Maxillary Sinus Volume and Its Effect on Treated Impacted Canines

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Abstract: The goal of study was to explore the role of 3D CBCT (cone beam computer tomography) in detecting impacted canines and their movement to evaluate the influence of orthodontic therapy parameters on treatment options, and to monitor quality of healing process based on shape and size of sinus maxillae volume. It is known that the volume of maxillary sinus plays an important role in patients with impacted teeth. The prospective study consisted of 26 individuals. For each individual, pre-treatment and post-treatment CBCT data were acquired. Changes of size, and position of impacted canine in 3D CBCT image before and after therapy were prepared using 3D reconstruction. Volumetric measurements of the maxillary sinuses were performed before and after orthodontic therapy of impacted canines, using InVivo6 software. The main effects MANOVA performed on linear measurements showed metric differences between pre-op and post-op images. A paired *t*-test showed no statistically significant differences between pre-op and post-op values of the sinus volume. Changes of size and position of impacted canine in 3D image before and after therapy were precise and reproducible, using 3D reconstruction in three planes – horizontal, midsagittal, and coronal. The linear measurements showed metric differences between pre-op and post-op images.

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Introduction

The maxillary canine is one of the most important teeth of the dental arch, essential for functional and stable occlusion and playing an important role in aesthetics (Servais et al., 2018). These teeth are the most frequently impacted teeth after the third molars (Alqerban et al., 2014) with an incidence ranging from 0.9 to 2.2%. Patients requiring orthodontic treatment related to an impacted maxillary canine account for 1% to 5% of the total orthodontic therapy (Celikoglu et al., 2010). Radiographic examinations represented by conventional two-dimensional (2D) radiographs (panoramic, periapical, occlusal, and lateral cephalograms) have been used in orthodontic practice for many years. However, their diagnostic value for localizing an impacted maxillary canine has been questioned because 2D image deformation (Eliasova et al., 2021) makes it difficult to accurately localize the canine and visualize root abnormalities.

The prevalence of impacted maxillary canines has been reported to range from 1.7 to 4.7% (Lövgren et al., 2019). They occur more frequently in females than in males and impaction is more frequently observed in the maxilla than in the mandible and affects both sides of the dental arch simultaneously in approximately one quarter of all cases (Mazurová et al., 2015). The maxillary canine is the second most common impacted tooth after the third molar, with a prevalence of 1–3%, depending on population studies (Mazurová et al., 2015; Eslami et al., 2017). The maxillary impacted canine is more often located palatally (85%) than labially (15%) (Grisar et al., 2019). Root dilaceration is reported to be present in up to 59.5% of the cases (da Silva Santos et al., 2014). Depending on the position of the impacted tooth, we distinguish between complete impaction when the affected tooth is covered by both hard and soft tissues and partial impaction, when the impacted tooth is covered by soft tissue only. Exact etiological factor has not been specified. The cause is probably multifactorial, with genetics playing the largest role (Becker and Chaushu, 2015).

The maxillary canines play a key role in facial aesthetics, development of the dental arch, and occlusion. Despite a relatively simple diagnosis supported by clinical and radiological examination, it is not uncommon to find an impacted canine in an adult patient. Treatment of this anomaly later in life carries some risks of complications and failure.

Various diagnostic methods are used to localize the impacted teeth. The techniques allow for the practitioner to predict the orthodontic treatment, surgical therapy, including also autotransplantation or possible canine extraction followed by implant insertion (Eslami et al., 2017). The diagnostic process begins with a clinical examination and palpation of the alveolar bone and is followed by radiographic evaluation. However, classic 2-dimensional (2D) conventional radiographs, mainly orthopantomograms (OPG), have two disadvantages – the information limit resulting from anatomic superimposition and geometric distortion of the imagery with poor visibility, and misrepresentation of structures surrounding maxillary impacted canines (Eliasova et al., 2021). Reliance on 2-dimensional imaging restricts the ability of clinicians to predict the length of treatment (Schubert and Baumert, 2009). Contrary to conventional radiography, cone beam computed tomography (CBCT) produces three-dimensional (3D) volumetric data in the axial, coronal, and sagittal planes. Eslami et al. (2017) in a systematic review confirmed that CBCT was more accurate than conventional radiographs in localizing impacted maxillary canines.

It is known that the volume of the maxillary sinus plays an important role in patients with impacted teeth (Schubert and Baumert, 2009). The maxillary sinus is a bilateral air-filled cavity located in the maxillary complex (Tassoker et al., 2020). The maxillary sinuses are surrounded by the ethmoid bone, nasal concha, palate, and lacrimal bone. The floor is formed by the alveolar processes of the maxilla. The roots of the premolar and molar and canine are separated from the maxillary sinus by a compact bone. For patients with impacted canines, anatomical shape and size and other pathological findings have been shown to affect the volume of the maxillary sinus and change its pneumatization (Emirzeoglu et al., 2007; Tassoker et al., 2020). Genetic and environmental etiologic factors were confirmed for maxillary canine impaction and the alveolar bone area was also increased on the impacted side compared than the non-impacted side (Oz et al., 2017).

The aim of the study was three-fold:

1) to explore the role of 3D CBCT in detecting impacted canines and their movement during the prospective study
2) to evaluate the influence of orthodontic therapy parameters on treatment options
3) to monitor the quality of healing process based on shape and size of sinus maxillae volume versus impacted and non-impacted canines.

Material and Methods

Subjects

The sample under study was composed of 26 individuals (21 females, 5 males).

For each individual, pre-treatment (pre-op) and post-treatment (post-op) CBCT data were acquired. The maxillary canine impaction was all the times unilateral. The mean age of patients prior to treatment was 13.5 years (females: 13.3 years, males: 14.4 years). When the treatment was concluded, it was 15.7 years (females: 15.3 years, males: 17.1 years). The timespan between pre- and post-treatment imagery ranged from seven months to 4.3 years.

The prospective study was conducted according to the recommendations of the American Dental Association (ADA). In accordance with the Declaration of Helsinki patients were requested to provide informed consent to the clinical examination and regular follow-ups by means of the informed consent form. The anonymity of the data obtained was strictly respected. Ethical approval for the study was obtained from the Ethics Committee. The exclusion criterion for one patient was as follows: the person was indicated for surgical removal of impacted canine due to resorption of root and treatment continued with the implant insertion.

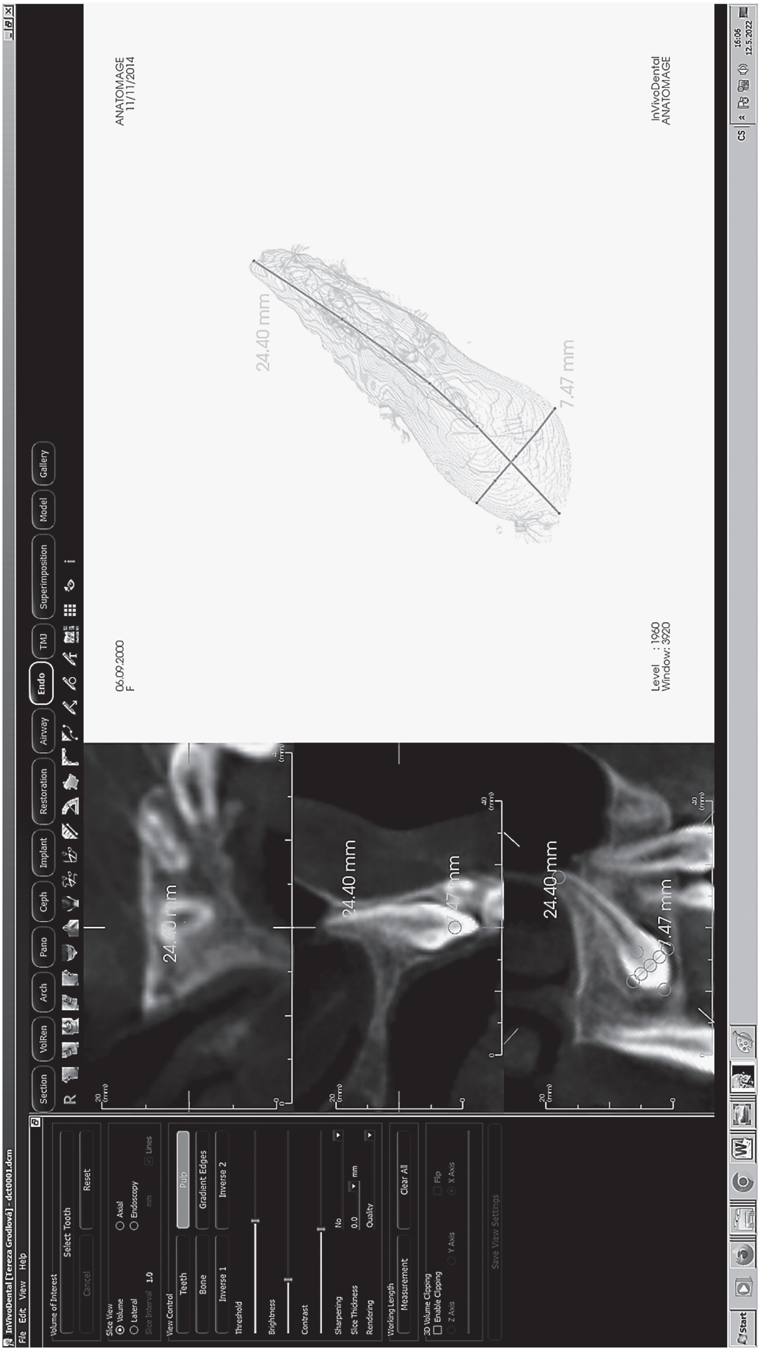

Figure 1 – The impacted canine before therapy with its 3D reconstruction in three planes: horizontal (points A-B); midsagittal; and coronal plane going through the canine cusp tip (C point).

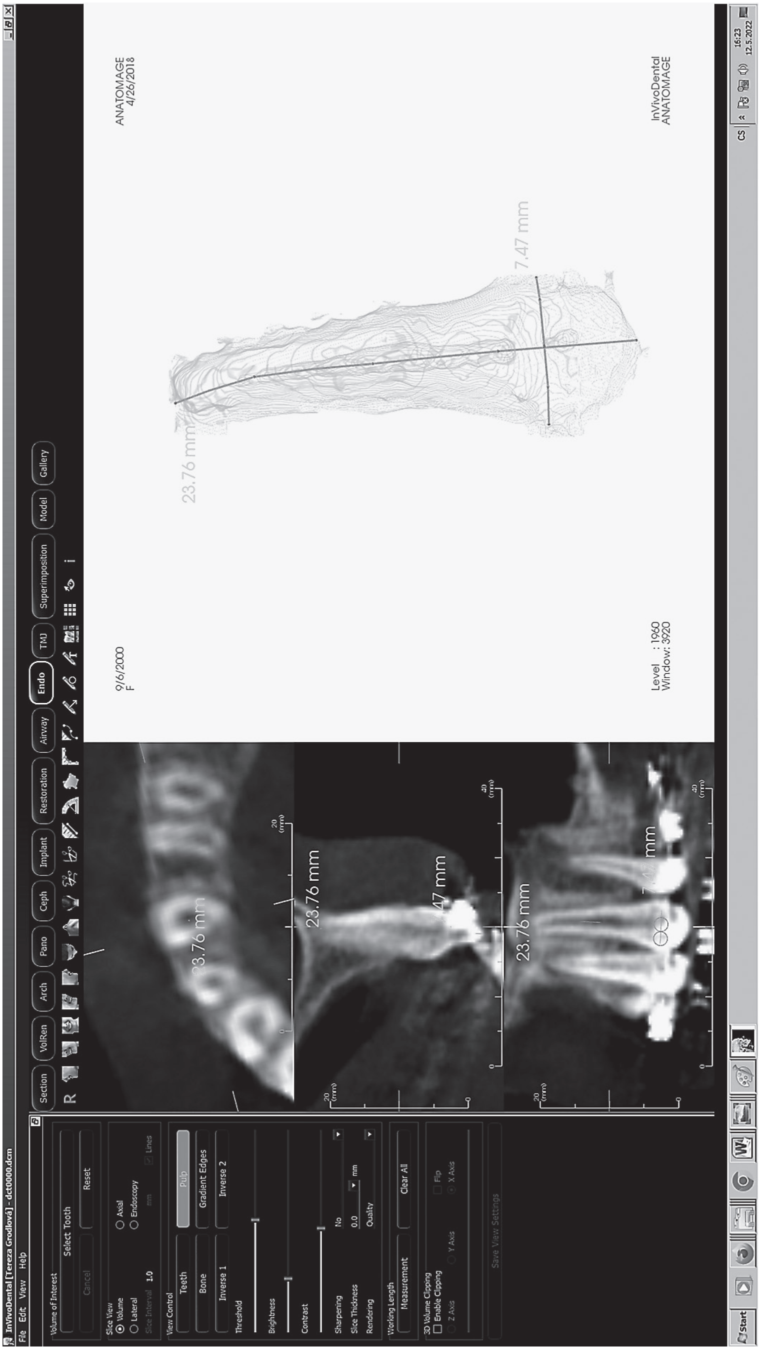

Figure 2 – The canine after therapy and its 3D reconstruction.

Treatment arrangement

For the radiological diagnosis, the Cone Beam Computed Tomography, KaVo Dental GmbH, Biberach, Germany (CBCT) was used to determine the position, number, shape, and size of impacted canines before and after therapy (Figure 1) with 17 cm × 23 cm FOV (field of view), 0.3 mm voxel size at 120 kV, 5 mA, according to manufacturer's directions. All CBCT examinations were indicated for surgical and orthodontic treatment; none of the examinations was performed solely for the purpose of this study.

Changes of shape, size, and position of impacted canine in 3D image before and after therapy were prepared using a 3D reconstruction and ENDO program (InVivo6 – Dental Anatomage Europe/Santa Clara, USA) (Figures 1 and 2).

Maxillary sinuses volumetric measurements

Volumetric measurements of the maxillary sinuses were performed before and after orthodontic therapy of impacted canines using also the InVivo6 software. Images were oriented in three spatial planes. The axial slice was adjusted to represent the Frankfort horizontal plane; the sagittal cross-section was used as the midsagittal plane; and the coronal slice was going through the furcation of the upper first molar roots. The volumes of right and left sinuses were measured individually step by step by Volume Render program (Figures 3 and 4).

For the pre-op sinuses, side differences were revealed for the pooled individuals as well as separately for patients with impacted and normal canines. The impacted canines, however, were associated with the sinus asymmetry merely at a 10% level of significance. For the post-op sinuses, all asymmetry comparisons (all together, impacted, normal canines) were shown statistically significant. In all cases the left-sided sinuses were larger than the right-sided.

Exploring impaction of canine teeth

Four linear measurements of the crania and canines were taken using the InVivo6 program. The measurements included: 1) the interlandmark distance between the right and left frontomalare orbitale points (A-B), 2) the shortest perpendicular distance between the line running through the right and left frontomalare orbitale points (A-B) and the canine cusp tip (right, left) (point C) (vector A-B), 3) the canine length measured from the canine cups tip to the apex, and 4) the canine width taken at the widest part of the crown. Furthermore, the volume of the maxillary sinus was taken, again, using measuring functionalities available in the InVivo6 program. Asymmetry in bilateral measurements was expressed in terms of right-to-left differences. In all cases, the measurements were acquired on volumetric visualizations.

Each 3D image – all distances, vectors and volumes were measured repeatedly twice after one month calculating intra-operator error. The differences between repeated measurements (intra-operator error) were tested in the pair-wise manner

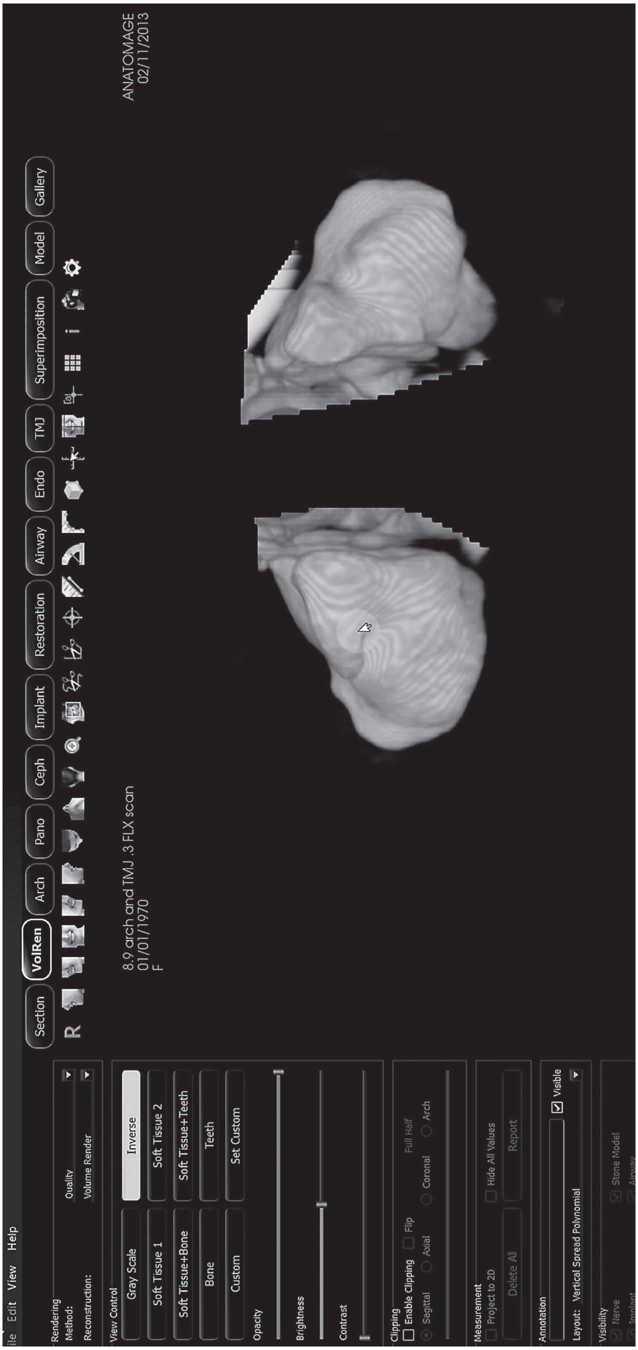

Figure 3 – Segmentation process during three-dimensional reconstruction of maxillary sinuses.

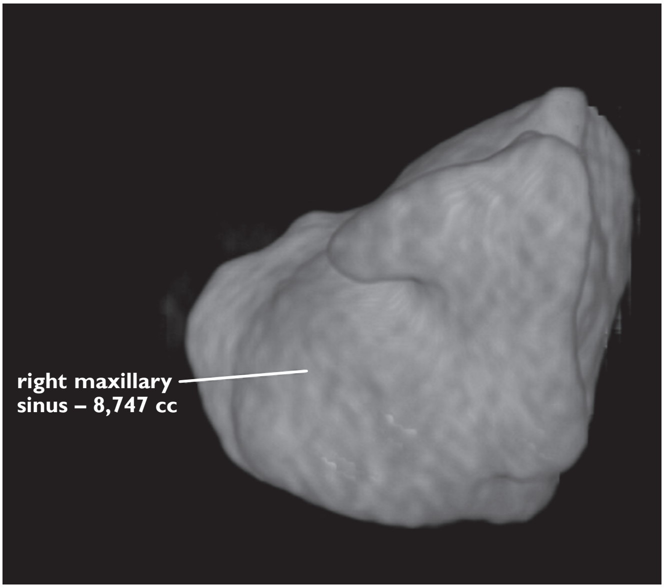

Figure 4 – Volumetric measurement of right maxillary sinus – 8747 mm³ was automatically calculated in Volume Render program.

by the Repeated Measures ANOVA. Prior to testing, assumptions were verified by a Levene's test. Side-related differences were tested by paired *t*-tests. While relationships between measurements and continuous parameters (age, duration of treatment) were tested by Pearson's correlation coefficient, differences by categorical variables (impacted/normal tooth, pre-op/post-op image) were explored by a *t*-test and a multivariate analysis of variance. Statistical tests were performed at a 5% level of significance, if not stated otherwise.

Results

The results were inserted to the following Tables 1 and 2. The Repeated Measures ANOVA showed no statistically significant differences between two sets of measurements for any of the linear nor volumetric measurements.

All measurements, except for the crown width, correlated positively with age (R ranging from 0.2 to 0.46). Logically, the strongest relationship was shown for the A-B distance. A-B line as well as the tooth length also showed positive relationships with the duration of treatment (R ranging from 0.22 to 0.42) (Table 3). The volume of the maxillary sinus correlated positively with the A-B line and with the perpendicular distance from the line to the canine cusps tip (vector A-B) (Table 4). When tested separately for groups (pre/post-op, side, normal/impacted canines), the positive correlations varied largely among groups with no specific pattern.

The presence of normal and impacted canines was distributed evenly on the right and left side sides. No side-related prevalence was observed for impacted canines (chi-square, P-value = 0.575) (Tables 5 and 6).

Table 1 – Descriptive statistics was prepared for repeated measurements

Measurement	Repeat measurement	Valid NM	Mean	Median	Minimum	Maximum	SD
A-B	1	104	93.064	92.910	78.530	102.620	5.204
	2	103	92.914	93.500	77.640	103.390	5.495
Length – canine	1	103	22.214	22.180	16.580	29.770	2.365
	2	103	22.127	21.640	16.670	29.920	2.381
Width – canine	1	103	7.619	7.470	6.080	11.300	0.897
	2	103	7.589	7.440	5.840	11.930	0.937
Distance A-B	1	103	65.942	66.310	51.350	77.930	6.024
	2	103	65.918	66.190	51.650	77.280	5.958
Right sinus – volume	1	50	9.973	9.703	5.868	18.712	2.541
	2	50	9.974	9.768	5.882	18.723	2.536
Left sinus – volume	1	52	11.713	11.722	3.465	18.806	2.790
	2	52	11.769	11.735	3.481	18.724	2.821

NM – number of measurements; SD – standard deviation

Table 2 – Descriptive statistics of the sinus volume grouped by pre/post treatment and types of canines

	Stage	Normal/ impacted	NI	Means	Median	SD	Min	Max
Right sinus	pre-op	R	14	9.084	9.122	1.606	6.507	12.273
	pre-op	N	11	10.758	9.958	3.216	5.868	18.359
	post-op	R	14	9.645	9.859	1.852	7.073	13.294
	post-op	N	11	10.736	9.791	3.305	6.091	18.712
Left sinus	pre-op	N	10	10.401	11.050	2.646	3.465	12.440
	pre-op	R	16	11.362	11.185	2.942	5.360	16.476
	post-op	N	10	12.792	13.094	1.283	9.559	13.961
	post-op	R	16	12.209	11.620	3.209	5.512	18.806

R – retained; N – normal; NI – number of individuals; SD – standard deviation

The main MANOVA effects performed on linear measurements showed metric differences between measurements of normal and impacted teeth as well as between pre-op and post-op images. Post-hoc tests specified that of the measurements studied, differences between impacted and normal teeth and pre-op and post-op images were significant in canine position expressed in terms of vector A-B distance.

In addition to MANOVA, side differences of the measurements were tested by an unpaired and paired *t*-test. The unpair variant revealed statistically significant

Table 3 – Pearson's correlation coefficient between the measurements and continuous variables

Measurement	Age	TS
A-B	0.404	0.224
Length	0.226	0.386
Width	0.116	0.133
Vector A-B	0.391	0.085
Maxillary sinus	0.202	0.032

TS – time span between to two repeated measurements

Table 4 – Pearson's correlation coefficient between the measurements and volume of the maxillary sinus

Measurement	Maxillary sinus
A-B	0.425
Length	–0.066
Width	0.011
Vector A-B	0.331

Table 5 – Among-group variation in the linear measurements

Normal/impacted	Left-sided		Right-sided		Total
	NI	%	NI	%	
Normal	10	45.45	12	54.55	22
Impacted	16	53.33	14	46.67	30
Total	26	50.00	26	50.00	52

NI – number of individuals

Table 6 – Main effects MANOVA

	Test	Value	F test	Effect	Error	P-value
Intercept	Wilks	0.002	9839.549	4	96	0.000
Normal/impacted	Wilks	0.620	14.679	4	96	0.000
Body side	Wilks	0.953	1.180	4	96	0.325
Pre/post-treatment	Wilks	0.830	4.927	4	96	0.001

Table 7 – Linear regression analysis

		SS	Degrees	MS	F test	P-value
Right sinus	age	4906.551	1	4906.551	628.041	0.00
	error	382.811	49	7.812		
Left sinus	age	7095.668	1	7095.668	831.822	0.00
	error	435.044	51	8.530		

SS – sum of squares; MS – mean sum of squares

Table 8 – Paired *t*-test testing differences in regression residuals between pre-treatment and post-treatment sinuses

Subset	Sinus residuals		Mean	SD	NI	Diff.	SD	*t*-test	P-value
Pooled	right	pre-op	0.689	2.578	25	0.984	1.129	4.358	0.000
		post-op	–0.295	2.952					
	left	pre-op	0.285	2.981	26	0.173	1.725	0.511	0.614
		post-op	0.112	2.901					
Impacted	right	pre-op	0.026	1.396	14	1.134	1.112	3.816	0.002
		post-op	–1.107	2.145					
	left	pre-op	0.451	2.905	16	0.572	1.189	1.925	0.073
		post-op	–0.121	3.532					
Normal	right	pre-op	1.532	3.468	11	0.793	1.174	2.239	0.049
		post-op	0.740	3.583					
	left	pre-op	0.019	3.240	10	–0.466	2.273	–0.648	0.533
		post-op	0.485	1.526					

SD – standard deviation; NI – number of individuals

differences in the canine width, with the left teeth being, on average, wider than the right ones (t = 2.249, P-value = 0.027). The same results were revealed by the paired *t*-test (t = 2.411, P-value = 0.0196). When treated by groups, normal canines showed side-related differences in canine length, and vector A-B distance, where the left-sided measurements were larger in both cases. In contrast, the left and right impacted canines differed in width, where the right-sided teeth were narrower, and in vector A-B distance, where the right-sided teeth were positioned in an upper position than the left-sided canines.

No side-related differences were revealed for the pre-op group, while in the post-op teeth the sides varied in the canine width, where the left-sided teeth were wider than those on the right side.

Maxillary sinus

A paired *t*-test showed no statistically significant differences between pre-op and post-op values of the sinus volume when the individuals with impacted and normal canines were pooled. When tested separately, patients with impacted canines exhibited enlarged sinuses once the treatment was concluded. The results were valid for both sides. For the left sinuses, however, the enlargement occurred also in patients with normal canines. To test whether the enlargement was affected by the underwent treatment as opposed to be merely the factor of age-related sinus growth, a linear regression analysis was first conducted with the individual's age as the independent variable and the sinus volume as the dependent variable (for right and left sinuses separately) (Tables 7 and 8). Then, regression residuals were tested for the differences between pre-op and post-op volumes by a paired *t*-test.

The analysis has confirmed that, indeed, there were differences between the pre-op and post-op volumes of the maxillary sinus once the volume was controlled for age variations (Table 8). On the right side, post-op sinuses of the individuals with impacted canines showed smaller volume than expected by the age model. The same results were shown on the left side, but these differences were not statistically significant at a 5% level of significance (albeit significant at a 10% level). For the sinuses associated with normal canines, the pre-op and post-op residuals were, on average, all of positive values. This means that the regression generally underestimated their real volume, i.e. the retarded growth was not present. Yet, there were still differences between the pre-op and post-op sinuses on the right side.

According to a *t*-test, the right-to-left differences were revealed between the pre-op and post-op sinuses at a 10% level of significance, where the post-op ones exhibited greater asymmetry than the pre-op ones ($t = 1.868$, P-value = 0.069). When the canine groups were considered, the median R-L differences for post-op sinuses were larger than for the pre-op sinuses, but none of the tests returned as statistically significant.

When performed on age-controlled residuals, however, no asymmetry was revealed for any of the comparisons.

Discussion

Our study has confirmed that the 3D CBCT reconstruction with the special program ENDO based on three planes, i.e. the horizontal plane (A-B), the midsagittal plane, and the coronal plane going through (vector A-B), allowed us to produce precise 3D images which were reproducible in time for linear or volumetric measurements. These results were important for orthodontic and maxillofacial plans of therapy. Real 3D measurements only in three planes explain methodologic diversity and possible different complexity levels of the subjects between the studies in the Eslami systematic review (Eslami et al., 2017) and can help us in the decision-making process.

All our measurements, except for the crown width, correlated positively with age (R ranging from 0.2 to 0.46). Logically, the strongest relationship was shown for the A-B distance. A-B line as well as the tooth length also showed positive relationship with the duration of treatment (R ranging from 0.22 to 0.42). This was to be expected as all patients were subadults at the beginning of the study and these increments in craniofacial measurements reflect growth changes. We also witnessed the differences between measurements before and after treatment as a result of the age-related growth. For the maxillary sinus, however, the opposite trend was present for the post-op sinuses with impacted canines once the age-dependency was controlled. This suggests that the impaction affected the size of the maxillary sinus.

As stated above, the process of resorption teeth can be difficult to diagnose with conventional two-dimensional (2D) dental radiographs, especially if the canine is located in the direct palatal or buccal position relative to the roots of adjacent teeth

(Celikoglu et al., 2010). CBCT provided improved detection rates (63%) of root resorption associated with impacted canines. The measurements using "Three-Dimensional Leeds Orthodontic Root Resorption Target Scale" can evaluate the subjective nature of CBCT images (Ericson and Kurol, 1988). Resorption of incisors alongside ectopic maxillary canines have been studied with computed tomography (CT). The vast majority (93%) of ectopic canines were found to be in contact with the roots of the adjacent lateral incisor and a significant number (19%) were in contact with the central incisor. In contrast, only 49% of normally positioned canines contacted the lateral incisor. Almost half (48%) of ectopically erupting maxillary canines had resorption of the maxillary incisors, with 38% and 9% found on the lateral and central incisors, respectively (Ericson and Kurol, 2000). More recent studies using CBCT similarly found that impacted maxillary canines had some degree of resorption on the incisors with 62% and 10% of these found on the lateral and central incisors respectively (Aktuna Belgin et al., 2019).

Our statistic measurements based on the specific 3D software program ENDO which compare all 3 planes: the horizontal plane (points A-B); the midsagittal plane; the coronal plane going through the canine cusp tip (C point) showed metric differences between measurements of normal and impacted teeth, and pre-op and post-op images were significant in canine position expressed in terms of vector A-B distance.

Of the four paranasal sinuses, the maxillary sinus is known to be the largest and the first to develop (Emirzeoglu et al., 2007). An interesting fact is that its shape and size have no significant effect on the low, high, and normal face growth groups (Ericson and Kurol, 2000). These results are especially important for maxillofacial surgery planning. The results by Aktuna Belgin et al. (2019) showed that the volume of the maxillary sinus decreased with increasing age. It was also found that the sinus volume was statistically significantly higher in males than in females in the age group of 18–24 years (Walker et al., 2005).

Our study has confirmed that there was no statistically significant difference in volume between the right and left maxillary sinus and that the maxillary sinus volume in males was significantly higher than that of females (Jawad et al., 2016; Okşayan et al., 2017). According to a *t*-test, the post-op sinuses exhibited greater asymmetry than the pre-op ones.

Conclusion

The role of 3D CBCT in detecting impacted canines and their movement during the prospective study is the basis of orthodontic therapy. Changes of shape, size, and position of impacted canines in 3D image before and after therapy were very precise and reproducible using 3D reconstruction and program ENDO (InVivo Dental Anatomage) in all three planes – horizontal, midsagittal and coronal.

The influence of 3D orthodontic therapy parameters on treatment options are the following:

The linear measurements showed metric differences between the measurements of normal and impacted teeth as well as between pre-op and post-op images. All measurements, except for the crown width, correlated positively with age. The A-B line as well as the tooth length also showed positive relationships with the duration of treatment. Healthy and impacted canines were distributed evenly on the right and left sides, showing thus no prevalence of the body side.

In our prospective study, monitoring the healing process quality based on the shape and size of sinus maxillae volume and also on impacted and non-impacted canines had no direct influence on face growth, but was important for 3D surgery treatment plan.

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