Determination of a suitable modelling technique for adhesive FRC constructions

Irina K. Lutskaya, Natalya V. Novak, Valeri P. Kavetsky

Abstract

The current problem in modern dentistry is the restoration of a complete dental arch. It is recommended to close even single-tooth gaps in all circumstances, as the loss of just one tooth can result in deformations in the dental arch, occlusal interferences, inflammatory and dystrophic changes in the periodontium and functional disorders of the masticatory muscles in the long term [2, 3, 8]. If small gaps are not treated in good time, they develop into more pronounced aesthetic defects, which have negative consequences for the patient's emotional and mental well-being [4, 6, 8]. Advances in stomatological materials have led to a considerable improvement in the minimally invasive treatment of tooth defects using adhesive, fibre-reinforced composite (FRC) constructions [1, 5, 7, 9].

However, without clear indications for determination of the type of adhesive bridge, errors and complications can also arise in the case of tooth restorations with glass fibre reinforcement.

The aim of this investigation was to increase treatment efficiency for small dental arch defects by means of specific positioning of glass fibre reinforcements when fabricating adhesive FRC constructions.

Materials and research methods

This study into the fabrication of adhesive FRC constructions employed the GrandTec glass fibre reinforcements (VOCO) and Grandio composite (VOCO).

The mathematical modelling of the stressed-deformed state (SDS) of adhesive FRC constructions in the "Tooth – Replacement Tooth" system was performed with the help of the IT centre at the Joint Institute of Mechanical Engineering of the National Academy of Sciences of Belarus (NASB) and the ANSYS finite element software (ANSYS Inc., USA). 4 finite element models of FRC constructions were created as a study subject, differing in the quantity and positioning of their glass fibre strands. Model 1 featured a vertical glass fibre strand (Fig. 1), model 2 had a horizontal glass fibre strand (Fig. 2), model 3 was equipped with two parallel, vertical glass fibre strands (Fig. 3) and model 4 had two glass fibre strands positioned perpendicular to each other (one horizontal, one vertical) (Fig. 4). Maximum values for expanding and equivalent node stresses (von Mises stresses) were used as calculation results.

Laboratory tests

The strength of the models in the "Tooth – Composite – Glass Fibre" system was determined by the destructive investigation method using displacement methods in accordance with GOST R51202-98, Section 6.3. The test was performed in Department no. 4: Material Research and Testing of the Institute of Powder Metallurgy with an Instron 1195 universal testing machine (UK).

A total of 120 sample constructions with crowns/composite restorations/glass fibre reinforcements were tested. All the samples were split into four groups: Group I had no glass fibre reinforcement, Group II included vertical glass fibres, Group III included horizontal glass fibres and Group IV contained horizontal and vertical glass fibre strands positioned in retention cavities in the abutment teeth.

Clinical tests

The clinical work was performed at the chair for general and therapeutic stomatology at the Belarusian Medical Academy of Post-Graduate Education in the period from 2008 to 2012. In total, 110 glass-fibre-reinforced adhesive constructions were produced for different dental arch areas.

Results of the mathematical modelling of the stressed-deformed state of glass-fibre-reinforced adhesive constructions

The analysis of quantitative and graphic data collected in mathematical examinations of the stressed-deformed state of glass-fibre-reinforced constructions showed that, in all cases, the highest expanding and equivalent stresses (von Mises stresses) in the composite developed at the lowest point of connection (at the tooth neck) between the central section of the replacement tooth and the molar. When only vertical stress was applied, the highest mechanical stress values were recorded in constructions with one vertical glass fibre strand (expanding stresses: 16.0 MPa; equivalent stresses:
15.1 MPa) or two vertical glass fibre strands (expanding: 13.5 MPa; equivalent: 12.7 MPa). When combined stresses were applied, the highest mechanical stress values were recorded in constructions with one glass fibre strand in different positions: vertical (expanding: 45.4 MPa; equivalent: 42.8 MPa); horizontal (expanding: 52.2 MPa; equivalent: 49.2 MPa). It was proven that constructions with two perpendicular glass fibre strands (one positioned horizontally and one vertically, model 4), the mechanical stresses occurring under vertical loading in the replacement tooth areas subjected to the highest stresses were reduced by up to 21.2 % compared with constructions with just one vertical glass fibre reinforcement (model 1) (expanding stresses from 16.0 down to 12.6 MPa and equivalent stresses from 15.1 to 11.9 MPa). In the case of combined loading, the mechanical stresses were reduced by up to 20 % (expanding stresses from 52.2 to 41.7 MPa and equivalent stresses from 49.2 to 39.4 MPa) compared with just one horizontal glass fibre strand (model 2).

Test results for adhesive bond strength

The strength was calculated using the formula $\tau cp = F/S$, where F represents the maximum stress values obtained in the laboratory tests, at which an adhesive fracture between the tooth and construction was to be expected, and S represents the values for the contact surface between the tooth and construction, as determined for the investigated models in the "Tooth – Composite – Glass Fibre" system. The analysis of the calculation results revealed that the models in Group I (no glass fibre reinforcement) displayed the lowest strength of 4.85 (0.12) MPa. A comparison of the values for the model groups revealed that the bond strengths of models in Groups II and III, which were equipped with glass fibre reinforcement (vertical and horizontal respectively), were statistically significantly higher ($p < 0,001$, t-test) compared with the bond strength of Group I models, and measured up to 9.02 (0.15) MPa. A comparison of the strength values for the models in Groups II and III revealed that there was no significant statistical difference between them ($p > 0,05$, t-test). The strength of the models in Group IV, with additional horizontal positioning of the glass fibre end pieces, was statistically significantly higher ($p < 0.001$, t-test) compared with the bond strength of the models in Groups II and III and attained 17.34 (0.06) MPa.

The comparative analysis of the loadings of adhesive FRC restorations shows that when the version with two glass fibre strands perpendicular to each other (model 4) is employed, the mechanical stresses in the regions of the FRC frameworks, which are subjected to high masticatory loads, are reduced by up to 21.2 % in comparison with the version featuring just one horizontal or vertical glass fibre strand.

The laboratory and mathematical tests conducted as well as personal clinical observations allow a differentiated determination of the production method for adhesive bridges, depending on the location of the respective defect:

- In the case of gaps in the aesthetically important **anterior region**, the recommendation is to place the glass fibre strand **vertically**, perpendicular to the alveolar margin. When the glass fibre reinforcement is positioned thus, there is sufficient space available for the sculpting at the base of the incisor and the tooth morphology.
- In the case of gaps in the **premolar region**, the recommendation is **horizontal** alignment of the glass fibre reinforcement, parallel to the alveolar margin. This allows a considerable increase in the resistance (stability) of the construction to vertical masticatory pressure.
- In the case of gaps in the **molar region**, the recommendation is to produce a reinforced construction **with two glass fibre** strands positioned either parallel or perpendicular to each other.

Reconstructive treatment

Reconstructive treatment is performed for single-tooth gaps. X-ray diagnostics with the aim of identifying individual peculiarities with regard to cavity size and position as well as the condition of the osseous tissue of the alveolar process are necessary for all patients requiring adhesive FRC restorations.

Minimal preparation of the abutment teeth was required for the fabrication of the construction, i.e., retentive surfaces were created for retention of the glass fibres. The size of the retentive surfaces is determined based on the width of the glass fibre strand. The clinical situation and the functional purpose of the adhesive bridge are important for their positioning (in particular the need to satisfy aesthetic criteria or restore masticatory function).

The reinforcing glass fibre strand (GrandTEC, VOCO) was used for fabrication of the adhesive FRC framework and a composite (Grandio, VOCO) for the veneering and luting. The glass fibre strands have good biocompatibility and better strength properties compared with systems without fillers. No special measures are required in the practice for their use. The nanohybrid restorative material Grandio has a high flexural strength and thus a high marginal stability. A low degree of polymerization shrinkage (1.6 %) and high surface hardness result in excellent marginal integrity and outstanding resistance to masticatory loading.

Case 1

In the case of a patient with a missing incisor (Fig. 5), the restoration was fabricated on the adhesive glass fibres positioned vertically, perpendicular to the alveolar margin. This made it possible to achieve the maximum contact surface between the composite and the glass fibre strand for construction of the missing tooth.

The usual working steps in the adhesive composite technique were performed when modelling the adhesive construction. The requisite material shade was selected using the shade guide. The next step was to plan the restoration, including odontometrics and odontoscopy.

The recesses for reinforcement of the glass fibre band were positioned on the approximal surfaces of the abutment teeth towards the side with the defect (Fig. 6). The height of the prepared surfaces corresponded to the width of the glass fibre reinforcement; the depth was 1-2 mm (slightly recessed into the dentine), and the length corresponded to almost the entire width of the approximal surface. The surfaces were positioned in such a way that they did not affect the incisal edge, the gingival region or the vestibular surfaces of the teeth. Sharp edges and projecting margins were smoothed with a fine-grain bur.
The length of the reinforcement was determined by positioning a thin strip of film with tweezers in such a way that its end was in close contact with the prepared surface of one of the teeth. The strip was then routed to the opposite tooth and pressed against the prepared surface. The glass fibre reinforcement was cut to size based on the determined length of the strip (Fig. 7).

The prepared surfaces were etched with etching gel (phosphoric acid), rinsed with water and blown dry briefly with a stream of oil-free air. An adhesive was then applied. The adhesive was then light-cured and covered with a layer of flowable composite (Grandio Flow, VOCO). Tweezers were used to press one end of the glass fibre strand against the prepared surface of the distal tooth from vestibular to palatal. The glass fibre strand was bent in such a way that it reached the mesial tooth. The outside of the other end of the glass fibre strand was pressed onto the approximal surface of this tooth (Fig. 8).
The embedded glass fibre strand was then light-cured in position.

The remainder of the procedure was similar to that for the fabrication of a veneer. A yellowish, opaque layer was applied in the cervical region (Fig. 9). In order to replace the missing dentine, the next step was to apply a lighter dentine material and sculpt the mamelons (Fig. 10).
The translucent and enamel shades were then applied (Fig. 11). This was followed by contouring of the macro- and microreliefs prior to the polishing and fluoridation of the abutment teeth.

Case 2

In the case of a patient with a missing premolar (Fig. 12), the glass fibre strand was positioned horizontally parallel to the alveolar margin (Fig. 13).

In terms of masticatory function, this type of construction can support higher loads – the retentive surfaces on the approximal surfaces on the side towards the defect were prepared parallel to the vertical axis of the tooth in this case.

The depth and width of the prepared surfaces corresponded to the width and thickness of the glass fibre strand; the height was determined based on the parameters of the approximal surface of the tooth.

The working steps: Isolation of the operating site with a rubber dam, preparation and creation of retentive surfaces; determination of the length of the required glass fibre strand for fabrication of the adhesive bridge; adhesive preparation (etching of retentive surfaces, rinsing with water, application of adhesive, light-curing); positioning and adaptation of the glass fibre strand in the cavity using a flowable composite, light-curing. Sculpting of the central section of the adhesive bridge (Fig. 14). Due to receding gums, a gingiva-coloured composite was used (Amaris Gingiva, VOCO) (Fig. 15-16), which imitated the gingival papillae and the gingival margin (Fig. 17-18).

Case 3

A right-angled reinforcement comprising two strand sections was planned for the FRC construction in the molar and premolar region: one strand was positioned parallel and the other perpendicular to the gingival margin (i.e., one vertical and one horizontal). This version can be seen in (Fig. 19-24). The box-shaped preparation of the cavity walls ensured the adaptation of the glass fibre strand (Fig. 19). The exact length of the strand was determined using the narrow strip of film (Fig. 20). Two strand sections were cut to the required length with scissors (Fig. 21).

Following adhesive preparation (Fig. 22), the flowable universal restorative material (Grandio Flow, VOCO) was applied to the prepared vestibular surfaces of the cavity. Tweezers were used to press one end of the strand up against the internal horizontal surface of the prepared cavity of the distal tooth and fed to the mesial tooth.

The other end of the strand was adapted to the prepared surface, parallel to the alveolar ridge (Fig. 23). Each individual section of the construction was cured separately. The stability of the construction was increased through the use of the second strand section, which we positioned perpendicular to the first section onto the vertical cavity walls and fixed in position on the prepared surfaces using a flowable composite (Fig. 24). Premolar and molar cavities were restored with light-curing composite. Opaque dentine material was applied as the main layer. The next step involved the application of the enamel shades and the sculpting of the tooth surface relief.

The construction was reinforced here with two parallel glass fibre strands, which is indicated in cases of carious cavities or restorations of molars (Fig. 25). Taking the individual tooth morphology into consideration, the retentive surfaces were then filled and the central section of the adhesive bridge fabricated. The restoration was then sculpted, cured and finished.

Conclusion

The efficacy of the treatment for individual defects in the dental arch can be increased considerably by specific positioning of the glass fibre strands, thereby ensuring the high functional and aesthetic quality of a composite restoration.

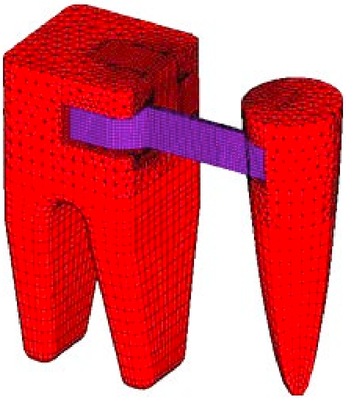

Fig. 1: Model 1: Vertical positioning of the glass fibre strand

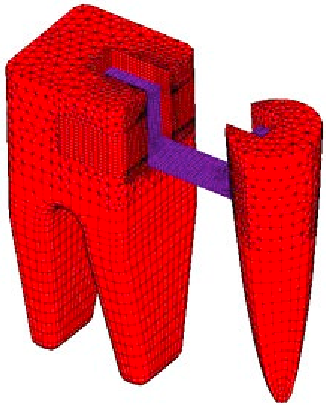

Fig. 2: Model 2: Horizontal positioning of the glass fibre strand

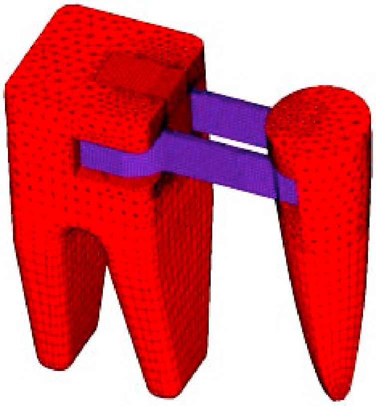

Fig. 3: Model 3: Parallel positioning of the glass fibre strands

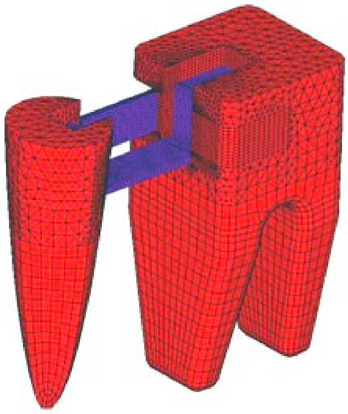

Fig. 4: Model 4: Perpendicular positioning of the glass fibre strands

Fig. 5: The gap at 21 (upper left central incisor)

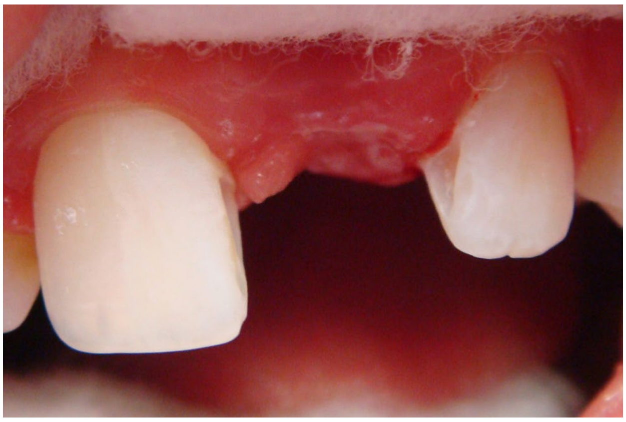

Fig. 6: Prepared retentive surfaces on the distal surface of tooth 11 (upper right central incisor) and the mesial surface of tooth 22 (upper left lateral incisor)

Fig. 7: GrandTEC glass fibre strand (VOCO)

Fig. 8: Adaptation of the strand

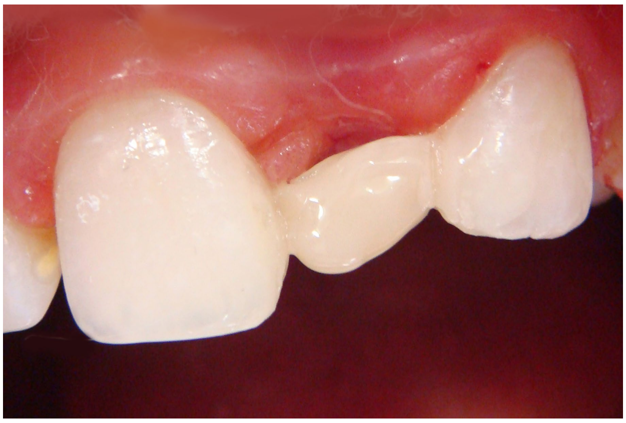

Fig. 9: A layer of opaque composite was applied to the glass fibre reinforcement

Fig. 10: Sculpting of the mamelons

Fig. 11: The tooth being replaced (21) has been completely shaped

Fig. 12: Gap at 14 (upper right first premolar) in combination with atrophy of the alveolar margin

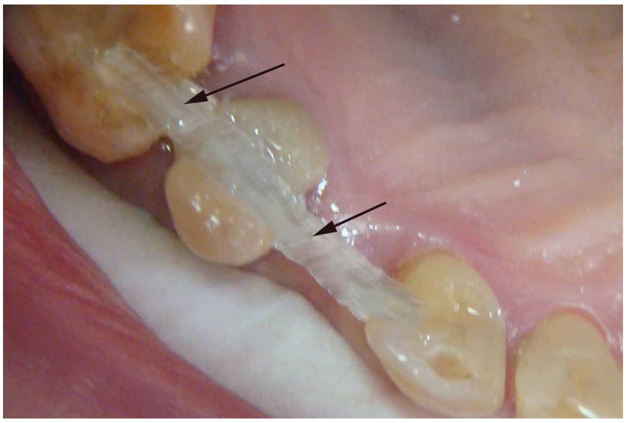

Fig. 13: The glass fibre strand was positioned on the prepared surfaces of teeth 16, 15 and 13

Fig. 14: The base of the missing tooth was sculpted using an opaquer

Fig. 15: The gingiva-coloured composite Amaris Gingiva (VOCO)

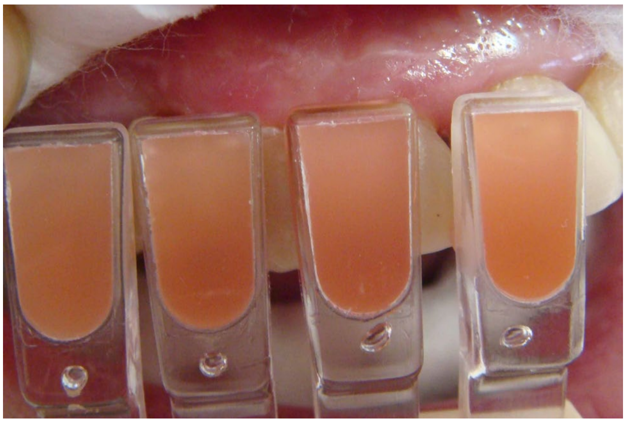

Fig. 16: The colour of the gingival margin was determined using the shade guide

Fig. 17: The tooth being replaced (14) and the gingival papilla are now sculpted

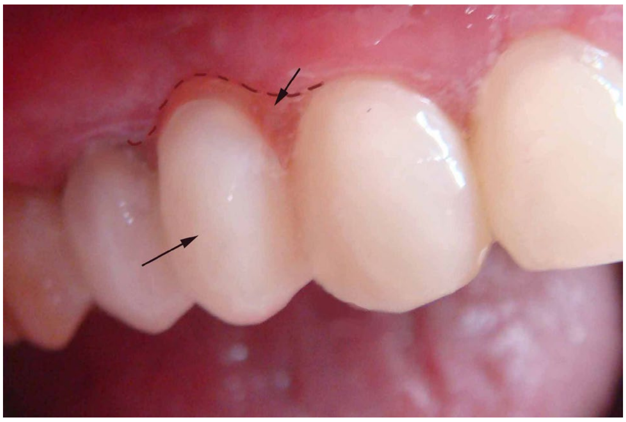

Fig. 18: The missing tooth 14 was replaced with the composite replacement tooth; the gingival margin was sculpted with gingiva-coloured composite

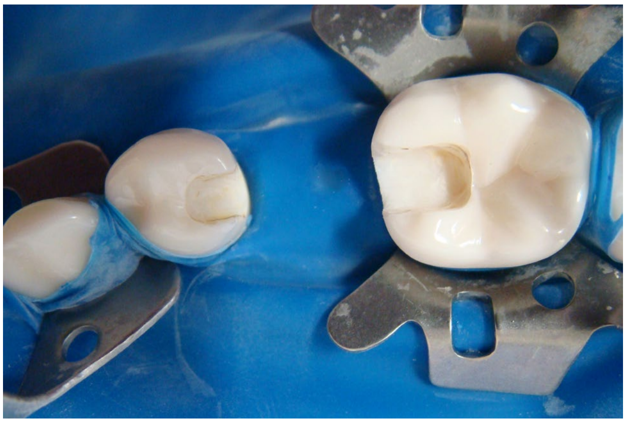

Fig. 19: Prepared retentive surfaces for positioning of the glass fibre strand

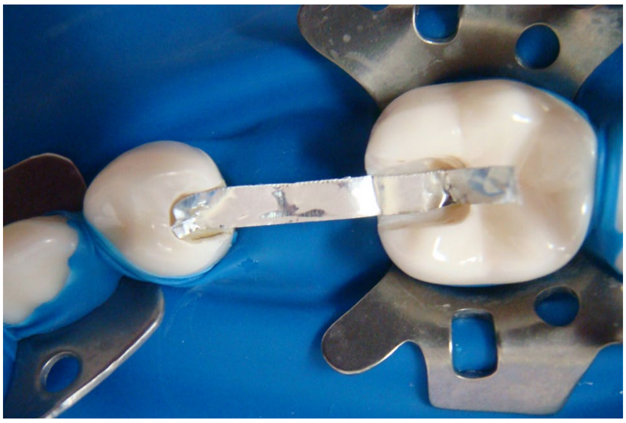

Fig. 20: Precise determination of the length of the glass fibre strand using a strip of film

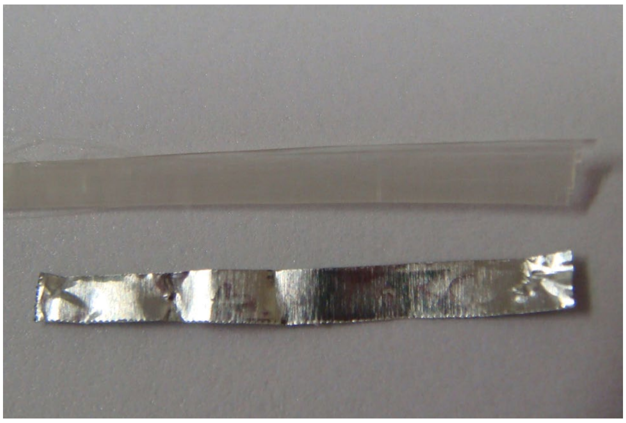

Fig. 21: The length of the strand corresponds to the length of the strip of film

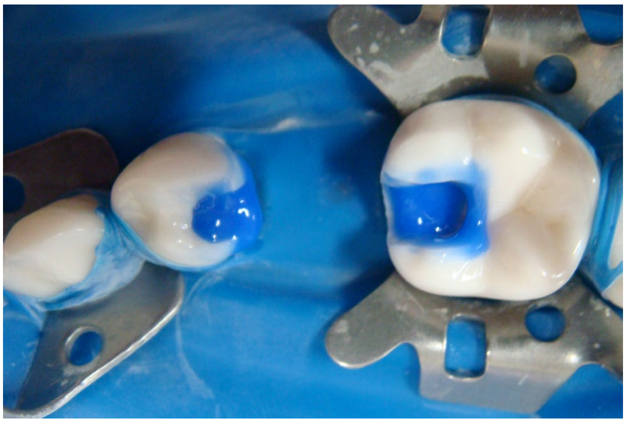

Fig. 22: Conditioning of the dental hard tissue (abutment teeth)

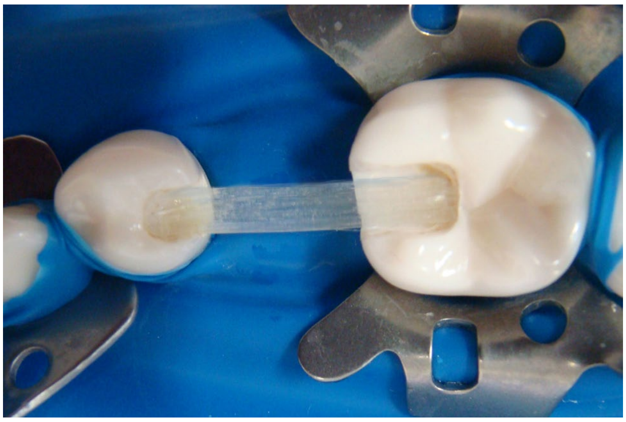

Fig. 23: Horizontal positioning of the glass fibre strand

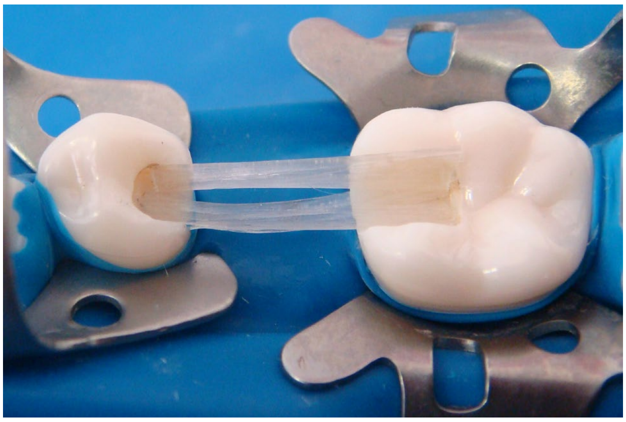

Fig. 24: Two strand sections were reinforced at right angles

Fig. 25: Adaptation of two parallel glass fibre reinforcements

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The authors

Prof. Irina K. Lutskaya, Head of the Faculty of Preventive and Conservative Dentistry at the Belarusian Medical Academy of Post-Graduate Education (BelMAPGE), Minsk

Dr. Natalya V. Novak, Assistant at the Faculty of Preventive and Conservative Dentistry at the Belarusian Medical Academy of Post-Graduate Education (BelMAPGE), Minsk

Valeri P. Kavetsky, Assistant at the Faculty of Preventive and Conservative Dentistry at the Belarusian Medical Academy of Post-Graduate Education (BelMAPGE), Minsk

E-mail: info@belmapo.by