IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)
e-ISSN: 2279-0853, p-ISSN: 2279-0861.Volume 15, Issue 3 Ver. X (Mar. 2016), PP 28-34
www.iosrjournals.org

Bone Formation by Orthodontic Tooth Movement and Its Stability over Time

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Abstract:
Aim: *Orthodontic tooth movement can lead to the creation of bone. The purposes of the study were to investigate the amount of bone formed in orthodontic patients during treatment (maxillary canine distalization) and retention and to assess the long-term stability of the new bone.*
Material and Method: *The sample consisted of 80 patients with 128 missing lateral incisors who were treated with distalization of the maxillary canines. They were examined at the beginning of orthodontic treatment (T1), at the end of treatment (T2), 2 year afterf treatmen (T3A), and 5 years after treatment (T3B). The influence of canine´s inclination and its distance from the central incisor at T1 on the amount of bone created and the bone mass stability over time were assessed. Vestibular width of the alveolus was measured on casts at the level of the bone ridge and 5 mm apically from the alveolar ridge. Canine inclination to the alveolar ridge was recorded, as well as the height of the alveolar ridge.*
Results*: During treatment, T1 to T2, the alveolar ridge width was reduced by 4%, and the height decreased by 0,26 mm; during the retention periods (T2-T3A, T2- T3B), the alveolar ridge reduction was 2% on average, with individual variances, and height decreased by 0,38 mm on average. No correlation was found between canine inclination or between the canine distance from the central incisor at T1 and the amount and stability of the bone created by the orthodontic movement.*
Conclusions*: The bone created through orthodontic tooth movement was stable in both the horizontal and vertical directions. Changes in the width of the alveolus were not related to the amount of bone at the place of agenesis at the beginning of treatment. When the canine erupts next to the central incisor , favorable conditions affect the formation of the bone mass through distalization of the canine at the site of the missing lateral incisor.*
Keywords: *Bone stability, canine inclination and distance, changes of alveolar ridge in time, missing maxillary lateral incisors, orthodontic tooth movement*

I. Introduction

Bone formation is a normal histological process of resorption and apposition of the bone which arises due to the balanced osteoclastic and osteoblastic activity. By an orthodontic bodily movement, the new bone forms in the path of its movement [1-7]. There are different types of treatment that can by applied in the patients with missing maxillary lateral incisors. These include canine substitution, resin-bonded bridges, conventional fixed bridges, and implants. The choice of the treatment depends on certain relevant criteria [1-7]. The ability to create the appropriate amount of space is an important factor. Orthodontic treatment plays a fundamental role, since it provides the required space through the appropriate tooth movement.

If a lateral incisor were extracted or avulsed, the buccolingual thickness of the alveolar ridge narrows by about 23 % during the first 6 months. After 5 years, the ridge narrows an additional 11 %, so the averall ridge shrinkage is about 34%. However, orthodontic tooth movement can lead to the creation of bone. As a tooth is moved orthodontically through the alveolus, remodeled bone forms behind the root [9] and this bone is retained along the width of the tooth that was moved [10,11]. This principle is true even when the alveolus is narrow [12]. Spear et a1[13] reported that, after space had been created for lateral incisors, the labiolingual alveolar dimension narrowed by less than 1% over 4 years. However, their sample size was small, and no other studies have corroborated their findings.

The purposes of our investigation were to determine the changes in the bone mass in the vertical and horizontal dimensions during orthodontic space opening, the changes in ridge dimension after a period of retention, and whether the canine inclination and its distance from the central incisor before treatment affect the amount and stability of bone created through distal movement of the maxillary canine.

II. Material and method

The sample consisted of 80 patients with a total of 128 sites that were missing lateral incisors. These subjects were collected from the Department of Orthodontics at the Clinic of Dental Medicine in Olomouc, Czech Republic, and from 5 private orthodontic practices. In all subjects, space was opened for future prosthetic replacement of the lateral incisor. Maxillary dental casts of each subject were available at the beginning of orthodontic treatment (T1), at the end of active orthodontic treatment (T2), and after a period of retention (T3). The T3 time period was subdivided into 2 parts: 2 years after treatment (T3A) and 5 years after treatment (T3B). Panoramic radiographs were taken at T1,T2, T3A, and T3B. The ages of the subjects ranged from 11.2 to 31.2 years at T1, with a mean age of 18.06 years. The age range was 13.1 to 32.5 years at T2, with a mean of 19.8 years. At T3, the ages ranged from 16.2 to 34.9 years, with a mean of 23.83 years.

We used the following selection criteria: (1) all patients were missing at least 1 maxillary lateral incisor, and they had complete orthodontic treatment with fixed appliances; (2) the treatment involved canine distalization, with Angle Class 1 canine relationships achieved in all patients; (3) good quality panoramic radiographs were taken on the same device for each patient; (4) good quality dental casts were available at the appropriate times; and (5) the canines were not recontoured.

In 25 patients with unilateral agenesis, the opposite side was measured as the control group. We measured the width of the alveolar ridge at the site of the canine and the lateral incisor on the control side.

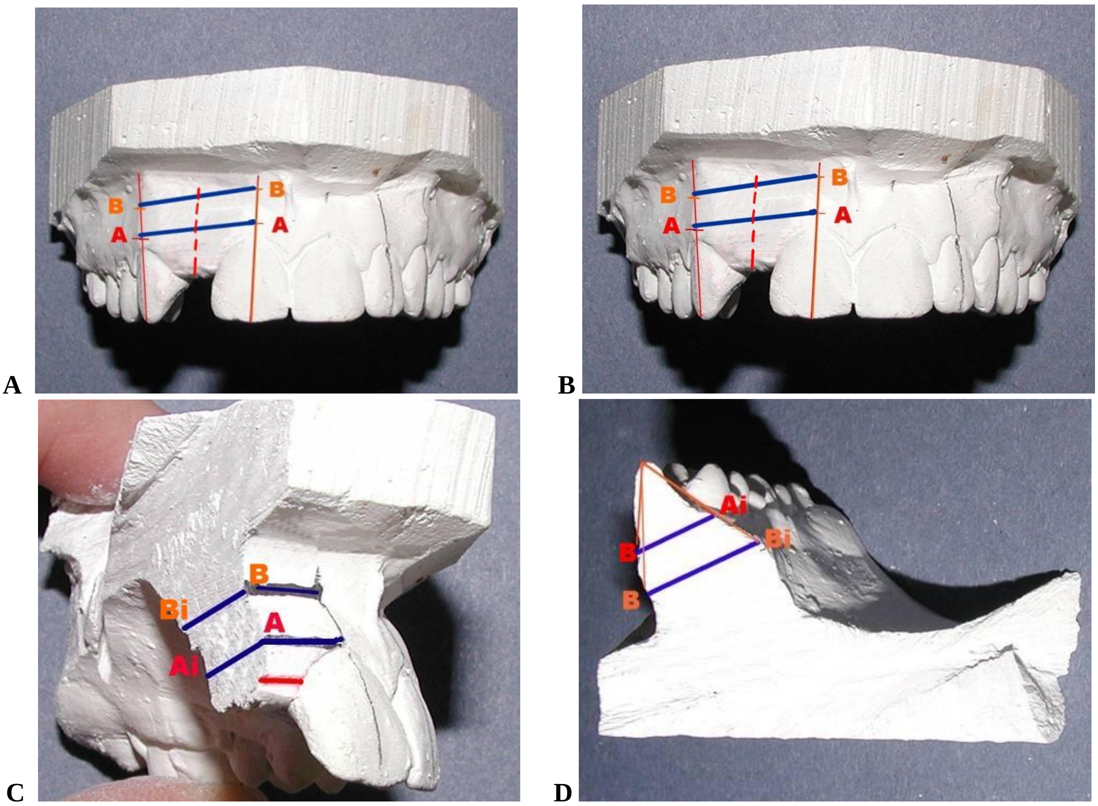


Figure 1: Dental cast analysis: **A**, Point A, level of the alveolar bony ridge 1mm apiccaly from the cementoenamel junction; point B, 5mm apiccaly from the alveolar ridge; and the connecting lines on the vestibular side at the place of agenesis. **B,** Points Ai and Bi on the palatal side; the connecting lines at the place of agenesis. **C,** Connecting lines A to Ai and B to Bi at the place of agenesis. **D,** Connecting line A to Ai and B to Bi at the place of canine.

In the dental cast analysis, the distance between the canine and the central incisor was measured on the casts with a digital caliper at the level of the alveolar ridge at T1, T2, and T3. The sample was divided into 2 groups based on the distance between the canine and the central incisor at T1. The first group consisted of 77 sites with canine-to-central incisor distances up to 1.5 mm. The second group consisted of 50 sites with canine-to-central incisor distances greater than 1.5 mm.

The thickness of the alveolar ridge at the place of the missing maxillary lateral incisor was measured at Point A (level of the bony alveolar ridge 1 mm apically to a line connecting the cementoenamel junctions of adjacent teeth) and at Point B (5 mm apically to the alveolar ridge) (Fig 1). The points measured on the dental casts were first determined with panoramic radiographs. The distance between the tip of the canine cusp and the canine alveolar ridge (at Point A) in the long axis of the tooth, and the distance between the tip of the canine and point B in the long axis of the tooth were measured on the panoramic radiograph at T1.

The same measurements were made for the central incisors. The long axes of the canine and the central incisor were traced on the dental casts at T1, T2, and T3 (the crown and alveolar ridge helped with the orientation). These values were traced on the dental casts made at T1, T2, and T3 from the both labial and palatal sides (Fig 1, A and B). At the site of the missing lateral incisor, a line was established perpendicular to the occlusal plane. Then connecting lines were used to establish Points A and B on the vestibular side, and Ai and Bi on the palatal side (Fig. 1, A and B).

The dental casts made at T1, T2, and T3 were cut vertically in the middle of the alveolar ridge between the canine and the central incisor, perpendicular to the occlusal plane. In the sectioned dental casts, connecting fines A to Ai and B to Bi were established to depict the thickness of the alveolar ridge at 2 levels (Fig. 1, C and D). We measured and compared these distances during orlhodontic treatment (T1-T2) and after treatment (T2-T3A and T2-T3B).

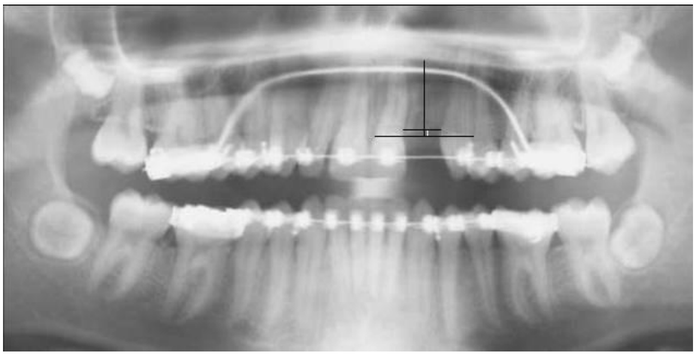


Figure 2: Measurement of alveolar ridge height at the place of agenesis

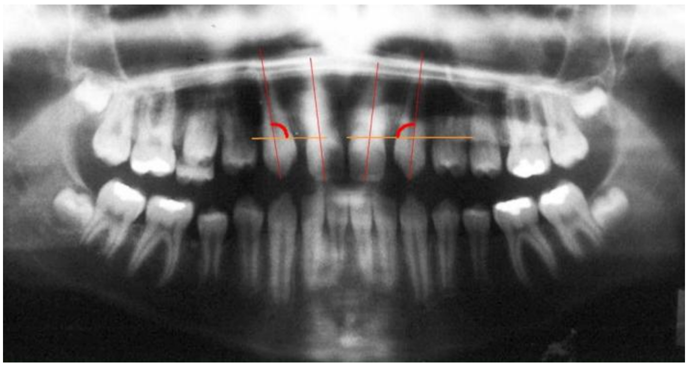


Figure 3: measurement of the angle between the canine and the alveolar ridge (canine inclination)

The level of the alveolar ridge at the site of the missing lateral incisor was measured at T1, T2, and T3. A line between the cementoenamel junctions of the adjacent teeth was established. A perpendicular line was extended from the middle of this line to the alveolar ridge and measured (Fig. 2).

We also measured the inclination of the canine to the alveolar ridge. It was defined as the angle between the axial aspect of the canine and the line running through the alveolar ridge (Fig. 3). The sample of patients was divided into 3 groups according to the angle between the canine and the alveolar ridge. The first group involved 43 sites with a canine inclination up to 90°at T1. The second group had 51 sites with a canine inclination be-tween 90° and 100° at T1. The third group consisted of 33 sites with a canine inclination over 100° at T1.

The measurement error was established by randomly selecting 26 subjects. Their dental cast and radiographic measurements were repeated by the same person (S.N.) after 2 weeks. Statistical analysis of the differences between the first and second measurements was performed. To calculate the measurement error (S*x*), we used the Dahlberg's formula [14],

$$Sx = \sqrt{\sum \frac{D^2}{2N}}$$

where D is the difference between the original and control measurements, and N is the number of repeated measurements. The errors in measurements of the thickness of the alveolar ridge were 0.33 mm at the site of the missing incisor and 0.25 mm at the site of the canine. The errors were 0.51 mm in measurements of linear distances and 4° in angular measurements. These values were considered acceptable.

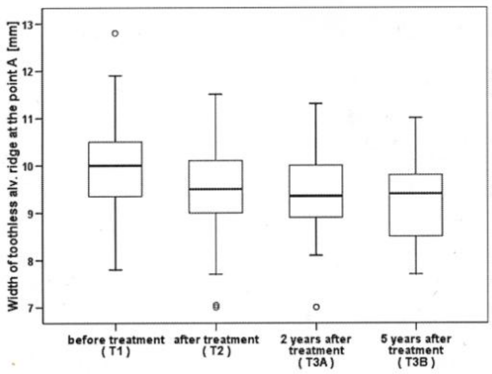
Statistical analysis

The differences in thickness of the alveolar ridges at Points A and B at T1, T2, and T3 were evaluated with paired t tests. The sign test was used to compare the change in the height of the alveolar ridge. The Student t test for 2 independent samples and a correlation analysis were used to determine the relationship between the distance of the canine and central incisor at T1, for the amount of the bone created at T2, and its stability at T3A and T3B. Statistical significance of the relationship between the canine inclination at T1 and the amount of the bone formed at T2, and of the relationship of the canine inclination at T1 and the bone mass stability at T3 was evaluated by analysis of variance (ANOVA). The correlation of the canine inclination and its distance from the central incisor at T1 and the amount of bone formed from canine distalization were also evaluated by correlation analysis. Testing of significance was performed at the 0.1%, 1%, and 5% levels ($P < 0.001$, $P < 0.01$, and $P < 0.05$).

III. Results

Measurements at the control sites obtained from 25 sets of casts at T1, T2, and T3 showed decreases in the thickness of the alveolar ridge at Point A of 1.5% from T1 to T2. Two years after treatment, the decrease was 2.5% (T1-T3A); 5 years after treatment, the ridge thickness had decreased by 2.0% (T1-T3B). The change of the alveolar thickness at Point B was 1.4% between T1 and T2. Two years after treatment, it had decreased by 1.9% (T1-T3A), and 5 years after treatment it was 0.4% narrower (T1-T3B).

In the edentulous site (level A, Fig. 1, A), the width of the new alveolar ridge was 4.0% smaller at Point A from T1 to T2, and it was further reduced by 1.6% from T2 to T3A, and by 2.2% from T2 to T3B. So, from T1 to T3B, the alveolar ridge narrowed by 6.2%.



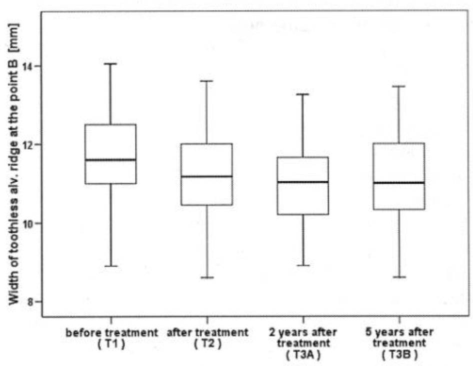


Figure 4: Width of toothless alveolar ridge at Point A at T1, T2, and T3
Figure 5: Width of toothless alveolar ridge at Point B at T1, T2, and T3

		n	mean (mm)	SD (mm)	max. (mm)	min. (mm)
Width of toothless alv.ridge at the point **A**	before treatment (T1)	127	9.94	0.87	12.80	7.80
	after treatment (T2)	126	9.53	0.82	11.50	7.00
	2 years after treatment (T3A)	62	9.37	0.88	11.30	7.00
	5 years after treatment (T3B)	27	9.23	0.82	11.00	7.70
Width of toothless alv.ridge at the point **B**	before treatment (T1)	127	11.60	1.07	14.05	8.90
	after treatment (T2)	126	11.21	1.02	13.60	8.60
	2 years after treatment (T3A)	62	10.96	1.04	13.25	8.90
	5 years after treatment (T3B)	27	11.19	1.13	13.45	8.60
Width of alv.ridge of the canine at the point **A**	before treatment (T1)	127	11.29	0.75	13.80	9.30
	after treatment (T2)	126	11.12	0.68	12.95	9.20
	2 years after treatment (T3A)	62	10.98	0.71	12.95	9.50
	5 years after treatment (T3B)	27	10.94	0.60	12.20	10.00
Width of alv.ridge of the canine at the point **B**	before treatment (T1)	127	13.26	1.03	16.30	10.80
	after treatment (T2)	126	13.03	1.03	16.25	10.25
	2 years after treatment (T3A)	62	12.80	1.13	16.25	10.25
	5 years after treatment (T3B)	27	13.12	1.06	15.30	10.00

Table I. Changes in the width of the alveolar ridge

The overall change from T1 to T3A was 0.58 mm (SD, 0.71; P <0.0001). So the width of the alveolar ridge narrowed by 5.6%. The overall change from T1 to T3B was 0.61 mm (SD, 0.76; P <0.0003; Table 1; Fig. 4).In the edentulous site (level B, Fig. 1, A), the width of the newly created alveolar ridge decreased by 4.0% at Point B from T1 to T2, and further reduced by 2.2% from T2 to T3A, and by 0.2% from T2 to T3B. So the alveolar ridge reduced by 4.2%. The overall change from T1 to T3A was 0.83 mm (SD, 0.97; P <0.0001). So the width of the alveolar ridge was reduced by 6.2%. The overall change from T1 to T3B was 0.35 mm (SD, 0.63; P <0.0077; Table 1; Fig. 5).

The mean labiolingual width of the canine alveolar ridge at T1 at Point A was 11.29 mm (SD, 0.75). The overall change from T1 to T3B was 0.31 mm (SD, 0.52; P <0.004). So the alveolar width decreased 2.8% from T1 to T3B. The mean labiolingual width of the canine alveolar process at T1 at Point B was 13.26 mm (SD, 1.03). The overall change from T1 to T3B was 0.31 mm (SD, 0.39; P <0.0003). So, the alveolar width decreased 2.4% from T1 to T3B (Table 1).

The distance between the canine and the central incisor had an impact. The differences between the bone created in the groups with the canine-to-central incisor distance up to 1.5 mm and more than 1.5 mm were not proven statistically according to the Student independent samples. The same was found for the stability of the created bone mass (Table II). Correlation analysis proved a minor negative correlation between the neck canine-to-central incisor distance at T1 and the width of the alveolar ridge at Point B at T1 (Fig 6, Table II). There was no statistically significant relationship between the canine to central incisor distance at T1 and the amount of bone at T2, and the stability of the bone at T3.

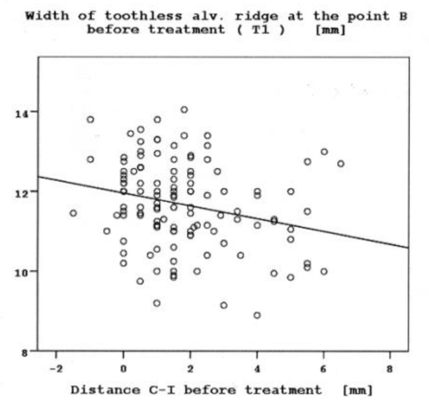


Figure 6. The amount of bone was smaller at T1 with the increasing canine-to-canine incisor distance

		width of toothless alveolus at the point B			
		before treatment (T1)	After treatment (T2)	2 years after treatment (T3 A)	5 years after treatment (T3 B)
distance C-I before treatment (T1)	correlation	**-0.246(**)**	-0.135	-0.190	-0.201
	sig. (2-tailed)	0.005	0.133	0.142	0.315
	n	127	125	61	27

**. Correlation is significant at the 0.01 level (2-tailed).

Table II. Correlation analysis: statistically significant smaller width of the alveolar ridge before treatment in greater C-I distance

In the analysis of the panoramic radiographs, the canine inclination had an impact. The statistical relationships between the canine inclination at T1 and the amount of bone created through the canine distalization during the space opening (T1-T2), and the bone mass stability were evaluated (T2-T3A, T2-T3B). There was no relationship between the canine inclination at T1 and the amount of bone at T2, as well as bone mass stability at T3. There were no correlations between the canine-to-central incisor distance and the angle between the canine and the alveolar ridge, and the amount of newly formed bone.

The alveolar ridge height adjacent to the edentulous site decreased by 0.26 mm (SD, 0.49) at the end of treatment (T1-T2), by 0.41 mm (SD, 0.65) by 2 years posttreatment (T1-T3A), and by 0.38 mm (SD, 0.53) by 5 years after treatment (T1-T3B).

IV. Discussion

The results of this study showed that the alveolar width of the edentulous ridge created by distalizing the maxillary canines was reduced by 4.0% from T1 to T2, by 1.6% from T2 to T3A, and by 2.2% from T2 to T3B. The labiolingual width measured 5 mm apically to the level of the bony ridge reduced by 4.0% from T1 to T2, by 2.2% from T2 to T3A, and by 0.2% from T2 to T3B. Few studies have explored this topic. The study by Kokich [11] involved 20 patients with missing lateral incisors. Using dental casts and panoramic radiographs, he found several changes occurring in the edentulous alveolar ridge. The loss of bone mass was less than 1% from the end of treatment to 4 years after treatment. The minimum resorption changes of the alveolar ridge were attributed to the orthodontic creation of the implant site obtained by bone deposition after root movement. Kokich reported that the reduction of the alveolar ridge width was less than 2% from the end of the therapy to 5 years after treatment. So it seems that the bone formed by canine distalization is stable in the long term. Our results suggest a 2% reduction of bone mass of the alveolar ridge width; however, the changes measured after 2 and 5 years were not significant. Even in the group measured 5 years after treatment, the edentulous ridge was reduced at Point B only by 0.2%.

Beyer et al [15] studied 14 patients with a total of 26 missing lateral incisors. They reported losses of bone mass of 0.4% at the beginning of therapy to 2.7% at its completion. The bone deficit increased to 5.2% at the time of implant placement. However, they measured the overall surface of the alveolar ridge required for the implantation, not the labiolingual distance. Therefore, they suggested that it is more appropriate to start orthodontic treatment involving canine distalization at a later time. Beyer et al also stated that patients who started treatment later and reached age 16.5 years at the end of the treatment are closer to the time of implantation, and thus the period of the continual bone atrophy is shorter. However, our study showed that the bone produced by canine distalization is stable, and the reduction in width of the alveolar ridge is minimal 5 years after treatment. Our study suggests that age does not play a crucial role in the decision when to start orthodontic space opening for a missing lateral incisor. The early beginning of treatment together with the ideal opening of the space and the temporary substitution with an adhesive bridge is 1 possible solution. Early treatment might agree with the patient's wishes.

A previous study reported a 34% reduction of the alveolar ridge after the extraction of maxillary anterior teeth [12]. Another study dealing with missing mandibular second premolars reported that the width of the alveolar ridge reduced by 25% at 3 years after the extraction of the deciduous second molar [8]. During the next 4 years, the resorption decreased to 4%. We focused on the maxilla and specifically the lateral incisors. It is difficult to compare different areas of jaws with different bone relationships and different vascular systems. Ostler and Kokich [16] assessed the changes of the alveolar ridge width also in teeth adjacent to the place of missing mandibular second premolars. The alveolar ridge of the mandibular first premolar was reduced by 4% from the beginning of treatment to 6 months posttreatment. We also reported a reduction of the width of the canine alveolar ridge adjacent to the missing lateral incisor, as well as the change in the width of the lateral incisor alveolar ridge on the control side. The results show that the alveolar ridge was reduced by 2.4% on average from T2 to T3A and T3B. However, we must consider that 2.4% corresponds to 0.34 mm (SD, 0.50); thus, from a clinical viewpoint, the loss is virtually insignificant.

lt is important to plan the development of the site for a future implant. After the loss of a deciduous lateral incisor, the canine erupts into the area. The deciduous canine guides the permanent tooth; therefore, it is advisable to extract it before the permanent canine moves distally. Thus, we can prevent labiolingual resorption of the alveolar bone. When the canine is moved distally and space is opened for the implant, the root of the canine forms an appropriate amount of alveolar bone [9, 13]. We found that the amount of bone at the edentulous site is significantly greater if the canine is located next to the central incisor. By distalization of the erupted canine, the bone should form along the width of the canine root. It might appear that the loss of alveolar bone at the site of the future implant is greater when development of the implant site is not planned. How should we improve implant site development with regard to obtaining sufficient and stable bone? Should the canine first be moved closer to the central incisor, with their roots parallel, and then distalized by bodily movement (to open the space for the implant)? Will a greater amount of bone be created? Our research did not prove the assumption. The results and charts make it clear that the amount of bone at Point B at the end of the therapy is greater in the group with the canine-to-central incisor distance up to 1.5 mm. However, the relation between the canine-to-central incisor distance at the beginning of therapy and the amount of bone in the edentulous site at the end of the therapy was not statistically significantly different. The position of the canine before therapy did not influence the bone mass stability, either. If the canine erupts next to the central incisor, the bone amount in the edentulous site is significantly greater, and thus the situation is more favorable, as we have already mentioned. The relationship between the amount of bone at the edentulous site at the end of the therapy and the canine inclination at the beginning of the therapy did not influence the width of the edentulous alveolar ridge. In the group of patients with the angle between the canine and the alveolar ridge up to 90° (parallel roots), there was a greater amount of the bone mass at Point A at the end of the therapy. However, we did not prove statistically significant differences between the groups with different canine inclinations before therapy and the bone mass and its stability after orthodontic therapy.

We evaluated the change in the edentulous alveolar ridge height over time. Vertical changes in the bone level in the group assessed 2 and 5 years after the therapy are trivial. The bone formed by the canine distalization was stable in the vertical direction also. Ostler and Kokich [16] reported that the alveolar ridge height at the site of missing mandibular second premolars decreased by 2% from T1 to T3. Thilander et al [17] reported that, if the distance between cementoenamel junction and the alveolar ridge exceeds 2 mm, resorption occurs. However, they emphasized individual variance. They recorded the most significant decrease in height between implant placement and its loading. Before implantation in the maxillary anterior area and after implant loading, the loss was less significant. These results correspond to those of Esposito et al [18].

V. Conclusion

The changes in width and height of the alveolar ridge were studied after distal movement of the maxillary canine in patients with missing maxillary lateral incisors. The distal movement of the canine created alveolar bone, and the width in the middle of the edentulous space after movement was virtually the same as before movement. The bone created by distalization of the canine in the edentulous site was relatively stable. The reduction of the alveolar width after 2 and 5 years was relatively small. The distance between the canine and the central incisor before treatment did not influence the ridge width or its stability. The relationship between the canine inclination at T1 and the amount of bone created during distalization of the canine was not statistically significantly different. In pafients with agenesis of maxillary lateral incisors, it is possible to move canines distally during adolescence and then wait to place implants when facial growth is complete, without concern about resorption of bone in the edentulous ridge.

In the present days we are working on the follow-up study 10 years after this investigation.

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