Influence of artificial aging on the fracture strength and stiffness of Targis/Vectris fixed partial dentures

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Objective: To evaluate the effect of artificial aging on the fracture strength and stiffness of fiber-reinforced composite fixed partial dentures (FPDs). **Method and Materials:** Twelve FPDs were replicated using Targis/Vectris resin composite (Ivoclar Vivadent) and randomly divided in 2 groups. Group A was artificially aged for 900 hours in a weathering machine using dry/wet cycles and 534 W/m^2 irradiations with wavelengths ranging from 300 to 800 nm. Group B (control) was stored in 100% relative humidity at 37°C ± 1°C for 900 hours. The FPDs were luted on metal abutments with Variolink II resin cement (Ivoclar Vivadent). The flexure stress was applied on the pontic at a descending speed of 1.0 mm/min until complete failure. Fracture strength, stiffness, and number of cracks produced on the FPDs were statistically analyzed. **Results**: Targis veneering material in the control group fractured at a mean of 913 ± 130 N, whereas in the aged group it failed at a mean of 722 ± 154 N (P = .042). The mean fracture load of aged FPD frameworks was slightly lower than that of the controls: 1,532 ± 237 N and 1,578 ± 257 N, respectively (P = .758). The stiffness at 400 N was not significantly different between the 2 groups. The number of cracks at Targis failure was higher in aged groups. **Conclusion**: Accelerated aging significantly reduced the strength of the Targis veneering composite, increasing its brittleness; however, it had no effect on the inner Vectris framework. *(Quintessence Int 2007;38:153–159)*

Key words: accelerated aging, fiber-reinforced composites, fixed partial dentures, flexural strength, metal-free restorations, polymer degradation

Vectris (Ivoclar Vivadent) and its veneering resin composite Targis (Ivoclar Vivadent) are a polymer-based, fiber-reinforced composite (FRC) system introduced in 1996 as an alternative to metal-ceramic and all-ceramic restoration materials.[1] Targis and Vectris are claimed to have the porcelain advantages of biocompatibility and esthetic appearance, along with favorable mechanical properties.[2–6] When compared with all-ceramic systems, they show similar marginal adaptation.[3,4] Other studies report less favorable data: After 3 years the survival rate was 38% for FRC crowns and 60% for FRC fixed partial dentures (FPDs),[7] which are far lower than the rates published for conventional porcelain-fused-to-metal crowns and FPDs.[8] Most of the FRC restorations exhibited signs of degradation, such as discoloration, marginal fractures, and occlusal wear.[9] Göhring

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et al[10] reported that the main failure of inlay FPDs after 5 years was veneering material delamination from the framework. Significant changes from baseline to the last recall were found for the following parameters: chipping of the veneering material, wear, surface texture, and staining. Another study on FRC FPDs reported, after 42 months, a survival rate of 75% and a functional survival rate of 93%.[11]

After accelerated aging, indirect resin composites of the new generation suffered color changes beyond a quantitative level that would be considered acceptable.[12] These changes suggest a certain chemical instability of the polymer matrix. The effect of accelerated aging on the mechanical properties of Targis/Vectris FPDs is still unknown.

Different from ceramics, dental polymer networks are not as chemically stable,[13,14] and simple water storage can modify their mechanical properties.[15,16] Water sorption through the polymer matrix produces hydrolytic effects on FRCs.[17,18] Other substances, like ethanol, can break the polymer chains.[19–21] Reduction of the material strength could lead to early failures and decay of the abutment teeth. Thus, the aim of this study was to evaluate the influence of accelerated aging on the fracture strength and stiffness of Targis/Vectris FPDs in an attempt to simulate the degradation caused by the oral environment.

METHOD AND MATERIALS

Three stainless steel casts simulating a missing first molar to be replaced with a 3-unit FPD were replicated using a computer-aided design/computer-assisted manufacture (CAD-CAM) milling technique by Ivoclar Vivadent; the minimum distance between the abutment teeth was 10.2 mm.

An impression of the abutments was made using a polyvinyl siloxane impression material (Express STD and Light Body regular set, 3M Espe) and poured with type IV hard gypsum (Fuji Rock, GC Dental). The waxup of a 3-unit FPD was made on the gypsum model to obtain an acrylic resin (Ivocron PE, Ivoclar Vivadent) prototype. Using a transparent polyvinyl siloxane impression material (Elite Transparent, Zhermack), 12 shells were fabricated starting from the prosthesis prototype. The shells allowed exact replication of 12 Targis/Vectris FPDs fabricated by a factory-trained (Ivoclar Vivadent) dental technician. A standard Vectris, vacuum-formed, fiber-weave reinforcement was used to make the framework of each FRC restoration. The Vectris frameworks were airborne-particle abraded and silanated using the Vectris Wetting Agent (Ivoclar Vivadent) to improve the bonding with the veneering composite. Targis was inserted in the transparent shells and applied on the Vectris framework. Then it was prepolymerized with a visible light–curing lamp (Targis Quick, Ivoclar Vivadent) and finally heat treated for 30 minutes at 90°C in the Targis Power Upgrade oven (Ivoclar Vivadent).

The FRC prostheses were finished and polished according to the manufacturer's instructions and stored in distilled water at 37°C ± 1°C for 21 days. Subsequently, they were randomly divided in 2 groups of 6 specimens each. The experimental group underwent the 900-hour artificial aging process according to the American Society for Testing and Materials test D2565 for accelerated aging of polymers, described by Powers et al[22] and May et al.[23] A weathering chamber (WOM Ci35, Atlas Electronic Device) was used with the following settings: 43°C constant temperature, 90% relative humidity, 534 W/m^2 radiation with wavelengths ranging from 300 to 800 nm generated by a 6,500-W xenon lamp, dry/wet cycles by means of distilled-water spray of 102 and 18 minutes, respectively. Control group specimens were hermetically stored in a glass container at 100% relative humidity at 37°C ± 1°C for 900 hours.

Before the fracture tests, all of the prostheses were luted with a dual-curing Variolink II cement (Ivoclar Vivadent) on the stainless steel models. The FPDs were luted with a force of 42 N applied with a lead cylinder block through a polyvinyl siloxane jig to evenly distribute the stress on the prostheses. The cementation and curing procedures were carried out according to the Variolink II manufacturer's instructions.

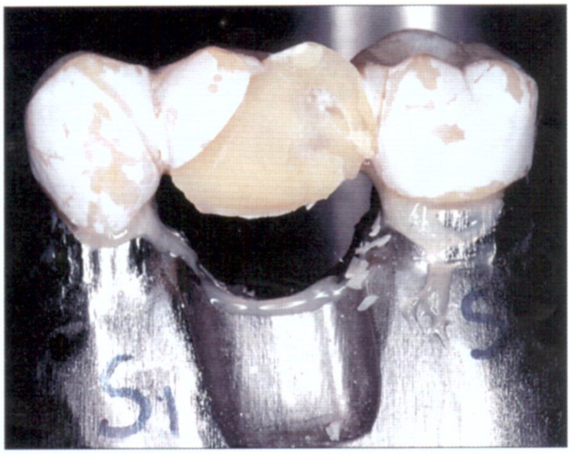

Fig 1 Targis and Vectris fractures of an aged specimen. Many cracks occurred during the flexure test. Note the dull white color of the altered resin composite surface.

Table 1 No. of macroscopic cracks observed in each specimen at Targis failure

Specimen no.	Aged group	Control group
1	9	4
2	7	3
3	8	5
4	9	5
5	10	4
6	8	4

$P < .05$ (Mann-Whitney test).

After cementation, load was applied to the specimens with a universal testing machine (Model 6021, Instron) by means of a steel beam with a radius of 5 mm placed transversally between the pontic molar cusps. The value of the force prior to the first, sudden load drop was considered the Targis fracture point. When the drop occurred, the load-displacement curve showed a peak, and the Instron machine stopped for 15 seconds to allow a rapid record of the cracks. The same operator always recorded the data. The test continued until the highest loading value was reached; this value was considered the ultimate fracture strength of the framework. The loading test was carried out at 23°C and 50% relative humidity at a descending speed of 1.0 mm/min. A similar testing method was previously used to test provisional fiber-reinforced FPDs.[24] The broken prostheses were removed from the steel casts, and the abutments were cleaned with 95% ethanol and prepared for the subsequent cementation. Each cast was used to test 4 FPDs.

The Instron machine software recorded the fracture resistance and displayed the values in N/mm curves. The stiffness of the prostheses was calculated during the fracture test using the linear deformation of the restorations when loaded with a force of 400 N. Student *t* test was used to compare the fracture resistance between the 2 groups and between the Targis and Vectris materials; Mann-Whitney test was used to compare the number of cracks. The level of significance was always set to $P < .05$. Failure pattern analysis was carried out using the scanning electron microscope (SEM) at various magnifications.

RESULTS

During the load application, the specimen failures occurred in 2 phases: *(1)* chipping and cracking of the Targis material, followed by its detachment from the fiber-reinforced framework, and *(2)* Vectris failure, which occurred later (Fig 1).

The mean forces required to fracture the Targis veneering composite were 913 ± 130 N in the control group and 722 ± 154 N in the experimental group; the difference was statistically significant ($P = .042$). Fracture of the fiber-reinforced frameworks occurred at significantly higher values: 1,578 ± 257 N and 1,532 ± 237 N for the control group and aged group, respectively. Student *t* test showed no significant difference ($P = .758$).

The number of cracks at Targis failure load (Table 1) was significantly higher in the aged group ($P < .05$). The linear deformation of the specimen at 400 N was 0.34 ± 0.046 mm and 0.31 ± 0.044 mm in the control group and aged group, respectively. Thus, the calculated stiffness was 1,186 ± 162 N/mm and 1,270 ± 181 N/mm; the difference was not statistically significant ($P = .4$).

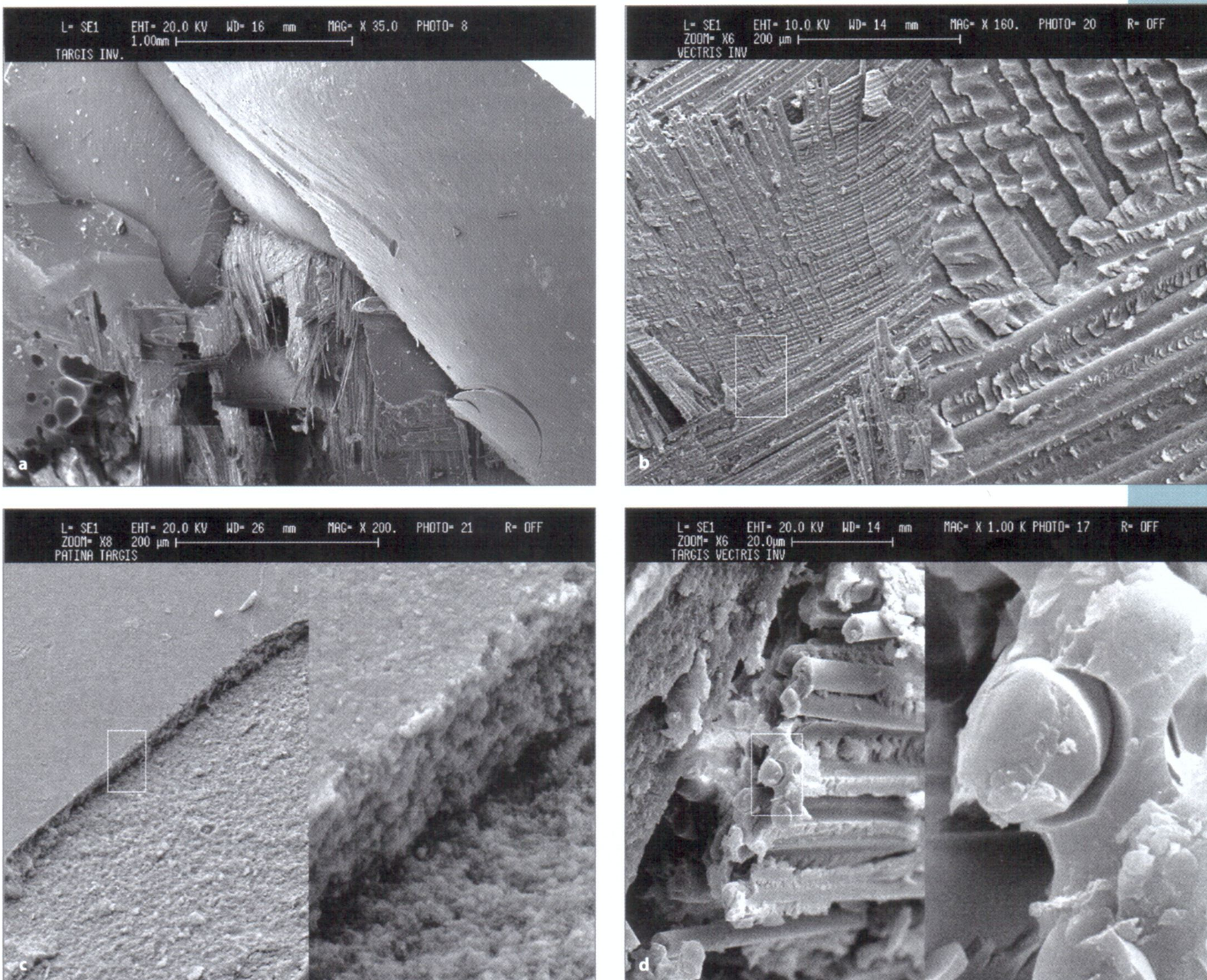

Fig 2 Scanning electron microscopy (SEM) images of some specimens. *(a)* A cohesive fracture of Targis and its delamination from the broken fiber framework. Close to the Vectris surface, the veneering composite shows some bubbles. *(b)* Vectris surface from which Targis delaminated. Notwithstanding the accelerated aging of the specimen, the adherence of the matrix to the fibers seems good. *(c)* The layer of altered Targis resin composite can be clearly seen in this SEM image. The thickness of this friable, dull white coating ranged from 20 to 30 µm. It is supposed to be composed of inorganic particles held together by highly degraded resin remains. *(d)* Broken E-glass fibers of the Vectris framework of an aged specimen.

SEM observation demonstrated that the Targis veneering composite fractured cohesively and delaminated from the framework fibers (Figs 2a and 2b). The surface color of the aged specimens changed to a dull white (see Fig 1). SEM analysis of the white areas showed a thin layer of altered composite material (Fig 2c).

DISCUSSION

The aging effect achieved in a weathering chamber greatly accelerates the degradation of resin composite caused by the constant-temperature water storage alone. Powers et al[22] reported that a weathering protocol similar to that employed in this study was thought to produce the equivalent of 1 year of clinical service in 300 hours. The artificial aging technique used ultraviolet (UV) light exposure and dry/wet cycles to simulate the degradation effect existing in the oral cavity. Although the conditions of the weathering chambers are nominally far from that of the oral environment, in the mouth there are various deteriorating factors that may act in the same way. These factors include ethanol, propionic acid, water, and saliva enzymes (hydrolases). Ethanol introduced with alcholic beverages breaks the covalent bonds in organic polymers,[19,20] acting like UV radiation.[25] An analogous effect is caused by propionic acid, a byproduct of bacterial plaque.[21,26] Water penetrates the polymer network and, in many polymer matrices, acts as a plasticizer.[15–17] The softened resin composite material is more susceptible to mechanical microcracking during mastication, resulting in enhanced wear.[27] Furthermore, water and ethanol have a hydrolytic effect on the silane bond of the filler-particle surfaces, lowering the strength[28,29] and the fracture toughness of resin composite materials.[19] Interfacial debonding may also occur at the glass fiber–resin matrix interface of FRC as a consequence of water uptake, reducing strength, stiffness, and fatigue resistance.[30,31] Water reduces the strength of E-glass fibers exposed to the moisture and subsequently could impair the polymer-fiber adhesion obtained with the silane coating.[9,17] Although, in a comparative study, Vectris showed the highest flexural strength and elastic flexural modulus after water storage,[30] all these effects should be considered when the fiber frameworks are exposed to oral fluids.

Artificial aging created a layer of altered resin composite of about 20 to 30 μm in thickness (see Fig 2c). Macroscopically, the layer was friable and could be removed with a sharp instrument. This type of surface degradation could be due to a massive alteration and loss of the Targis polymer matrix, with the remains of the ceramic filler giving a dull white color. The hypothesis is that the resin matrix was severely altered by the UV light. The influence of this surface degradation on fracture strength is unknown; however, a rough, uneven surface may act as a stress inducer, increasing the occurrence of cracks. This could explain why the highest number of cracks was recorded in aged specimens.

Unlike Targis, the Vectris fiber-reinforced framework proved to be unaffected by the aging process, showing similar fracture resistance in both groups. This finding is relevant since the strength of the framework affects the functional survival rate of the FPD.

The frameworks of the prostheses were shielded by the Targis veneering composite, which suffered the deteriorating effect of the aging process: Actually, the first Targis fracture of aged FPDs occurred at significantly lower values than in the controls. The failure patterns of veneering composite were significantly different ($P < .05$) between the groups (see Table 1): All the control specimens fractured with few cracks starting from the load application area on the pontic, whereas the aged FPDs showed more cracks, in some cases located on the crowns. This finding suggests an embrittlement of the Targis composite. A brittle veneering material is not effective to sustain the impact forces that may occur on the restoration surface, so the loss of resin composite fragments may be expected at a greater extent.

Embrittlement has been accompanied by an increase in rigidity. The force/displacement analysis at 400 N showed that the aged FPDs were stiffer than the controls, although the difference was not statistically significant. The increase of the FPDs' rigidity probably reflects molecular modifications of the resin matrix underneath the altered layer. The stiffness of a multi-unit FPD should be high to resist occlusal forces without deformation. Thus, the material stiffness was determined at 400 N since this force is about 80% of the mean value reported for maximum functional load on posterior teeth.[32]

Delamination of the veneering composite from the framework was observed in both groups as the most common Targis failure (see Figs 1, 2a, and 2b). This occurred before the framework rupture, which involved glass fibers with limited pullout from the resin (Fig 2d). In previous studies, delamination has been reported as a common failure pattern of Targis/Vectris inlay FPDs.[6,33–35] Detachment of veneering material and subsequent Vectris-fiber exposure was also observed in clinical studies,[9,10,36,37] suggesting that the interface is a stress-concentration area or a weak point of the FPD structure. Stress concentration may arise from the different mechanical properties of Targis and Vectris materials. They have different elastic moduli and different flexural strengths: Vectris Pontic, with an elastic modulus of 36 GPa and a flexural strength of 1,300 MPa, is stiffer and stronger than Targis, which has a modulus of only 12 GPa and a flexural strength of 170 to 200 MPa,[34,38] depending on the dentin or enamel material composition. Thus, the stress concentration should be compensated by a strong adhesion between the veneering composite and the fiber framework. Although a silane coupling agent (Vectris Wetting Agent) has been used to improve the adhesion between glass-fiber framework and veneering composite, it is difficult to bond Vectris and Targis to each other because the resin component of Vectris is cross-linked and highly polymerized.[39] All these considerations support the Targis failure pattern observed in this study.

CONCLUSION

This study showed that artificial aging reduced the strength of and increased the crack occurrence in the veneering material (Targis), while it did not alter the strength of the fiber-reinforced framework (Vectris). Early fractures or detachment of veneering composite may be expected as a consequence of intraoral aging. More long-term clinical studies are required prior to making clinical recommendations.

ACKNOWLEDGMENTS

The authors thank the personnel of the Quality Control Laboratory of Basell Polyolefins SpA, Ferrara, Italy, for providing the weathering and Instron machines used in this study.

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