Acta of Bioengineering and Biomechanics
Vol. 14, No. 1, 2012

Original paper

Experimental strength analysis of orthodontic extrusion of human anterior teeth

GRZEGORZ MILEWSKI[1]*, ANNA HILLE[2]

[1] Division of Experimental Mechanics and Biomechanics, Cracow University of Technology, Cracow, Poland.
[2] Institute of Dentistry, Collegium Medicum, Jagiellonian University, Cracow, Poland.

The paper presents the strength tests, in terms of in vitro examinations, of restored mesial incisor crowns after endodontic treatment with modelled orthodontic extrusion procedure. The strength tests were carried out for 25 teeth randomly divided into groups with various degree of root reduction. The analysis was done for the following quantities: the force to fracture, the work to fracture, the energy of the first micro-crackings and breaking, the total displacement. Statistical analysis with the use of the Kruskal–Wallis test was done in order to assess the significance level in four tooth groups. Numerical simulations of periodontal ligament effort due to the orthodontic extrusion have also been carried out.

Key words: *orthodontic extrusion, endodontic cure, incisor, strength examination, FEM*

1. Introduction

Controlled tooth extrusion is described as a consolidation of the natural eruptive tooth movement in occlusion plane by the application of an additional tensile force coming from special elastic tractions, mobile or permanent devices (figure 1). That treatment stimulates periodontal ligament and the surrounding bone tissues and finally leads to the bone remodelling of both the alveolar process and the bone area close to the root apex. Orthodontic extrusion, among other applications, is considered to be a supplementary method whose aim is to prepare properly teeth for further prosthetic treatment. In the case of subgingival bone resorption, the treatment becomes an alternative to tooth extraction. The main advantage of the method is a maintenance of own tooth root together with periodontal ligament and adjacent bone tissue. The orthodontic extrusion enables us to avoid tooth extraction as well as following bone resorption and dental arch disorders. Depending on the value and duration of the loading applied, two kinds of extrusion procedure are used in clinical practice: the so-called slow and fast extrusion. In the first case, the total force applied to one-root tooth should not exceed 0.3 N and the total root displacement should be less than one mm per week, while in the fast extrusion, the load can be increased to 0.5 N. The procedure usually goes on for 4–8 weeks [1].

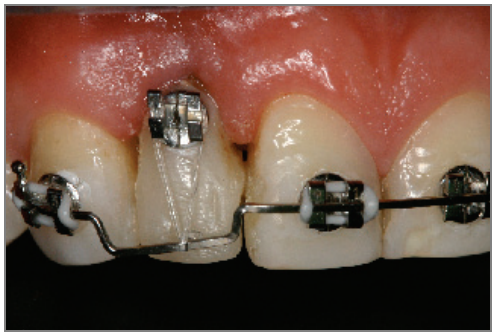

Fig. 1. Example of anterior tooth extrusion by means of permanent orthodontic apparatus and polymeric ligature

* Corresponding author: Grzegorz Milewski, Division of Experimental Mechanics and Biomechanics, Cracow University of Technology, al. Jana Pawła II 37, 31-864 Cracow, Poland. E-mail: milewski@mech.pk.edu.pl

Received: March 23rd, 2011
Accepted for publication: January 3rd, 2012

The aim of the work was to determine the strength properties, in terms of in vitro examinations, of restored anterior tooth crowns after endodontic treatment with modelled orthodontic extrusion procedure. In particular, the main goal of the paper was to prove that the decrease of the contact area between a tooth root and the surrounding tissues, due to the preceding tooth eruption, does not essentially influence the strength parameters of the reconstructed teeth. Numerical simulations of periodontal ligament effort due to the orthodontic extrusion have also been carried out.

2. Material and methods

Tooth samples were selected and prepared in Dental Clinic "Dentist" in Cracow. There were examined 25 human mesial incisors extracted mainly due to the parodontopathy or orthodontic therapeutic indications (figure 2).

Roots of all teeth were prepared for the endodontic treatment and then randomly divided into four groups marked with 10, 12, 14 and 16. The basic dimensions of tooth samples in all the groups are shown in tables 1 and 2.

Fig. 2. Examples of extracted incisors qualified for crown preparations simulating endodontic treatment with modelled orthodontic extrusion procedure

Number 1 stands for mesial incisor, while 0, 2, 4, 6 denote the degree of root reduction (mm) in the simulated orthodontic extrusion due to the tooth crown cut and following crown reconstruction at the required height. Group 10 is the reference group, i.e., the crowns of teeth were reconstructed in a standard way, with no root reduction. In groups 12, 14 and 16, the roots of teeth were cut 2, 4 and 6 mm, respectively, below a tooth anatomical neck. Then all the teeth were subjected to the same procedure for endodontic curing. Restorations were carried out with the use of OliPost Light glass fiber root post and nano-hybrid composite material, i.e. OliCo esthetic. Consecutive stages of clinical tooth preparation, retentive post insertion and crown reconstruction are shown in figure 3. Until the

Table. 1. Basic sample dimensions of tooth of reference group (group 10) and in group of teeth with 2 mm root reduction before final reconstruction (group 12)

Number of tooth	Group 10			Group 12		
	Root length	Mesial-distal dimension	Lateral dimension	Root length	Mesial-distal dimension	Lateral dimension
1	14.3	8.5	6.2	14.1	6.3	5.6
2	15.5	7	5.3	13.6	6.4	6.2
3	13.8	6.6	6.8	13.3	5.9	5.0
4	14.3	6.1	6.2	12.8	6.0	4.7
5	14.0	6.2	6.1	13.0	6.5	7.0
6	–	–	–	13.0	6.0	6.3
7	–	–	–	10.8	6.1	5.8

Table. 2. Basic sample dimensions in groups of teeth with 4 mm and 6 mm root reduction before final reconstruction (groups 14 and 16)

Number of tooth	Group 14			Group 16		
	Root length	Mesial-distal dimension	Lateral dimension	Root length	Mesial-distal dimension	Lateral dimension
1	12.8	6.1	6.0	12.4	6.6	5.5
2	16.0	7.2	6.2	13.5	7.0	5.3
3	13.0	6.3	6.3	11.2	6.0	6.0
4	13.0	6.2	6.0	13.2	6.2	6.2
5	12.0	7.2	5.1	15.0	6.5	6.0
6	16.2	6.8	5.6	14.5	7.2	6.2
7	–	–	–	16.0	6.0	6.7

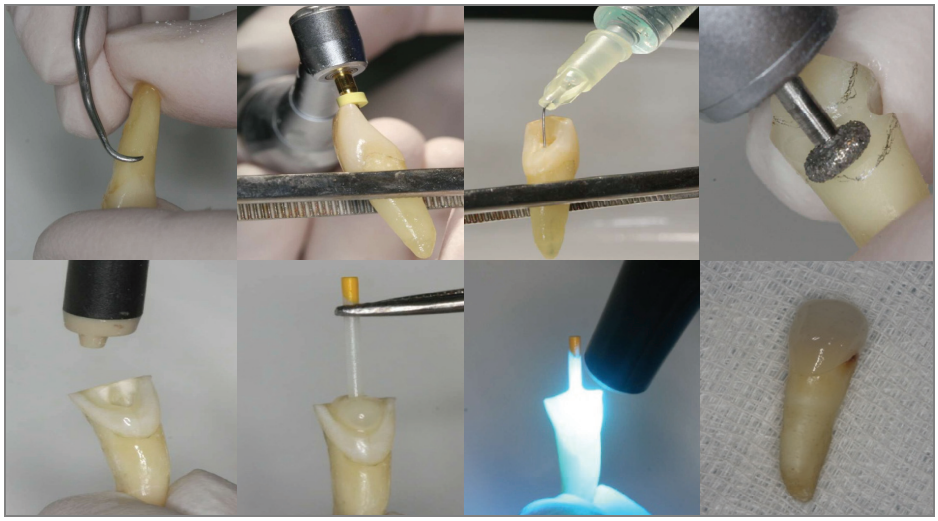

Fig. 3. Consecutive stages of tooth preparation simulating endodontic treatment with modelled orthodontic extrusion procedure

strength tests the tooth samples were preserved in a solution of a physiological salt.

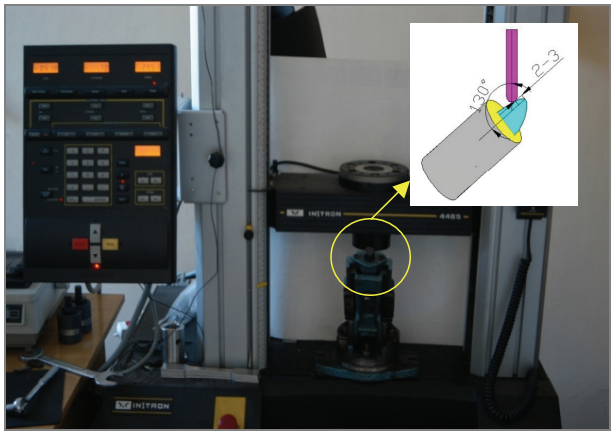

Fig. 4. Strength examination of incisor tooth sample after endodontic reconstruction and simulations of clinical method of orthodontic extrusion

The strength tests and the numerical simulations were carried out at the Cracow University of Technology, the Division of Experimental Mechanics and Biomechanics. The roots of reconstructed tooth samples were fitted in an epoxy resin and aluminum and a special clamp was prepared for the strength tests. The experiments were done under in vitro conditions by means of an universal strength machine, Instron 4465. As there are no standard procedures for such tests [2], [3], instead of an opposite tooth a stainless steel ball of 2.5 mm diameter was applied. The terms of a proper occlusion for anterior teeth were modelled which meant that the occlusal loading was applied at an angle of 130° to the long axis of a tooth. The tests were done with strain rate of 0.5 mm/min at a room temperature and standard humidity (figure 4).

3. Results

The strength analysis was done for the following parameters: the force to fracture (kN), the work to fracture (J), the energy of the first micro-cracks and breaking (J), and the displacement (mm). There are no direct ways or explicit standards allowing in vitro strength examination of tooth crowns or reconstructed tooth crowns. Except for the commonly used quantity of ultimate force, the assessment of the energy of fracture (in some papers defined as the work to fracture) as well as the maximal displacement result in a better estimation of biological system response to

Table 3. A set of statistical values of force and energy to fracture for all reconstructed incisor groups

Tooth group	Number of samples	Force to fracture (kN)/energy to fracture (J)				
		Maximal value	Minimal value	Medium value	Standard deviation	Median
Group 10	5	2.065/2.057	1.154/0.624	1.490/1.113	0.359/0.570	1.474/0.924
Group 12	7	1.203/1.678	0.623/0.455	0.947/0.921	0.203/0.453	0.998/0.861
Group 14	6	1.488/2.234	0.749/0.623	1.196/1.302	0.331/0.583	1.349/1.193
Group 16	7	1.577/0.865	0.633/0.217	0.995/0.600	0.303/0.216	0.912/0.658

mechanical loadings. Those parameters were used in several papers, including [18]–[20]. A set of statistical values of the force and the energy to fracture for all the reconstructed incisor groups is presented in table 3, while the diagram of medium values of the measured and calculated strength quantities is shown in figure 5.

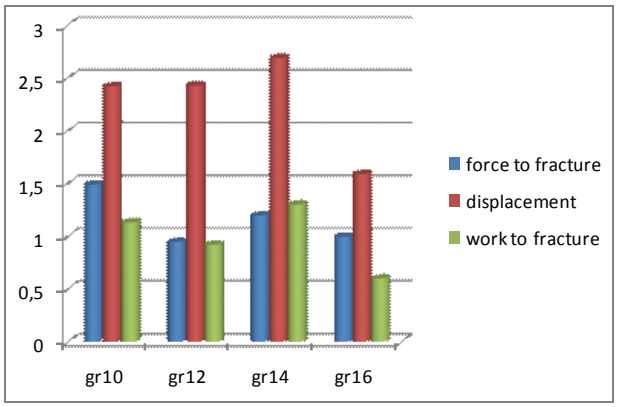

Fig. 5. Medium values of strength parameters of incisor tooth samples after endodontic reconstruction and simulation of clinical method of orthodontic extrusion

The force and the energy to fracture, which result in crown destruction classified as unable to be reconstructed, were taken into account as the most fundamental. In the reference group 10 with natural root settlement, the most resistant tooth withstood the ultimate force of 2.065 kN. For other teeth in this group the values of the force to the fracture ranged from 1.154 to 1.532 kN. For comparison, in group 14 for the majority of samples this range was from 1.336 to 1.448 kN, while for two others the values of the ultimate force were 0.749 and 0.802 kN. The differences between the values of strength parameters in separate group of teeth corresponded to the differences in the geometry of teeth, mainly in root length and in cross-sectional dimensions. The larger the surface of a tooth contact with the surrounding tissue, the better the strength results. However, some tendency can be expected, the degree of tooth reduction results in a decrease of strength parameters. For groups 10, 12, 14, 16 the averages of the ultimate forces were, respectively, 1.490, 0.947, 1.196 and 0.995 kN.

Statistical analysis with the use of the Kruskal–Wallis test was done in order to assess the significance level in the four tooth groups [4]. The Kruskal–Wallis test is commonly used in medical or biomedical sciences in order to assess the statistical significance of the series of experimental data. Additionally, the test of multiple comparison was applied if the four groups differed in kind. The results of the statistical tests were considered as statistically significant if the significance level was less or equal to 0.05. The calculations were done by means of STATISTICA 7.1 software package. Graphical representation of the averages of the force and the work to fracture for all the tooth groups and the significance levels calculated with the use of the Kruskal–Wallis test are given, respectively, in figures 6 and 7. No statistical variance analysis was carried out.

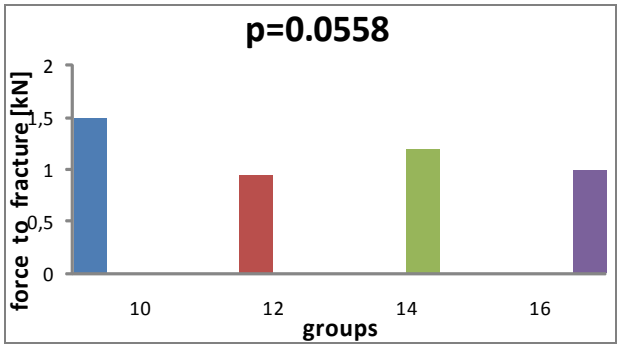

Fig. 6. Medium values of force to fracture for all tooth groups and significance level calculated with the use of Kruskal–Wallis test

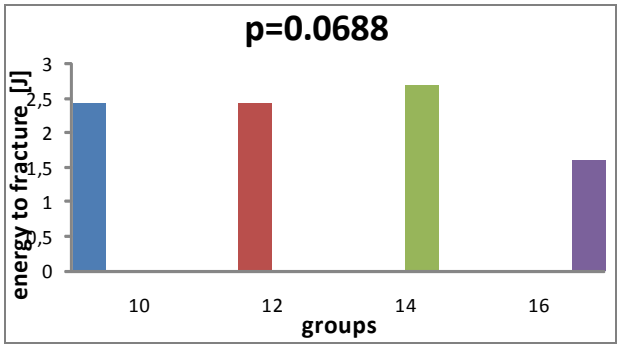

Fig. 7. Medium values of energy to fracture for all tooth groups and significance level calculated with the use of Kruskal–Wallis test

The analysis revealed that from the statistical point of view there was no significant differences between the teeth cured by means of orthodontic extrusion and the reference teeth with regard to the force and the energy to fracture. However, the clinical observations proved that extrusion procedure deteriorated tooth mechanical properties and the tooth–bone junction. Despite that the method of orthodontic extrusion is recommended due to its numerous advantages.

The proper response of periodontal ligament to stress in a clinical procedure of orthodontic extrusion becomes the factor of a crucial importance. In vitro experimental tests show that periodontal ligament of 20–49 years old men is able to carry maximal stresses of 1.4–3.0 MPa, depending on a group of teeth [5].

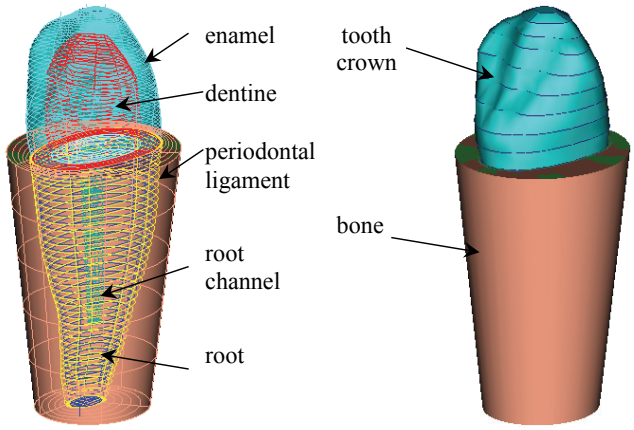

Fig. 8. Numerical model of canine with periodontal ligament and piece of mandibular bone designed in CAD program on a basis of 3D scanning with the use of Leitz PMM 12106 machine

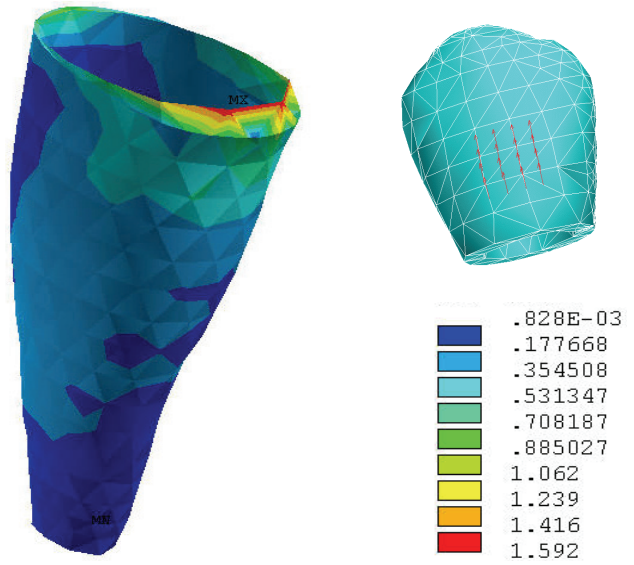

Fig. 9. Distribution of von Mises equivalent stress in periodontal ligament for simulation of tooth extrusion at 44 N

For anterior teeth, i.e., incisors and canines, the ultimate stress ranges from 1.5 to 1.7 MPa. The aim of the paper was also to simulate periodontal ligament effort due to the orthodontic extrusion. Periodontal ligament, a fibrous connective tissue surrounding the tooth root and linking it to the alveolar bone, was modelled as an elastic thin layer characterized by Young's modulus of 67 MPa and Poisson's ratio of 0.47, practically as an incompressible body [6]–[9]. However, some authors suggest that periodontal ligament reveals non-linear stress–strain behaviour [10], [11], while others suggest quasi-linear viscoelastic one [12]. The numerical model of canine with periodontal ligament and the piece of mandibular bone designed in CAD program on a basis of 3D scanning with the use of Leitz PMM 12106 machine is shown in figure 8.

Numerical calculations carried out by means of finite element method (FEM) in ANSYS software package show that the maximal force of extrusion at which the stresses do not exceed the critical values reaches 44 N. At that loading the maximal effort of periodontal ligament increases to 1.59 MPa and is concentrated near the gingival line. However, the areas where the effort is greater than 1 MPa are more extensive (figure 9).

4. Discussion

The origin of orthodontic extrusion goes back to the early eighties of the twentieth century when SIMON et al. [13] used that procedure to extrude endodontically treated teeth in dogs. The fundamentals of the method are based on the well-known theories of bone remodelling and the principle that the periodontal ligament which consists of collagen fibers is linked to the alveolar bone. The tensile loading applied to the destroyed tooth results in the deposition of new bone and finally in an increase of vertical height of the existing defect. More than 25 years later DANESH-MEYER and BRICE [14] proved that additional phenomenon, a coronal migration of the overlaying periodontal tissue and marginal gingival one, occurs when the tooth is being extruded. In 1993, the paper by SALAMA and SALAMA [15] proved to be the next milestone in the orthodontic extrusion method development. They reported that teeth with a hopeless prognosis could be extruded for 6 weeks, and retained for additional 6 weeks prior to extraction and implant placement which allowed a normal bone formation in the area of the alveolar process. In the meantime, the following guidelines for orthodontic extrusion procedure were set down [16]: constant force of 0.15 N (SI units) for slow extrusion for anterior teeth and 0.5 N for posterior teeth at the displacement rate no higher than 2.0 mm per month. Nowadays, the so-called slow and fast extrusion procedures are used in clinical practice. Additionally, the retention and stabilization of no less than one month for every month of active extrusion is recommended [1], [16].

The Editorial Board of the *Journal of Endodontics* published in 2008 a literature-based study guide to the methods of orthodontic extrusion [17]. The review of the essential endodontic literature shows that the majority of papers deals with the clinical aspects of the extrusion as well as histological examination of bone

formation due to the method applied. That tendency was also supported by an overall review paper on orthodontic extrusion presented in 2011 by Dentistry Today [30].

The strength examination in terms of in vitro tests of tooth restorations after endodontic treatment with modelled orthodontic extrusion procedure is a very unique scientific problem. In Polish literature, both dental and engineering, the problem does not arise at all. In the international literature, there is also little description of such an examination. The authors mainly concentrate on so-called ferrule effect and its influence on restored tooth fracture resistance [21]–[27]. All authors prove that the use of a ferrule, i.e., the parallel walls of dentine extending a crown to the shoulder of the preparation, becomes a very important design principle of crown preparation. The ferrule effect when restoring root-filled teeth with a post-retained crown increases the strength of the restored teeth.

As mentioned above, the applications of preceding orthodontic extrusion in the endodontically-treated teeth restored with root dowels as well as the description of its influence on tooth fracture resistance can be noticed only in a few papers [28], [29]. MENG et al. [28], [29] examined the first mandibular premolars in order to evaluate the effect of ferrule preparation length on the fracture resistance after simulated surgical crown lengthening and after forced tooth eruption of the endodontically-treated teeth restored with a carbon fiber-reinforced post-and-core system. Laboratory strength tests were carried out to find only the values of ultimate fracture force for the tooth reconstructions with simulated forced tooth eruption which provided ferrule preparations of 1.0 and 2.0 mm. The authors concluded that an increased apical ferrule preparation was responsible for a significant increase in fracture resistance, but not for simulated crown lengthening. The results correspond to the data presented in the paper for extruded mesial incisors, being characterized by lower resistance to fracture compared with that of the teeth with natural root settlement; however, the results are statistically insignificant.

Taking the above into the consideration, our method of determining the strength parameters of restored anterior tooth crowns after endodontic treatment with modelled orthodontic extrusion procedure seems to be original and unique. This concerns both the method of root reduction in simulated procedure of orthodontic extrusion and the strength parameters chosen to be analyzed, i.e. force and work to fracture and the energy of the first microcracking and breaking.

5. Conclusions

The anterior teeth cured by means of orthodontic extrusion are characterized by lower strength properties compared to the group of reference teeth with natural root settlement; however, statistically there are no significant differences between those groups with regard to the force and energy to fracture. From the clinical point of view orthodontic extrusion is highly recommended as it allows tooth extraction to be avoided, which is in agreement with the modern dentistry way of treatment, according to which the best implant is patient's own maintained root.

References

[1] BACH N., BAYLARD J.F., VOYER R., *Orthodontic extrusion: periodontal considerations and applications*, Journal of Canadian Dental Association, 2004, 70, 11, 775–780.

[2] SORRENTINO R., *A study into the laboratory techniques for investigating the resistance to fracture and the clinical performances of endodontically-treated teeth restored with fiber posts and different restorative materials configurations – mechanical tests and finite element analyses*, PhD thesis, University of Siena, School of Dental Medicine, Siena, 2006.

[3] SORRENTINO R., SALAMEH Z., ZARONE F., TAY F.R., FERRARI M., *Effect of post-retained composite restoration of MOD preparations on the fracture resistance of endodontically treated teeth*, The Journal of Adhesive Dentistry, 2007, 9, 1, 49–56.

[4] GŁOWACKI M., *Strength tests of tooth crowns cured by means of orthodontic extrusion followed by prosthetic reconstruction* (in Polish), MSc thesis, Cracow University of Technology, Cracow, 2008.

[5] KOMATSU K., *Mechanical strength and viscoelastic response of the periodontal ligament in relation to structure*, Journal of Dental Biomechanics, 2010, Article ID 502318, 18 pages, doi:10.4061/2010/502318.

[6] BECKER B., NÄGERL H., KUBEIN-MEESENBURG D., FANGHÄNEL J., *Elastic properties of live human periodontal ligament*, Proceedings of 2nd World Congress of Biomechanics, Amsterdam, 1994, 331b.

[7] YOSHIDA N., KOGA Y., PENG CH.-L., TANAKA E., KOBAYASHI K., *In vivo measurement of the elastic modulus of the human periodontal ligament*, Medical Engineering & Physics, 2001, 23, 8, 567–572.

[8] WANG S.-J., SHYH-YAU WANG S.-Y., *In vivo measurement of the elastic modulus of the human periodontal ligament*, Medical Engineering & Physics, 2001, 23, 567–572.

[9] MANDEL U., DALGAARD P., VIIDIK A., *A biomechanical study of the human periodontal ligament*, Journal of Biomechanics,1986, 19, 8, 637–645.

[10] TOMS R.S., LEMONS J.E., BARTOLUCCI A.A., EBERHARDT A.W., *Nonlinear stress–strain behavior of periodontal ligament under orthodontic loading*, American Journal of Orthodontics and Dentofacial Orthopedics, 2002, 122, 2, 174–179.

[11] NATALI A.N., PAVAN P.G., SCARPA C., *Numerical analysis of tooth mobility: formulation of a non-linear constitutive law for the periodontal ligament*, Dental Materials, 2004, 20, 7, 623–629.

[12] TOMS R.S., DAKIN G.J., LEMONS J.E., EBERHARDT A.W., *Quasi-linear viscoelastic behavior of the human periodontal ligament*, Journal of Biomechanics, 2002, 35, 10, 1411–1415.

[13] SIMON J.H., LYTHGOE J.B., TORABINEJAD M., *Clinical and histological evaluation of extruded endodontically treated teeth in dogs*, Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics, 1980, 50, 361–371.

[14] DANESH-MEYER M.J., BRICE D.M., *Implant site development using orthodontic extrusion: a case report*, New Zealand Dentistry Journal, 2000, 96, 18–22.

[15] SALAMA H., SALAMA M., *The role of orthodontic extrusive remodeling in the enhancement of soft and hard tissue profiles prior to implant placement: a systematic approach to the management of extraction site defects*, International Journal of Periodontics and Restorative Dentistry, 1993, 13, 312–333.

[16] KORAYEM M. et al., *Implant site development by orthodontic extrusion: a systematic review*, Angle Orthodontist, 2008, 78, 752–760.

[17] *Orthodontic Extrusion: An Online Study Guide*, Journal of Endodontics, 2008, 34, 5, suppl. 1, e143–e145.

[18] MILEWSKI G., *Strength aspects of biomechanical bone–implant interaction in dentistry* (in Polish), Cracow Univ. of Technology Publish., s. Mechanics, No. 89, Cracow, 2002, DSc thesis.

[19] MILEWSKI G., KROMKA-SZYDEK M, *Fundamentals of dental biomechanics* (in Polish), Cracow Univ. of Technology Publish., Cracow, 2010.

[20] BĘDZIŃSKI R. (ed.), *Biomechanics* (in Polish), Vol. 3, s. Mechanics, Polish Acad. of Sci. Publish., Warsaw, 2011.

[21] STANKIEWICZ N., WILSON P., *The ferrule effect*, Dental Update, 2008, 35, 222–228.

[22] SORENSEN J.A., ENGELMAN M.J., *Ferrule design and fracture resistance of endodontically-treated teeth*, Journal of Prosthetic Dentistry, 1990, 63 (5), 529–536.

[23] GEGAUFF, A.G., *Effect of crown lengthening and ferrule placement on static load failure of cemented cast post-cores and crowns*, Journal of Prosthetic Dentistry, 2000, 84, 169–179.

[24] AKKAYAN B., *An in vitro study evaluating the effect of ferrule length on fracture resistance of endodontically-treated teeth restored with fiber-reinforced and zirconia dowel systems*, Journal of Prosthetic Dentistry, 2004, 92 (2), 155–162.

[25] DAWSON D., *In vitro fracture resistance of endodontically-treated central incisors with varying ferrule heights and configurations*, Journal of Prosthetic Dentistry, 2005, 93 (4), 331–336.

[26] PEREIRA J.R., de ORNELAS F., CONTI P.C., do VALLE A.L., *Effect of a crown ferrule on the fracture resistance of endodontically-treated teeth restored with prefabricated posts*, Journal of Prosthetic Dentistry, 2006, 95 (1), 50–54.

[27] AL-HAZAIMEH N., GUTTERIDGE D.L., *An in vitro study into the effect of the ferrule preparation on the fracture resistance of crowned teeth incorporating prefabricated post and composite core restorations*, International Endodontic Journal, 2001, 34 (1), 40–46.

[28] MENG Q.-F., CHEN L.-J., MENG J., CHEN Y.-M., SMALES R.J., YIP K.-H., *Fracture resistance after simulated crown lengthening and forced tooth eruption of endodontically-treated teeth restored with a fiber post-and-core system*, American Journal of Dentistry, 2009, 22 (3), 147–150.

[29] MENG Q.-F., CHEN Y.-M., GUANG H.-B., YIP K.H.-K., SMALES R.J., *Effect of a ferrule and increased clinical crown length on the in vitro fracture resistance of premolars restored using two dowel-and-core systems*, Operative Dentistry, 2007, 32 (6), 595–601.

[30] www.dentistrytoday.com