Original scientific papers UDK 616.314.5:615.242–07
doi:10.5767/anurs.cmat.110201.en.062M

BOND STRENGTH COMPARISON OF THREE CORE BUILD-UP MATERIALS USED TO RESTORE MAXILLARY INCISOR TEETH

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Abstract: The aims of this study were to examine the ultimate strength of the restored maxillary incisors with composite resin, dental amalgam and glassionomer cement as a transitional restoration. Fifty-six extracted human maxillary central incisors with intact and carious dentin were used. The control group consisted of eight unrestored teeth with intact dentin. Artificial defect in dentin was up to the half of the anatomic crown of the tooth. After core build-up procedure, each root of every specimen was mounted in autopolymerizing acrylic resin blocks which were stored in distilled water at 37°C one day before testing. Then it was placed in a specially adapted jig at an angle of 130 degrees to labio-palatal axis and subjected to a controlled load that was recorded in a universal testing machine at a crosshead speed of 1 mm per minute until failure occurred. There were no significant differences among control group and restored teeth with composite resin and dental amalgam with intact dentin ($p<0.05$). In the group with carious-affected dentin, there were no differences among restorative materials and the values were statistically significantly lower in comparison to the control group. Based on the date obtained, we concluded that the highest overall strength of restored incisors with intact dentin, when 50 per cent of the coronal part of the tooth is missing, was achieved by using composite resin and dental amalgam as a transitional restoration and as a core build-up material. The caries-affected dentin led to lower bond strength of restored teeth. Also it has been concluded that composite resin has the best bond and tensional strength ratio.

Keywords: bond strength, composite resin, core build-up, dental amalgam, glass ionomer cements, transitional restoration.

INTRODUCTION

A core build-up is a restoration placed in a severely damaged tooth in order to restore the bulk of the coronal portion of the tooth [1]. It is suggested that the placement of a core is needed when more than 50 per cent of the coronal part of the tooth is missing [2]. A core is defined as a part of preparation for an indirect restoration consisting of restorative material [3]. Cores provide retention and resistance form for crowns [4,5]. Cores also act as transitional restorations before crown preparation [4].

Strength is only one of the criteria for the selection of core material, but it is a crucial one. Stronger core materials better resist deformation and fracture, provide more equitable stress distributions, and reduce probability of tensile and compressive failure, greater stability and greater probability of clinical success. Compressive strength is considered to be a critical indicator of success because high compressive strength is necessary to resist masticatory and parafunctional forces [6].

Restorative materials commonly used as core materials are silver amalgam, glass ionomer cement, glass ionomer cermet, autocured titanium containing composite resin, resin-modified glass ionomer cement and light-polymerized hybrid composite resin [6]. Most of these materials were not specifically developed for this purpose, but as a consequence of their properties, have found application in core build-up procedures [1].

Several studies were undertaken to measure mechanical properties of direct core build-up materials such as: compressive strength [1,6,7], diametrical tensile strength [1,6], elastic modulus [1], flexural strength [1], shear bond strength [8]. Tirado et al. [5]

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showed the effect of thermal cycling on the fracture toughness and hardness of five core build-up materials. The clinical performance of two adhesively retained composite resin core materials were evaluated in vivo study and compared with metal-added glass ionomer cement [9]. Burke et al. [10] examined fracture resistance of core materials with and without crown preparation in an in vitro study.

Amalgam has traditionally been used as the best core build-up material [3,4], although there are some disadvantages [3,9]. Several properties of glass-ionomer cements [5,11] make these materials attractive for using in practice [5,12–15]. There are many well-known advantages of using composite resins as core build-up materials [3,4,8,9,16]. Composite resin also have some disadvantages, some of which include: high technique sensitiveness [3], difficulties in distinguishing tooth from core during preparation, dentine bond can be ruptured by polymerization contraction [3,17–20].

Most clinical adhesive procedures involve altered forms of dentin, such as sclerotic or caries-affected dentin [21–25]. It has been demonstrated that micro hardness measurements correlate well with the degree of mineralization. Namely, micro hardness is significantly lower in caries-affected dentin [21,25]. In the operative treatment of carious lesions in dentin, the morphology and nature of prepared dentin surface influences bonding of adhesive restorative materials [22,25].

The purposes of this study were to examine the ultimate strength of restored maxillary incisors with different restorative materials and the ability of core build-up materials to perform as transitional restoratives. The following hypotheses were tested: (1) Bond strength depends on the restorative material used, such as composite resin, dental amalgam and glass ionomer cements; (2) Bond strength depends on the quality of dentin (intact and carious-affected); and (3) After the initial separation of restoration, the process of bending deformation is started [26]. Further separation process depends on the ratio of tensile and compressive strength of restoration. While the first [1,4–7, 9, 11, 27] and the second [23–25] statements have already been tested, the third hypothesis presented in this study is new.

MATERIAL AND METHODS

A total of 56 extracted human maxillary central incisors had been collected. The teeth belonged to patients from 30 to 60 years old. The experimental group consisted of 32 teeth with intact dentin and 24 teeth with carious dentin. The extracted teeth were cleaned and stored in distilled water at 4°C [28,29] up to 3 months [30]. Each group of core materials (composite resin, dental amalgam and glass-ionomer cements) was used on eight experimental teeth with normal dentin and on eight teeth with caries-affected dentin. Group division of the specimen is shown in Table 1. The sample was composed of teeth with an average length of 23 ± 1 mm. Artificial defect in dentin was made by tungsten carbide bur (n. H245; Bassler USA, Savannah, Ga) and a water-cooled high-speed hand piece (Midwest 8000i; Dentsply Professional Division, York, Pa). Part of dentin was removed up to the half of the anatomic crown of the tooth. The value of the artificial defect was in the inciso-cervical direction 7 ± 0.5 mm, in mesio-distal 3.5 ± 0.3 mm, and in labio-palatal direction measured at the floor of the defect 7 mm ± 0.5 mm. The defect was located in the proximal part of the tooth crown (Figure 1). In all situations, two walls of tooth remained preserved. Caries was removed with round burs in a low-speed contra-angle hand piece (40.000). The caries- affected dentin characteristics after preparation are: discolored, harder than removed dentin and stained pink.

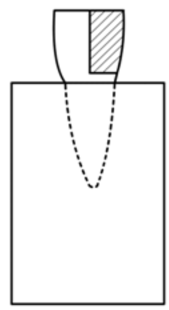

Figure 1. Diagram of tooth preparation and restoration

Core build-up was done following the placement of matrix band around the incisor. The core materials used in this study included reinforced glass-ionomer cements (Argion; Voco, Cuxhaven, Germany), hybrid light polymerized composite resin (Admira; Voco, Cuxhaven, Germany) and dental amalgam (Ekstrakap-D III; ICN Galenika, RS). All materials were used precisely according to the manufacturer's instructions as described for core materials.

A parallelometer (Parascop; Bego, Bremen, Germany) was used to align the restored teeth in the block. The experimental teeth were mounted in autopolymerizing acrylic resin blocks (4 x 2.5 x 2.5 mm) 2 mm below cementoenamel junction and stored in distilled water at 37^{o} C one day before testing. For the purpose of testing each specimen was first placed and secured in a specially adapted jig.

Table 1. Group division of specimen according to the type of restorative materials and quality of dentin

Incisors	Composite resin	Dental amalgam	Glass-ionomer cements	Control group	Total
Intact dentin	8	8	8	8	32
Carious-affected dentin	8	8	8	0	24
Total	16	16	16	8	56

The angle of the load for incisors was 130 degrees to the long axis of the tooth. It simulates the range of angles (130-135 degrees) which made axis of maxillary and mandibulary central incisors as in dentoalveolar class I.[21-23] The angle between maxillary and mandibulary incisors measured from oral side is calculated in the following way: Since inclination of maxillary central incisor in labio-palatal direction is 28 degrees and inclination of mandibulary central incisor in labio-palatal direction is 22 degrees, we have: 180 – (28 +22) =130 degrees (Figure 2).

The loading was directed to the palatinal surface of the teeth. The contact location was between incisal and middle third of the tooth (2 mm apical to the incisal edge) (Figure 3) and at the point of connection between restorative material and tooth structure (Figure 4). The loading device was of conical shape with an angle of 82 degrees and with the tip radius of R=0.8 mm.

The experiment was done in the universal testing machine (model 1122; Instron Corp, Norwood, Mass) where controlled loads to the teeth at a crosshead speed of 1 mm per minute until the failure occurred were applied. The failure threshold (ultimate strength) was defined as the maximum load that specimen could withstand. The force at the fracture was noted and registered (Figure 5).

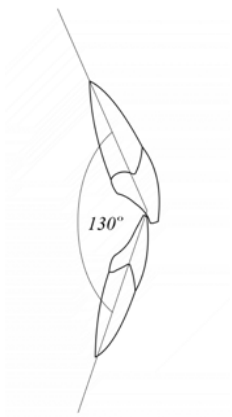

Figure 2. Angle of load for incisors

Data was numerically evaluated by using the standard descriptive and comparative statistics. The programs for calculating derived basic statistic parameters were written and executed by computer's program language Pascal. Within the descriptive statistics, for parameter's characteristics the values were set: mean values and standard deviation. In the light of comparative statistics, two-way analysis of variance (ANOVA), Holm's *t* test and Student's test were used for evaluation of the medium value (score) of attributes among the observed groups. Besides the classical analysis of variance (ANOVA), Kruskal-Wallis test of rang was done.

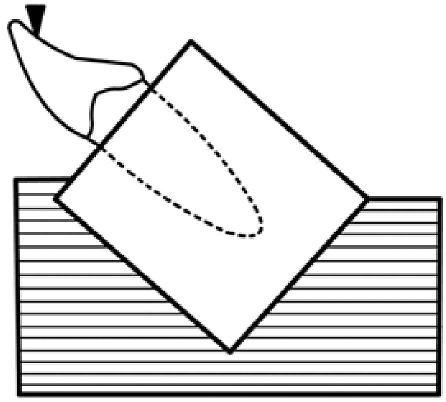

Figure 3. Proximal view of the loading

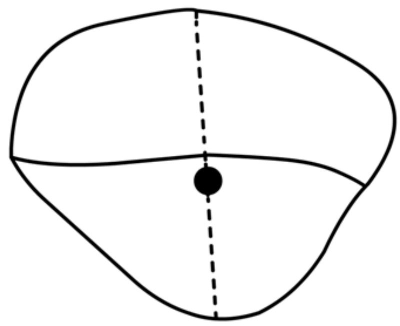

Figure 4. Occlusal view of the contact loading

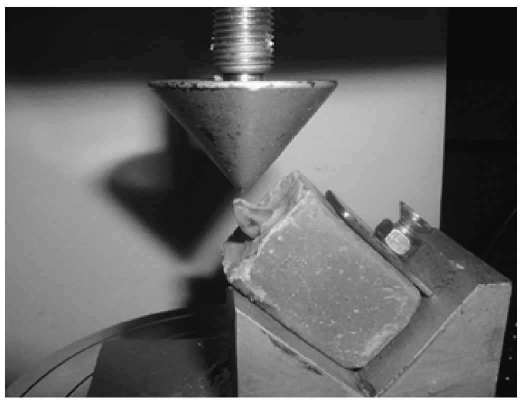

Figure 5. The procedure of loading of experimental tooth

RESULTS

As shown in Table 2, the highest value of fracture force is 260.9 N ±116.8. It is obtained in controlled group (no restoration) of intact incisors. The value obtained for the group of restored teeth with intact dentin is in the second place. The mean value of the strength ranges from 213.5 N for restored teeth with composite resin, through 209.5 N for restored teeth with amalgam, and to some lower values 163.4 N for the restored teeth with GIC.

In the group of teeth with caries-affected dentin, the values are significantly lower and they range from 158.2 N when using composite resin, through 105.9 N for GIC, to 103.6 N for amalgam. These results are shown in Table 3.

Comparing the mean values of fracture forces between the control group and the group with restored teeth, the following was performed: ANOVA analysis (F=4.06, *P*=.002) and Kruskal-Wallis test for ranges. The results obtained by those two tests are correspondent. Holm's *t* test is recommended as a first choice for the analysis of differences between groups within the analysis of variance.

Table 2. Values of fracture forces for the restored teeth with intact dentin

Force [N] $\overline{X} \pm S$	Incisors
Control	260.9 ± 116.8
Intact teeth – composite resin	213.5 ± 89.8
Intact teeth - amalgam	209.5 ± 84.4
Intact teeth - GIC	163.4 ± 59.8

Table 3. Values of fracture forces for the restored teeth with carious-affected dentin

Force [N] $\overline{X} \pm S$	Incisors
Control	260.9 ± 116.8
Carious-affected dentin – composite resin	158.2 ± 59.8
Carious-affected dentin - amalgam	103.6 ± 52.7
Carious-affected dentin - GIC	105.9 ± 81.8

The vertical axis in Figure 6 shows the values of fracture forces, while the horizontal lines among the columns show the score obtained by Holm's *t* test, where the risk *P*<.05 is marked by full line and the insignificant values are not marked at all. There are no significant differences between the control group and restored teeth with composite resin and amalgam with intact dentin. Also, there are no significant differences in values of fracture forces between restored group with composite resin and amalgam with intact dentin. In the group with the carious-affected dentin, there is no difference among restorative materials, but the values are statistically significantly lower with the control group. The fracture force corresponding to the teeth with the intact dentin restored with the GIC are significantly lower compared to the control group.

The fracture occurred between the surface of the teeth and the restoration on 54 teeth, which is 96.43 per cent. This is understood as an adhesive fracture.

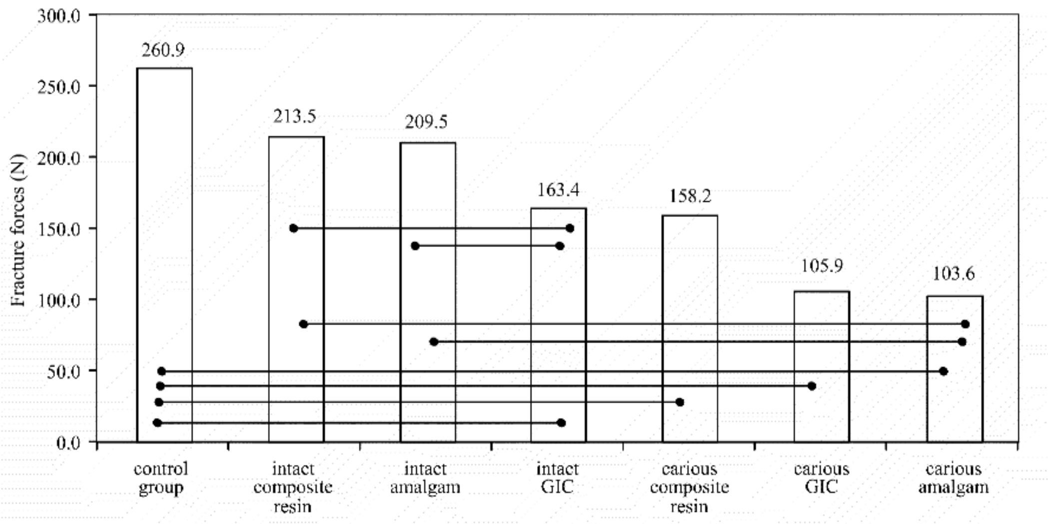

Figure 6. Values of fracture forces (N) and their correlation for the whole specimen

DISCUSSION

Studies of the structure of human dentine and evaluation of various approaches to dentine bonding require the use of extracted teeth, which should be unaltered at the time of evaluation [30]. For the purpose of this study, teeth were stored in distilled water on 4°C up to 3 months as in other experiments

[6,7,16,17,23,30], and maximally recommended time was respected.

The issue of exothermal reaction during setting acrylic resin block has appeared as a risk factor for the change of the structure of dentin during the experiment. This problem has been solved, for the purpose of this paper, in the following way: (1) the hole was made in the acrylic resin block, (2) the hole corresponded in its dimensions to average root although it was a bit looser, and (3) the hole was laid with the thin layer of acrylic resin.

Many authors measured mechanical properties of direct core materials [1,5-8,10]. Bond strength of restored teeth was measured in this study. The results of this study have shown that the material of choice for incisors with intact dentin includes hybrid composites resin and dental amalgams, and they are as strong as intact, unrestored incisors. These results are in agreement with the results of other authors [1,4-6,27]. Burke et al. [10] have concluded that teeth restored with amalgam were most fracture resistant. Combe et al. [1] measured compressive strength of three composite resin materials, glass-ionomer cement and dental amalgam. Cohen et al. [7] have showed that composite resin had statistically significantly higher fracture resistance comparing to GIC and amalgam.

The results of this study show that composite resin has the highest value of fracture force for both intact and carious-affected dentin. For additional explanation on this observation, refer to the Figure 7. The figure shows restored tooth before the failure occurred (Figure 7a) and after the failure (Figure 7b). As it can be seen in Figure 7b, after separation, the restoration is in the state of bending, since the point of application of loading is at the interface between restoration and tooth. Thus, there are two zones in it with different stresses, compression and tension, separated by the neutral surface. In all restorative materials used, the compression strength is larger than the tension strength. However, the composite resin has the best bond strength vs. tension strength ratio. Thus, it required the highest force to start separation of the restoration and once the separation started it had enough tensile strength to sustain the force. The maximal value of the tensile stress at the point *D* is given as [26]:

$$s_D = \frac{Fl}{I} h_D ,$$

whereby *F* is the loading force, *l* is the distance between the point of application of force and separation point, *I* is axial moment of inertia of the cross-section of the restoration and $\eta_D = h/2$ is the half width of the restoration. The value of σ_D must be lower than the value of tensile strength for specific material, because otherwise the separation will stop and the restoration will break. On the other hand if the bond strength σ_{Bond} is low, the restoration will separate from the tooth. In this study σ_{Bond} was relatively low. Thus, it can be concluded that in "ideal" situation, bond vs tension strength ratio of core material σ_{Bond}/σ_D must be as high as possible.

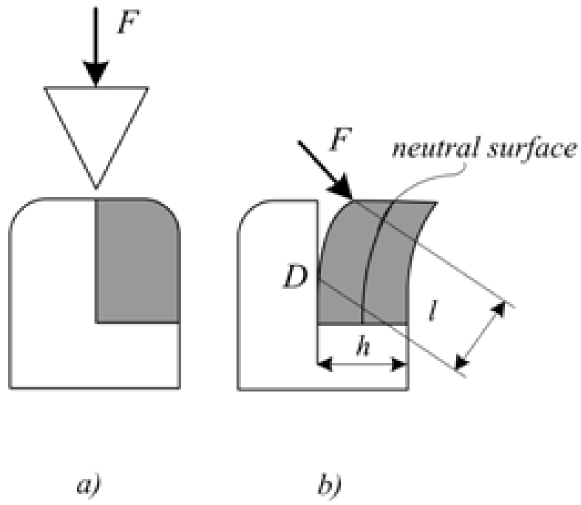

Figure 7. Loading configuration before the separation a) and after the separation b)

Results of this study indicate that restored incisors with carious-affected dentin had lower fracture resistance than the control group. The structure of dentin is very important when using the composite resin [16,23-25,29]. Caries changes the structure of dentin and that is why in this study specimens were divided into two groups. Yoshiyama et al. [23] have found that many specimens of resin-bonded caries-affected dentin failed cohesively in dentin, presumably because it was weaker than the bonding resin. This did not occur in normal dentin, where the bonds failed adhesively.

The results of this study show that the resistance of incisors restored with composite resin and amalgam which were exposed to caries was statically significantly lower than the control group.

Many researches evaluated the bonding capability of GICs to dentin [12-15]. Almost all of these studies were carried out on extracted teeth. All these in vitro studies proved the fact that the bonding of GICs to dentin is poor (weak) or nonexistent. These results could be attributed to the conditions of the experiment, that is, to the use of nonvital teeth [12].

The experiment in this study was carried out on the extracted teeth, which needed to have the same condition for all tested materials. This was a shortcoming of the study.

Gateau et al. [11] established that silver reinforced GIC had statistically higher degree of inefficiency in comparison to the amalgam and composite resin. This is identical with the findings of this paper. Adhesive type of fracturing of restored teeth happened in the majority of situations (96. 43 per cent) in this in vitro study. Stober et al. [9] also found in their in vivo study that all observed failures showed signs of adhesive fracturing, or a combination of adhesive and cohesive fracturing, respectively. Practice proved that there are many incisors damaged by caries. In literature, there is no clear position as to whether such tooth should be restored by restorative material or artificial crowns. The aim of this paper was to determine which material proved as the most suitable for the transitional restoration before crown preparation. Kovarik et al. [27] state that artificial crowns in experiments fail to determine the forces that separate between dentin and core build- up material; therefore, in this paper the loading was applied exactly between tooth and core build up material without artificial crown.

CONCLUSION

Within the frameworks of this study, it can be concluded that when 50 per cent of the coronal part of the tooth is missing, the suggested core build-up materials for incisors with intact dentin are composite resin Admira and dental amalgam Ekstrakap-D III. These materials are effective for foundation restorations in incisor teeth intended for crowning. The results of this study indicate that the optimal bond strength vs tensional strength ratio of the restorative material is achieved in composite resin. This suggests that in the situation when large (in this article 50 per cent) part of the coronal tooth is missing, bond strength should be increased and this will lead to an increase of σ_{Bond}/σ_D.

Caries affects the bond strength of the restorative material and dentin and leads to lower mechanical properties of restored teeth.

Also, experiments in this study prove that by applying the force on the restored teeth, adhesive (not cohesive) type of fracture will happen.

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ЈАЧИНА ВЕЗЕ ТРИ РЕСТАУРАТИВНА МАТЕРИЈАЛА НА ЦЕНТРАЛНИМ МАКСИЛАРНИМ ИНЦИЗИВИМА

Сажетак: Циљ ове студије је био да се провери ултимативна јачина рестаурисаних максиларних инцизива применом композита, денталних амалгама и глас-јономер цемената. У студији су коришћени екстраховани, хумани, максиларни, централни инцизиви са претходно кариозним и интактним дентином; укупно 56 зуба. Контролну групу је сачињавало осам нерестаурисаних, интакних зуба. Препарација зуба обухватала је половину анатомске круне зуба. Након рестаурације, корен зуба је заливан у акрилатне блокове и чуван у дестилованој води на 37 степени C дан пре тестирања. Узорци зуба су постављани у специјално направљене носаче под углом од 130 степени у лабио-палатиналном правцу и излагани контролисаној сили у универзалној кидалици са брзином оптерећења 1 mm у минути, све до момента лома. Резултати показују да не постоји статистички значајна разлика у сили лома између контролне групе и зуба рестаурисаних композитом и денталним амалгамима ($p < 0,05$). У групи са претходно каријесним дентином не постоје разлике између примењених материјала и вредности силе лома су статистички значајно ниже у поређењу са контролном групом. На основу добијених резултата, највише силе лома добијене су код зуба рестаурисаних композитом и денталним амалгамима са претходно интактним дентином. Зуби чији је дентин претходно био измењен каријесом имали су нижу вредност силе лома. Такође је закључено да композитна смола има најбољи однос јачине везе и вучне снаге.

Кључне речи: јачина везе, композитне смоле, надоградња круничног дела зуба, дентални амалгами, глас-јономер цементи, прелазна рестаурација зуба.