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Analysis of Dental Supportive Structures in Orthodontic Therapy

Ivana Savić Pavičin[1], Nataša Ivošević-Magdalenić[2], Tomislav Badel[3], Krešimir Bašić[4] and Jadranka Keros[1]

[1] University of Zagreb, School of Dental Medicine, Department of Dental Anthropology, Zagreb, Croatia
[2] Private practice in orthodontics, Čakovec, Croatia
[3] University of Zagreb, School of Dental Medicine, Department of Prosthetic Dentistry, Zagreb, Croatia
[4] Private dental practice, Zagreb, Croatia

A B S T R A C T

The purpose was to define the impact of orthodontic appliances on the density of the underlying dental bone tissue. Radiographic images of teeth were made in 27 study subjects before and twelve months after fixed orthodontic appliances were carried. The radiographs were digitalized and the levels of gray at sites where the greatest bone resorption was expected were transformed into optic density. In the standardization and comparison of values from the first and the second measurements the copper calibration wedge – a stepwedge – was used. Optic densities in the observed sites were compared with optic densities of the calibration wedge and expressed as their thickness equivalent. The study results showed no statistically significant difference in bone densities, indicating that the orthodontic therapy was properly planned and carried out and that excessive forces were not used in the applied correctional procedures.

***Key words**: bone density, densitometry, functional orthodontic appliance*

Introduction

The action of orthodontic devices produces forces that by their strength, direction and duration stimulate histophysiologic resorption processes and alveolar bone apposition, resulting in tooth movement in the desired direction. In the course of a demanding and long-term therapy it is important to monitor bone density and intactness of dental root structures.

As the tooth movement occurs in a long time, the system and moments of forces causing the movement are considered immobile and can be analyzed by the laws of statics. A radiograph is used for routine determination of bone density; however a computerized densitometry is a much more precise method since it enables the standardization of radiographic images and consequent maximum reduction of assessment errors[1].

The purpose of the study was to define the following:

- Efficacy of the applied method in the analyses of bone tissue during fixed orthodontic therapy;
- Whether different anomalies and sex affect the changes in bone tissue during fixed orthodontic therapy;
- Whether the extraction of the first premolar affects the bone density during fixed orthodontic therapy.

It has been decided that for the purpose of the study the intraoral micro-densitometry be used (by X-ray films of radiovisiography (RVG) sensors). Other methods of bone density assessment include: gamma photon absorptiometry[2], X-ray double-photon absorptiometry[3], single or double photon absorptiometry[3–5], quantitative computerized tomography[6–8], and neutron activation analysis[9].

A routine X-ray imaging is the simplest method of bone density determination. However, at least 30%, and in some cases even 50 to 60% of bone mass loss is needed for a naked eye to see these bone changes in a standard radiograph[10]. Computerized densitometry provides solution to the problem, although a precise standardization of X-ray images is needed in order to reduce the errors to the smallest possible extent[11].

As bone resorption is a long-term process it is important to be able to compare the two radiographs taken in

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different time intervals. The standardization of radiographs is obtained in a way to add several layers of material of known density to the imaging site. The additional material should be denser than any part of the sample material and in this way it becomes the point of reference for determination of the surrounding structures density. The material of known density is positioned on x-ray film immediately prior to imaging procedure in order not to shade the essential part of the analyzed sample; this is referred to as a stepwedge, or calibration wedge[12].

Subjects and Methods

The study included 27 subjects (10 male and 17 female subjects) of approximately the same age (14 and 15 years of age), in whom the clinical examination, craniofacial analysis and occlusion analysis showed the need for a fixed orthodontic therapy, provided they were never before submitted to such a therapy. The study was approved by the Research Ethics Committee of the University of Zagreb. A written informed consent was obtained from all participants. Specialist orthodontic examination of each patient was performed by two orthodontic specialists in the Department of Orthodontics of Dental Polyclinic in Zagreb. Besides sex of the subjects the following was important for the purpose of the study: whether the first premolar was extracted or not and the time of the last extraction. The majority of study subjects exhibited severe crowding. The studies mentioned so far were carried out as part of standard therapeutic procedures and their methods were not in discrepancy with standard diagnostic and therapeutic treatment.

In the course of the study analysis was made of bone density around the roots of the upper canines and the upper first and second premolars, on seven points in every tooth (ROI – region of interest). The bone regions along the mesial and distal sides of dental roots were analyzed in their cervical, medial and apical thirds, and in the apical region. In the patients with extracted first premolar bone density in the remaining site was measured in three levels corresponding to cervical medial and apical thirds of the adjacent teeth roots. The selection of the observed points was based on the assumption that the changes in bone density would be most prominent in these points and on the fact that the teeth with only one root are easier to analyze.

Computerized densitometry by X-ray film and RVG sensors is used in the determination of bone density. The procedures were the following: standardization of research conditions by stepwedge, determination of the level of gray, determination and comparison of optic densities, and statistical analysis of results.

Two radiographs were taken for each study subject: one before the application of a fixed orthodontic appliance and one twelve months after initiation of orthodontic therapy. Specific attention was given to imaging conditions, i.e. identical position of the image and the patient, and equal exposition. The PLANMECA X-ray instrument was tuned to the average electrical voltage of 66kV at 66 mA/s current constant and 0.25 s exposition time. The Kodak 31x41 cm films were used and processed in DURR DENTAL automatic chamber through a 7-minute program.

Prior to exposition a stepwedge was positioned in the lower right corner of the radiographic film, so it could not interfere with the study sample. The densities in the radiographs were compared with the density of the stepwedge. As reported in current reference literature[10], so far the five-layer stepwedges were commonly used; yet, for the purpose of our study a special stepwedge was designed containing ten layers of 50–500 μm thick copper and one layer of 440 μm thick lead. For its density similar to normal bone density, copper is the most appropriate material for designing a stepwedge. The normal density of human bone is about 1.83 g/cm^3. Since lead is known for its highest specific density, it is commonly used as a point of reference. Greater number of layers provides for greater measurement precision, i.e. determination of copper stepwedge equivalent.

All radiographs are digitalized in a standard way[9,13] by Pix S1 Pro 3040x2016 resolution digital camera (3 resolutions). The digitalized radiographs were properly stored and processed by Scion Image (Beta 4.0.2) software, specifically designed for densitometric measurements. The levels of gray were read in the scale ranging from 0 to 255. Following the definition of the level of gray ranges, the densities of other points could be compared with the density of the stepwedge. It should be pointed out that the gray level scale is not a linear one, meaning that if one segment of the sample material is twice as dense as the other, it does not mean that the level of gray will be two times lesser. It results from the properties of the X–ray film, in which the relation between the amount of the absorbed X-rays and shading is not a linear one. In order to rectify this, the levels of gray should be brought into relation with the actual amount of the absorbed X-rays. It is achieved through the transformation of the level of gray into relative optic density.

The levels of gray are transformed into optic densities by the following formula: ROD = $\log_{10}$ multiplied with the total number of levels of gray/the observed level of gray. Only then it is possible to deduct the optic density of the background from the optic density of a stepwedge, by which the values of pure optic density (POD) are obtained for every copper stepwedge, without superposing of soft and hard tissues.

In order for two radiographs of our patients made at two different time intervals to be compared, the values of densities of certain points should be expressed in terms of equivalent values of copper stepwedge thickness in the following way: 1. Optic density of the desired point is determined first[8]; 2. Then follows the determination of interval of the stepwedge at the site of the examined point[9]; 3. The stepwedge equivalent is defined for the desired point in a way to calculate the linear equation involving two points[10]. Linear equation should be calculated for each single interval. The greater is the number of levels of a stepwedge the more precisely will be defined the equivalent of the stepwedge for each point to be analyzed.

Results

The total of 513 measurements was obtained for 27 study subjects: 232 mesial (4 to 12 per patient, or 45%), 206 distal (3 to 11 per patient, or 40%), and 75 apical (1 to 4 per patient, or 15%). There were 10 male patients (37%) and 17 female patients (63%). The number of measurements per patient ranges from 7 to 24. Compression was the prevailing anomaly (52%), while other anomalies comprised the remaining 48%. The distribution of patients with regard to the first premolar has shown that 63% of them did have their first premolar, while 32% of patients had their first premolar extracted.

Descriptive measures are presented ($\bar{X}$ – arithmetic mean, SD – standard deviation, N – sample size) according to the type and status of teeth (with or without the first premolar). Comparison was made between the first and the second measurement results. The examination was conducted for the group with compression and the group with other anomalies. The first and the second measurement results were compared for each single measurement point. The obtained statistical significance of difference (p) is presented as exact probability of error when rejecting the 0-hypothesis.

All distributions of significant variables for the first and the second measurements were tested within a group for normality by Smirnov-Kolmogov test. The group is defined according to the point of measurement, type of tooth, being in the group of anomalies, and presence or absence of the first permanent premolar.

None of the distributions showed statistically significant decline from the normal distribution. Hence the parametric, i.e. the Student t-test was used in the analysis of independent samples (between groups of anomalies) and t-test for samples of pairs (for the measurement before and after orthodontic therapy); the level of statistical significance was $p<0.05$.

In identical conditions (the same study subject, the same tooth and the same point of measurement) the average of all measurement results is recorded as study data and presented in table. The comparison results of the first and the second measurements on apex between the group of patients with compression and the group of those with other anomalies are shown in Table 1. The comparison results of the first and the second measurements on distal points between the group of patients with compression and the group of those with other anomalies are shown in Table 2. The comparison results of the first and the second measurements on mesial points between the group of patients with compression and the group of those with other anomalies are shown in Table 3.

TABLE 1
COMPARISON RESULTS FOR THE FIRST AND THE SECOND APICAL MEASUREMENTS BETWEEN THE GROUP WITH COMPRESSION AND THE GROUP WITH OTHER ANOMALIES

Tooth		Measurement					
		First			Second		
		t	df	p	t	df	p
Canine	First premolar extracted	0.26	6	0.807	0.11	6	0.919
	First premolar not extracted	1.06	15	0.306	0.62	10.4	0.554
Second premolar	First premolar extracted	1.01	7	0.346	0.24	7	0.817
	First premolar not extracted	0.74	14	0.471	0.27	14	0.794
First premolar		2.08	21	0.050	0.45	21	0.656

(Student t-test, $p<0.05$)

TABLE 2
COMPARISON RESULTS FOR THE FIRST AND SECOND DISTAL MEASUREMENTS BETWEEN THE GROUP WITH COMPRESSION AND THE GROUP WITH OTHER ANOMALIES

Tooth		Measurement					
		First			Second		
		t	df	p	t	df	p
Canine	First premolar extracted	0.77	5	0.478	0.43	5	0.685
	First premolar not extracted	0.30	14	0.768	0.40	14	0.694
Second premolar	First premolar extracted	2.27	3	0.108	2.06	3	0.132
	First premolar not extracted	1.19	12	0.258	0.91	12	0.380
First premolar		1.21	15.5	0.244	0.26	19	0.795

(Student t-test, $p<0.05$)

TABLE 3
COMPARISON RESULTS FOR THE FIRST AND SECOND MESIAL MEASUREMENTS BETWEEN THE GROUP WITH COMPRESSION AND THE GROUP WITH OTHER ANOMALIES

Tooth		Measurement					
		First			Second		
		t	df	p	t	df	p
Canine	First premolar extracted	0.96	6	0.375	0.65	6	0.539
	First premolar not extracted	0.57	15	0.577	0.55	15	0.592
Second premolar	First premolar extracted	0.75	7	0.475	0.26	3.6	0.807
	First premolar not extracted	0.81	15	0.433	0.13	15	0.896
First premolar		0.44	22	0.667	0.45	22	0.660

(Student t-test, $p<0.05$)

Discussion and Conculsion

Bone resorption and apposition are biological processes occurring during each orthodontic treatment and they result in the shift of a tooth in desired direction. However, when the force produced by an orthodontic appliance is too strong, excessive resorption of the supportive bone and surface of the dental root may occur. These changes usually take place in the apical region, causing shortening of dental root and destabilization of a tooth[14–16].

Resorption of dental root during fixed orthodontic therapy is the result of many causes. It may vary from person to person, and even between different teeth of the same individual. External root resorption commonly appears as superficial, inflammatory and substitutional. Root resorption caused by orthodontic appliance belongs to the group of superficial resorption type and occurs most often in the apex of the root[7,18].

Kotaro Miyoshi et al.[19] have investigated the changes in parodontal tissue of a rat as response to orthodontic force with regard to the time of measurement. It has been shown that the effects of the force significantly differ with regard to the time of the day when the force is applied. The study has also shown that there is significant difference in the shift of teeth and response of parodontal tissue when orthodontic force is applied in different time of the day. The results indicate that the daily rhythm in bone metabolism significantly affects orthodontic therapy, i.e. stronger bone activity has been noticed during the day than during the night.

Rupp[20] states that the degree of resorption changes depending on the type of anomaly, i.e. the ectopic eruption of a cuspid can cause extensive resorption in the region of lateral incisors. In such a situation during the first six to nine months of orthodontic therapy the upper incisors are more often exposed to resorption than other teeth, whereas the degree of risk increases with every following therapy. The orthodontic therapy is an additional problem in the care of previously traumatized teeth [21]. Parodontal changes also increase the resorption risk. Nowadays many methods have been tried in order to investigate this relation into more detail.

Brezniak and Wasserstein[20] report that in some patients the root resorption has been noticed prior to initiation of fixed orthodontic therapy; it is usually caused by previous trauma or other changes. As today more and more adults decide to take fixed orthodontic therapy, there is an increased risk of greater number of undesired influences on its outcomes, particularly in view of the fact that the age, genetic factors, smoking, certain drugs, etc., have been found to definitely affect the therapeutic results.

The orthopantomograms enable the detection of changes in bone tissues only at more than 30% of bone loss. Computerized densitometry, however, enables the solution of the problem by precise standardization of radiographs, for it reduces the error to the smallest possible extent. In many studies of bone density[10,11] calibration instruments are used – wedges made of different materials and with different numbers of layers, or levels. The most commonly used wedge is the one referred to as a five-level stepwedge. For the purpose of our study the 11-level copper stepwedge was designed. The 10 levels were made of copper of known density, while the 11th one was made of lead because of its extreme density for which no other element presented on X-ray image could have its density greater than the lead. The more levels the stepwedge has the more precise will be the defined thickness equivalent of the stepwedge for each investigated point.

The advantage of our method is in its additional procedure of deduction of relative optic background densities under each level of a copper stepwedge. It is important since it enables elimination of all undesired structures superimposed over the stepwedge.

As the relation between relative optic density and actual density is not a linear one, the function should be selected that would describe the non-linearity. If the stepwedge has a small number of levels[6], non-linearity is approximated by the polynomial of a higher degree. In our study the linear function $y=ax+b$ was used between each two single points of the stepwedge. Adding the levels to a calibration wedge proved successful in increasing the precision of measurement. In this case it is sufficient to define the polynomial of the first degree between each two neighboring points in order to obtain thickness equivalents of the stepwedge. The study results have shown that the 11-level stepwedge is sufficiently precise for proper insight into the resorption status of the supportive dental structures.

The method of intra-oral micro-densitometry may be used to diagnose the resorption changes in bones that are greater than 10%. The results of our study, in which densitometric analysis was made by using 11-level stepwedge, have shown that there is no statistically significant difference in the changes of bone density of dental supportive structures during twelve-month fixed orthodontic therapy. However, the possibility cannot be ruled out that in some brief time intervals during the therapy the value of resorption changes may have reached the range of even 10%, but the extreme reactivity of osseous system in children has obviously soon enough established the satisfactory bone mass, which in no stage could significantly weaken the stability of bone mass and consequently the success of the therapy.

It can be concluded that the proper selection of fixed orthodontic therapy is a prerequisite to successful treatment; the therapy should be based on the previously performed indispensable diagnostic procedures and the properly adjusted orthodontic force that does not cause undesired and excessive bone resorption. Furthermore, every patient, parent, or adoptive parent should be informed about the possibility of root resorption of one or more teeth during fixed orthodontic therapy[14–20].

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I. Savić Pavičin

University of Zagreb, School of Dental Medicine, Department of Dental Anthropology, Gundulićeva 5, 10000 Zagreb, Croatia
e-mail: savic@sfzg.hr

ANALIZA POTPORNOG SUSTAVA ZUBA PRIJE I NAKON FIKSNE ORTODONTSKE TERAPIJE

SAŽETAK

Svrha je rada bila utvrditi utjecaj ortodontskih naprava na gustoću podležećeg koštanog tkiva zuba. Dvadesetsedmorici ispitanika načinjene su rendgenske slike zuba prije postavljanja te nakon dvanaest mjeseci nošenja fiksne ortodontske naprave. Slike su digitalizirane, a izmjerene razine sivila na mjestima gdje se očekivala najveća resorpcija kosti, pretvorene su u optičke gustoće. U standardiziranju i usporedbi vrijednosti iz prvog i drugog mjerenja korišten je bakreni kalibracijski klin, a optičke su gustoće na promatranim mjestima uspoređene s optičkim gustoćama kalibracijskog klina te izražene kao ekvivalent njihove debljine. Rezultati istraživanja nisu pokazali statistički značajnu razliku u gustoći kosti, što ukazuje da je terapija ispravno planirana i provedena te da u poduzetim korekcijskim zahvatima nisu primjenjene prevelike sile.