Reinforcement of maxillary dentures with silane-treated ultra-high modulus polyethylene fibers

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Abstract: Midline fractures appear to be the most common problem in maxillary complete dentures, and they can be prevented by reinforcement of the base material. In this clinical trial, complete upper dentures made for patients having a history of midline fractures, that were reinforced with ultra-high modulus polyethylene fiber in woven form. This fiber was treated with a silane-coupling agent and sandwiched between acrylic dough. Laboratory procedures were conducted easily and conventionally, without any special equipment. At the end of 18 months, all of the dentures were well accepted and did not show any signs of fracture. (J. Oral Sci. 43, 103-107, 2001)

Key words: midline denture base fracture; maxillary denture; silane-coupling agent.

Introduction

The midline denture base fracture is one of the most common types of fracture encountered. It has been shown to result from flexural fatigue due to cyclic deformation of the base whilst in function. Hargreaves (1) stated that the physical properties of methyl methacrylate did not deteriorate with time, but clinical function induced stresses which, after a period of a few years, brought about a deterioration in the denture base material and hastened failure. During function, flexure of the denture base occurs along the midline. It has also been established that maxillary dentures were subject to bending deformation with tensile stresses occurring at the labial aspect and lingually to the incisors on the polished surfaces (2). The area lingual to the incisors is the most heavily stressed and the incisal notch represents a point of weakness in that it might act as a stress raiser and contribute to midline fracture of maxillary dentures (3). While denture bases deform under loading, this deformation may be exacerbated by other factors, such as variations in denture base contours (1), changes in supporting tissues (4,5), and tooth wear (6).

Various approaches can help to reduce the incidence of midline fracture of denture bases. Most of the fractures can be avoided by the application of the main prosthodontic principles during denture construction. Moreover, various modifications of poly (methyl methacrylate) resin have been proposed as solutions to the fracture problem, since flexural fatigue of the denture base resin has been shown to be a factor in the clinical failure of PMMA resin dentures (1,7).

Johnston et al. (8) stated that grafted PMMA resin withstood repeated flexure better than other commonly available denture base resins. Also, an improvement of the mechanical properties of PMMA can be achieved by using cross-linking agents (9). These methods are well known in plastic technology, but may produce difficulty in processing. Ease of manipulation of the reinforcing material is another critical factor from a practical view and becomes an important selection criterion. Recently, much attention has been directed to fiber incorporation into PMMA, namely, glass (10,11), carbon (12,13), kevlar (14,15) and polyethylene (16-33) fibers. Among these, ultra-high modulus polyethylene (UHMPE) fibers have become the most attractive material, because of their biocompatibility, natural appearance, chemical stability and high impact properties. On the other hand, polyethylene fiber does not
have any polar groups and has very low surface energy, which makes the adhesion between fiber and polymer weak and does not result in satisfactory flexural strength (16). Several methods of surface treatment were therefore tried, such as plasma treatment (16,17,31,32) and chemical treatments (10,20), to improve the interfacial adhesion between the fiber and denture acrylic. Results obtained from previous laboratory investigations on PE fiber filled acrylics and also clinical trials (22,26,29,30) were found to be sufficiently encouraging to construct the dentures for clinical use.

In this clinical experiment, we constructed 8 complete upper dentures for patients with a history of recurrent midline fracture. Dentures were reinforced with one layer of silane-treated woven UHMPE fiber and the effect of these reinforced materials on clinical performance were followed.

**Materials and Methods**

In the construction of complete upper dentures, standard dental techniques were applied for both clinical and laboratory procedures. The only difference from conventional laboratory techniques occurred at the stage of packing the acrylic resin as explained below. A heat-polymerized poly (methly methacrylate) was chosen as a base material (Meliodent Bayer Dental, Newbury, Berkshire, U.K.). This denture base was reinforced with one layer of woven ultra-high modulus polyethylene (UHMPE) fiber (Dyneema SK 66, DSM High-Performance Fibers, B.V. Netherlands). The relevant properties were given in a previous study (33). The UHMPE fiber was treated with a commercially available silane coupling agent (SCA) (Dynaslan VTMOEO vinyl-tris-(2-methoxyethoxy)silane, HÜLS, VEBA-GROUP CO, Germany), prior to placement in the resin.

Eight complete upper dentures were produced for patients having a history of dentures fractured along the midline. The causes of midline fractures in the complete dentures are summarized in Table 1. All of them had been fractured in the first year of use after delivery. Also, one denture was prepared in a similar way to observe fiber/resin integration. This denture had a cross section taken from the mid-palatal region and was evaluated using a scanning electron microscopy (SEM, JSM 6400, Japan).

The patients were called at regular intervals to see their clinical performance and were still under study at the end of the 18-month period. Considering the fact that the lifetime of the present dentures is about one year, an 18-month period in clinical application was rather satisfactory.

**Laboratory Procedures**

After the usual flasking and elimination of the wax base pattern, acrylic dough, prepared according to the manufacturer's recommendations was divided into two parts. The first part was placed in the upper mold and a PVC spacer (Drusoft, Dreve Dentamid, Unna, Germany), 0.3 mm thickness, was put on it. This spacer was previously shaped on the duplicate cast and suitably sized to fulfill coverage of the palatal surface extending to the labial flanges. The denture-bearing surface (cast) was covered with sodium alginate and packed with acrylic resin. By placement on a sheet of cellophane, it was attempted to divide the mass of acrylic resin into two halves of approximately equal thickness. The mold was pressed in a hydraulic press (Rucker PH, Birmingham, U.K.) and a slow closing pressure was applied to the flask and the excess resin was allowed to flow out. The flask was kept in the press for 1 minute, and then the excess material trimmed away. One layer of woven mat cut previously, with specially designed scissors (Tipo, Spesial Stahl, Solingen, Germany), in the same size and shape as the PVC protective midliner, was treated with SCA, immersed into VTMOEO silane for 1 minute and let dry for several minutes before application in the recess created by the spacer. This woven mat, that

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>Cause of fracture</th>
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<tbody>
<tr>
<td>3</td>
<td>Notably resorbed residual ridge; poor fit</td>
</tr>
<tr>
<td>3</td>
<td>Deep notching in midline labial frenium</td>
</tr>
<tr>
<td>1</td>
<td>Tooth wear; poor fit, poor occlusion</td>
</tr>
<tr>
<td>1</td>
<td>Occlusal imbalance due to torus palatinus</td>
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had a 0.3 mm thickness, was positioned in its place, and then the flask was closed and re-pressed. Processing was carried out using long-cycle polymerization, i.e. at 74°C for 6h, followed by at 100°C for 1h. Next, the flask was allowed to cool at room temperature prior to deflasking. Polishing was performed in the conventional manner. Denture base thickness at the mid-palatal region was about 2.5 mm. A resultant base is presented in Figs. 1 and 2.

Results
The pink color of the acrylic resin was not changed by the placement of fiber in it. There were no protruding fibers on the polished and fitting surfaces. The dentures were well tolerated by all of the patients, and the dentures did not demonstrate any cracks or fractures. On control visits, it was observed that the labial tissue in contact with the flanges and palatal mucosa remained comfortable and healthy, without any signs of inflammatory reactions.

SEM fractograph, as seen in Fig. 3, revealed the presence of good adhesion between the fiber and polymer matrix, when the woven mat was treated with SCA. The traces of acrylic denture that appeared on fibers showed that there existed a strong adhesion. The basis of SCA treatment was the initial hydrolysis and condensation of SCA on the fibers of the UHMPE woven mat. The reactive vinyl group was then expected to react freely with the acrylic denture material during polymerization.

Discussion
Most midline fractures can be prevented by careful attention to design and construction of dentures, particularly at the laboratory stages. On the other hand, incorporation of various fibers can provide a base material possessing better physical strength. At present, much interest has been turned to ultra-high modulus polyethylene fiber because of its properties. In this clinical trial, we placed one layer of woven mat of UHMPE fiber into denture base resin. All of these dentures were well accepted by the patients without any fracture. Use of woven mats is advantageous, because, it can be extended over the entire denture and does not spoil the natural appearance of the dentures. Furthermore, optimum thickness of the denture base in the mid-palatal region was not compromised with the use of one layer of woven mat UHMPE fiber of a 0.3 mm thickness. The laboratory procedure was not time consuming and did not require any specialized equipment. Since the woven mats were sandwiched between acrylic dough, no protruding fibers on the polished and fitting surfaces were observed. Furthermore, the examination of the mucosa positioned under the prosthesis did not show any sign of inflammation at the end of the 18-month period.

The results of many studies related to the mechanical properties of PE-reinforced PMMA are in agreement with the present finding that PE incorporation into resin enhances the impact strength (17,18,33), whereas flexural strength and moduli are not changed (19). It has been stated that chemical interaction on the surface of the fiber and PMMA provides a strong bond. When good stress transfer was realized, the adhesion between fiber and matrix, and consequently flexural strength, will be increased (16). Unfortunately, untreated PE is not a good candidate for obtaining good adhesion because of its low surface energy and poor ability to become wet. Braden et al. (17), stated that the etching of fibers by electrical plasma could promote the adhesion between fibers and PMMA. Alternatively,
interfacial adhesion can be improved by chemical means, namely, SCA treatment. In this case, as seen in Fig. 3, pretreatment of woven mat with SCA (VTMOEO) revealed that there existed an interaction between the UHMPE fiber and the acrylic. Therefore, SCA, after hydrolysis and condensation on the surfaces, is very effective at improving adhesion between them.

Finally, this system can be suggested for routine uses. This system eliminates much of the problem of denture base fracture and can maximize patient’s comfort at a low cost.

References
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