{3}™ v. 3.2 (Image Instruments GmbH, Chemnitz, Germany). The use of specialized digital tracing software simplifies cephalometric analysis by identifying anatomical landmarks and calculating the corresponding measurements. Moreover, it offers ethnicity-, sex-, and age-specific reference standards. The anatomical landmarks were manually identified by the investigators [13].

There were several reference planes used in this analysis. The Frankfort Horizontal plane (FH) is defined by a line passing through the lowest point on the inferior margin of the orbit and the highest point on the superior margin of the external acoustic meatus. The mandibular plane is defined as a line tangent to the inferior border of the mandibular corpus. Upper incisor long axis is defined by the line connecting the incisal edge and root apex of the most prominent maxillary central incisor. Lower incisor long axis is defined by the line connecting the incisal edge and root apex of the most prominent mandibular central incisor. The most prominent central incisor is the maxillary or mandibular central incisor that exhibits the most anterior projection on a lateral cephalometric radiograph (incisal edge, crown labial curvature, root apex). In cases of bilateral incisor superimposition on lateral cephalometric radiographs, the most anteriorly positioned (most prominent) incisor was selected for tracing. The longitudinal axis of the selected incisor, defined by the incisal edge and root apex, was used as the dental reference axis for the corresponding angular measurements. This selection criterion was applied consistently to all radiographs.

The cephalometric analysis included the measurement of the following parameters. SNA (82° ± 2°, McLaughlin) and SNB (80° ± 2°, McLaughlin) describe the antero-posterior position of the maxilla and the mandible, respectively, relative to the anterior cranial base

(S-N); decreased values indicate retrognathism and increased values indicate prognathism. ANB (angle between point A, nasion and point B; 2° ± 2°, McLaughlin) expresses the sagittal jaw relationship, with decreased values suggesting skeletal Class III and increased values suggesting skeletal Class II. The inclination of the mandibular plane to the cranial base was assessed with S-N/Go-Gn (angle between the Sellae-nasion line and the mandibular plane (gonion-gnathion); 32° ± 5°, McLaughlin): decreased values indicate horizontal growth with a tendency toward deep bite, and increased values indicate vertical growth with a tendency toward open bite. Facial convexity was measured with N-A-Pog (nasion-point A-pogonion angle; 0° ± 5°), where decreased values correspond to a concave profile and increased values to a convex one [6].

Incisor position was evaluated by using the interincisal angle (135° ± 5°, Downs analysis), where decreased values indicate proclined incisors and increased values indicate retroclined incisors. Upper incisors position was evaluated by determining the Max1-FH angle (110° ± 2°, Downs analysis), where decreased values indicate retroclined and increased values show proclined upper incisors. The gonial angle, Ar-Go-Me (articulare-gonion-menton; 130° ± 7°, Jarabak analysis), describes the relation between the mandibular corpus and ramus; decreased values indicate anterior mandibular rotation, and increased values indicate posterior rotation. Facial divergence was assessed using the FMA angle (25° ± 3°, Tweed analysis), with lower values indicating a hypodivergent pattern and higher values a hyperdivergent pattern. Finally, IMPA (88° ± 3°, Tweed analysis) describes the inclination of the lower incisors, with decreased values indicating retroclination and increased values indicating proclination of the lower incisors [6].

Based on the initial panoramic and lateral cephalometric radiographs, clinical photographs, and study casts, patients were classified according to anteroposterior relationship between the maxilla and mandible as: Class I, Class II, or Class III. Thus, a harmonious sagittal jaw relationship defines skeletal Class I, while skeletal Class II reflects a distal position of the mandible relative to the maxilla, and skeletal Class III a mesial one. These discrepancies can arise from maxillary, mandibular, or combined skeletal factors, and are usually evaluated using cephalometric measurements [14]. Skeletal classification was determined using the ANB angle. The ANB angle was interpreted as follows: values over 4° indicated skeletal Class II, values under 0° indicated skeletal Class III, and values between 0° and 4° indicated skeletal Class I. The ANB-based class was then compared with the sagittal relationship indicated by the dental and facial records: the molar and canine relationships on the study casts and the facial profile on the lateral extraoral photographs. The ANB-based class was retained whenever at least one of these records agreed with it, and was changed only when the molar relationship, the canine relationship and the facial profile all consistently indicated the same different class. These cases were assessed independently by both examiners and the final class was assigned only when they agreed. Using this procedure, 13 of 187 patients (7%) were reclassified: 7 from Class II to Class I, 3 from Class I to Class II, and 3 from Class I to Class III.

Patients' age and sex were retrieved from the dental records, and all this data collection was performed by a single calibrated examiner. A standardized workflow was followed. Each patient had their clinical data, including age and sex, collected from the dental records. An individual folder was then prepared for each patient, containing their age and sex, the initial panoramic radiograph, intraoral and extraoral photographs, the initial lateral cephalometric radiograph, and the corresponding study cast for direct evaluation. The panoramic radiographs and photographic records were evaluated as described above, and the study casts were physically examined by the investigators.

Cephalometric analysis of the lateral radiographs was then performed by the first examiner using three analytical methods (Riedel, Roth-Jarabak, and Tweed), with the resulting

measurements and observations included into a dedicated Excel database. An independent cephalometric analysis of the same radiographs was subsequently carried out by the second examiner, using the same three methods, with the corresponding data recorded in a separate Excel database. After a 25-day interval, the first examiner repeated the cephalometric analysis using the same three methods, inserting the data into a separate database to minimize measurement bias; the second examiner likewise repeated the analysis after the same interval, recording the results separately to minimize examiner-related bias. Finally, all collected data were consolidated into a single centralized Excel database and subjected to statistical analysis. Reliability for the diagnosis of skeletal anomalies and for the SNA, SNB, S-N/Go-Gn, FMA, IMPA, Max1-FH, Ar-Go-Me, interincisal, and N-A-Pog angles was assessed by a gold-standard evaluator, an orthodontic specialist with more than 10 years of experience. This evaluator diagnosed all 187 individuals using the panoramic radiographs, study casts and the lateral cephalometric radiographs (for the angular measurements) aided by the OnyxCeph^{3}™ v. 3.2 software (Image Instruments GmbH, Chemnitz, Germany). A second evaluator performed the same diagnostic assessment under identical conditions for comparison. After a 25-day interval, both investigators repeated the same procedure to allow calculation of inter-examiner reliability for all 187 lateral cephalometric radiographs.

2.4. Reliability

All 187 records were analyzed by examiner 1 and, independently, by examiner 2 (blinded to each other's results). Both repeated the tracings after 25 days. Intra-examiner reliability compared each examiner's two sessions. Inter-examiner reliability compared the first sessions. All 187 cephalograms were re-measured. Intra-examiner reliability was excellent for both examiners (ICC = 0.967–0.999, lower 95% confidence limits ≥ 0.947), as was inter-examiner reliability (ICC = 0.976–0.999). Cohen's kappa showed perfect agreement ($\kappa = 1$) for skeletal classification, both within and between examiners. Dahlberg's method error was ≤ 0.52° for SNA, ANB, SNB, S-N/Go-Gn, N-A-Pog, interincisal angle and Max1-FH, and approximately 1° for Ar-Go-Me, FMA and IMPA.

2.5. Statistical Analysis

Data were analyzed using IBM SPSS Statistics, version 31.0.2.0 (IBM Corp., Armonk, NY, USA), and Microsoft Excel (Microsoft Corp., Redmond, WA, USA). Quantitative variables were expressed as means with standard deviations (Mean (±SD)) or as medians with interquartile ranges (Median (IQR)), depending on the data distribution, while qualitative variables were reported as frequencies and percentages. Associations were analyzed using the Pearson correlation coefficient (r) when both variables followed a normal distribution; otherwise, the Spearman rank correlation coefficient (rho) was used. The strength of the correlation was interpreted on the absolute value of the coefficient as follows: weak (<0.3), fair (0.3–0.49), moderate (0.5–0.79), and very strong (≥0.8), adapted from Chan [15]. The threshold for statistical significance for all tests was set at $\alpha = 0.05$.

Two separate multiple linear regression models were constructed with Max1-FH and IMPA as dependent variables. Candidate predictors were selected a priori to represent the sagittal and vertical skeletal pattern, while avoiding variables that are mathematically derived from, or share a reference plane with the dependent variable or with other predictors. The model for Max1-FH included SNA, ANB, S-N/Go-Gn, Ar-Go-Me, age and sex. FMA was not included because it shares the Frankfort horizontal plane with Max1-FH. The model for IMPA included SNA, ANB, age and sex. S-N/Go-Gn, FMA and Ar-Go-Me were not included because, like IMPA, they are constructed on the mandibular plane, so their association with IMPA would partly reflect a shared reference line rather than an independent relationship. In both models, SNB was not entered because it is a linear combination of SNA and ANB

(ANB = SNA-SNB), N-A-Pog was not entered because of its strong dependence on the sagittal jaw relationship expressed by ANB, and the interincisal angle was not entered because it is geometrically derived from the inclinations of both incisors. Linearity and homoscedasticity were evaluated by plotting standardized residuals against standardized predicted values; the normality of the residuals was assessed using histograms and normal probability plots (P-P plots) (Supplementary Figures S1 and S2), multicollinearity was assessed using variance inflation factors (VIF) and tolerance values, with VIF < 5 considered acceptable.). Highly influential observations were identified using standardized residuals ($|z| > 3$), leverage values, and Cook's distance (values > 1 were considered influential) (Supplementary Tables S1 and S3). As a sensitivity analysis, coefficients were re-estimated using bootstrap (1000 resamples, bias-corrected and accelerated 95% confidence intervals, fixed seed). Qualitative variables were compared using the Chi-square test. Quantitative variables, compared across skeletal classes (I, II, and III), were analyzed using ANOVA or the Kruskal–Wallis test. The 11 *p*-values resulting from these comparisons were adjusted collectively, as a single family of tests, using the Benjamini–Hochberg method to control the false discovery rate (FDR), adjusted *p*-values < 0.05 were considered significant. For the variables that remained significant after the BH adjustment, pairwise comparisons (I vs. II, I vs. III, II vs. III) were performed using the Tukey HSD/Kramer test following ANOVA, and using the Dunn test with Bonferroni correction of *p*-values following the Kruskal–Wallis test. For continuous variables, the intraclass correlation coefficient (ICC—two-way random-effects model, absolute agreement) and the Dahlberg error were calculated, while Cohen's kappa coefficient was used for skeletal classes.

3. Results

3.1. Description of the Analyzed Variables

The study group consisted of 187 patients, of whom 49.73% were female and 50.27% were male. Skeletal Class II was the most common anomaly (48.13%). The distribution by sex was not statistically significant among the three skeletal classes ($\chi^2 = 0.764$, $p = 0.683$). The qualitative characteristics of the patients (sex and skeletal anomaly) are presented in Table 1, and the distribution of patients according to sex and skeletal classes is presented in Figure 1.

Table 1. Characterization of the analyzed qualitative variables.

Variable		*n* (%)
Sex	Female	93 (49.73%)
	Male	94 (50.27%)
Skeletal class	I	68 (36.36%)
	II	90 (48.13%)
	III	29 (15.51%)

The median age of the participants was 26.40 (11.0) years, ranging from 18 to 47.7 years. The mean SNA angle was 82.83° ± 4.04°, the median SNB angle was 79° (7.45°), and the median ANB angle was 4.3° (4.65°), ranging from −7.30° to 9.70°. The N-A-Pog angle ranged from −17.30° to 19.80°. The median values for S-N/Go-Gn, FMA and Ar-Go-Me were 32.7° (10.50°), 24° (9.50°) and 124° (11°), respectively. The mean interincisal angle (II) was 131.43° ± 12.27°. The maxillary incisor inclination (Max1-FH) ranged from 95.10° to 133° (mean 115.31° ± 8.45°), and the mandibular incisor inclination (IMPA) ranged

from 66° to 108° (median 91° (14°)). Table 2 presents a description of the quantitative variables analyzed.

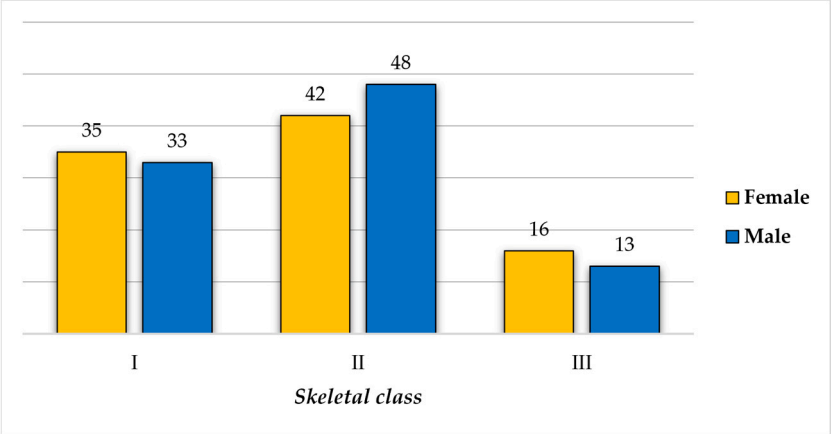

Figure 1. Distribution of patients according to sex and skeletal classes.

Table 2. Characterization of the quantitative variables analyzed.

Variable	Mean (±SD)/ Median (IQR)	Minimum Value	Maximum Value
Age	26.40 (11)	18	47.70
SNA angle	82.83 ± 4.04	71.90	92.80
ANB angle	4.30 (4.65)	−7.30	9.70
SNB angle	79 (7.45)	67.30	94.0
S-N/Go-Gn angle	32.70 (10.5)	18.30	48.60
N-A-Pog angle	5.70 (10.4)	−17.30	19.80
Interincisal angle	131.43 ± 12.27	103.90	158
Max1-FH angle	115.31 ± 8.45	95.10	133
Ar-Go-Me angle	124 (11)	111	149.20
FMA angle	24 (9.5)	11	42
IMPA angle	91 (14)	66	108

3.2. Association Between Incisors Inclination and Other Angles

3.2.1. Association Between the Maxillary Incisor Inclination (Max1-FH) and the Interincisal Angle, as Well as the SNA, SNB, N-A-Pog, FMA, S-N/Go-Gn, and Ar-Go-Me Angles

A moderate inverse relationship was observed between Max1-FH and the interincisal angle ($r = -0.627$). Fair positive correlations were found with SNA ($r = 0.439$) and SNB (rho = 0.480), and fair negative correlations with S-N/Go-Gn (rho = −0.434) and FMA (rho = −0.412). Weak negative associations were observed with ANB (rho = −0.201), N-A-Pog (rho = −0.214) and Ar-Go-Me (rho = −0.212). All correlations were statistically significant ($p < 0.05$). Table 3 presents the correlations between the maxillary incisors (Max1-FH) and the angles analyzed.

Table 3. Correlations between the maxillary incisor inclination and the analyzed angles.

Correlations	r/rho	*p*-Value
Max1-FH vs. SNA	0.439	<0.001
Max1-FH vs. ANB	−0.201	0.006
Max1-FH vs. SNB	0.480	<0.001
Max1-FH vs. S-N/Go-Gn	−0.434	<0.001
Max1-FH vs. N-A-Pog	−0.214	0.003
Max1-FH vs. interincisal angle	−0.627	<0.001
Max1-FH vs. Ar-Go-Me	−0.212	0.004
Max1-FH vs. FMA	−0.412	<0.001

3.2.2. Association of Lower Incisor Inclination (IMPA) with the Interincisal Angle and the SNA, SNB, N-A-Pog, FMA, S-N/Go-Gn, and Ar-Go-Me Angles

Correlations between the lower incisor inclination (IMPA) and the analyzed angles (SNA, ANB, SNB, S-N/Go-Gn, N-A-Pog, interincisal angle, Ar-Go-Me, FMA) were mostly fair. A fair direct association was observed between IMPA and ANB (rho = 0.485), and a moderate direct association with the N-A-Pog angle (rho = 0.535). Negative correlations were found between the lower incisor angle and S-N/Go-Gn (rho = −0.300), Ar-Go-Me (rho = −0.477), and FMA (rho = −0.338). A moderate negative correlation was observed between IMPA and the interincisal angle (rho = −0.795). On the other hand, weak associations were observed between IMPA and SNA (rho = 0.216) and SNB (rho = −0.101), respectively. With the exception of the correlation between IMPA and SNB, all other correlations were statistically significant. Table 4 presents the correlations between the lower incisors inclination (IMPA) and the analyzed angles.

Table 4. Correlations between the mandibular incisor inclination and the analyzed angles.

Correlations	rho	*p*-Value
IMPA vs. SNA	0.216	0.003
IMPA vs. ANB	0.485	<0.001
IMPA vs. SNB	−0.101	0.169
IMPA vs. S-N/Go-Gn	−0.300	<0.001
IMPA vs. N-A-Pog	0.535	<0.001
IMPA vs. interincisal angle	−0.795	<0.001
IMPA vs. Ar-Go-Me	−0.477	<0.001
IMPA vs. FMA	−0.338	<0.001

3.3. Regression Analysis of the Incisors

3.3.1. Regression Analysis of Maxillary Incisors (Max1-FH)

A linear regression model was constructed to analyze the extent to which Max1-FH is associated with SNA, ANB, S-N/Go-Gn, and Ar-Go-Me, as well as with age and sex. This model was estimated on a sample of $N = 187$ observations. No significant multicollinearity was observed (VIF values between 1.002 and 4.221; minimum tolerance 0.237), with all values falling below the threshold of 5. The standardized residuals ranged from −2.246 to 2.209 (none exceeding ±3), and the maximum value of Cook's distance

was 0.055, indicating that there was no significant influence (Supplementary Table S1). The model was statistically significant ($p < 0.001$) and explained 32.3% of the variance in the Max1-FH indicator (coefficient of determination (R^2) =0.323; adjusted $R^2 = 0.300$). SNA, ANB, and the Ar-Go-Me angle made significant contributions, whereas age, S-N/Go-Gn, and sex did not contribute significantly. Following validation using the bootstrap method, the three angles remained significant predictors (SNA: $p < 0.01$, BCa 95% CI 0.365 −1.131; ANB: $p = 0.003$, BCa 95% CI −0.910–−0.230; and Ar-Go-Me: $p = 0.015$, BCa 95% CI −0.495–−0.054) (Supplementary Table S2). Table 5 presents the coefficients of the linear regression model for the maxillary incisor angle (Max1-FH).

Table 5. The linear regression model coefficients for the maxillary incisor angle (Max1-FH).

Predictor	*B* [1]	SE [2]	t	*p*-Value	95% CI		VIF [3]
					Lower	Upper	
Age	−0.073	0.075	−0.970	0.333	−0.222	0.076	1.130
SNA angle	0.732	0.183	4.001	<0.001	0.371	1.093	2.034
ANB angle	−0.577	0.175	−3.302	0.001	−0.922	−0.232	1.642
S-N/Go-Gn angle	−0.060	0.152	−0.393	0.695	−0.359	0.240	4.221
Ar-Go-Me angle	−0.279	0.109	−2.570	0.011	−0.493	−0.065	2.567
Sex (male)	0.218	1.035	0.210	0.834	−1.824	2.260	1.002

$N = 187$, [1] B = unstandardized regression coefficient; [2] SE = standard error, [3] VIF = variance inflation factor.

3.3.2. Regression Analysis of Mandibular Incisors (IMPA)

A linear regression model was constructed to analyze the extent to mandibular incisors angle (IMPA) is associated with SNA, ANB, as well as with age and sex. No significant multicollinearity was observed (VIF values between 1.002 and 1.054; minimum tolerance 0.949), and the standardized residuals ranged from −2.373 to 2.267. The maximum Cook's distance was 0.058, suggesting the absence of any disproportionate influence (Supplementary Table S4). The model for IMPA was statistically significant ($p < 0.001$) and explained 27.3% of the variance ($R^2 = 0.273$; adjusted $R^2 = 0.257$). SNA and ANB made significant independent contributions, whereas age and sex did not. The two angles remained significant predictors following validation using the bootstrap method (SNA: $p < 0.01$, BCa 95% CI 0.355–0.927; and ANB: $p \leq 0.001$, BCa 95% CI 0.856–1.651) (Supplementary Table S4) Table 6 presents the coefficients of the linear regression model. This model was estimated on a sample of $N = 187$ observations.

Table 6. The linear regression model coefficients for the mandibular incisors angle (IMPA).

Predictor	*B* [1]	SE [2]	t	*p*-Value	95% CI		VIF [3]
					Lower	Upper	
Age	0.018	0.088	0.203	0.839	−0.155	0.191	1.050
SNA angle	0.638	0.159	4.006	<0.001	0.324	0.953	1.054
ANB angle	1.241	0.166	7.486	<0.001	0.914	1.568	1.010
Sex (male)	−0.325	1.252	−0.260	0.796	−2.795	2.145	1.002

$N = 187$, [1] B = unstandardized regression coefficient; [2] SE = standard error, [3] VIF = variance inflation factor.

3.4. Analysis of the Skeletal Anomaly

When comparing cephalometric angles and age across skeletal Classes I, II and III, significant overall differences were observed for all variables except age ($p = 0.195$), SNA ($p = 0.690$) and Ar-Go-Me ($p = 0.208$) (Table 7). In pairwise comparisons using the Dunn test with Bonferroni correction, ANB, SNB and N-A-Pog differed significantly between all three classes (adjusted $p < 0.001$ for each comparison). S-N/Go-Gn differed between Classes I and II ($p = 0.020$) and between Classes II and III ($p = 0.002$), but not between Classes I and III. IMPA was higher in Class II than in Class I and Class III ($p < 0.001$ for both), with no difference between Classes I and III ($p = 1.000$). The interincisal angle and FMA differed only between Classes I and II ($p < 0.001$ and $p = 0.009$, respectively). Max1-FH was higher in Class III than in Class I ($p = 0.002$) and Class II ($p < 0.001$), with no difference between Classes I and II ($p = 0.983$).

Table 7. Comparison of the analyzed variables between skeletal classes.

Variable	Class I	Class II	Class III	*p*-Value	*p*-Adjusted	Pairwise Comparisons		
						I vs. II	I vs. III	II vs. III
Age	23.10 (9.20)	27.85 (8.83)	22.40 (15.70)	0.195	0.229	—	—	—
SNA angle	83.35 (6.03)	81.90 (4.97)	83.70 (4.60)	0.690	0.690	—	—	—
ANB angle	2.60 (2.42)	6.05 (2.65)	−3.00 (3.20)	<0.001	<0.001	<0.001	<0.001	<0.001
SNB angle	79.05 (5.83)	76.15 (5.97)	85.20 (6.90)	<0.001	<0.001	<0.001	<0.001	<0.001
S-N/Go-Gn angle	31.10 (14.20)	35.15 (9.18)	27.50 (10.70)	<0.001	<0.001	0.020	0.502	0.002
N-A-Pog angle	3.50 (7.00)	9.80 (5.12)	−7.60 (11.10)	<0.001	<0.001	<0.001	<0.001	<0.001
Interincisal angle	136.80 (12.83)	125.80 (21.85)	128.00 (19.40)	<0.001	<0.001	<0.001	0.310	0.229
Max1-FH angle	114.45 ± 7.81	114.22 ± 8.70	120.71 ± 7.24	<0.001	<0.001	0.983	0.002	<0.001
Ar-Go-Me angle	125.50 (14.00)	122.85 (8.90)	127.00 (11.00)	0.208	0.229	—	—	—
FMA angle	19.00 (10.00)	26.00 (6.00)	23.00 (9.00)	0.009	0.012	0.009	1.000	0.252
IMPA angle	86.00 (11.25)	97.00 (13.50)	87.00 (18.00)	<0.001	<0.001	<0.001	1.000	<0.001

4. Discussion

This study determined how the inclination of the maxillary (Max1-FH) and mandibular (IMPA) incisors relates to the sagittal and vertical skeletal pattern in 187 adult patients. The main findings were that SNA and ANB were independently associated with both incisor inclinations. SNA showed a positive association in both models, whereas ANB showed opposite directions, being negatively associated with Max1-FH and positively associated with IMPA. In addition, Ar-Go-Me was independently associated with maxillary incisor inclination. Bivariate analyses also revealed significant associations between vertical skeletal parameters and both incisor inclinations, although these relationships were not consistently

maintained in the multivariable regression models. Max1-FH was higher in Class III, and IMPA was higher in Class II, whereas IMPA in Class III did not differ significantly from Class I.

Regarding the interincisal angle, it showed the strongest association with both Max1-FH and IMPA. Because this angle is geometrically derived from the inclinations of the maxillary and mandibular incisors, part of this association reflects its mathematical construction rather than an independent biological relationship. Accordingly, the strong association should not be interpreted as independent evidence that the two incisor groups undergo coordinated biological compensation. Nevertheless, the findings demonstrate a close relationship between maxillary and mandibular incisor inclination and are consistent with the compensatory relationships previously described in patients with sagittal skeletal discrepancies, including skeletal Class III malocclusion [7,8,16].

Moreover, after adjustment for the other variables, a larger ANB angle was associated with less proclined maxillary incisors and more proclined mandibular incisors, a pattern consistent with dentoalveolar compensation of the sagittal discrepancy. In contrast, SNA was positively associated with both Max1-FH and IMPA. Because ANB was held constant in the models, the SNA coefficient reflects a more anterior position of both jaws relative to the cranial base, which was associated with greater proclination of both incisors. IMPA was not significantly correlated with SNB. This agrees with the results published by Kirschneck et al. (2013), who concluded that mandibular position itself was not directly associated with incisor inclination [12]. More recent evidence also indicates that incisor compensation in skeletal Class III is related to the magnitude and configuration of the underlying skeletal discrepancy rather than occurring uniformly across all patients. Mathapun and Charoemratrote reported associations between skeletal parameters and both maxillary and mandibular incisor compensation, while emphasizing variability according to the specific skeletal components involved [8]. Similarly, Chunduru et al. found that the amount of mandibular incisor compensation increased with increasing Class III severity, with IMPA decreasing progressively as ANB became more negative [16]. A recent systematic review and meta-analysis further demonstrated substantial dentoalveolar compensation in skeletal Class III, with both maxillary incisor proclination and mandibular incisor retroclination contributing to the compensation pattern [17].

Skeletal class comparisons followed the same general direction. Lower incisors have been reported as more proclined in Class II and more retroclined in Class III, supporting dentoalveolar adaptation to the underlying sagittal discrepancy [18]. Our results confirmed the first part: IMPA was significantly higher in Class II than in Class I. In Class III, however, IMPA did not differ significantly from Class I. Chunduru et al. reported that mandibular incisor compensation became progressively greater with increasing skeletal Class III severity [16], while Mathapun and Charoemratrote similarly demonstrated that incisor compensation was not uniform across different skeletal Class III configurations [8]. The recent systematic review by Ramesh et al. also found substantial variability in the magnitude of dentoalveolar compensation among Class III patients [17]. The absence of a statistically significant difference in IMPA between Classes I and III should be interpreted cautiously and does not establish equivalence between the groups.

Significant maxillary incisor proclination together with mandibular incisor retroclination has been reported in severe skeletal Class III cases [10]. Our results matched only the maxillary component, since Max1-FH was significantly higher in Class III than in Classes I and II. The Class III patients in our sample may have had less severe discrepancies (median ANB −3.0°), and the subgroup was relatively small. Recent studies support the importance of skeletal severity when interpreting this pattern. Chunduru et al. found that, as Class III severity increased, the relative contribution of mandibular incisor compensation increased,

whereas maxillary incisor compensation tended to decrease [16]. Similarly, Ramesh et al. reported that the magnitude of both maxillary and mandibular dentoalveolar compensation varies considerably among Class III patients [17]. Therefore, the relatively mild and heterogeneous Class III phenotype in the present sample may partly explain why significant mandibular incisor retroclination was not observed.

This variability is clinically relevant because the extent of pre-existing dentoalveolar compensation should be considered when determining the degree of incisor decompensation before orthognathic surgery [19]. Three-dimensional evidence has shown that presurgical dental decompensation is accompanied by remodeling of the mandibular symphysis and that the relationship between incisor movement and the surrounding alveolar structures must be considered when planning surgical-orthodontic treatment [20]. More recently, Liang et al. demonstrated that excessive mandibular incisor movement during presurgical decompensation of severe Class III malocclusion may be associated with cortical bone deterioration, emphasizing the need to individualize the acceptable range of incisor movement rather than applying a uniform angular target [21]. Although these considerations are relevant to presurgical orthodontic planning, the present study did not directly evaluate surgical-orthodontic treatment outcomes or the periodontal safety of incisor decompensation. Thus, the present findings support the principle that the degree of incisor compensation should be evaluated within the individual skeletal and dentoalveolar context before determining treatment objectives.

In Class II, the reduced interincisal angle was primarily associated with mandibular incisor proclination, while Max1-FH did not differ significantly from Class I. Class II division 2 patients show retroclined maxillary incisors that reduce upper lip prominence, increase the nasolabial angle, and slightly reduce the Holdaway angle compared with Class II division 1 and Class I patients [12,22]. Because we pooled both subtypes, their potentially different maxillary incisor inclinations may have offset each other at the group level. This limitation is particularly relevant when interpreting the absence of a significant Class II–Class I difference in Max1-FH. Interincisal angle magnitude has also been linked to the degree of vertical overbite, particularly in division 2 patients [12], and overbite was not recorded in the present study.

Concerning the vertical skeletal pattern, S-N/Go-Gn and FMA were inversely correlated with both incisor inclinations, in line with the generally reported relationship between vertical facial morphology and incisor position [7]. Recent evidence has further demonstrated that mandibular incisor position and inclination vary according to vertical skeletal pattern. Derwich et al. reported significant relationships between the sagittal position of the lower incisors, facial profile characteristics, and skeletal vertical dimension [5]. Similarly, Aloufi et al. demonstrated differences in mandibular incisor angulation and position among different vertical facial patterns [23]. These findings are consistent with the significant bivariate correlations observed between IMPA and both S-N/Go-Gn and FMA in our sample. However, because these vertical parameters were not included in the multivariable regression model for IMPA, their independent associations with mandibular incisor inclination could not be assessed in the present study.

Lower incisor position has been shown to increase progressively with the S-N/Go-Gn angle, and this was tied to symphyseal morphology: hyperdivergent patients tend to present a narrower, more elongated symphysis and a less prominent chin [18,24]. Those findings concern a linear position, whereas our IMPA is an angular measure, and symphyseal morphology was not assessed, so the two findings are not directly comparable. We also found that Ar-Go-Me correlated inversely with IMPA. However, it was not entered in the IMPA regression model because it shares the mandibular plane with IMPA. A reduction in gonial angle has been linked to a horizontal growth pattern with anterior mandibular

rotation [25]. Our Class II patients had higher S-N/Go-Gn and FMA values than Class I, whereas a reduced lower anterior facial height has been repeatedly described in Class II patients, although not all authors found this association significant [12,26]. An important finding of the present study is the difference between the bivariate correlations and the multivariable regression results. Although S-N/Go-Gn showed a significant negative correlation with Max1-FH, this association was no longer statistically significant after adjustment for the other variables included in the regression model. This suggests that the bivariate relationship may partly reflect shared variance with other skeletal parameters rather than an independent association. These findings highlight the importance of considering the interdependence among cephalometric measurements when interpreting individual regression coefficients. Therefore, the relationship between vertical skeletal morphology and maxillary incisor inclination should be interpreted in the context of the overall craniofacial pattern rather than on the basis of isolated correlations or regression coefficients.

Our findings regarding maxillary incisor inclination are also broadly consistent with contemporary cephalometric research. Bou Assi et al., in a sample of 498 orthodontic patients, reported differences in maxillary incisor inclination across sagittal skeletal patterns and found evidence of maxillary incisor compensation in the sagittal dimension [27]. Their findings support the concept that maxillary incisor inclination is influenced by the underlying sagittal skeletal relationship. However, their results also suggest that the relationship between maxillary incisor inclination and vertical morphology is more complex, reinforcing the need to interpret individual cephalometric variables within the overall craniofacial pattern rather than in isolation [27].

Clinical implications. Zhou et al. and Galdi et al. have proposed that incisor position should be evaluated relative to each patient's individual dentoskeletal and soft-tissue framework rather than against normative values derived from heterogeneous populations, given the substantial variability in compensation patterns across skeletal classes [28,29]. Our results support this view. Incisor inclination differed across sagittal skeletal classes, while bivariate analyses also showed associations with vertical skeletal parameters. These findings suggest that a single normative target may not be appropriate for all patients. Recent evidence similarly supports individualized assessment of lower incisor position according to vertical skeletal morphology and facial profile characteristics [5], while contemporary studies of Class III malocclusion emphasize that the amount of incisor compensation varies with skeletal severity and configuration [8,16,17]. Clinically, the findings highlight the variability of incisor inclination across sagittal skeletal patterns and support the importance of evaluating incisor position within the individual dentoskeletal context. However, the present study does not establish specific orthodontic treatment targets or demonstrate that individualized targets improve treatment outcomes. The present study adds population-specific evidence from Romanian adults to the existing literature on dentoskeletal relationships. As the sample was recruited from Oradea, Romania, the findings provide regional data but should not be considered representative of the entire Romanian population. Further studies involving larger and more geographically diverse Romanian samples are needed to assess the generalizability of these findings.

Certain limitations of the present study should be acknowledged. First, because the sample was recruited exclusively from Oradea, Romania, the findings may have limited generalizability. Second, the study is retrospective and cross-sectional, so the observed associations cannot be interpreted as causal. Third, Class III was represented by a relatively small subgroup, which limits the stability and precision of the pairwise comparisons. Fourth, Class II Divisions 1 and 2 were not analysed separately. Fifth, cephalometric measurements are subject to landmark identification and tracing error, which varies with the method used, although intra- and inter-examiner reliability were excellent in our sample.

In addition, landmarks were identified manually by trained examiners. Deep-learning-based automated landmark detection has shown high accuracy [30], comparable to that of experienced examiners [31] and may improve the efficiency and reproducibility of such measurements in larger samples. Sixth, SNA, SNB, and ANB are mathematically related, and this interdependence was considered when selecting variables for the multivariable regression analyses. Because the skeletal classes were defined by the sagittal relationship (ANB), differences in ANB, SNB and N-A-Pog among classes reflect the classification itself and carry no inferential information. In addition, 13 patients (7%) were assigned to a skeletal class that differed from their ANB-based class after evaluation of the dental and facial records. The class comparisons were not repeated using strictly ANB-defined groups, although the multivariable regression analyses, which used ANB as a continuous variable are independent of the classification procedure. Moreover, the interincisal angle is geometrically coupled to the maxillary and mandibular incisor inclinations and its contribution is partly mathematical, while S-N/Go-Gn and FMA are strongly correlated. Consequently, statistically significant regression coefficients should not be interpreted as evidence of independent biological mechanisms. Finally, soft-tissue variables, functional habits, vertical overbite, and periodontal characteristics were not assessed. Future prospective studies with larger Class III samples, separate analyses of Class II subtypes, three-dimensional assessment of the alveolar housing, and soft-tissue and periodontal outcomes would clarify how skeletal pattern and incisor position interact. Moreover, further studies using analytical approaches that explicitly account for the geometric dependence among cephalometric variables may help distinguish true biological adaptation from relationships arising from measurement construction.

5. Conclusions

In this Romanian orthodontic adult sample, maxillary and mandibular incisor inclinations showed significant adjusted associations with sagittal skeletal parameters (SNA and ANB). Maxillary incisor inclination was also independently associated with the gonial angle (Ar-Go-Me). Vertical skeletal parameters were significantly correlated with incisor inclinations in the bivariate analyses. However, S-N/Go-Gn was not independently associated with Max1-FH, and vertical parameters were not entered in the IMPA model. No statistically significant associations with age or sex were identified. Incisor inclination differed among skeletal classes, with maxillary incisors showing greater proclination in Class III and mandibular incisors showing greater proclination in Class II. No statistically significant difference in mandibular incisor inclination (IMPA) was identified between Classes I and III. These findings highlight the variability of incisor inclination across sagittal skeletal patterns and the importance of considering individual dentoskeletal characteristics during orthodontic assessment. However, given the cross-sectional design, the observed associations should not be interpreted as evidence of longitudinal dentoalveolar compensation or causal relationships.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/diagnostics16233998/s1. Table S1: Diagnostic statistics for residuals and influential observations in regression models for the maxillary incisor angle (Max1-FH); Table S2: Bootstrap estimates of the linear regression coefficients for the maxillary incisor angle (Max1-FH); Table S3: Diagnostic statistics for residuals and influential observations in regression for the mandibular incisors angle (IMPA); Table S4: Bootstrap estimates of the linear regression coefficients for mandibular incisors angle (IMPA); Figure S1: Regression diagnostics for the maxillary incisor angle: Max1-FH vs. age, SNA angle, ANB angle, S-N/Go-Gn angle, Ar-Go-Me angle and sex; Figure S2: Regression diagnostics for the mandibular incisors angle: IMPA vs. Age, SNA angle, ANB angle, and sex.

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