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Morphological Evaluation of the Incisive Canal in the Aspect of the Diagnosis and Planning of Orthodontic Treatment—CBCT Study

Anna Ewa Kuc [1,*], Jacek Kotuła [1], Jakub Nawrocki [1], Ewa Szeląg [1], Beata Kawala [1], Joanna Lis [1] and Michał Sarul [2]

1 Department of Dentofacial Orthopaedics and Orthodontics, Wroclaw Medical University, Krakowska 26, 50-425 Wroclaw, Poland; j_kotula@poczta.onet.pl (J.K.); ewa.szelag@umw.edu.pl (E.S.); beata.kawala@umw.edu.pl (B.K.); joanna.lis@umed.wroc.pl (J.L.)

2 Department of Integrated Dentistry, Wroclaw Medical University, 50-425 Wroclaw, Poland; michal.sarul@umw.edu.pl

* Correspondence: annaewakuc@wp.pl

Abstract: Background: Understanding the anatomy of the incisive canal is crucial for effective diagnosis and treatment planning in clinical orthodontics. This is because, during orthodontic tooth movement, there is a risk of contact between the roots of the upper central incisors and the incisive canal. Objective: The aim of this study was to assess the anatomical variability of the incisive canal using cone beam computed tomography (CBCT), as well as to evaluate its correlation with age, sex, and the position of the maxillary central incisors. There are only a few studies on this topic. Materials and methods: We analysed CBCT data from 67 patients aged from 13 to 49 years. This study was conducted at the Wroclaw Medical University. Measurements were performed twice by two independent researchers, and intra-observer error and correlation were calculated. The mean difference between the first and second observations and between observers was also assessed. We examined the dimensions of the incisive canal and its relationship to the roots of the upper central incisors in relation to age and gender. Results: Our study results revealed a significant correlation between the width and length of the incisive canal. Males exhibited a significantly greater canal length at the lowest point of the incisive canal on the palatal wall. Additionally, males had wider canals compared to females. The analysis of canal width and distance between the most mesial point of the root and the line passing through the most anterior point of the incisive canal showed a negative correlation in all age groups of men. The analysis of incisal inclination and incisal canal inclination showed a very strong relationship, especially in the age group of 13 to 20 years. Several potential risk groups of contact between the roots of central incisors and the incisive canal have been identified based on their structure and the planned incisors' orthodontic movement. Conclusions and implications: Knowledge of the anatomy of the incisive canal and the use of 3D imaging in high-risk patients can prevent resorption of the incisor root by considering the individual anatomical conditions of the patient when planning orthodontic tooth movement. We recommend performing a CBCT scan before starting orthodontic treatment in the case of moderate and significant retraction of the incisors, or a significant change in their inclination due to the wide anatomical diversity of the incisive canal, especially in adult patients.

Keywords: anatomy; CBCT; root resorption; incisive canal; nasopalatine canal; retraction; radiology; orthodontic treatment; orthodontic diagnosis; orthodontic treatment planning

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1. Introduction

Orthodontic treatment of class II and III skeletal malocclusions, both through camouflage and orthognathic surgery, is associated with appropriate orthodontic preparation involving proclination (labial movement), lingual movement, retraction, or torque movements of the upper incisors. Since all these manipulations occur in the anterior segment of the maxilla, the anatomy of this area is of key importance in the diagnosis and planning of orthodontic movements that will not violate the bone envelope of this section and will not lead to the direct contact of the maxillary incisor roots with the palatal/vestibular cortical bone or the cortical bone of the incisive canal. Previous studies by other authors have shown that such contact may cause complications such as incisor root resorption, and dehiscence and/or fenestration [1–6]. A systematic review found that the risk of incisor root resorption is increased by root contact with the incisive canal [5]. Accurate diagnostics based on 3D imaging are needed to assess the diversity of the morphology of the incisive canal and its relationship with the incisor roots.

The incisive canal serves as a communication between the oral and nasal cavities. It ends in the oral cavity in the incisal fossa below the incisive papilla, immediately behind the upper central incisors [6]. It is surrounded on each side by thick cortical bone and contains nerves and vessels supplying the upper incisors and the anterior part of the palate. The assessment and knowledge of the anatomical features of the incisive canal, its structure, size, and changes in inclination depending on age, sex, as well as parameters determining the position of the maxillary incisors, can help effectively prevent severe complications of orthodontic treatment, such as root resorption. These need investigation due to the insufficient assessment of this region on routinely performed panoramic radiographs and cephalometric images [7].

The growth and development of soft and hard tissues are closely function-related. Since the skeletal unit is responsible for protecting and supporting the functional matrix, the size, shape, and position of anatomical structures change in order to meet the functional needs [8]. Therefore, it is very likely that the anatomy of the incisive canal may depend on age, sex, position of the upper incisors, direction of facial growth, and muscle activity. It may also be more or less susceptible to reconstruction and remodelling resulting from orthodontic manipulations, depending on parameters such as age, sex, or applied orthodontic forces [1].

As a result of advances in 3D imaging in recent years, publications showing the morphological diversity of the incisive canal have appeared. However, their results are ambiguous. Some studies [8–19] indicated a significant impact of sex, age, and growth direction on the anatomical and morphometric features of the canal, supporting the need to consider the risk of complications when planning orthodontic and surgical interventions involving the anterior maxilla. However, others [6,7,20] have not shown such a relationship. Therefore, prior to orthodontic range of motion planning, it is important to identify high-risk patient groups that require thorough diagnostics, including CBCT of this segment, to minimise this risk. For years, there has been a debate as to whether CBCT should be performed before orthodontic treatment. Risk analysis in individual age and sex groups may answer the question of whether such an extended diagnosis is indicated.

Cephalometric images are routinely used in orthodontic treatment planning, especially to assess the anterior-posterior relationship where the ANB angle is considered the gold standard in assessing the sagittal-mandibular relationship [21]. However, neither this nor a panoramic radiograph is sufficient to illustrate the area of the incisive canal in relation to the upper incisors.

Objective

The aim of this study was to define risk groups according to the anatomical variability of the incisive canal using cone beam computed tomography (CBCT), as well as to evaluate the correlation of the canal shape (width, length, and inclination) with age, sex, and position of the upper central incisors. There are only a few studies on this topic.

2. Materials and Methods

2.1. Participants

This study used CBCT records found in the resources of the Department of Maxillofacial Orthopaedics and Orthodontics of the Wrocław Medical University. CBCT images of 67 patients (35 women and 32 men) aged 13 to 49 years were analysed. CBCT scans taken between 2017 and 2021 prior to orthodontic treatment were used as part of the orthodontic diagnostic process.

The criteria for inclusion of the patient's CBCT records in the study group were as follows:

(1) Complete development of the upper incisor roots.
(2) Clearly visible maxilla.
(3) Patients with permanent dentition.
(4) Without a history of orthodontic treatment.
(5) Generally healthy patients with no history of bone diseases.

Exclusion criteria:

(1) Missing maxillary incisor(s).
(2) Maxillary incisor pathology.
(3) Developmental anomalies of the incisive canal (additional canals in the area of the incisive canal, as well as clear asymmetries).
(4) Poor quality of CBCT, preventing accurate measurements.
(5) The presence of imaging artifacts hindering measurements in the anterior maxillary region.
(6) Incomplete root development.
(7) Root resorption due to trauma or inflammation.
(8) History of previous orthodontic treatment.

The participants were classified into groups according to sex and age. Four age groups (16–18 participants) have been created:

A. 13–20 years.
B. 21–29 years.
C. 30–39 years.
D. 40–49 years.

Ethical approval from the Bioethical Committee of the Wroclaw Medical University was granted for our study (nr KB-231/2021, accessed on 19 March 2021), providing that all the data were anonymised (as was the cases in our study). In accordance with the decision of the bioethics committee, patients were comprehensively informed about the assumptions, risks, consequences for the body, and benefits of the study. Patients received a full written justification and information that they could withdraw from the study at any time without any consequences for their participation in the comprehensive orthodontic treatment process. Patients under 18 years of age as well as their parents signed with informed consent to participate in the study.

Patients over the age of 13 were included in the study because the treatment of patients of this age requires the use of fixed appliances, which are used to carry out precise, large-scale tooth movements. Significant tooth movements during treatment with fixed appliances significantly affect the possibility of roots of the central incisors contacting with the incisive canal. In treatment with removable appliances at an earlier age, such significant shifts are not made, which is associated with a lower risk of contact of the roots of the central incisors with the incisive canal. Therefore, the potential benefits of such diagnostics outweigh the health costs associated with exposing younger children, even before their growth spurt, to the significant risks from absorbed radiation associated with CBCT projection.

2.2. Data Acquisition and Measurements

CBCT was performed with a CS 9600 Carestream Dental. The exposure parameters were as follows: 120.00 KV, 6.3 mA, an exposure time of 20.00 s, and a dose of 814.18 mGy/cm^2. The Frankfurt plane was parallel to the floor. CS 3D Imaging (Carestream Dental LLC) was used for measurements. The measurements were performed twice independently by two investigators (experienced orthodontists with many years of experience), and the mean result was used in the statistical analysis. Intra- and inter-observer reliability tests were performed for CBCT measurements, $p < 0.005$.

The following measurements were taken:

A. Horizontal plane separately for each level—L1, L2, and L3:
   1. Incisive canal width—|Cl-Cl|.
   2. Antero-posterior IC—|Ca-Cp|.
   3. Distance between the most mesial point of the root and the tangent passing through the most anterior point of the incisive canal—|Rm-Cat|.
   4. Distance from Cl to the posterior edge of the incisor root—|Cl-Rpt|.
   5. Distance between roots |Rm-Rm|.

B. Sagittal plane:
   1. Angle formed by the long axis of the incisor and the palatine plane—CP angle.
   2. Angle formed by the long axis of the incisive canal and the palatine plane—IP angle.

C. Coronal plane:
   1. Angle formed by the long axes of the central incisors (values above zero for convergent roots, negative values for divergent roots).

L1, L2, and L3 were determined in sagittal planes as follows: L1—the lowest point of the incisive canal on the palatal wall, L2—half the distance between L1 and L3, and L3—the height of the top of the maxillary central incisor (Figure 1).

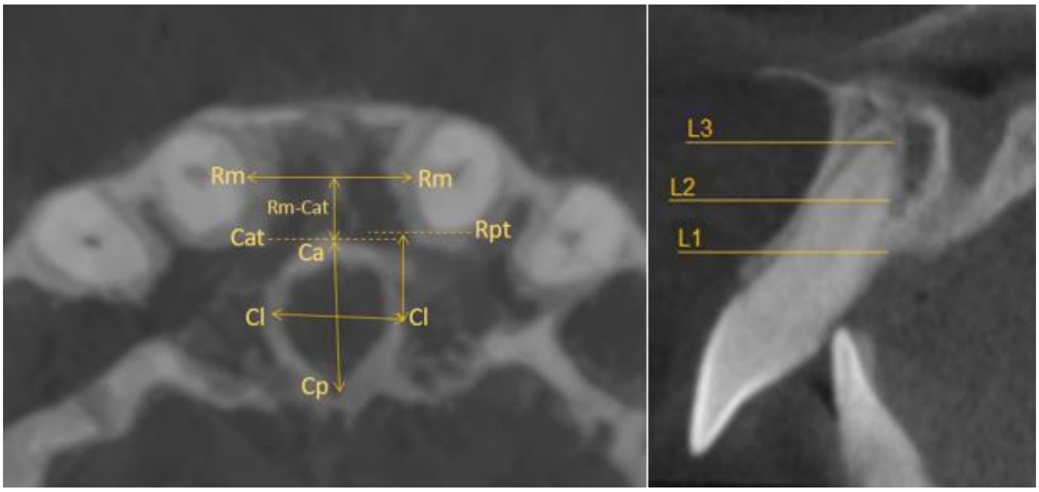

Figure 1. Measurement scheme.

Measurement landmarks:

Rm—the most mesial point of the root U1.

Rp—the most posterior point of the root U1.

Cl—the most lateral point of the incisive canal.

Ca—the most anterior point of the incisive canal.

Cat—tangent to Ca.

Rpt—tangent to Rp.

The long axis of the incisor was determined by connecting the incisal edge with the root apex (Figure 2).

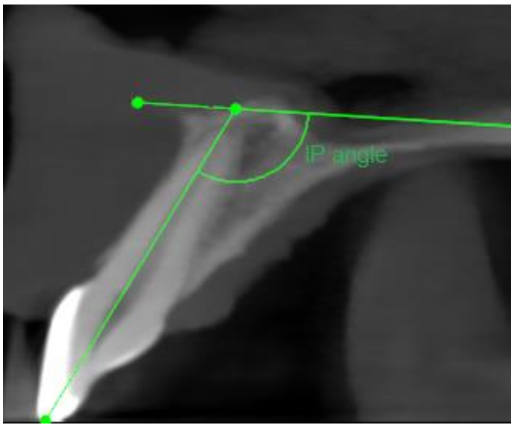

Figure 2. An angle formed by the long axis of the incisor and the palatal plane.

The long axis of the canal was determined by connecting a point midway between the labial and palatal walls of the incisive foramen and a point midway across the width of the canal in the predetermined palatal plane (Figure 3).

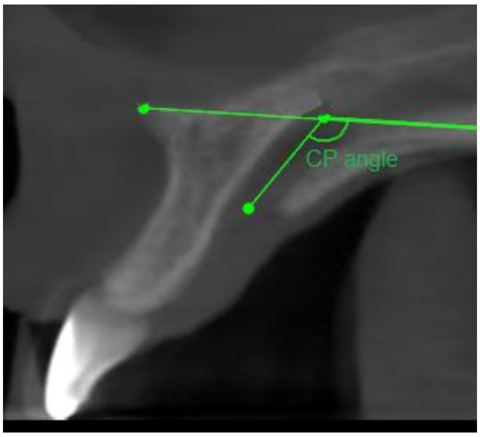

Figure 3. An angle formed by the long axis of the incisive canal and the palatal plane.

2.3. Statistical Analysis

The analysis of the research results was carried out using the statistical package Statistica 13.3 by Tibco. After determining the basic statistical measures, the hypothesis of the normality of the empirical distribution was verified using the Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) tests. The normality of the distribution of variables was also assessed graphically using histograms and standard probability plots of the variables.

In the case when at the significance level of $p = 0.05$, the null hypothesis H_0 was adopted. If the distribution of the analysed variable is normal, parametric tests, the t-test or the classic ANOVA analysis of variance were performed. In addition, for the ANOVA analysis, the assumption about the homogeneity of variance in the groups was verified by performing a Levene's test. After the verification of the assumptions of the ANOVA test and rejection of the null hypothesis of no differences in the compared populations, post-hoc tests were performed.

For selected groups of variables, a correlation analysis based on the Pearson linear correlation coefficient was performed. The assessment of the interdependence of variables was based on the Guilford classification [22]:

$|r| = 0$—no correlation.

$0.0 < |r| \leq 0.1$—almost no correlation.

$0.1 < |r| \leq 0.3$—weak correlation.

$0.3 < |r| \leq 0.5$—moderate correlation.

0.5 < ∣r∣ ≤ 0.7—high correlation.
0.7 < ∣r∣ ≤ 0.9—very high correlation.
0.9 < ∣r∣ < 1.0—almost complete correlation.
∣r∣ = 1—complete correlation.

In the next part, a test of the significance of the correlation coefficient was performed. This test was carried out in order to check whether the determined correlation in the tested sample also occurs in the population from which the sample was taken.

The power of the tests is not less than 0.6 with a significance level (type I error) of 0.05 performance.

For each of the tests performed, the differences were considered statistically significant if $p < 0.05$.

3. Results

3.1. Width vs. Length of Incisal Canal

3.1.1. Level 1 (L1)

The analysis of the correlation between the width and length of the canal showed varied results. For the whole group of patients, this correlation was statistically significant ($p < 0.05$), but moderate (r = 0.375), and indicated an increase in the length of the canal with an increase in its width. This correlation was found to be high (r = 0.557, $p < 0.05$) in the male group, but weak and statistically insignificant in the female group (r = 0.150, $p < 0.05$). Interestingly, the results varied between age groups. A very high and statistically significant correlation (r = 0.845, $p < 0.05$; r = 0.761, $p < 0.05$) was found in the 13 to 20-year-old women and men group, showing a linear increase in the dimensions of the incisive canal and a relationship between length and width. This high to very high correlation was maintained in the group of men and women aged 21 to 29 years (r = 0.729, $p < 0.05$) and in the total group of men, regardless of age. A different situation was observed among women over 30 years of age, where a negative, moderate, and statistically insignificant correlation was found, indicating that the length of the canal decreased with increasing width (Table 1).

Table 1. Width (Cl-Cl) vs. length (Ant—post dimension of the canal) of incisal canal—L1.

Gender/Age	Mean Width (SD)	Mean Length (SD)	r(X,Y)	r^2	t	*p*
F 13–20	4 (±0.81)	4.49 (±0.97)	0.845	0.71	4.19	0
M 13–20	4.03 (±0.82)	4.53 (±1.57)	0.762	0.58	2.63	0.05
F 21–29	4.61 (±0.89)	4.16 (±0.62)	0.729	0.53	2.82	0.03
M 21–29	4.5 (±1.33)	4.79 (±0.52)	0.536	0.29	1.56	0.17
F 30–39	4.68 (±1.36)	4.01 (±0.8)	−0.318	0.1	−0.82	0.44
M 30–39	4.4 (±1.06)	4.73 (±0.82)	0.668	0.45	2.2	0.07
F 40–49	4.78 (±0.52)	4.27 (±0.62)	−0.417	0.17	−1.21	0.26
M 40–49	5.04 (±0.96)	4.79 (±1.14)	0.618	0.38	2.08	0.08

3.1.2. Level 2 (L2)

For the L2 level, a positive and high correlation was found both in all patients and by sex (r = 0.687, $p < 0.05$; r = 0.752, $p < 0.05$; r = 0.621, $p < 0.05$). This high correlation was maintained in all age groups, both female and male, reaching an almost full level in the group of men aged 21 to 29 years (r = 0.945, $p < 0.05$) (Table 2).

Table 2. Width (Cl-Cl) vs. length (Ant—post dimension of the canal) of incisal canal—L2.

Gender/Age	Mean Width (SD)	Mean Length (SD)	r(X,Y)	r^2	t	*p*
F 13–20	3.58 (±0.97)	3.46 (±0.56)	0.753	0.57	3.03	0.02
M13–20	3.66 (±0.98)	3.54 (±1.66)	0.629	0.4	1.81	0.13
F 21–29	4.29 (±0.87)	4.02 (±1.02)	0.815	0.66	3.72	0.01
M 21–29	3.86 (±1.43)	4.05 (±1.33)	0.945	0.89	7.08	0
F 30–39	4.19 (±1.33)	3.88 (±0.97)	0.361	0.13	0.95	0.38
M 30–39	4.14 (±1.13)	3.73 (±1.15)	0.876	0.77	4.45	0
F 40–49	4.66 (±0.64)	4.16 (±0.52)	0.479	0.23	1.44	0.2
M 40–49	4.22 (±1.12)	4.39 (±1.13)	0.623	0.39	2.11	0.07

3.1.3. Level 3 (L3)

For L3, there was also a positive high and very high correlation in all patients and all age groups, both in men (r = 0.728, $p < 0.05$) and women (r = 0.655, $p < 0.05$), with an almost complete correlation in women aged 21 to 29 years (r = 0.935 $p < 0.05$) and in men aged 30 to 39 years (r = 0.920 $p < 0.05$), while the strength of this relationship was lower and statistically insignificant in men aged 21 to 29 years and women aged 40 to 49 years compared to other groups (Table 3).

Table 3. Width (Cl-Cl) vs. length (Ant–post dimension of the canal) of incisal canal—L3.

Gender/Age	Mean Width (SD)	Mean Length (SD)	R(X,Y)	r^2	t	*p*
F 13–20	3.93 (±1.13)	3.59 (±0.95)	0.72	0.52	2.75	0.03
M13–20	3.49 (±1.2)	3.53 (±1.58)	0.729	0.53	2.38	0.06
F 21–29	3.68 (±0.8)	3.77 (±1.25)	0.936	0.88	7.03	0
M 21–29	3.28 (±0.9)	2.94 (±0.8)	0.128	0.02	0.32	0.76
F 30–39	4.06 (±1.19)	3.43 (±1.09)	0.678	0.46	2.26	0.06
M 30–39	4 (±1.59)	3.24 (±1.63)	0.921	0.85	5.78	0
F 40–49	4.46 (±1.02)	4.2 (±1.17)	0.423	0.18	1.23	0.26
M 40–49	4.49 (±0.97)	3.83 (±0.93)	0.71	0.5	2.67	0.03

3.1.4. Width and Length across Groups

The width of the canal at the L1 level was similar for both men and women, while its length differed considerably and statistically significantly ($p < 0.05$) and was greater in men than in women. At the L2 level, both width and length were similar in women and men. At the L3 level, the width was still similar, while the length differed significantly and was smaller in men vs. women. Considering age groups, a high variation was observed in the 21 to 29-year age group, where the L1 canal length was definitely higher in men than in women, with similar findings in the 30 to 39-year and the 40 to 49-year age groups. The values were similar for other levels and other groups.

3.2. Width vs. Inclination of the Upper Central Incisors (Convergent/Divergent)

3.2.1. L1 level

Angulation of the upper central incisors did not correlate with canal width when analysing the total group or by sex. The absence of a correlation was statistically significant. However, a high correlation was found at the L1 level in both women and men aged 13 to 20 years. This correlation was negative in the group of women (r = −0.617), which means that the interapical distance increases with increasing canal width, while in the case of men (r = 0.640), this correlation was positive, i.e., the wider the canal, the more convergent the roots. A high positive correlation was present in the group of men up to 30 years of age. Patients aged 30 to 39 years showed strong negative correlations. A strong negative correlation was found in women up to 40 years of age. Between the ages of 21 and 40 years, the correlation was also negative but less strong. Correlations in the age groups did not show statistical significance (Table 4).

Table 4. Width (Cl-Cl) vs. inclination of upper central incisors (convergent/divergent)—L1.

Gender/Age	Mean Width (SD)	Mean Inclination of the Central Incisors (SD)	r(X,Y)	r^2	t	*p*
F 13–20	4 (±0.81)	0.11 (±6.13)	−0.617	0.38	−2.08	0.08
M13–20	4.03 (±0.82)	−1.29 (±7.95)	0.64	0.41	1.86	0.12
F 21–29	4.61 (±0.89)	−1.72 (±4.8)	−0.492	0.24	−1.49	0.18
M 21–29	4.5 (±1.33)	−2.13 (±5.79)	0.623	0.39	1.95	0.1
F 30–39	4.68 (±1.36)	−4.13 (±6.03)	−0.225	0.05	−0.57	0.59
M 30–39	4.4 (±1.06)	0.63 (±2.77)	−0.536	0.29	−1.55	0.17
F 40–49	4.78 (±0.52)	−1.11 (±8.51)	−0.53	0.28	−1.65	0.14
M 40–49	5.04 (±0.96)	−1.61 (±4.41)	0.262	0.07	0.72	0.5

3.2.2. L2 Level

At the L2 level, correlations of varying strength were observed, and the trend in both men and women was similar to that at the L1 level. The exception was the group of men aged 30 to 39 years where, unlike other groups of men, the correlation was high and negative (r = −0.546), but statistically insignificant.

3.2.3. L3 Level

No correlations were found at the L3 level.

3.3. Inclination of the Incisors (Angle Formed by the Long Axis and the Palatal Plane) vs. Inclination of the Incisal Canal

A positive and very strong correlation was found between the inclination of the incisors and the inclination of the canal in the group of women aged 13 to 20 (r = 0.828, $p < 0.05$) and 40 to 49 years (r = 0.603). In the case of men, a moderate and negative correlation was observed between 13 and 20, and 30 and 39 years of age (r= −0.429; r= −0.495; $p > 0.05$), respectively. A strong, positive, and statistically significant correlation was found for those aged 20 to 29 years (r = 0.868, $p < 0.05$). In the general breakdown by sex, only women showed a statistically significant, yet moderate, correlation between these parameters. Graphs presenting statistical values for incisor and canal inclination in women and men confirm the above relationships (Table 5).

Table 5. Inclination of the incisors (angle formed by the long axis and the palatal plane) vs. inclination of the incisive canal.

Gender/Age	Mean Angle Formed by the Long Axis of the Incisor and the Palatal Plane (SD)	Mean Angle Formed by the Long Axis of the Incisal Canal and the Palatal Plane (SD)	r(X,Y)	r^2	t	*p*
F 13–20	113.33 (±7.25)	107.44 (±10.91)	0.828	0.69	3.91	0.01
M13–20	115.71 (±11.86)	103.14 (±7.29)	−0.429	0.18	−1.06	0.33
F 21–29	109.11 (±11.03)	105.22 (±9.34)	0.238	0.06	0.65	0.54
M 21–29	113.38 (±6.23)	109.13 (±8.2)	0.868	0.75	4.28	0.01

Table 5. *Cont.*

Gender/Age	Mean Angle Formed by the Long Axis of the Incisor and the Palatal Plane (SD)	Mean Angle Formed by the Long Axis of the Incisal Canal and the Palatal Plane (SD)	r(X,Y)	r^2	t	*p*
F 30–39	99.63 (±7.67)	102.63 (±6.23)	0.385	0.15	1.02	0.35
M 30–39	113.88 (±5.79)	107.25 (±3.77)	−0.496	0.25	−1.4	0.21
F 40–49	104.78 (±14.4)	105.44 (±7.73)	0.603	0.36	2	0.09
M 40–49	109.33 (±9.59)	112.67 (±8.93)	0.169	0.03	0.45	0.66

3.4. Width vs. Rm-Cat

The relationship between canal width and the distance between the most mesial point of the root and the tangent passing through the most anterior point of the incisive canal was observed only in the men's group and was negative in all age groups. This indicates that the wider the canal, the closer the roots are to the cortical bone of the incisive canal. On the other hand, a very strong and strong correlation was observed in the group of men aged 13 to 20 years (r = −0.745) and 40 to 49 years (r = −0.578) at L1. At L2, this strong negative correlation occurred only in the group of men aged 13 to 20 years (r = −0.565). However, at the L3 level, a strong negative correlation was found in all age groups, except for the group aged 30 to 39 years. In the case of women, a strong and positive correlation at the level of L1 and L3 was found only in the age group of 40 to 49 years (r = 0.677, $p < 0.05$; r = 0.662). This means that the narrower the canal, the closer it is to the roots. In other cases, the correlation was either almost absent or weak. Taking into account the general division between women and men, the correlation was absent and statistically insignificant, while in men a moderate but statistically significant correlation was observed. The results of the group were statistically significant only at the L1 level in the group of women aged 40 to 49 years.

3.5. Width, Length vs. Age, and Sex

No significant relationship was observed between the group of women and men in terms of canal width. Canal length was definitely shorter in women than in men at L1, the same at L2, and definitely longer at L3. It showed the greatest discrepancies at all levels in the youngest group of 13 to 20 years old, both in women and men. Characteristically, the length of the canal at the L1 level decreased in women up to the age of 39 years and increased again after the age of 40 years. In men, the length of the canal at this level was similar between all age groups. In women, we observed an increase in the anteroposterior dimension of the L3 canal with age, while in men it remained at a similar or slightly increased level. None of the results were statistically significant ($p > 0.05$). The mean width of the canal at L1-L3 was 4.52 mm, 4.09 mm, and 3.94 mm, respectively, while the anteroposterior measurement was 4.47 mm, 3.92 mm, and 3.58 mm, respectively.

3.6. Incisor Inclination vs. Age and Sex

It was observed in women that the inclination of the incisors relative to the maxillary base decreased with age up to 40 years of age, after which point it began to increase, in contrast to men, where the inclination of the incisor increased with age, but without a statistically significant level.

3.7. Rm-Cat vs. Angulation of the Upper Central Incisors (Convergent/Divergent)

CBCT showed a negative correlation in the group of young men aged 13 to 20 years (r = −0.930, $p < 0.05$), at all levels between the angulation of the roots of the upper central incisors and the distance between the most mesial point of the root and the tangent passing through most anterior canal point. It can be assumed that the more convergent the roots, the smaller the distance to the canal. In the case of women, a similar correlation occurred only at the age of 40 to 49 years (r= −0.554) and was statistically insignificant.

4. Discussion

The purpose of this study was to assess parameters such as width, anteroposterior length (AP), and inclination of the incisive canal depending on age, sex, and inclination of the upper incisors, and to identify a correlation between these parameters. This will allow the identification of groups of patients with an increased risk of complications in the form of resorption of incisor roots treated orthodontically. Knowing the risk of complications related to the anatomical structure of the incisive canal, it may turn out that an orthodontic compromise will be necessary in a certain population of patients to protect the roots and the periodontal apparatus rather than strive to achieve cephalometric standards. Previous studies have focused mainly on the analysis of the shape of the canal, its length from the nasal cavity to the oral cavity, the average diameter of the canal, as well as the relationship of these parameters with age, sex, type of malocclusion, or direction of facial growth [12–15,20,23,24].

Our research assessed the width of the canal in relation to age and sex. We described a relationship between the canal width and the angulation of the central incisors, as well as a correlation between the incisor inclination and the canal inclination.

There was a clear relationship between the width of the canal and its AP length. In most age groups, the increased canal length was accompanied by an increased width at all levels (L1, L2, and L3). This means that people with a wide canal who require posterior root movement may be at an increased risk for two reasons. This is primarily due to the increased length of the AP canal. This may result in a smaller initial root-to-canal distance. Additionally, the width of the canal may exceed the inter-root distance between the central incisors. Only women over 30 years of age showed a negative correlation of these two parameters, i.e., they are characterised by a larger canal width than length. The inter-root distance in relation to the canal width may be of greater diagnostic importance in these patients than the AP root distance from the canal.

Due to the significantly greater canal length at L1, men had a higher risk of cervical root-canal contact than women. In women, the length of the AP canal was definitely greater at L3 than in men. In the group of women, more attention should be paid when planning treatment involving axial retraction, torquing, or inclination of the incisor root due to the greater risk of apical contact.

Studies in women have shown that the divergence of the incisor root increases with increasing canal width, which seems logical. For men aged 13 to 30 years, this correlation was negative, i.e., the wider the canal, the more parallel or convergent the roots. The analysis of the above data, especially at the L1 level, should lead to a more extensive diagnosis in men with parallel or convergent incisors on a panoramic radiograph. In this situation, there is a high likelihood that contact with the incisive canal will occur during incisor retraction or excessive torquing. This is due to the interapical distance being smaller than the width of the canal. It is this structure, not the cortical bone of the palate of the maxillary alveolar process, that may stand in the way and determine the degree of possible retraction. Women may be less at risk of resorption in this regard. This is all the more important as studies by Cho et al. showed that in over 60% of patients, the width of the canal is greater than the interroot distance [14].

Analysis of the incisor inclination and the incisive canal inclination showed a very strong relationship, especially in the age group of 13 to 20 years. In women, the canal inclination increased with the increasing posterior movement of the incisors, while in men the opposite occurred. This parameter indicates a potential increased risk of resorption in this group of women in the case of excessive posterior movement of the incisors. The risk of pericervical contact is increased here. Men are probably at less risk in this respect, but more research is needed on this topic. Similar results were seen in women aged 40 to 49 years and men aged 30 to 39 years. When planning the treatment of upper incisor protrusion, the structure of the palatal canal should be taken into account, especially in connection with the posterior rotation of the mandible. Studies have shown that individuals with posterior mandibular rotation have a narrower maxillary alveolar ridge [8].

Analysis of canal width and distance between the most mesial point of the root and the tangent passing through the most anterior point of the incisive canal showed a negative correlation in all age groups of men. The wider the canal, the shorter the distance between the roots and the canal. This may be related to the convergence of the incisors in the case of larger canal widths. The strongest correlation at the L1 level again confirms the increased risk of contact and possible resorption in the pericervical region in men. At L2, boys aged 13 to 20 years were most at risk. In women, the correlation at the level of L1 and L3 occurred in the age group of 40 to 49 years. The roots here were located closer to the canal, which had a reduced width. In women in this age group, there was an increased risk of excessive movement of the incisors within the tongue, e.g., in the case of decompensation of class III malocclusion. Different results were obtained by Costa et al. [8]. They found no gender-dependent relationship between the interroot distance of the upper central incisors and the anterior border of the incisal canal or the sagittal or vertical skeletal patterns.

Regarding the width of the canal in the aspect of gender, this research confirmed the results obtained by Costa [8]. Men had greater canal widths compared to women. Similar results were previously obtained [7,25,26]. Our research has confirmed the sexual dimorphism of the incisive canal. At the same time, it was noted that the incisive canal had a cross-sectional shape similar to a circle at the L1 level and an ellipse at the L3 level with a larger transverse dimension. These findings suggest that incisor retraction after maxillary expansion should be performed with care.

The increasing AP dimensions of the canal in women over 40 years of age at the L3 level suggests a greater risk in the case of axial retraction of the incisors, especially after maxillary osteodistraction, during which the width of the canal increases. On the other hand, increasing the width of the incisive canal in relation to the length of the anteroposterior with age in women up to 40 years of age also increases the potential risk of incisor resorption after maxillary expansion. This is due to the high risk of greater canal width than the interroot distance.

Various complications can occur during orthodontic treatment. Root resorption is mild in most cases and does not adversely affect the prognosis of the affected teeth. Unfortunately, some patients experience extensive root reduction, which may even lead to tooth loss. The etiology of resorption is not fully understood. In this place, contact of the roots with the vestibular or palatal cortical bone of the alveolar process is increasingly indicated. Similarly, the probability of resorption as a result of contact with the cortical bone surrounding the incisal canal can be assumed [1–5].

According to Kaley, the risk of severe resorption is highest in the case of the upper incisors and amounts to 3%, while the same risk increases 20 times when the roots are moved into contact with the palatal cortical plate of the alveolar process [27]. Similarly, contact with the cortical plate of the incisive canal may also increase the risk of resorption, which is discussed in detail in a systematic review on this topic [5].

Incisor retraction, excessive labial or lingual movement, and intrusion or extrusion are high-risk factors for resorption. Class II or III skeletal malocclusions, open and deep bites, which are managed after the end of growth, usually require either treatment with orthodontic camouflage or decompensation of the defect before orthognathic surgery. In both cases, an extensive range of orthodontic movement may be necessary, depending on the severity of the defect. Skeletal anchorage has contributed to the possibilities and scope of this movement, which does not change the fact that movement should still take place within the bone envelope. Knowledge of the anatomy of the incisive canal, which may interfere with retraction, torque, intrusion, and lingual movement of the upper incisors, e.g., during decompensation of class III malocclusion, is essential for the proper planning of orthodontic treatment. It reduces the risk of root resorption.

The anatomy of the incisal canal combined with the knowledge of the different widths of the maxillary alveolar bone may be crucial in preventing root resorption. Handelman [28] showed that patients with mandibular posterior rotation are characterised by a narrower maxillary alveolar process than those with anterior rotation. On the other hand, Sadek, Poraj, and Gracco [29–31] described a greater thickness of the alveolar process in the anterior part of the maxilla in brachycephalic patients. Furthermore, changes in the width of the maxillary alveolar ridge before and after retraction may be correlated with the magnitude of this movement. This suggests that greater diagnostic and therapeutic attention should be paid to patients with an initially narrow alveolar ridge [32]. Zhang [33] reported that the tipping of the incisor causes more bone resorption than axial movement. It is puzzling, however, that in some patients there is a strong root resorption as a result of contact of the root with the cortical bone, while in others, despite the bone separation, the entire roots are preserved. The applied orthodontic force may play a role, but further research is needed to confirm this hypothesis.

The structure of the incisive canal and the anterior part of the maxillary alveolar process are important for root torque. Ten, Hoeve, and Mulie [34] demonstrated root resorption that extended from the apex and along the palatal surface of the root. It developed as a result of excessive root torque. It could have been related to contact with both the cortical bone of the palatal and canal.

The last published study on the anatomy of the incisive canal determined the distance of the roots of the upper incisors from the canal depending on the growth pattern. There were gender differences, especially in the hypodivergent group. The authors also noted that this information may be useful in clinical practice [35].

Figures 4–11 show CBCT and X-ray images of a patient with resorption of the left upper central incisor root due to contact of the mesial and posterior part of the root with the cortical bone of the incisive canal after retraction and lingual movement of the upper incisors. Probably, earlier knowledge of such a risk could allow for the use of greater angulation of the incisors and bypassing of the cortical bone of the canal and, thus, prevent resorption. After analysing the images, it can be assumed that the height at which the root contacts the canal may determine the extent of resorption. The lower the height, the greater the root shortening. Further research is needed to confirm this hypothesis.

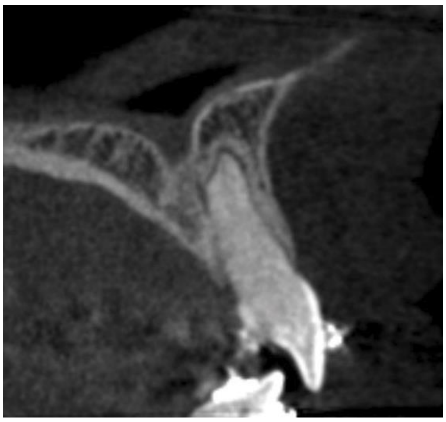

Figure 4. Root resorption of upper incisor after contact with incisal canal CBCT—sagittal plane.

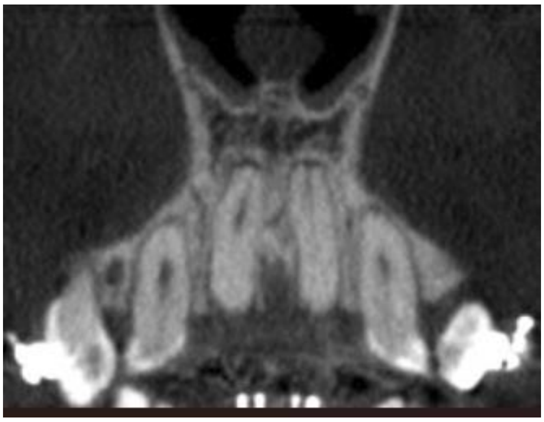

Figure 5. Root resorption of upper incisor after contact with incisal canal CBCT—coronal plane.

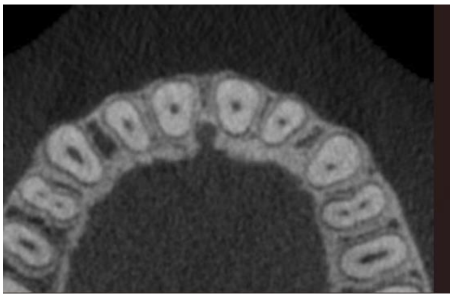

Figure 6. Contact of upper incisor's root with incisal canal CBCT.

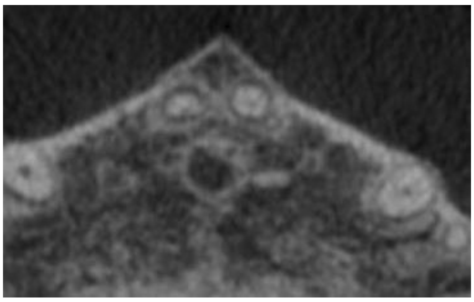

Figure 7. Contact of upper incisor's root with incisal canal CBCT.

Figure 8. Rtg before treatment.

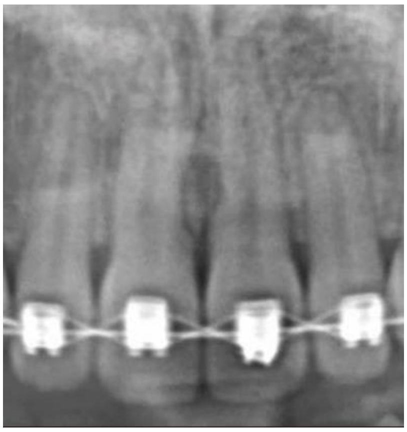

Figure 9. Rtg during treatment.

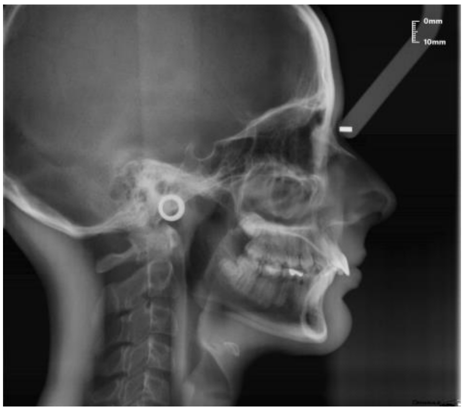

Figure 10. Cephalometric before treatment.

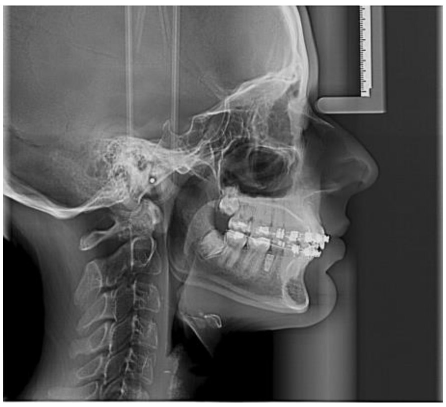

Figure 11. Cephalometric during treatment.

When qualifying patients for one of the groups with a potential increased risk (Table 6) of root contact with the incisive canal and the palatal cortical bone, orthodontic diagnosis should be individualised. These patients need baseline CBCT, brackets with greater angulation for the upper central incisors, or treatment planning based on a setup with 3D imaging. It may turn out that during decompensation of class II and III malocclusions and open bite as preparation for orthognathic surgery, achieving the correct textbook parameters of the incisors would require violating the bone envelope and the associated resorption of the incisors. At this point, it seems most reasonable to accept an orthodontic compromise rather than strive at all costs for the goal, i.e., textbook cephalometric standards, following the principle of primum non-nocere. The validity of initial treatment consisting of maxillary widening and decompensation of the upper incisors during the growth period, even with extensive class III malocclusions or open bites qualifying for orthognathic treatment in adulthood, should also be considered so as to reduce the scope of surgery in the future and avoid movements of the upper incisors at risk of resorption. Previous studies have confirmed the possibility of alveolar bone remodelling in response to orthodontic movement in growing patients [36]. Unfortunately, the vestibular and palatine cortical bone as well as the cortical bone surrounding the canal may constitute "orthodontic walls" that should not be crossed in adults, as such movements can result in both root resorption and bone dehiscence [37]. Meanwhile, contact of the root with the cortical bone during malocclusion decompensation in conjunction with orthognathic procedures is a much stronger risk factor for incisor resorption, which may be additionally increased by long and narrow roots [38].

Table 6. Risk groups for sex, age, and orthodontic movements in relation to the anatomy of the incisive canal.

Risk Factor	Potential Risk Group
Incisive canal width	Males
AP canal length	Males—cervical (excessive lingual movement of the incisors) Females—apical (axial movement, torquing, and proclination) Females over 40 years—lingual movement, torquing and retraction, especially after osteodistraction
Root angulation of the upper central incisors (convergent/divergent)	Males aged 13–30 years (axial movement, excessive torque, and proclination)
Canal inclination vs. incisor inclination	Age 13–20 years Females—pericervical (lingual movement, excessive retraction) Males—apical (proclination, torque and axial movement)
Canal width vs. root distance from the canal	Males—pericervical (lingual movement, excessive retraction) Males 13–20—L2 (axial movement) Females over 40 years—pericervical and apical (all movements)

Taking into account the safety of orthodontic treatment, we should not forget about the levels of force released by orthodontic wires. They can vary significantly, with the same diameter, depending on the brand of wire, and also change due to the influence of the oral environment on the properties of the wire material itself [39–41].

One of the limitations of this study is the number of patients, its cross-sectional nature, and the associated limitations.

5. Conclusions

This research we carried out showed a different width of the incisal canal depending on the gender. The anteroposterior length of the canal largely depended on its width. The inclination of the canal depended on the inclination of the incisors in different age groups. The width of the canal depended on the sex-related converging or diverging position of the incisors. Knowledge of the anatomy of the incisive canal and the use of 3D imaging in high-risk patients can prevent resorption of the incisor root by considering the individual anatomical conditions of the patient when planning orthodontic tooth movement. It is reasonable to consider performing CBCT before the start of orthodontic treatment in the case of moderate and significant retraction of the incisors or a significant change in their inclination due to the high anatomical diversity of the incisive canal area, especially in adult patients.

More high-quality studies are needed, primarily RCTs with a clearly defined methodology, for better-quality analyses and more reliable conclusions.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available because the data was provided in a raw form to the statistician for analysis, potentially remaining incomprehensible to others without detailed explanations.

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

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