Acta of Bioengineering and Biomechanics
Vol. 14, No. 3, 2012

Original paper
DOI: 10.5277/abb120312

A biomechanical model for a new incremental technique for tooth restoration

IVAN N. SARCEV[1]*, BRANISLAVA S. PETRONIJEVIC[1], TEODOR M. ATANACKOVIC[2]

[1] Clinic of Dentistry, Faculty of Medicine, University of Novi Sad, Novi Sad, Serbia.
[2] Department of Mechanics, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia.

The objective of this study is to introduce a modified incremental technique that leads to improved marginal adaptation and to develop a mathematical model that explains the results obtained. The technique proposed is a two-step incremental technique that reduces volume of a resin that is polymerized at each step and eliminates the central point in resin, so that the stresses are additionally reduced. In the first step, the resin is placed in the cylindrical cavity with a conical dental instrument embedded in the middle of restoration. After polymerization, the conical dental instrument is removed and the conical hole is filled with the second layer of composite and polymerized. This technique is a variant of a method where singular stress point is eliminated. We modified the previous technique by introducing a conical dental instrument into the centre of the cavity. The procedure proposed was compared with the bulk and horizontal layer incremental technique. This study confirmed that the incremental type placement technique used here has better marginal adaptation than bulk technique and horizontal two-layer incremental technique although it has *larger* C-factor in the first step than the two-layer incremental technique. Thus, the elimination of the central point of restoration leads to better marginal adaptation. Conical shape of the cavity that is filled in the second step makes this technique easy to apply in clinical conditions. A mathematical model describing stresses in the restoration shows stress reduction as a consequence of applying the procedure proposed.

Key words: *composite resin, marginal adaptation, incremental technique*

1. Introduction

Light-cured composite resins are the materials of choice for direct restorations, based on their high potential for bonding to the enamel and dentin, their improved mechanical properties as well as aesthetics. However, these materials have impediments related to marginal integrity and leakage due to the polymerization shrinkage [9]. The shrinkage is caused by closer packing of molecules in the polymer network compared to the individual monomer molecules during the polymerization process [11]. The composite shrinkage is also influenced by material properties [7], cavity configuration [8], irradiation time and intensity [1], degree of conversion [6], and elasticity of the dentin and enamel substrate. The phenomenon of contraction stress development in dental composite restoratives is highly complex, and despite many investigations, remains of significant clinical concern. In general, stresses and strains in dental materials are of both theoretical and pragmatic importance. For example, stresses at the boundaries and at tooth crowns have been studied in detail in [16], [17].

In an earlier work, a mathematical model of composite shrinkage has been developed that shows the influence of irradiation time on stresses [20]. There are many ways of improving marginal adaptation. Let us mention the following: material upgrade, (development of new materials with lower volumetric contraction), placement technique (the method proposed in this study belongs to this group), and cavity configuration (low-

* Corresponding author: Ivan N. Sarcev, Clinic of Dentistry, Faculty of Medicine, University of Novi Sad, Hajduk Veljkova 12, 2100 Novi Sad, Serbia. Tel.: +381 656227500, e-mail: ivansarcev@gmail.com
Received: February 17th, 2012
Accepted for publication: June 25th, 2012

ering the C-factor). When the ratio between the bonded to un-bonded composite–dental surfaces, i.e., C-factor is higher than 1, the stress generated by the composite shrinkage may exceed the bond strength to the cavity walls and produce marginal gaps which may in turn be the reason for secondary caries, marginal discoloration or post-operative sensitivity [10], [12]. In our work, the C-factor is 3.7 if bulk-filling technique is applied, so that marginal gaps may occur.

Introduction of nanoparticles in a filler reduces the stresses and leads to better marginal adaptation. For comparative study of nanofillers, see [22]. Recently, a class of novel nanocomposites was developed [23] that have smaller volumetric shrinkage and increased mechanical strength.

Restoration placement techniques are widely recognized as a major factor in the modification of shrinkage stresses [18], [19]. To reduce stress generated by polymerization shrinkage, it is often recommended to apply and cure composite resins in layers. Various incremental layering techniques have been proposed [4], [14], [21]. These techniques, whilst reducing the shrinkage stress, also have to be practical and should not extend the time required to perform the restoration.

Unless the volumetric contraction in dental composites is eliminated or significantly reduced, there will be the need for developing strategies that reduce stresses developed in dental composites as a result of volumetric contraction.

This research is based on the result of work [18], where it is shown that the lower shrinkage stresses and therefore a better marginal adaptation, can be achieved by an incremental type placement technique, where volume of the resin that is polymerized is reduced and the singular stress point in the resin is eliminated. Here we modify the shape of the cavity that is filled in the second step making it conical. We believe that the conical shape is easier to use in clinical praxis. An open problem is to determine the optimal ratio of the diameter of the cavity and diameter of the conical pin that is placed in cavity in the first step of restoration. This problem will be addressed later.

2. Materials and methods

2.1. Cavity preparation

Thirty intact non-carious, non-restored human third molars were stored in a 0.5% chloramine solution at 4 °C and used within 1 month after extraction. The teeth were cleaned with scalers and polished with pumice. The buccal enamel was ground using a diamond bur (ISO No: 806316250524014 KerrHawe SA, Bioggio, CH) in a high speed hand-piece with copious air–water spray, to expose a flat dentin surface and then finished with wet SiC 400,600 and 1000-grit paper. Standardized cylindrical cavities (3 mm in diameter, 2 mm deep) with all margins in dentin were prepared using diamond bur (ISO No: 806314109524014 Kerr, Orange, CA, USA) in a high speed hand-piece with copious air–water spray. Fine grained diamond burs (ISO No: 806314109514014, KerrHawe SA, Bioggio, CH) were used for finishing the preparations. A new bur was used after every other preparation. The cavities were examined under 10× magnification to check for any imperfect finishing lines and/or any visible pulp exposure.

2.2. Restorative procedure

The properties of the material used in this study are shown in table 1. A light-cured flowable composite (Vertise Flow; Kerr Corporation, Orange, CA, USA) was used. It has a remarkable high volume shrinkage [24] of 4.40%. The filling material was handled according to the manufacturer's instructions. A thin layer (< 0.5 mm) of self-adhering flowable composite was applied to each cavity and continuously brushed for 20 s. Excess material was removed with the brush provided and light-cured for 20 s with a LED curing light (Bluephase, 8-mm tip, Ivoclar Vivadent AG, Schaan/Liechtenstein, Serial No. 1642263). Subsequently, with regard to the different resin composite filling techniques used in this study, the teeth were randomly divided into three groups ($n = 10$):

- Group 1: *Bulk filling technique*. Composite was placed in one increment, light-cured for 20 s, and additionally for 20 s (with a 20 s dark period in-between) to make curing time identical for all experiments (total 40 s). The duration of the dark period was chosen on the basis of previous results [20].
- Group 2: *Horizontal incremental technique*. Composite was placed in two horizontal consecutive layers. Each increment was light-cured for 20 s (total 40 s) with a 20 s dark period.
- Group 3: *Proposed incremental technique.* Composite was placed in two consecutive increments. In the first step, cavity was bulk filled by dispensing tip. A conical pin (diameter 1.5 mm, height 2 mm, angle at vertex 20.56°) was embedded in composite resin approximately through the center of the cavity. The first increment was light-cured for 20 s and the conical

Table 1. Material used in the present study.
(Information provided by the manufacturer)

Material	Type	Manufacturer	Fillers	Organic matrix	Lot number
Vertise® Flow	Self-adhering flowable composite	Kerr Corporation, Orange, CA, USA	Prepolymerized filler, barium glass, nano-sized colloidal silica, nano-sized ytterbium fluoride, 70 wt.%	GPDMA (Glycerol phosphate dimethacrylate) and methacrylate co-monomers	3435366

dental instrument removed from the composite resin. After 20 s the second increment inside the conical hole was placed with a dispensing tip (d = 0.8 mm), and light-cured for 20 s (total 40 s).

All photo-polymerizing steps were performed with a light guide held perpendicularly and within 4 mm of the cavity floor [2]. The high power curing mode (HIP) was employed throughout the study, the light output from the curing unit was verified by a built-in radiometer. The intensity of curing light was 1000 mW/cm^2. Immediately after the filling procedure, the excess resin was removed by gentle wet grinding with SiC papers through 1000-grit until the cavity margins were exposed and then rinsed with copious amounts of water to remove the polishing surface debris. In figure 1(a), we show a tooth after the first step of restoration by the technique proposed. In figure 1(b), a cross-section of the tooth is shown after the second step. It shows that after restoration no voids are noticeable.

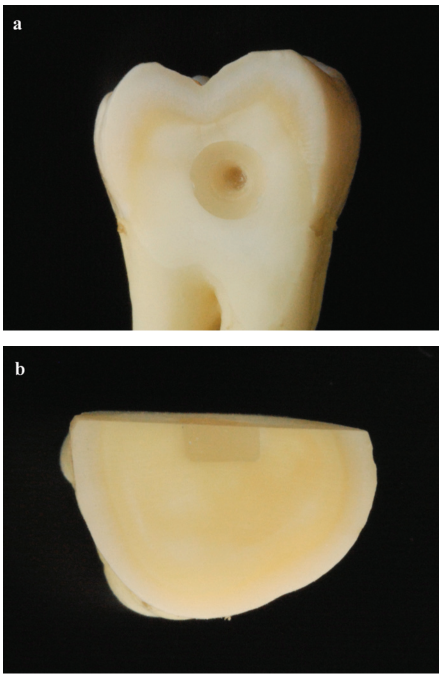

Fig. 1. (a) The cavity after the first step of restoration technique proposed, (b) cross-section of a tooth with finished restoration proposed

The restored teeth were stored in a container with 100% relative humidity for 24 h to prevent dehydration.

2.3. Model

We assume that the composite is in a plane state of stress [3]. Our assumption is based on the fact that stresses in the direction perpendicular to the upper plane of the composite are equal to zero, so that (approximately) out of plane forces are equal to zero. Thus, we consider a thin layer of the composite loaded by forces resulting from adhesive stresses.

The relevant equilibrium equations may be reduced to:

$$r^2(\sigma_r)'' + 3r(\sigma_r)' = 0\,, \tag{1}$$

subject to the following boundary conditions:

$$\begin{aligned} &\sigma_r(r=R) = T_a && \text{for Groups 1 and 2,} \\ &\sigma_r(r=R) = T_a,\quad \sigma_r(r=r_0) = 0 && \text{for Group 3,} \end{aligned} \tag{2}$$

where:

σ_r – radial component of the stress,

r – polar coordinate (see figure 3),

R and r_0 – outer and inner radii, respectively,

the prime denotes differentiation with respect to r, i.e., $(\cdot)' = \frac{d}{dr}(\cdot)$,

T_a – adhesive stress at the cylindrical boundary of the restoration.

The solutions for the case of composite with and without pin read:

$$\text{case a)}\ \ \sigma_r = T_0, \quad \text{case b)}\ \ \sigma_r = \frac{R^2 T_0}{R^2 - r_0^2}\left[1 - \frac{r_0^2}{r^2}\right]. \tag{3}$$

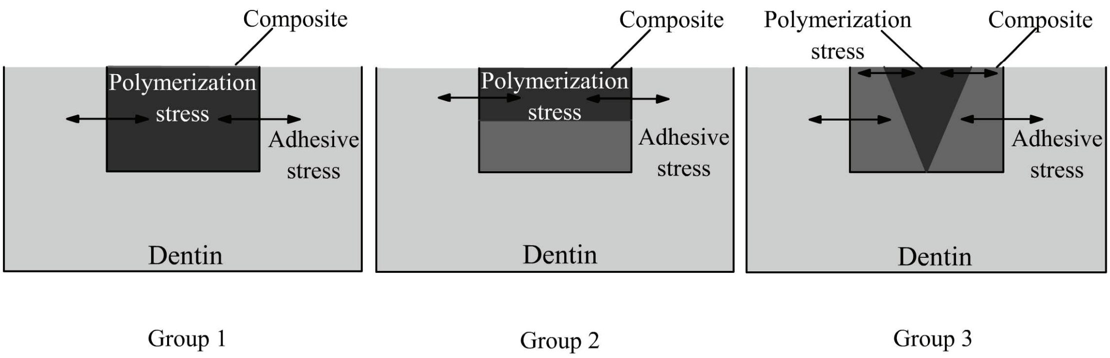

Fig. 2. Group 1: bulk technique, Group 2: horizontal layering technique, Group 3: proposed incremental technique

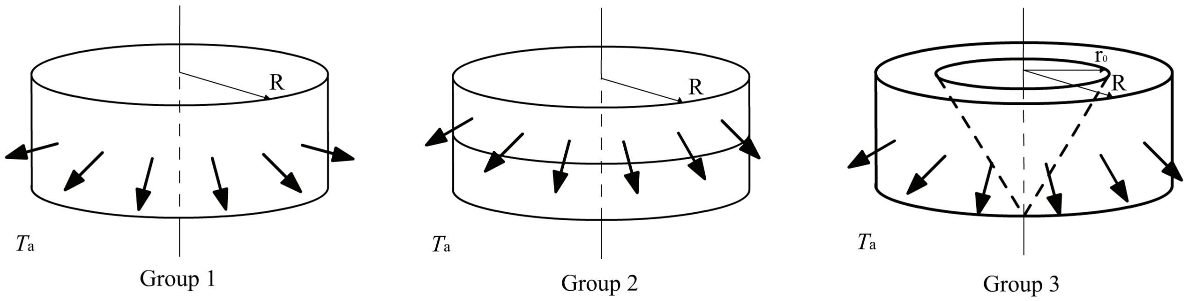

Fig. 3. The composite restorations: bulk, horizontal layer incremental, and proposed incremental techniques

The component of the displacement vector in the radial direction becomes:

$$u = \frac{r}{E}[(r\sigma_r' + \sigma_r - \nu\sigma_r)], \quad (4)$$

where:

E – modulus of elasticity,

ν – Poisson's ratio.

In writing (4) we used equation of equilibrium in the radial direction $\sigma_r' + (\sigma_r - \sigma_\theta)/r = 0$ together with the expression for the strain in circular direction $\varepsilon_\theta = u/r$. By using (3) in (4) we obtain the displacement at the boundary in cases a) and b) as:

$$u(R) = \frac{R(1-\nu)}{E} T_0 \quad \text{for Groups 1 and 2,}$$
$$u(R) = \frac{1}{E}\left[\frac{2Rr_0^2}{R^2 - r_0^2} + R(1-\nu)\right] T_0 \quad \text{for Group 3.} \quad (5)$$

In our case, due to the volumetric contraction ($\Delta V/V$), as a consequence of polymerization, there will be change in the outer radius of the composite, i.e., $\Delta R_i = (\Delta V_i/V_i)^{1/3}$ i = 1, 2, 3. This contraction of the radius is eliminated by the deformation of both composite and tooth structure [11] caused by the stress at the interface T_0. Neglecting the deformation of the dentin we set $\Delta R = u(R)$ for all three groups, so that solving for T_0 we obtain:

$$(T_0)_{\substack{\text{Group 1}\\ \text{Group 2}}} = \frac{E(\Delta V_i/V_i)^{1/3}}{R(1-\nu)},$$
$$(T_0)_{\text{Group 3}} = \frac{E(\Delta V_i/V_i)^{1/3}}{R(1-\nu) + 2\dfrac{Rr_0^2}{R^2 - r_0^2}}. \quad (6)$$

It is obvious from (6) that for the same material, i.e., for fixed $(\Delta V_i/V_i)^{1/3}$, E and ν in Group 3, the stress at the outer radius R is smaller than the stress in Groups 1 and 2, and therefore, the marginal adaptation is better. The numerical values of stresses may also be obtained by the finite element method (in which case no plane stress hypothesis is needed). Also the deformation of the tooth structure (here assumed to be zero) may be taken into account. Such an analysis is more involved and requires information about mechanical properties of the dentin and assumption about cavity configuration. Equation (6), however, shows qualitatively the effect of the proposed procedure on the reduction of marginal stress.

3. Results

3.1. Marginal adaptation

The mean values for the parameter "continuous margin" of all three techniques are presented in table 2. The statistical analysis demonstrated statistical difference between the bulk filling technique (60.17%), horizontal incremental technique (75.74%) and the proposed incremental technique (85.4%), for the parameter "continuous margin".

Table 2. The marginal adaptation expressed as mean, minimal and maximal percentage of the parameter "continuous margin" for the three groups

	Group 1			Group 2			Group 3		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Marginal adaptation	60.17	5.85	82.44	75.74	52.03	100.0	85.4	67.89	100

Table 3. Results of Mann–Whitney U-test

Mann–Whitney U-test		
Variable	U-value	p-value
Group 1 vs Group 2	35.00	0.26
Group 1 vs Group 3	12.50	0.005
Group 2 vs Group 3	26.00	0.07

Note: statistically significant differences between the different filling techniques (Mann–Whitney U-test, $p \leq 0.05$).

3.2. Evaluation of the marginal adaptation and SEM observation

After the samples had been prepared the length of the gap between the restoration and the dentin was determined from SEM photographs by using AutoCAD program. In figure 4, we show a typical sample prepared for SEM observation.

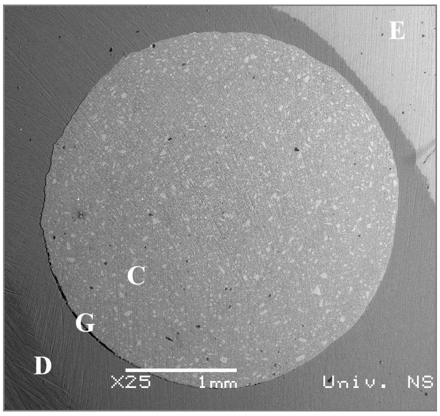

Fig. 4. A representative SEM image from Group 3: composite–dentin interface showing the gap between composite restoration and dentin. D – dentin, G – gap, C – composite resin, E – enamel

4. Discussion

In this work, we propose a two-step incremental method for improvement of marginal adaptation. In the bulk technique (Group 1), the C-factor is given as [12] C1 = $[R^2\pi + 2R\pi H]/R^2\pi = 3.667$. In horizontal and proposed incremental technique (Group 2 and Group 3), the C-factor is determined for each step. Thus, in the first step for the horizontal layering technique, the C-factor is C2a = $[R^2\pi + R\pi H]/R^2\pi = 2.33$. In the proposed incremental technique (Group 3) the C-factor in the first step is determined as C3a = $[R^2\pi + 2R\pi H]/[(R^2 - r^2)\pi + r\pi\sqrt{r^2+H^2}\,] = 2.508$. In the second step for horizontal layering technique and proposed technique, the C-factors are denoted by C2b and C3b, respectively. Note that for Group 2 the C-factors in both steps are the same C2b = C2b. For the proposed incremental technique (Group 3), the C-factor in the second step (in which the conical cavity is filled) is C3b = $r\pi\sqrt{r^2+H^2}/r^2\pi = 2.848$. Observe that in the horizontal layering technique the C-factor (C2a) is smaller than in the proposed method (C3a) and the proposed method has better marginal adaptation. This result is in agreement with the conclusion reached earlier [12] where it was stated that C-factor is inversely related to shrinkage stress (smaller C-factor leads to larger shrinkage stress). Since higher stresses lead to marginal debonding it follows that smaller C-factor may lead, and it does in our experiments in Group 2, to larger debonding. Thus, our results are in agreement with the results of WATTS and SATTERTHWAITE [25]. We attribute the fact that smaller C-factor (Group 2) leads to larger debonding to the filling configuration in the first step of the restoration used in Group 3 that allows for stress relaxation. Namely, after the first step in the proposed method, there is a stress relaxation process, especially at the top of cavity. This stress relaxation leads to an increase in the diameter of the conically shaped cavity that is filled in the second step. Also, it was concluded that microleakage seems to be related to the restoration volume, but not to its "C" factor [5]. In the proposed method the volume in the first step of restoration was $V3_1$ = 12.9 mm^3, while in Group 2 it was $V2_1$ = 7.07 mm^3. However, in the proposed method (Group 3) the larger volume of composite resin did not cause larger debonding due to the elimination of a singular stress point. In the second step, where in both filling techniques (Group 2 and Group 3) the singular stress point was present, the volume of resin was significantly smaller in Group 3 ($V3_2$ = 1.18 mm^3) than in Group 2 ($V2_2$ = 7.07 mm^3).

In the second step of the proposed method, the stresses due to polymerization may cause cracks on the composite/composite interface (in a SEM analysis (see figure 4) no cracks were noticed on the composite/composite interface) and/or the interface between the dentin and the composite polymerized in the first step. By the choice of r_0 it is possible to balance polymerization stresses in both steps. In the proposed technique the volume of the resin in the first step is much larger than the volume in the second step. Consequently, it has "good" properties of the bulk technique [13], [15]. The second layer, as shown by the experiments in this work, although small in volume, is positioned at the point where stresses are high so that its influence on the stress distribution is important.

5. Conclusion

Within the limitations of this study, it can be concluded that the use of the proposed incremental technique reduces the marginal debonding of composite restorations with respect to the bulk filling technique and two-step horizontal incremental filling technique. This reduction is connected with the stress reduction due to the elimination of singular stress point at the center of the cavity. The model used in this work (see equation (6)) predicts this reduction, since:

$$\frac{(T_0)_{\text{Group 3}}}{(T_0)_{\substack{\text{Group 1}\\ \text{Group 2}}}} = \frac{R(1-\nu)}{R(1-\nu)+2\dfrac{Rr_0^2}{R^2-r_0^2}} < 1. \tag{7}$$

Acknowledgement

This research was supported by the Ministry of Science Grant No. 174005.

References

[1] ANDERS A., PEUTZFELDT A., van DIJKEN J.W.V., *Effect of power density of curing unit, exposure duration, and light guide distance on composite depth of cure*, Clin. Oral. Invest., 2005, 9(2), 71–76.

[2] ARAVAMUDHAN K., RAKOWSKI D., FAN P.L., *Variation of depth cure and intensity with distance using LED curing lights*, Dent. Mater., 2006, 22(11), 988–994.

[3] ATANACKOVIC T.M., GURAN A., *Theory of elasticity for scientists and engineers*, Birkhauser, Boston, 2000.

[4] BARDWELL S., DELIPERI D.N., *An alternative method to reduce polymerization shrinkage in direct posterior composite restorations*, J. Am. Dent. Assoc., 2002, 133(10), 1387–1398.

[5] BRAGA R.R., BOARO L.C., KUROE T., AZEVEDO C.L., SINGER J.M., *Influence of cavity dimensions and their derivatives (volume and 'C' factor) on shrinkage stress development and microleakage of composite restorations*, Dent. Mater., 2006, 22(9), 818–823.

[6] BRAGA R.R., FERRACANE J.L., *Contraction stress related to degree of conversion and reaction kinetics*, J. Dent. Res., 2002, 81(2), 114–118.

[7] CHARTON C., COLON P., PLA F., *Shrinkage stress in light-cured composite resins: Influence of material and photoactivation mode*, Dent. Mater., 2007, 23(8), 911–920.

[8] CHOI K.K., RYU G.J., CHOI S.M., LEE M.J., PARK S.J., FERRACANE J.L., *Effects of cavity configuration on composite restoration*, Oper. Dent., 2004, 29(4), 462–469.

[9] DAVIDSON C.L., FEILZER A.J., *Polymerization shrinkage and polymerization shrinkage stress in polymer-based restoratives*, J. Dent., 1997, 25(6), 435–440.

[10] DAVIDSON C.L., DE GEE A.J., *Relaxation of polymerization contraction stresses by flow in dental composites*, J. Dent. Res., 1984, 63(2), 146–148.

[11] FERRACANE J.L., *Developing a more complete understanding of stresses produced in dental composites during polymerization*, Dent. Mater., 2005, 21(1), 36–42.

[12] FEILZER A.J., DE GEE A.J., DAVIDSON C.L., *Setting stress in composite resin in relation to configuration of the restoration*, J. Dent. Res., 1987, 66(11), 1636–1639.

[13] HUYSMANS M.C., van der VARST P.G., LAUTENSCHLAGER E.P., MONAGHAN P., *The influence of simulated clinical handling on the flexural and compressive strength of posterior composite restorative materials*, Dent. Mater., 1996, 12(2), 116–120.

[14] LINDBERG A., van DIJKEN J.W.V. HÖRSTEDT P., *In vivo interfacial adaptation of class II resin composite restorations with and without a flowable resin composite liner*, Clin. Oral. Invest., 2005, 9(2), 77–83.

[15] LOGUERCIO A.D., REIS A., BALLESTER R.Y., *Polymerization shrinkage: effects of constraint and filling technique in composite restorations*, Dent. Mater., 2004, 20(3), 236–243.

[16] MILEWSKI G., HILLE A., *Experimental strength analysis of orthodontic extrusion of human anterior teeth*, Acta of Bioengineering and Biomechanics, 2012, 14(1), 15–21.

[17] MILEWSKI G., *Numerical and experimental analysis of effort of human tooth hard tissues in terms of proper occlusal loadings*, Acta of Bioengineering and Biomechanics, 2005, 7(1), 47–59.

[18] PETROVIC Lj., DROBAC M., STOJANAC I., ATANACKOVIC T., *A method of improving marginal adaptation by elimination of singular stress point in composite restorations during resin photo-polymerization*, Dent. Mater., 2010, 26(5), 449–455.

[19] PARK J., CHANG J., FERRACANE J., LEE I-B., *How should composite be layered to reduce shrinkage stress: incremental or bulk filling?* Dent. Mater., 2008, 24(11), 1501–1505.

[20] PETROVIC L.M., ATANACKOVIC T.M., *A model for shrinkage strain in photo polymerization of dental composites*, Dent. Mater., 2008, 24(4), 556–560.

[21] REIS A.F., GIANNINI M., AMBROSANO B.G.M., CHAN D.C.N., *The effects of filling techniques and a low-viscosity composite liner on bond strength to class II cavities*, J. Dent., 2003, 31(1), 59–66.

[22] TAKAHASHI H., FINGER W.J., WEGNER K., LUTTERODT A., KOMATSU M., WÖSTMANN B., BALKENHOL M., *Factors influencing marginal cavity adaptation of nanofiller containing resin composite restorations*, Dent. Mater., 2010, 26(12), 1166–1175.

[23] WU X., SUN Y., XIE W., LIU Y., SONG X., *Development of novel dental nanocomposites reinforced with polyhedral oligomeric silsesquioxane (POSS)*, Dent. Mater., 2010, 26 (5), 456–462.

[24] WEI Y.-J., SILIKAS N., ZHANG Z.-T., WATTS D.C., *Hygroscopic dimensional changes of self-adhering and new resin-matrix composites during water sorption/desorption cycles*, Dent. Mater., 2011, 27(3), 259–266.

[25] WATTS D.C., SATTERTHWAITE J.D., *Axial shrinkage-stress depends upon both C-factor and composite mass*, Dent. Mater, 2008, 24(1), 1–8.