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Effect of Ultrasonic Versus Manual Cementation on the Fracture Strength of Resin Composite Laminates

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Clinical Relevance

Indirect composite laminates, when cemented ultrasonically, resulted in repairable failures as opposed to indirect composite laminates cemented under hand pressure.

SUMMARY

This study evaluated the effect of conventional versus ultrasonic cementation techniques on the fracture strength of resin composite laminates. In addition, the failure modes were assessed. Window-type preparations 1 mm above the cemento-enamel junction were made on intact human maxillary central incisors (N=60) of similar size with a depth cutting bur. All the prepared teeth were randomly assigned to six experimental groups (10/per group). Using a highly filled polymeric material (Estenia), laminates were produced and finished. The standard thickness of laminates in original tooth form was achieved using the impression molds made prior to tooth preparation. A three-step bonding procedure and dual polymerized resin composite cement (Panavia F 2.0) was employed. The cementation surfaces of the laminates were conditioned (CoJet-Sand, 30 µm SiO_2) and silanized (ESPE-Sil). Laminates in Groups 1, 2, 3, 4 and 5 were cemented by five different operators under finger pressure and Group 6 was cemented ultrasonically (Amdent). After excess removal, the laminates were light polymerized. The specimens were stored in water at 37°C for one month prior to the fracture test (universal testing machine, 1 mm/minute). Failure types were classified as: a) Cohesive failure within the composite laminate (Type A), b) Adhesive failure between the tooth and laminate (Type B) and c) Chipping of the laminate with enamel exposure (Type C). No significant difference was found among the mean fracture strength values of the laminates in all the experimental groups (ANOVA, *p*=0.251). The mean fracture strength values in descending

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order were: 513 ± 197, 439 ± 125, 423 ± 163, 411 ± 126, 390 ± 94, 352 ± 117 N for Groups 2,5,4,3,1 and 6, respectively. The majority of failure types was Type A (30/60). While Type B failure was not observed in Group 6 (0/10), Group 1 presented a more frequent incidence of this failure (6/10). The two cementation techniques did not effect the fracture strength of composite laminates, but failure types varied between groups, being more favorable for the ultrasonically cemented group.

INTRODUCTION

Laminate-type restorations offer minimal invasive applications in dentistry. With such restorations, missing dental tissues could be restored and color and/or form of dentition could be corrected with minimal intervention, thereby, extensive, irreversible tooth reduction could be avoided. The adhesion of laminates does not rely on mechanical retention principles. Therefore, their chemical adhesion both to enamel/dentin and the inner surfaces of laminates with synthetic resins plays a significant role in the long-term durability of such restorations.

With the introduction of adhesive resins, the shortcomings of conventional cements during cementation are eliminated to a great extent. On the other hand, during adhesive cementation, certain requirements should be fulfilled. Among them, film thickness is of particular importance. Cement film thickness is dependent on several parameters, such as the viscosity, filler particle size, ambient conditions (temperature and humidity) and physicochemical interactions between the luting agents and the substrate surfaces (surface wettability or surface energy).[1] Low film thickness is desirable to seat the laminates properly and prevent possible microleakage, plaque accumulation and associated caries. Conversely, the thick cement layer may absorb more water and saliva, and consequently impair the bond strength of the resin cement at the laminate-tooth interface. The varying thickness of the cement layer also leads to uneven distribution of the chewing forces at the interface and contraction stresses of the resin during polymerization.[2]

Depending on the skills of the operator and the pressure applied at the cementation stage, the cement film thickness may differ, and this may result in inconsistent viscosities before bonding laminates. Furthermore, hand-mixed cements may also generate air incorporation. Ultrasonic techniques based on oscillation principles are meant to achieve an even thickness of cement at the tooth-restoration interface.[3] The vibration produced by a dental ultrasonic instrument may be used to alter the viscosity of resin-based luting cements during seating of the laminates. The technique requires light placement of the ultrasonic instrument against the laminate for a few seconds. The vibration of the tip passes through the restoration to the underlying material. The oscillating drive is operated at ultrasonic frequencies to produce extremely rapid microscopic strokes that are transmitted to a tip at the end of the handpiece.[4-5] Ultrasonic vibrations change the viscosity of the cement and, in turn, allow the restoration to slip into place easily. Since operator hand pressure may vary with every individual, using vibration in this manner not only reduces film-thickness and minimizes the potential leakage that may occur at the margins of the laminate,[6] but it also results in an equal spread of the resin underneath the laminate. It can be hypothesized that ultrasonic cementation may lead to better resin polymerization and improved adhesion of the laminates to the tooth.

The current study evaluated the effect of two cementation techniques, namely ultrasonic versus conventional, on the fracture strength of resin composite laminates and assessed the failure modes.

METHODS AND MATERIALS

Specimen Preparation

Sixty caries, restoration and root canal treatment-free human maxillary central incisors of similar size stored in distilled water with 0.1 percent thymol solution at room temperature were selected from a pool of recently extracted teeth. In order to determine that the enamel was free of crack lines, all the teeth were evaluated under blue light transillumination. The teeth were stored in distilled water up to three months until the experiments. The enamel surfaces were cleaned and polished using water and fluoride-free pumice (3M ESPE AG, Seefeld, Germany) with a prophylaxis brush, rinsed with water and dried using an air syringe.

Prior to preparation, an impression was taken of each tooth using a high precision condensation silicone (Zhermack, Marl, Germany) to obtain molds for creating laminate veneers of the original form and shape of the teeth. A window type of tooth preparation without incisal overlap was made with a depth cutting bur specially designed for laminate preparations (Swiss Dental Products, Intensiv SA, Grancia, Switzerland; Batch #M-9306). After 0.7 mm depth cuts were made, the preparation was finalized using a round-ended tapered diamond chamfer bur (Swiss Dental Products; Batch #: S-4180, FG-2309). The preparations ended 1 mm above the cemento-enamel junction. Smooth margins were created to prevent stress concentration zones. All the prepared teeth were randomly assigned to six experimental groups (N=60, 10/per group).

Using a highly filled polymeric material (Estenia, Kuraray Co, Kurashiki, Japan) (Shade E1), 60 indirect laminate veneers were prepared according to the manufacturer's instructions. Standard thickness of the laminates in the original form of the teeth was achieved using the impression molds made before tooth preparation. For each tooth, an individual laminate was produced. After initial light-polymerization (Demetron LC, SDS Kerr, Germany, Light intensity: 500 mW/cm^2), both light and heat-polymerization were achieved using the polymerization unit advocated by the manufacturer (Tecnomedica, Bareggio, Italy). Excess composite around the margins was removed and the laminates were finished using finishing burs (Swiss Dental Products, FG-2309) and polished (Sof-Lex discs, 3M ESPE, St Paul, MN, USA).

Cementation of the Laminate Veneers

Dual polymerized resin composite cement (Panavia F2.0, Kuraray) was used for cementation of the laminates. A three-step bonding procedure was employed to ensure good adhesion of the resin cement in case dentin was exposed. Preparation surfaces to be bonded were acid-etched with 35% H_3PO_4 (Ultra-etch, Ultradent Products Inc, USA) for 30 seconds. After rinsing with water and air-drying, primer (Quadrant Unibond Primer, Cavex, Haarlem, The Netherlands) and bonding agent (Quadrant Unibond Sealer, Cavex) were applied onto the labial surfaces of the teeth according to the manufacturer's instructions.

The cementation surfaces of the laminates were conditioned with alumina particles coated with silica (CoJet-Sand, 30 µm SiO_2, 3M ESPE, Seefeld, Germany) using a chairside air-abrasion device (Dento-Prep, RØNVIG A/S, Daugaard, Denmark) from an approximate distance of 10 mm until the surface became matte and then silanized (ESPE-Sil, 3M ESPE). Silane coupling agent was allowed to react with the surface for five minutes.

Hand-pressure from a group of clinicians was practiced on a scale and, from the group of clinicians, five operators were incorporated into the current study. The operators were not informed about the objective of the study, instead, they were instructed to apply finger pressure during cementation. Fifty composite laminates were cemented by five different operators under finger pressure (Group 1, 2, 3, 4, 5). The cement was mixed by the principal investigator (MÖ) throughout the experiment. One group (Group 6) was cemented employing the ultrasonic cementation technique based on oscillation principles (Amdent, Nynäshamn, Sweden). The tip of the cementation device was held perpendicular to the surface after seating the laminate veneer on the prepared tooth surface. Excess cement was removed from the margins using an explorer followed by a microbrush. The restoration was then light-polymerized (Demetron LC) for 40 seconds from the mesial, distal, incisal and cervical directions. Oxygen inhibition gel (Oxyguard, Kuraray) was applied around the margins of the laminates to ensure complete polymerization of the cement and it was then rinsed thoroughly.

Figure 1: *Application of the load cell to the laminate-tooth interface until fracture in a universal testing machine.*

Fracture Strength Test

Teeth that had the cemented laminate veneers were perpendicularly embedded in polymethylmethacrylate (Autoplast, Condular, Wager, Switzerland) up to their cemento-enamel junction in the middle of the plastic rings (PVC, diameter: 2 cm, height: 1 cm). The specimens were stored in water at 37°C for one month prior to the fracture test, which was performed in a universal testing machine (Zwick ROELL Z2.5MA, 18-1-3/7, Zwick, Ulm, Germany). In order to simulate the clinical situation as closely as possible, the specimens were mounted to a metal base and load was applied at 137° at a crosshead speed of 1 mm/minute from the incisal direction to the laminate-tooth interface (Figure 1).[7] The maximum force used to produce the fracture was recorded.

Failure Analysis

Following the fracture strength tests, digital photos were taken of the specimens. Using a software program (CorelDRAW 9.0, Corel Corporation and Coral Ltd, Ottawa, Canada), the failure types were determined by two calibrated operators at 20x magnification. The failure types were classified as: a) Cohesive failure within the composite laminate (Type A), b) Adhesive failure between the tooth and laminate (Type B) and c) Chipping of the laminate with enamel exposure (Type C).

Statistical Analysis

Statistical analysis was performed using the SAS System for Windows, release 8.02/2001 (Cary, NC, USA). The means of each group were analyzed by one-way analysis of variance (ANOVA). *P*-values of less than 0.05 were considered to be statistically significant in all tests.

RESULTS

No significant difference was found between the mean fracture strength of the laminates in all the experimental groups (ANOVA, $p=0.251$). The mean fracture strength values in descending order were: 513 ± 197, 439 ± 125, 423 ± 163, 411 ± 126, 390 ± 94 and 352 ± 117 N for Groups 2,5,4,3,1 and 6, respectively (Figure 2).

Failure types and distribution for each experimental group are presented in Table 1. The majority of failure types experienced in all the experimental groups was cohesive failure within the laminate in the form of chipping (Type A) (30/60). While Type B failure was not observed in Group 6 (0/10), Group 1 presented a more frequent incidence of this failure (6/10).

DISCUSSION

Although direct or indirect laminate veneers offer a minimally invasive approach to the restoration of missing dental tissue, the most frequent failures associated with indirect laminate veneers are reported to be debonding or fracture and marginal degradation at the margins.[8] This is an important clinical problem, as it relates to the longevity of such restorations. Different testing methods and difficulty in measuring chewing forces result in a wide range of bite force values. The average chewing forces in the anterior region vary between 155 N and 200 N.[9] The results of the current study exhibited mean values that exceeded these values, ranging between 352 N and 513 N, indicating that composite laminate veneers could be considered strong enough to withstand chewing forces when cemented with the two methods tested.

No perfect tooth model currently exists for conducting fracture strength studies. Natural teeth show a wide variation, depending on age, anatomy, size, shape and storage time after extraction and, therefore, can cause difficulties in standardization. However, tooth preparation made on steel or resins[10] does not simulate the actual force distribution that occurs on laminate veneers cemented onto natural teeth. Therefore, the results of the current study could not be directly compared with that of other studies. However, considering the fracture strength results obtained with conventional or ultrasonic cementation, both methods could be used for clinical applications.

In the current study, MDP-based cement (Panavia F 2.0) was used, since it has been previously reported to deliver the best microtensile bond strength results for the resin composite used (Estenia).[11] Yamaga and others also reported that resin composites containing four functional urethane methacrylates (UTMA) had both hardness and fracture toughness greater than that of two-functional urethane methacrylates (UDMA).[11] This composite is characterized by a high filler/matrix ratio of 92%, with lanthanum oxide being the main filler. Other resin cements and composite laminate materials may present different results.

Unfortunately, laminated composites have a relatively poor mechanism for absorbing energy due to local impact damage where loading is normal to the laminate planes.[12] Failure analysis of the fractured laminates showed mainly cohesive failures of the laminate restorations in the form of chipping. Clinically, this type of failure could be considered more favorable, since it allows for intraoral repair options. The cohesive type of failure within the laminate material indicates good adhesion of the laminate to either dental tissue or the cement layer. Adhesive failures, on the other hand, show the weak link between the cement/tooth and the laminate veneer. Although the incidence was low in all groups, Type B failures were not observed in Group 6. Furthermore, Type C failures, indicating chipping of the laminate and enamel, were

Table 1: *Tabulation of Failure Types and Their Distribution for Each Experimental Group*

	Type A	Type B	Type C
Group 1	4/10	6/10	0/10
Group 2	4/10	3/10	3/10
Group 3	5/10	3/10	2/10
Group 4	6/10	2/10	2/10
Group 5	6/10	1/10	3/10
Group 6	5/10	0/10	5/10
Total	30/60	15/60	15/60

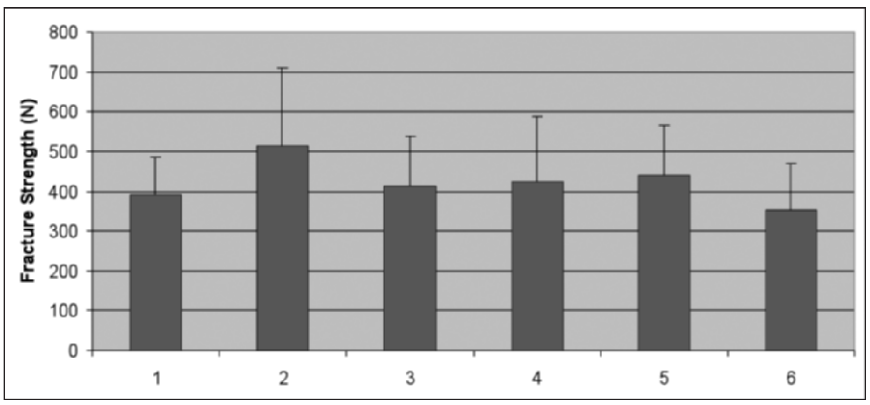

Figure 2: *The mean fracture strength (N) values for the experimental groups. Vertical lines represent the standard deviations.*

more frequently observed in Group 6. It can therefore be stated that, while ultrasonic cementation may not affect the final fracture strength of indirect composite laminates, it may affect failure types. Failure types were more favorable for the ultrasonically cemented group since, for both Type A and C failures, repair options could be an option in an attempt to prolong the service life of failed laminates. Future studies should not only report fracture strength but also the failure types of such restorations.

Unfavorable stress distribution on the adhesive layer and remaining tooth structure might potentially induce restoration failure. For both composite and/or ceramic laminates, adhesive cementation is imperative to ensure adequate bond strength between restorative material and tooth structure. An ill-fitting adhesive restoration is claimed to be the primary cause related to microleakage and recurrent caries.[13] A very thin adhesive cement layer may negatively impact the longevity of the cemented restoration. However, thick adhesive cement may also reduce support from the tooth and increase the risk of ceramic fracture. The influence of a precision fit on the microleakage of ceramic inlays showed that the variation in gap values ranging from 27 µm to 406 µm had no effect on the degree of microleakage when highly viscous resin cement was used.[14] There is no clear recommendation for the cement thickness of a bonded ceramic restoration. In a recent Finite Element study on cuspal coverage ceramic restorations, no correlation was found between cement thickness and microleakage in the remaining tooth structure.[15] The restoration types studied vary from inlays, onlays or cuspal coverage restorations, but adhesion principles remain the same. For this reason, microleakage tests were not considered, but the findings of the current study are being correlated in an ongoing clinical study in the clinics of the authors.

In a previous study, the favorable fit of inserts was found when ultrasonic tips were employed based on oscillation principles.[3] Such devices, available in the dental market, work under different amplitudes. Therefore, rheological properties of the cement at the adhesive interface may vary among different ultrasonic cementation devices. An operator's hand pressure may be difficult to define and may vary from dentist to dentist. While, in the current study, the operators presented different weights of hand pressure due to a non-significant difference between the groups in terms of fracture strength and the variations in failure types, the hypothesis may be partially rejected.

Under the influence of compressive cycle stresses, the damage associated with delamination may reduce the overall stiffness and residual strength leading to structural failure. Therefore, the behavior of laminates requires further investigation under fatigue conditions.

The specimens in the current study were stored in distilled water with thymol. Although it was previously shown that storage in thymol fixation decreases bond strength results,[17] in the current study, no significant effect was noted. Probably, when the adhesive surface area increased and the geometry became different from that of the shear bond tests,[17] especially at the bonded interface, factors such as storage conditions seemed to be less important. Furthermore, water sorption of the monomer matrix could also influence the fracture strength of laminates. In the current study, the specimens were water stored for only one month and no thermocycling was practiced. Therefore, the results represent the early clinical laminate failures not as a consequence of fatigue but as static stresses.[17]

CONCLUSIONS

The following can be concluded from the current study:

1. Hand-pressure versus ultrasonic cementation based on oscillation principles did not affect the fracture strength of resin bonded indirect composite laminates.
2. After ultrasonic cementation, failure types were more favorable.

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