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Intraoral Repair of Direct and Indirect Restorations: Procedures and Guidelines

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Clinical Relevance

This work summarizes reasons for failure, survival of repaired reconstructions, elaborates upon types and mechanisms of available surface conditioning methods, and presents operative dentists with practical guidelines for intraoral repair procedures.

SUMMARY

The service life of defective direct or indirect restorations could be prolonged by repair or relayering actions where durable adhesion of resin-based composite materials is established for longevity of repairs. The advances in adhesive technologies have introduced several surface conditioning concepts to adhere resin composites onto different restorative materials. The purpose of this report is to summarize reasons for failure, survival of repaired reconstructions, elaborate upon types and mechanisms of available surface conditioning methods, and present operative dentists with practical guidelines for intraoral repair procedures.

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INTRODUCTION

Complete replacement of failed restorations in dentistry is usually costly and time-consuming. Defective dental restorations can be replaced, but recently repair has also been recommended as a viable treatment option.[1-3] In dentistry, *repair* can be described as replacing the failed or broken part of a restoration with a new one while leaving the intact part of the restoration in place. When a restoration fails as a result of discoloration, microleakage, ditching at the margins, delamination, or simple fracture, it needs to be repaired or replaced. Partial replacement is often preferable. This can be achieved by adding a new layer of composite onto an existing one. Moreover, repair includes a limited risk for complications and reduced loss of sound tooth substance compared with complete replacement. Given that every replacement would lead to a larger preparation size, repairs could slow down the so-called restoration cycle.[4]

The advances in adhesive technologies in dentistry have not only enabled practitioners to reduce preparation size but also have increased the possibilities for repair without the need for conventional preparation for macro-mechanical retention. Intraoral repair of failed direct or indirect restorations is typically accomplished using resin-based composite materials (hereafter, composite). For adhesion of

composites to substrates other than tooth substance, a number of surface conditioning methods have been developed over the years on the basis of physical, physico-chemical, or chemical adhesion principles. Whereas in the physical conditioning methods, surface roughening is achieved using airborne particle abrasion, lasers, and etching agents such as acidulated phosphate fluoride, hydrofluoric acid, and phosphoric acid, the chemical conditioning methods involve the use of silane coupling agents and/or intermediate adhesive resins.[5-9] The overall conclusion is that the composition of the substrate is the most important determining factor in the success of the repair.

The objectives of this report are to summarize reasons for failure, survival of repaired reconstructions, elaborate upon types and mechanisms of available surface conditioning methods, and present operative dentists with practical guidelines for intraoral repair procedures.

REASONS FOR AND TYPES OF RESTORATION FAILURES ACCORDING TO CLINICAL STUDIES

Direct Restorations

In restorative dentistry, the most commonly used materials are amalgam and composite resin. In terms of clinical survival for posterior restorations, both materials show good long-term results and the mean annual failure rates vary between 1% and 3% after 10 years of service.[10-13] For amalgam and composite restorations the main reasons for failure are (secondary) caries and fracture of the restoration and tooth. However, clinical survival of dental restorations is a complex issue and does not only depend on the properties of the restorative material but also on several other clinical factors.[14] It may also be influenced by specific risk factors such as caries susceptibility,[11,13] bruxism,[15] socioeconomic status,[16] and tooth type.[13] The presence of these risk factors may increase the probability of failure up to four times.[15] It is remarkable that in many clinical trials high-risk patients are often excluded, resulting in an inclusion bias in these studies. Consequently, the outcome of clinical trials may not always be representative of the general population.

From these long-term survival data a difference in failure characteristics of large amalgam restorations and posterior composite restorations was found. Where amalgam restorations showed an increasing failure rate over a period of 12 years, composite restorations showed a more constant failure rate, especially in patients with a low caries risk.[11] In this low-risk group, the main reason for failure of an amalgam restoration was fracture of the tooth and occurrence of an incomplete fracture of the tooth (cracked tooth syndrome). On the contrary, in high-risk patients caries was more prominent as the main reason for failure and it seemed that amalgam performed somewhat better than composite in smaller-sized, three-surface restorations. Caries was more predominantly related to composite restoration than to amalgam restoration. This finding is consistent with other studies showing more secondary caries related to composite restoration compared with amalgam restoration in young patients.[17,18] The reason for this finding is still unclear and is a subject for further research.

One of the major problems with dental restorations in the long term is therefore complete or partial fracture of cusps or of the amalgam itself.[13,19] Little information is available in the literature on the incidence of cusp and restoration fractures. In two studies the incidence of cusp fractures was registered during a specific time period in general dental practices. For each new case of complete cusp fracture, the clinicians recorded information regarding location of the fracture, cause of the fracture, and restorative status prior to the cusp fractures.[20,21] Both studies found that molars more frequently experienced cusp fractures than premolars and maxillary molars presented more fractures of buccal cusps, whereas mandibular molars presented more fractures of lingual cusps. The majority of the cases had been restored on three or more surfaces; the more surfaces restored and the larger the dimensions of the preparation, the greater the risk of cusp fracture.[22] A great majority of fractures involved dentin exposure, whereas pulpal exposure occurred less frequently (<5%). Teeth with an endodontic treatment resulted more often in unfavorable fractures below the dentinoenamel junction.[20,21]

Failures of posterior composite restorations are often related to secondary caries and fracture of the restoration. However, the majority of composite restorations are placed in the anterior area. Unfortunately, very few data are available on the reasons and types of failure of anterior composite restorations. From these studies it was found that esthetics, bulk, and chip fractures were the main reason for failure in anterior restorations.[23,24]

Indirect Restorations

From a systematic review, with a mean follow-up time of 7.3 years, an annual failure rate was

reported for metal-ceramic single crowns of 0.88, resulting in estimated survival after five years of 95.7%.[25] All-ceramic crowns had an annual failure rate ranging between 0.69 and 1.96, resulting in an estimated survival rate between 90.7% and 96.6%. Various all-ceramic crowns showed different survival rates. When compared with metal-ceramic crowns early types of feldspathic/silica-based ceramics and zirconia crowns presented a statistically significant lower five-year survival of 90.6% and 91.2%, respectively. In contrast, lithium-disilicate reinforced glass ceramics (estimated five-year survival of 96.6%), glass-infiltrated alumina (estimated five-year survival of 94.6%), and densely sintered alumina (estimated five-year survival of 96.0%) were comparable to the metal-ceramics crowns.

For metal-ceramic crowns, ceramic chipping was the most frequent technical complication, with a cumulative five-year event rate of 2.6% (95% confidence interval [CI], 1.3%-5.2%). For all-ceramic crowns a tendency to more chipping of the veneering ceramic was observed for alumina and zirconia-based single crowns than for all other ceramic crowns. Fractures of the framework were rarely found with metal-ceramic crowns, whereas this was significantly more often found for all-ceramic crowns. A problem specifically found more for zirconia crowns was loss of retention.[25]

Despite the increased effort to improve the adhesion between the ceramic and the metal substrate, the published literature reveals that the reasons for failures cover a wide spectrum from thermal mismatch between the veneering ceramic and the metal framework to lack of calibration of the ceramic oven and laboratory mistakes to iatrogenic causes, or they are merely related to the inherent brittleness of the ceramics.[26] In some situations, these failures occur simply as a consequence of trauma.

All-ceramic restorations such as inlays, onlays, overlays, crowns, or fixed dental prostheses (FDPs) made of alumina or zirconia-based ceramic frameworks veneered with feldspathic porcelain are increasingly indicated in reconstructive dentistry, especially after the introduction of computer-aided design/computer-aided manufacturing technologies.

Ceramic fractures are usually due to lack of slow cooling of the furnace, anatomical support of the framework, inadequate framework-veneer proportion, inadequate firing procedures, lack of compatibility in thermal expansion coefficients of framework and veneering ceramic, fatigue, or simply trauma.[27] Failure of all-ceramic restorations (crowns, veneers, onlays, and inlays) is also related to individual risk factors. A 2.3-times greater risk of failure was found in patients with existing parafunctional habits.[28] From another study, it was also found that parafunctional habits resulted in statistically significant increased chipping of the veneering ceramic.[29]

Unfortunately, in the reports on the clinical longevity of indirect restorations, a real distinction has not always been made between success (no intervention needed) and survival (when only a repair is needed).[30] Thus, many failures such as chipping have often been considered successful, even when the chipped surface was polished.

REPAIR VS REPLACEMENT

The majority of restoration fractures occur supragingivally, indicating that in most cases repair of the fractured teeth is not difficult and can be achieved with a direct composite restoration.[31-33] When these restorations are repaired, there is minimal intervention to tooth structure compared with a total replacement. Moreover, repair is more cost-effective than replacement of the whole restoration.[34,35] Repair can be considered beneficial when it increases the longevity of dental restorations. When the first repair is not considered a failure, longevity of restorations may increase considerably, and annual failure may even decrease to less than 1%.[14,36] Hence, clinical trials should address contemplation of a repair action in reporting their results.

As for repair of direct restorations, in a systematic review, the Cochrane Collaboration evaluated the effects of repair versus replacement in the management of defective amalgam and composite restorations.[37,38] Unfortunately, no published randomized controlled clinical trial relevant to this review question could be identified. Because there is no clear consensus in the literature regarding when a failed restoration should be repaired or replaced, the best scientific evidence available is currently derived from several retrospective and prospective clinical trials and *in vitro* studies. In fact, repair is mainly indicated for localized shortcomings of the restorations that are no longer clinically acceptable. Repair is a minimally invasive approach that implies the addition of a restorative material, not only glaze or adhesive, with or without a preparation in the restoration and/or dental hard tissues.[3,5] Replacement of the restoration is indicated if multiple or severe problems and intervention needs are present

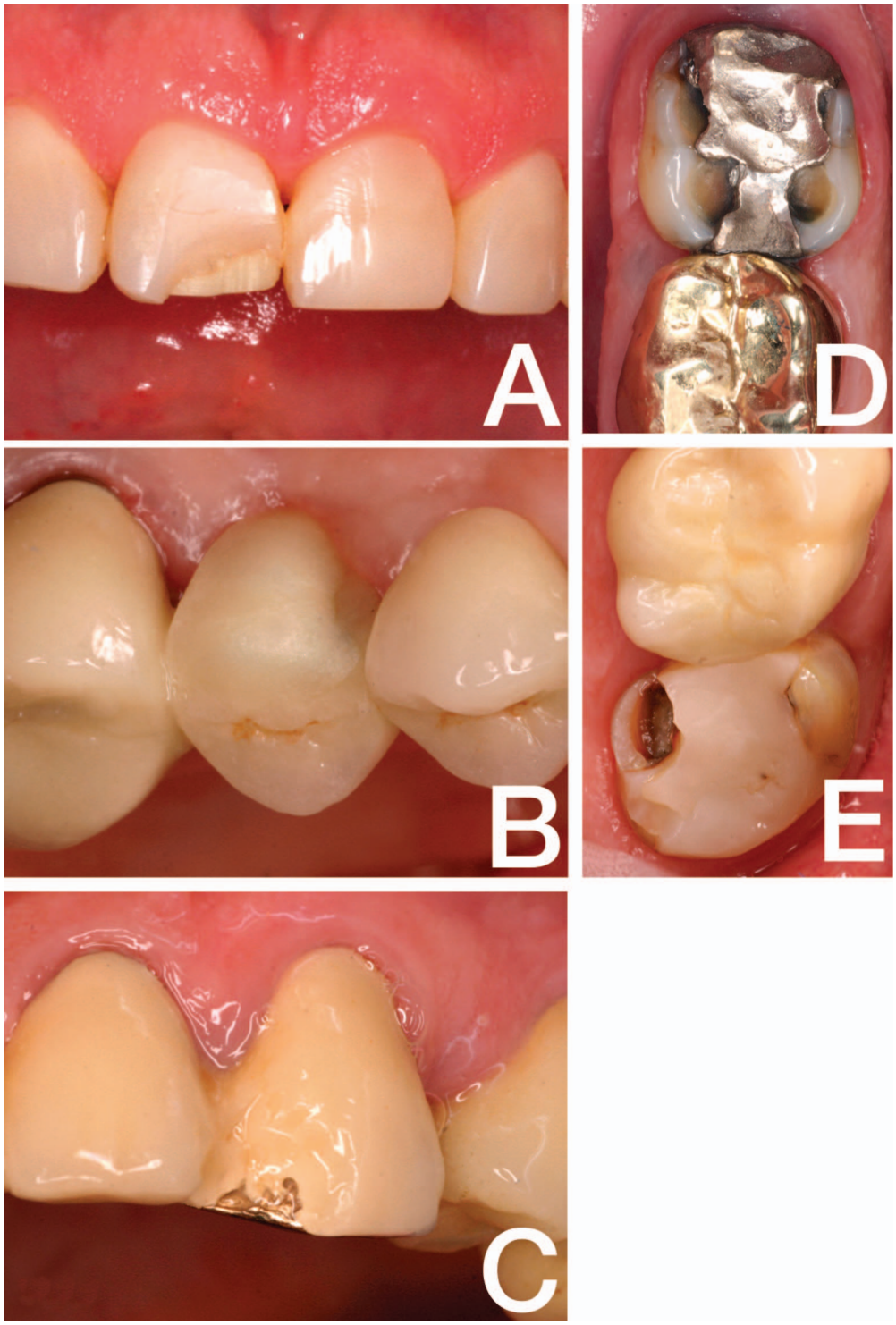

Figure 1. *(a): Cohesive failure of a composite restoration. (b): Cusp fracture next to a large composite restoration. (c): Marginal fractures next to an amalgam restoration. (d): Fracture of a metal-ceramic bridge, exposing framework. (e): Bulk fracture of the veneering ceramic on the pontic of a metal-ceramic bridge.*

and a repair option is not reasonable or feasible. Repair procedures are not always without risk because sometimes extension in the preparation is necessary, which may yield iatrogenic (pulp) damage and make the treatment complex and costly. Furthermore, little information is available for general dental practitioners on the decision when to repair or replace a failed restoration (Figure 1a-e).

Data from the Dental Practice-based Research Network (PBRN) showed that 75% of dentists are in favor of replacement and 25% in favor of repair of any kind of failed restoration.[39] The PBRN also reported factors associated with a greater likelihood of repair vs replacement: when the dentist has recently graduated from dental school, practicing in a solo or small group practice, being the dentist who placed the original restoration, when the restoration is in an older patient, when the original restorative material was not amalgam, when the restoration was in the molars, and when the old restoration contained fewer surfaces.

In a prospective longitudinal cohort study on failed amalgam restorations, repair was established as an effective alternative to replacement of restorations with marginal defects. Repair showed no significant deterioration and led to significantly lower failure rates than untreated defective restorations after a seven-year follow-up.[31] Another randomized clinical trial on the performance of repaired composite restorations over a period of 10 years showed similar results to those that were replaced, with the parameters of marginal adaptation quality, anatomy, and presence of secondary caries being similar in both groups.[32] According to the results of this study, the repair of defective composite resins as an alternative treatment to increase their longevity proved to be a safe and effective treatment in the long term.

When the results of clinical studies on repair of dental restorations are compared, it is remarkable that there is a large variation in deciding which restoration is considered to have failed—namely, in the studies of Gordan and others[31] and Fernandez and others,[32] restorations were replaced with only minor deficiencies. On the basis of modified United States Public Health Service criteria,[40] defective restorations were considered as failures when they were clinically diagnosed with secondary caries (Charlie), having marginal defects (Bravo), and/or undercontoured anatomical form-related defects (Bravo). These restorations were then either repaired or replaced. Alas, no control group was included in which no treatment was performed, and therefore the question remains whether an intervention was effective after all. On the other hand, in the study of Opdam and others,[36] restorations with large defects were included such as restoration or tooth fractures, broken cusps, or secondary caries and initial caries; the authors concluded that repairs can considerably enhance the longevity of dental restorations.

To date, clinical trials on the repair of indirect restorations are scarce. One available clinical study on repair of indirect restorations reported on the repair of metal-ceramic FDPs and their survival.[41] However, this study did not compare different repair techniques. Yet, the weakest link was found between the opaque resin and the metal that required secondary repairs.

PREREQUISITES WHEN REPAIRING A FAILED RESTORATION

For successful repair, a durable bond has to be established between the old restoration and the new repair material. Adequate surface conditioning of the substrate, selection of the adhesive resin and restorative material are therefore prerequisites. In order to provide sufficient attachment to old and aged restorations, surface conditioning may be realized by macromechanical or micromechanical retention and/or chemical adhesion. Whereas macromechanical retention can be achieved by creating retention holes, undercuts, or by simply roughening the surface with a coarse diamond bur, micromechanical retention is created by etching (eg, phosphoric acid or hydrofluoric acid) or air abrasion with alumina or alumina particles coated with silica particles. In addition, a chemical bond may be established between resin and inorganic filler particles by application of special primers such as silane coupling agents.

ACID ETCHING

Etching of substrates is typically achieved by phosphoric acid or hydrofluoric acid. Phosphoric acid is effective on enamel and dentin but has no direct effect on surface characteristics of composites, ceramics, and metals. However, etching has a beneficial effect on retention rates after repair due to a cleansing and degreasing effect on these surfaces.[7] Unlike phosphoric acid, hydrofluoric acid dissolves glass particles present in ceramics, and in most of the composites leaves the resin matrix unaffected. Because fewer inorganic filler particles are present in microfine composites, the effect of etching with hydrofluoric acid in this type of composite is particularly limited. Therefore, it is important to realize that the effect of hydrofluoric acid is largely dependent on the composition of the filler particles in the material. Composite resins containing zirconium clusters or quartz fillers, for instance, will react less upon hydrofluoric acid etching than on composite resins consisting of barium-glass fillers.[6] The diversity of resin-based restorative materials is also expressed in the variation of their filler size, morphology, amount, volume, distribution, or chemical composition, thus creating a

large variety of classification of composites. Nanohybrid composites with decreased filler size provide a larger surface area and thus a larger filler-matrix interface, being more prone to degradation through water uptake.[42] When nanohybrid composite resins were compared with microhybrid composites, a decreased stability was observed during water storage for nanohybrid composite resins.[43] The broad diversity of new materials requires the evaluation of their compatibility with respect to repairing ability. Unfortunately, often the history and type of failed composite could not be identified clinically unless it had been recorded in the patient's file.

When using hydrofluoric acid intraorally, direct contact with enamel and dentin as well as skin or mucosa should be avoided. On dentin and enamel a precipitate of calcium fluoride (CaF_2) is formed. This precipitate of CaF_2 could then prevent the infiltration of adhesive resin in the opened dentin tubuli, resulting in poor adhesion of composite to the contaminated enamel or dentin.[44-47] Contamination of the skin or mucosa with hydrofluoric acid is painless but may result in tissue necrosis in the deeper layers of the tissue.[48] To date, no side effects or negative reactions of hydrofluoric acid have been described in the dental literature.[49]

There is much uncertainty on the optimal concentration of hydrofluoric acid and the most effective duration of etching. A number of *in vitro* studies have dealt with this matter with a wide variety of materials and methods, making results difficult to compare directly.[7,50-58] Nevertheless, the general conclusion from these studies was that prolonged etching time does not necessarily result in better adhesion. Depending on the ceramic type and the composition of the glass matrix, prolonged etching time may remove dissolved glass particles from the surface, yielding to less roughness and a decreased wettability for the silane coupling agent.

AIR ABRASION

Airborne-particle abrasion is typically applied using chairside air abrasion devices for intraoral repairs operating under a pressure between two and three bars. The substrate material to be conditioned, metal, ceramic, composite, or amalgam, is abraded for approximately 10 seconds from a distance of approximately 10 mm to achieve a clean and rough surface. Prolonged duration of air abrasion may be needed for zirconia.[59] The abrasion particles consist of aluminum oxide particles with a size of 30 to 50 μm or aluminum oxide particles coated with a silicon-dioxide layer, where the latter is referred as "silicoating" or "tribochemical surface conditioning."[60] Alumina or silica particles coat the surface, which then make covalent bonds through the siloxane layer with the silane coupling agent. Given that one disadvantage of air abrasion is the aerosol with abrasive particles, a good suction device is mandatory to prevent aspiration of these particles.

SILANE COUPLING AGENTS

Following air abrasion, chemical adhesion can be established using special primers or monomers that react with the surface of a material.[61] The most common primer is a silane coupling agent that is also used in the fabrication of composites to adhere the inorganic filler particles chemically to the resin matrix. In dentistry, usually 3-methacryloxypropyltrimethoxysilane (MPS) is used, which is a bifunctional molecule. MPS silanes consist of, on one side, a methacrylate group that can react with the intermediate adhesive resin and composites, and, on the other side, a reactive silanol group that can form siloxane bonds with the alumina and/or silica present on the air-abraded or etched substrate surfaces.

Silane coupling agents are presently available in two types, either hydrolyzed or nonhydrolyzed. The hydrolyzed silanes are directly ready for use and should be applied as a separate step in the bonding procedure before the adhesive resin is applied. The nonhydrolyzed silane has to be activated first with an acid, usually an acidic monomer (ie, 10-methacryloyloxydecyl dihydrogen phosphate; 10-MDP), which is present in the primer or adhesive resin. Depending on the adhesive system, the silane coupling agent has to be mixed with the primer or adhesive resin. *In vitro* studies showed significant positive effects of the use of silane coupling agents in composite or ceramic repairs compared with those situations where no silane was used.[52,62-64]

Chemical adhesion of composites to precious and nonprecious metals could be achieved by applying special metal primers.[65] Whereas acid etching is not effective on a metal surface, air abrasion followed by metal primer application increases the adhesion significantly.[66] Some metal primers contain a 10-MDP monomer that chemically bonds to the oxides present on nonprecious metals and improves the wettability of the surface.[67,68] In addition, some metal primers also consist of the monomer 6-[N-(4-vinylbenzyl) propylamino]-1,3,5-triazine-2,4-dithione that makes a more durable chemical bond with the precious metals. These metal primers have to be applied after air abrasion, and subsequently adhesive resin is coated on the silanized/primed substrate surface.

Table 1: *Intraoral Repair Protocol for Ceramic Chipping or Fracture in Metal-ceramic Fixed Dental Prostheses*	
1	Clean both the ceramic and metal surface using fluoride-free paste or pumice
2	Remove glaze of the veneering ceramic surface at the margins to be repaired using a fine-grit diamond bur under water cooling and create a bevel
3a	Air abrade the metal surface only using a chairside air abrasion device, wash and rinse under copious water, and dry thoroughly. Then etch the ceramic margins where the repair composite will be adhered with 5% or 9.6% hydrofluoric acid (HF) for 20 to 90 s, depending on the manufacturer's instructions. Rinse for at least 60 s and dry
or	
3b	If intraoral use of HF is not desired, air abrade the ceramic surface and metal surface using a chairside air abrasion device, wash and rinse under copious water, and dry
4	Apply silane coupling agent on both the metal and the ceramic surface (one layer) and dry gently
5	If necessary, mask the metal surface with opaque resin and photopolymerize
6	Apply adhesive resin on the veneering ceramic, air dry, and photopolymerize
7	Apply resin composite incrementally, photopolymerize, finish, and polish the repair composite

Among all restorative materials, realizing a sustainable chemical bonding to zirconium dioxide remains problematic.[69] Because etching with hydrofluoric acid has little or no effect, physico-chemical conditioning with air abrasion followed by silane application containing MDP monomer has shown to be the most effective method to condition zirconium dioxide.[67-69]

Table 2: *Intraoral Repair Protocol for Chipping or Fracture in Composite Resin Restoration*	
1	Clean the composite surfaces using fluoride-free paste or pumice
2	Roughen the composite restorations at the margins to be repaired using a fine-grit diamond bur under water cooling and create a bevel
3a	Etch the composite margins where the repair composite will be adhered with 5% or 9.6% hydrofluoric acid (HF) for 20 to 90 s, depending on the manufacturer's instructions. Rinse for at least 60 s and dry
or	
3b	Air abrade the composite surface using a chairside air abrasion device, wash and rinse under copious water, and dry
4	Apply silane coupling agent on composite surface (one layer) and dry gently
5	Apply adhesive resin on the composite surface, air dry, and photopolymerize
6	Apply resin composite incrementally, photopolymerize, finish, and polish the repair composite

Table 3: *Intraoral Repair Protocol for Chipping or Fracture in Zirconia Fixed Dental Prostheses*	
1	Clean both the veneer and zirconia surface using fluoride-free paste or pumice
2	Remove glaze of the veneering ceramic surface at the margins to be repaired using a fine-grit diamond bur under water cooling and create a bevel
3a	Air abrade the zirconia surface only using a chairside air abrasion device for approximately 20 seconds, wash and rinse under copious water, and dry thoroughly. Then etch the ceramic margins where the repair composite will be adhered with 5% or 9.6% hydrofluoric acid (HF) for 20 to 90 s, depending on the manufacturer's instructions. Rinse for at least 60 s and dry
or	
3b	Air abrade both the zirconia and ceramic surface using a chairside air-abrasion device, wash and rinse under copious water, and dry
4	Apply silane coupling agent on both the zirconia and the ceramic surface (one layer) and dry gently
5	Apply adhesive resin on the zirconia and ceramic, air dry, and photopolymerize
6	Apply resin composite incrementally, photopolymerize, finish, and polish the repair composite

INTERMEDIATE ADHESIVE RESINS

Application of adhesive resin on the silanized surface increases the wettability of the composite to be used as repair material. The effect of different substrate materials for composite-composite repair varies strongly, and it is generally advisable, but not compulsory, to combine identical composite materials.[70] Unfortunately, in most clinical situations, the general practitioner does not know the composition of the failed restoration.

Adhesion to glassy matrix ceramics is well established by hydrofluoric acid etching, silanization, and adhesive resin application. Identical results for the repair of indirect composite restorations were found in which the use of airborne particle abrasion followed by a silane coupling agent adhesive resin resulted in the best surface conditioning.[53,71-74]

CLINICAL GUIDELINES AND PROTOCOLS

All kinds of repairs independent of the material type should start with careful examination and elimination of premature contacts. Because clean surfaces are essential for adequate adhesion, the substrate surfaces need to be cleaned with fluoride-free prophylaxis paste prior to conditioning procedures. Thereafter, the appropriate physico-chemical surface conditioning method should be applied to the corresponding substrate type. In Tables 1–4 different intraoral repair protocols are presented to help the general practitioner choose the optimal repair procedure.

Table 4:	*Intraoral Repair Protocol for Repair in Case of Multiple Substrates in Cervical Recessions Adjacent to Ceramic*
1	Clean the surfaces using fluoride-free paste or pumice
2	Roughen the tooth surface (dentin or enamel) and restoration(s) at the margins to be repaired using a fine-grit diamond bur under water cooling and create a bevel on the restoration(s)
3	First etch the tooth surface with phosphoric acid for 20 s, rinse, and dry. To protect tooth substrate, apply adhesive on the tooth surface, air dry, and photopolymerize. Then apply a thin layer of resin composite
4	Roughen the restoration(s) at the margins to remove possible excess of adhesive and/or composite resin using a fine-grit diamond bur under water cooling
5a	Etch the restoration margin(s) (including composite layer of step 3) where the repair composite will be adhered with 5% or 9.6% hydrofluoric acid (HF) for 20 to 90 s, depending on the manufacturer's instructions Rinse for at least 60 s and dry
or	
5b	Air abrade the restoration surface(s) (including composite layer of step 3) a using chairside air abrasion device, wash and rinse under copious water, and dry
6	Apply silane coupling agent on all restorations surfaces (including over composite first layer of step 3; one layer) and dry gently
7	Apply adhesive resin on the restoration surfaces, air dry, and photopolymerize
8	Apply resin composite incrementally, photopolymerize, finish, and polish the repair composite

CONCLUDING REMARKS

Repair of restorations that fail for technical reasons or due to fatigue could certainly prolong the survival of functioning restorations. When repair actions are contemplated, the least minimally invasive and most cost-effective method has to be practiced. Some minor defects around margins such as minor discoloration or ditching may not result in impaired function, and thus such failures could be only monitored instead of repaired or replaced.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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