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Aim and Scope

Operative Dentistry publishes articles that advance the practice of operative dentistry. The scope of the journal includes conservation and restoration of teeth; the scientific foundation of operative dental therapy; dental materials; dental education; and the social, political, and economic aspects of dental practice. Review papers, book reviews, letters and classified ads for faculty positions are also published.

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"Bridging the Gap". This cover, manipulated from a US Government World Map, is meant to bring to mind the struggle of the profession to find common ground amid the geo-political and economic struggles faced by states and regions. Image provided by Kevin Matis of Indianapolis, IN USA. Image manipulated in Adobe Photoshop CC from a 2005 US Government Map in the public domain.

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Editorial

The Use of Direct Composite

Jeffrey A Platt DDS, MS

Welcome to Supplement 7 of Operative Dentistry! I am excited to share this additional information for subscribers–especially when one considers that Supplement 6 was published nearly 15 years ago. Historically, the publishing of supplements was an expensive enterprise requiring additional sponsorship. With the transition to electronic submissions and the option of online only publication, this supplement is being offered online to our subscribers only. If you should desire to obtain a printed copy of Supplement 7 (for a reasonable fee to cover printing and postage), please contact our editorial office.

In an effort to highlight the work being done by European clinicians and scientists in the area of Operative Dentistry, this supplement focuses on the information presented at the 2014 Academy of Operative Dentistry European Section meeting held in Edinburgh, Scotland. The challenges that our European colleagues face in the provision of care are somewhat different from what we currently face in the United States. I believe it is extremely valuable for all of us to have open communication and to learn from each other through the treatment choices made in different cultures with various reimbursement and legal environments. At my request, Drs. Niek Opdam and Reinhard Hickel responded and graciously agreed to be guest editors of this supplemental issue.

Having taught Dental Materials for the past 27 years, I find it amazing that, purely from a materials perspective, if I needed to have a posterior restoration placed in my mouth today, I would prefer a gold restoration—the same as I would have chosen decades ago. But, honestly, how many gold restorations have I placed during my 31 years of practice? As one might guess, this number is small in relation to the number of dental amalgam restorations that were placed during the same time. How can it be that an inferior material essentially eliminated the use of a far superior material?! Although, the significantly decreased cost of dental amalgam was a primary factor, the technical ability of the dentist (who may have graduated last in the class) to successfully place the material was also a factor. Regardless of the reasons, the fact remains that an inferior material became the standard of care for the restoration of missing tooth structure.

What about today? The pressures are strangely different. They are shaped not just by economic pressure nor technique sensitivity concerns. Rather, in addition to environmental and occupational health concerns, the choice of restorative material is also driven by esthetic pressures.

For two weeks last summer, Indiana University School of Dentistry sent students to provide dental care in United States Federally Qualified Health Centers (FQHC). Our students also run a Student Outreach Clinic in an inner-city Indianapolis FQHC. All of these facilities treat low-income, uninsured individuals; the portion of the population with the highest incidence of dental caries. And, many of these FQHCs no longer allow dental amalgam to be placed. What is a student to do when they have been taught that dental amalgam is what should be used for direct restorations when placing large posterior restorations?

Gold or amalgam? Amalgam or resin composite? From a materials perspective, it may seem as though our profession is sliding down a slope in a bad way. Although there are a few places where the economics still seem to be of primary influence (eg. the U.S. military), the reality is that pressures are moving all of us away from dental amalgam restorations and towards the placement of direct resin restorations.

Much of the data comparing dental amalgam to resin composite which has been generated over recent decades has focused on the longevity of the individual restoration. And, historically, this has been a good measure of success. However, the growth in understanding of adhesive dentistry and how to use composite materials is changing the way we should evaluate the success of resin composites.

In my opinion, the Academy of Operative Dentistry European Section stands out as having a greater

understanding than anyone else of how to use resin composite to successfully manage dental caries in the world's population. After significant effort over several months, Drs. Opdam and Hickel have assembled this interesting and thought provoking group of articles contained in Supplement 7. I am very grateful and indebted to them for their willingness to undertake this challenging task.

May this supplement help stimulate thinking, broaden perspectives, and help us all tackle the pressures which dentistry is facing in our day. Enjoy!

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Guest Editorial

Operative Dentistry in a Changing Dental Health Care Environment

NJM Opdam • R Hickel

INTRODUCTION

A century ago, GV Black introduced his principles in operative dentistry and most of the dentists who had graduated before the end of the 20th century had been educated according to this work. However, changes in health care and patient status and behavior enabled development from this traditional type of operative dentistry.

The introduction of adhesive techniques has brought a major shift in the concepts of operative dentistry. Additionally, the possibilities of working in a minimally invasive fashion when restoring a tooth or even of utilizing noninvasive interventions can allow practitioners to overcome the disadvantages of traditional restorative dentistry, such as the high biological price that is paid for such restorations in terms of increased loss of tooth structure and, in turn, the higher risk of pulpal complications. Because the desire for placing lifelong, lasting restorations is a goal that is almost impossible to achieve with all of the different types of restorations (including implants), preserving tooth structure is a crucial issue. As most of the first restorations in a nonrestored tooth are placed as a result of caries, which is mainly a lifestyle problem, prevention should always be the first option. Since carious lesions can be active or inactive, nowadays it is recommended that the practitioner be much more conservative with operative interventions. As a result, operative intervention is recommended only in those cases where a caries lesion is clearly progressed into dentin and are cavitated, as these cannot be kept clean as a result of biofilm formation.1

At the same time, in developed countries, an increasing number of dentists are working in the field of dental care which has contributed to the availability of better information, increased motivation of patients, and improved oral health. From this perspective, it is not unusual that dentists are still focused on placing dental restorations, partially because reimbursement systems stimulate this. Meanwhile, as reimbursement systems have not been sufficiently adapted to the progress in prevention, diagnosis, and minimally invasive dentistry, the use of these developments is often discouraged.

The shift in health care is not only toward a more conservative and minimally invasive approach but also toward a more personalized approach.[2] New diagnostic methods, technologies, and knowledge have caused this shift that enables a personalized treatment plan for patients related to their individual diagnostic profile and risk assessment. In addition, the increased awareness of patients has led to the demand for a proper informed consent conversation during which all possible treatment alternatives are discussed with patients, leading them to make an informed choice.

This tendency in health care toward more tailored care and involvement of the patient in treatment choices cannot be ignored in terms of the principles of restorative dentistry. In guidelines for dental check-ups for patients, individual risk assessments and clinical vignettes were introduced,[3] enabling individualized treatment decisions and intervals for oral examinations. Risk factors that are to be recorded include caries risk, periodontal disease risk, erosion risk, and general health, but also possible aspects such as tooth wear susceptibility and parafunctional activity, such as grinding and clenching. These are possible risk factors that

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combine to yield a personalized risk profile that enables the provider to offer tailor-made informed treatment choices.

The final aims of this personalized treatment plan should be to identify early on those changes in risk factors and to help patients keep their oral function as long as possible during their lifetime and to provide the patients with a good quality of health and satisfaction about their dentition.

TRADITIONAL RESTORATIVE CONCEPTS

In light of the above, traditionally based concepts of restorative dental care should be subject to debate. Individual risk profiles and other factors potentially have a major influence on restoration longevity. Therefore, specific materials, depending on their properties, can result in long-lasting restorations in one patient and early failure in other individuals. Caries risk is identified as a factor that increases the risk for restoration failure by as much as four times,[4,5] and the limited information available on bruxism shows that an almost three times higher risk for restoration failure of composite resin is found in bruxing patients.[5] A higher failure rate by fracture is also true for ceramic restorations. In most clinical studies on newly formed ceramic and composite materials, severe bruxing patients are excluded, likely in an attempt to achieve a high restoration survival rate, but later the limitations on indications in daily practice are not well described.

In the last century, it was assumed that crowns protect damaged teeth; therefore, for more severely compromised teeth, crowns were normally recommended as "the best" restorative solution. But, it has been described that crowns on weakened teeth in high-risk patients may also result in more complications compared to more conservative solutions. For example, it has been shown that endodontic complications in painful cracked teeth are limited to less than 10% when a conservative, minimally invasive treatment concept is chosen,[6-8] while crowns placed on cracked teeth have resulted in 20% endodontic treatments after six years,[9] and the choice of an immediate endodontic treatment results in 14.5% tooth loss after two years.[10] A tendency in restorative dentistry today is to reduce the number of crowns and to develop more tooth-saving indirect concepts when large restorations have to be made. The bur can remove in a few seconds more tooth substance than the caries may destroy in months or even years.

Every preparation and restoration that is placed onto ground dentin possibly affects the dental pulp and in certain instances may result in pulp necrosis, which severely compromises tooth longevity. Therefore, new concepts for excavating deep caries lesions have been developed, such as ultraconservative caries removal leaving affected dentin,[11] stepwise excavation,[12] and indirect pulp capping, in an attempt not to expose the pulp and in the knowledge that lesion progression is stopped by the sealing of a restoration placed on top of carious dentin.

Longevity of the restoration is important, but it is also important to prevent future re-restorations that will lead to a much larger preparation size and increased risk for pulpal complications. Especially in those cases in which high- and multi-risk patients are treated restoratively, this more conservative approach and the practice of including "disease management" seems to be important.

The dental practitioner who desires to deliver restorative excellence, also must decide how to manage an imperfect restoration. Criteria have been developed to evaluate the quality of restorations over time[13] and are mainly used in scientific clinical studies. Updated and broadened FDI criteria were published in recent years.[14,15] But, in daily practice, many dentists are guided by gut feeling or misunderstanding of those criteria sending the dentist on the path to replacement. The tooth-saving concept that repairs defective restorations instead of replacing them is still not fully accepted. For imperfect restorations, Hickel and others[16] published four options on how to handle this situation depending on the type and extent of defect and they clearly supported to not always replace defective restorations. Gordan and others[18] and Martin and others[17] showed that repair/sealing had better results than did leaving the teeth untreated.

Guidelines for the general practitioner related to whether to monitor, repair, or replace a restoration while taking into account specific risk factors, including a proper informed consent procedure during which all options are well explained to the patient, were traditionally absent. This led to a non–evidence-based operative dental practice that may varied considerably among dental practitioners.

NEW RESTORATIVE CONCEPTS

Taking into consideration the principles of personalized health care and individual risk factors, a decision to restore a tooth should be based on risk assessment and diagnosis, resulting in an individual risk profile and disease management. The first treatment should aim to stabilize oral conditions

and should result in disease control by proper oral hygiene and adjusting dietary habits. First-time restorative interventions—if really necessary—should be kept to a minimum in terms of their extent with the realization that nearly every restoration needs to be replaced in the future. When restorative intervention is needed, a minimally invasive approach should be the first option, as this restoration will preserve the possibility for future restorative interventions without pulpal complications. This will lead to a so-called "dynamic restorative concept" in which the longevity of the tooth, rather than the longevity of the restoration, is the most important goal. According to this principle, a more conservative approach toward operative intervention for defective restorations is also the more favorable option compared with replacement. Although depending on the type and cause of repair, these restorations may have a limited longevity compared to new restorations, repaired restorations can be considered to have "survived: and therefore to have prolonged the longevity of existing restorations."[19]

Trends toward new concepts can also be seen for indirect restorations. The traditional concept that a crown should replace or at least cover all direct underlying restorations is often too invasive, and new concepts that include an additional indirect restoration on top of a direct restoration have been introduced. This has the further advantage that subgingival margins can be protected from moisture contamination by wedges and matrix bands instead of placing a crown with a sub-gingival adhesive luting agent, which is rather unpredictable in terms of good adhesion.

THIS SPECIAL ISSUE OF *OPERATIVE DENTISTRY*

This special issue of *Operative Dentistry* aims to put new trends and developments in restorative dentistry in a contemporary perspective. The key aspects of these new concepts in operative dentistry will be the subject of different articles that will deal with modern treatment planning, criteria for primary intervention, criteria for intervention on existing restorations, new principles for differentiating between direct and indirect techniques, considerations for repair, modern operative procedures, and clinical examples of cases treated according to modern principles. The aims of this issue are to share these considerations with the reader and to stimulate discussions on how to integrate these new concepts into general dental practice and dental education.

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From 'Direct Versus Indirect' Toward an Integrated Restorative Concept in the Posterior Dentition

NJM Opdam • R Frankenberger • P Magne

Clinical Relevance

The decision whether a required dental restoration should be direct or indirect is made daily in clinical practice. Guidelines for this decision are presented.

SUMMARY

Traditionally, indirect restorations are expected to have better longevity than direct restorations. The introduction of adhesive dentistry and the minimally invasive approach of restorative treatment has changed this. In this article, the differences in longevity between direct and indirect restorations in the posterior dentition are explained. In addition, the advantages and disadvantages of direct and indirect restorations placed in a minimally invasive way and using a proper adhesive technique are described.

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INTRODUCTION

Numerous dental restorations are placed each day in human teeth, mainly to restore defects caused by caries but also those caused by tooth wear (mechanical and erosive) and fracture.[1] In addition, because dental restorations have limited longevity, a significant part of restorative work by dentists includes replacing defective existing restorations.[2,3]

Basically, restoration replacement results in a restorative cycle of defective restorations being replaced by larger restorations that will someday fail again, which will lead to even larger restorations, possible root canal therapy, more risk for complications, and eventually tooth loss. This restorative cycle of death of the tooth was described by Elderton[4] in 1988 and Simonsen[5] in 1991. To reduce and maybe even interrupt this restorative cycle, which could possibly lead to prolonged tooth retention, different approaches must be considered:

- Postpone the first restoration as long as possible by using advanced diagnostic methods and caries detection techniques.
- Use less aggressive excavation and caries removal methods to maintain pulp vitality.

Table 1: *Review Articles on the Longevity of Dental Restorations*

Restoration Type	AFR	Authors	Year	Journal	Research Type
Direct restorations					
Amalgam	3%	Manhart and Hickel	2004	Operative Dentistry	Review
Amalgam	1%	Heintze and Rousson	2012	Journal of Adhesive Dentistry	Meta-analysis
Posterior composite	1%	Heintze and Rousson	2012	Journal of Adhesive Dentistry	Meta-analysis
Posterior composite	2%	Opdam and others	2014	Journal of Adhesive Dentistry	Meta-analysis
Glass-ionomer cement	7%	Manhart and Hickel	2004	Operative Dentistry	Review
Indirect restorations: inlays					
Inlay-composite	3%	Manhart and Hickel	2004	Operative Dentistry	Review
Inlay-gold	1%	Manhart and Hickel	2004	Operative Dentistry	Review
Inlay-ceramic	2%	Manhart and Hickel	2004	Operative Dentistry	Review
Ceramic CAD/CAM	2%	Manhart and Hickel	2004	Operative Dentistry	Review
Ceramic CAD/CAM	2%	Wittneben and others	2009	International Journal of Prosthodontics	Systematic review
Ceramic-CEREC	1%	Fasbinder	2006	Journal of the Canadian Dental Association	Review
Indirect restorations: crowns					
IPS Empress crowns	1%	Heintze and Rousson	2010	International Journal of Prosthodontics	Systematic review
All-ceramic crown	2%	Pjetursson	2007	Clinical Oral Implants Research	Systematic review
Metal-ceramic crown	1%	Pjetursson	2007	Clinical Oral Implants Research	Systematic review
All-ceramic FPD	2%	Sailer and others	2008	Clinical Oral Implants Research	Systematic review
Metal-ceramic FPD	1%	Sailer and others	2008	Clinical Oral Implants Research	Systematic review
Zirconia crowns: tooth supported	1%	Larsson and Wennerberg	2014	International Journal of Prosthodontics	Systematic review
Zirconia crowns: implant supported	1%	Larsson and Wennerberg	2014	International Journal of Prosthodontics	Systematic review

Abbreviations: AFR, annual failure rate; CAD/CAM, computer-aided design/computer-aided manufacturing; FPD, fixed partial denture.

- Reduce the amount of tooth substance loss by using minimally invasive preparation and restorative techniques.
- Improve the restoration seal, bonding, and overall quality for longer restoration survival
- Use a more conservative approach toward restoration replacement and maintenance by postponing, repairing, or refurbishing rather than always replacing completely.

Historically, indirect restorations, especially crowns, were considered long-lasting restorations, and the aim was for the restoration to be permanent. However, almost no restoration is really permanent, except the last one in a patient's lifetime. Traditionally, in a tooth that will be restored with an indirect restoration, all direct restorative materials are removed or are covered by the indirect restoration in an attempt to promote the restoration's longevity. This is mainly based on the assumption that an indirect restoration will have a better marginal fit and that indirect restorative materials are more resistant to deterioration over time due to wear, fracture, and discoloration. These traditional restorative concepts may be obsolete for two reasons:

1. Even though differences are noted *in vitro*, the clinical longevity of modern adhesive restorative materials, whether placed directly or indirectly or under ideal and less than ideal circumstances, does not differ significantly (Table 1).
2. Under less than ideal circumstances, certain risk factors may be present that are not related to the quality of the restorations or the different properties of direct and indirect restorations. These risk factors, such as high caries risk or bruxism, may impair restoration and tooth longevity independent from the type of material.[6,7]

For too long, the longevity of the restoration itself has been the focus of the attention. Today, it appears that it is more important to preserve the underlying tooth and the functioning of the dentition as a whole. In a good restorative concept, it is important to keep open future options for restorations as the present available restoration will fail in the future and will need replacement, repair, or adjustment. This is the essence of the biomimetics approach,[8] in which the aim is not to create the strongest restoration but rather a restoration that is compatible with the mechanical, biologic, and optical properties of underlying tissues. This article will discuss recent developments in restorative dentistry that aim to preserve a well-functioning dentition during a lifetime.

LONGEVITY OF RESTORATIONS

Clinical data on the longevity of dental restorations are widely available but have to be interpreted with caution. Prospective clinical trials are considered the best option to measure the longevity of dental restorations. Several systematic reviews based on prospective clinical trials have been published and Table 1 shows the results for several types of restorations. It is remarkable that direct composite restorations, indirect ceramic and composite restorations, and crowns of several designs do not differ that much in annual failure rates, which vary between 1% and 2%, according to recent review articles.[1,9–16] These studies conclude that indirect restorations, especially crowns, do not have better longevity.

A few drawbacks to these studies need to be mentioned. First, restorations in prospective clinical studies are mostly placed by calibrated operators in a university setting, which leads to optimal restorations that possibly last longer than those placed under real-life routine conditions in a general practice setting.[17] Second, patient selection for prospective studies likely includes motivated patients without such problems as high caries risk or bruxism, factors that are known to have a negative effect on the longevity of dental restorations.[6,7,18,19]

Therefore, it can be expected that a lower survival of restorations will be found in a general dental practice environment. Data are available from cross-sectional studies,[2,20–22] but this study design has been shown to grossly underestimate restoration longevity and results in findings of higher longevity for older materials. Thus, past conclusions that longevity of restorations in dental practices was as low as 3 years (median) for composites and 5 years for amalgam[21] are not justified as these calculations are based on these deceptive data for failed restorations.[23]

Data from longitudinal studies on longevity of dental restorations in a general practice environment are limited, and most are related to specific dentists[6,7,24] or public health dental care.[25–27] From these practice-based studies, annual failure rates of 1%-3% for composites have been found dependent on several factors, and these data are comparable to the outcomes of university studies. From an insurance database in the United Kingdom, 10-year survival rates of crowns have been reported to be 48% for porcelain fused to metal and 68% for full metal crowns.[28]

Therefore, it can be concluded that longevity data are no longer a justification for making a choice between direct and indirect restorations and between resin composite, metal, or ceramic materials.

SIZE OF THE DEFECT

Traditionally, small defects in teeth are treated with a direct restoration. For larger defects, including cusp replacement and deep cervical outline, different restorative options are available, either direct or indirect:

1. For large posterior and anterior defects, a direct composite restoration can be a feasible solution. Several studies have shown that a direct composite is suitable for restoration of large defects, including cusp replacement, and for treating cracked teeth,[6,29–33] The skills of the operator, who should be able to deliver an adequate restoration with appropriate morphology as well as proximal and intermaxillary contacts, seem to be the predominant limiting factor.
2. Inlay/onlay restorations are also considered to be an option for larger defects. They have the advantage of precision and better control on the final morphology and occlusion. However, the need for a tapered preparation design may result in increased tooth tissue loss. This can be prevented by using immediate dentin sealing[34,35] and direct composite buildups to remove undercuts. Inlay/onlay restorations fit in a modern restorative concept; however, technique sensitivity and demands for the operator are not reduced compared with direct restorations.
3. For a long time, crowns were considered the best restorations for severely compromised teeth. Disadvantages of crowns are that they require sufficient ferrule and that the outline should be extended considerably toward the cervical region which may result in loss of more tooth substance. The costs for crowns are considerable; therefore, some restorative dentists recommend alternative concepts.[36] Furthermore, traditional crown preparations cut many sound areas that have never been attacked by caries. This primarily means that the probability of endodontic complications is significantly increased compared with more defect-oriented preparations.
4. Indirect restoration with elevated margins.

When an indirect restoration is placed, typically all existing restorations are replaced or covered with the indirect restoration, which results in a considerable amount of tooth substance loss when trying to

achieve a divergent preparation design without undercuts, especially when a full crown is placed. A restorative technique has been introduced to deal with the problem that indirect adhesive inlays are difficult to cement without rubber dam or matrix *in situ* to protect the area from contamination when a deep subgingival proximal outline is present.[37–39] With this restorative concept, called deep margin elevation, the outline of the indirect restoration is elevated to the supragingival level.

There are other clinical approaches to this dilemma. Deep gingival margins can be exposed by surgical apical displacement of the supporting bone and gingiva. This may, however, compromise the attachment level and generate possible anatomical complications such as the proximity of root concavities and furcations. Once exposed to the oral environment, those areas can be problematic to maintain and may generate other complications. In the more conservative deep margin elevation technique, a base of composite resin is used to elevate the subgingival proximal margins underneath direct or indirect bonded restorations (Figures 1 through 3). The procedure, also called coronal margin relocation, is performed under rubber dam isolation with the placement of a matrix. In addition to the supragingival elevation of the margin, immediate dentin sealing and an adhesive composite resin base are used to reinforce undermined cusps, fill undercuts, and provide the necessary geometry for the inlay/onlay restoration.

ADHESION WITH LARGER RESTORATIONS

Traditionally, metal-based crowns are luted with glass-ionomers, zinc-carboxylate, or zinc-phosphate cement, materials that are somewhat forgiving in a relatively moist environment. The newer all-ceramic concepts require adhesive cementation based on composite bonding technology, as the preparations are less retentive, and optimal bonding of the restoration to the tooth is demanded.

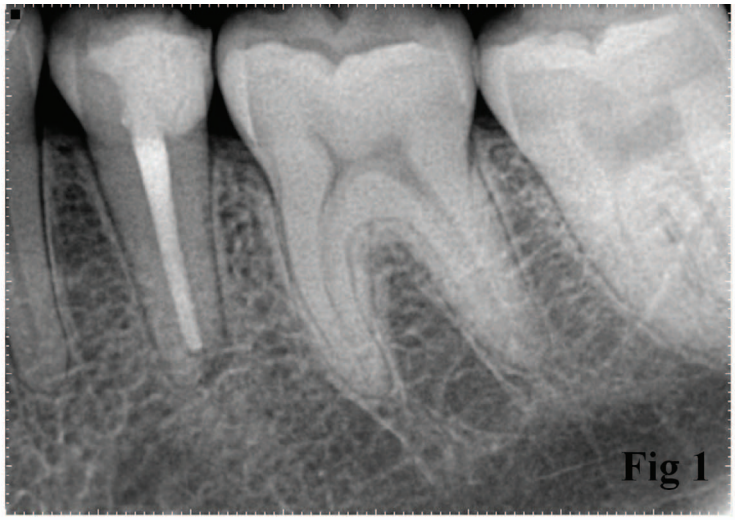
A possible problem arising with cementing full ceramic crowns with a subgingival margin is how to maintain a dry working field for the adhesive procedure. In operative dentistry, moisture control is often obtained with a rubber dam, but this is not the only option. Use of cotton rolls and suction as well as special devices, such as an isolation mouthpiece (Isolite Systems, Santa Barbara, CA, USA) and a proper matrix and wedge as applied with direct restorations, offer good moisture control even with subgingival restorations. For subgingival indirect restorations, placement of a wedge and matrix is difficult as it would compromise the fit of the restoration. Therefore, unless margins are clearly relocated supragingivally, placement of a rubber dam can be done but probably will not prevent contamination from the sulcus and hence an indirect, subgingivally placed adhesive restoration seems to be a lucky shot when it comes to the quality of the marginal fit.

The previously described deep margin elevation technique could provide a solution for this problem as the first subgingival part of a large restoration could be placed using a specially designed matrix (Figures 1-3), enabling the best possible moisture control. Thereafter, a rubber dam could be placed easily and a (supragingival) direct or indirect restoration could be placed adhesively without too many problems.

THE ULTIMATE CHALLENGE: PATIENTS WITH SEVERE EROSION AND TOOTH WEAR

The ultimate challenge for restorative treatment is a patient who suffers from severe tooth wear, especially one who is still relatively young. The main etiologic factors of severe tooth wear, including loss of vertical dimension, are erosion and bruxism. In particular, heavy bruxism can cause deterioration of teeth and dental restorations. For these patients the strongest restorations are required, but at the same time it has to be recognized that these restorations will have to be replaced in the future. Therefore, a treatment that mostly includes an increased vertical dimension would be minimally invasive and at the same time offer fracture-resistant restorations. Even wear/erosion accompanied by difficult anterior occlusal relationships (deep Class II or edge to edge) can be resolved in a minimally invasive way through occlusal therapy using the centric relation and the Dahl principle.[40] Indirect restorations that need sacrifice of a substantial amount of tooth substance are therefore not the first choice, although in these patients crowns are often still recommended. Clinical studies of restorations in patients with severe tooth wear are limited and include only a few studies with direct composites,[31,33,41] and those resulted in different levels of success. Several case reports have been published on minimally invasive indirect techniques using computer-aided design/computer-aided manufacturing (CAD/CAM) tabletop restorations or semidirect treatments using a mold intraorally and or using ceramic restricted to labial veneers.[42–44]

Posterior composites seem to be the most successful materials offering the most fracture-resistant



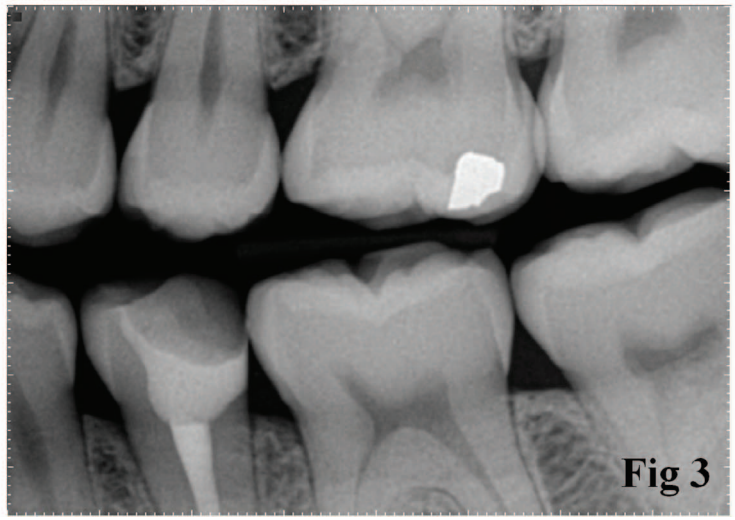


Figure 1. *Clinical case indicated for the deep margin elevation technique.*

Figure 2. *Super-curved matrix modified for elevation.*

Figure 3. *Post-elevation bitewing radiograph.*

restorations in cases of bruxism. *In vitro* studies confirm these results when fracture resistance of composites and ceramics bonded to dentin are tested. If this is the case, and clinical results should be obtained especially for indirect ceramic restorations in treating patients with tooth wear, then the question is why indirect restorations should be made if the purpose is to strengthen the tooth. Full metal restorations possibly have the best properties in this respect but are surely in decline. A recently published randomized clinical trial comparing indirect and direct restorations for premolar teeth with a cusp fracture showed no difference in performance.[32]

CONCLUSIONS AND RECOMMENDATIONS

Traditionally, reasons to choose indirect restorations ranged from indirect restorations are stronger to indirect restorations last longer, the defect is too large for a direct restoration, and subgingival margins in cementum require an indirect restoration. As can be concluded from this article, these reasons are no longer supported in contemporary dentistry. However, there are still some situations in which there are good reasons to choose an indirect over a direct technique, including the following:

- In large rehabilitations in which the dentition has to be restored extensively, indirect techniques allow for preoperative design with wax-up or digital wax-up and better management of occlusion and vertical dimension.
- In cases where optimal form and esthetics are required, indirect techniques have advantages, especially when ceramic materials are used.
- In cases in which a direct restoration is too difficult for the operator to make, sometimes an indirect restoration can be more successful.

Alternatively, direct restorations are more preferred

- When minimally invasive techniques are required, especially in high-risk and young patients.
- When low-cost treatments are the only option.
- When the dentist is skilled in direct techniques; for such operators, direct techniques are indicated in more situations.

In conclusion the following recommendations may be made:

1. Crowns have limited indications, namely, to replace an existing crown, for implant restorations, and occasionally to serve as bridges for abutment teeth. In most other cases less invasive options should be preferred.
2. Indirect or direct techniques should be minimally invasive and adhesive. Modern restorative techniques should include immediate dentin sealing, adhesive bases when required, and deep margin elevation in cases where indirect restorations have to be made.
3. The operator's skill in direct techniques is an important factor. Training in large direct composites should be part of the dental training program.
4. Indirect techniques should aim for predictable full mouth rehabilitations, as reconstructions can be supported by a preoperative diagnostic buildup/wax-up made by the dental technician or the dentist. CAD/CAM techniques might become increasingly important for these techniques.
5. For a subgingival outline the deep margin elevation technique may be the best option for indirect restorations. This technique can also be useful when placing deep and large direct restorations.
6. Ceramics offer the best esthetic properties, but because of their mechanical properties, they should be limited to the esthetic zone, especially for patients with bruxism.

Regulatory Statement

This work was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of the College of Dental Sciences, Radboud University Medical Centre, in the Netherlands.

Conflict of Interest

The authors 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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When and How to Intervene in the Caries Process

H Meyer-Lueckel • S Paris

Clinical Relevance

In addition to minimally invasive interventions, noninvasive and microinvasive options should be a focus in modern cariology in order to preserve dental hard tissues to a greater extent, as has been the case in recent decades.

SUMMARY

The decrease in caries prevalence in many industrialized countries and the improved knowledge about the etiology and pathogenesis of caries have shifted the focus of caries therapy over the past decades toward less invasive approaches. Studies on caries progression indicate that it is generally quite slow in most patients today which should lead to a reconsideration of the practice of early invasive intervention. Today noninvasive (eg, fluorides) and microinvasive (occlusal sealing, proximal infiltration) therapeutic options that address etiological factors are gaining importance. The goal of these therapies is to heal or at least to slow down the progress of the disease. Noninvasive treatments are mainly related to controlling pathogenic factors (ie, sugar consumption) and enhancing protective factors (mainly oral hygiene and fluorides). Microinvasive treatments do not rely on the compliance of the patient as much, since these treatments include a resinous material that is applied to serve as a diffusion barrier for acids formed by cariogenic bacteria in the overlying plaque. To establish a minimum intervention treatment strategy for caries, the disease must be diagnosed at an early stage. In addition to assessing caries lesions in single teeth, individual risk factors need to be identified so that the underlying causes related to patients' behavioral patterns that led to the disease can be addressed as well. The patient should be informed about the scientific evidence related to the treatment choices in a participative atmosphere. Decision trees may help to make the range of findings comprehensible and the therapeutic shared decision-making process understandable to the patients.

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INTRODUCTION

Minimum intervention has been proposed as the primary aim of modern caries therapy.[1] To fulfill this strategy, the fundamentals of caries histology and pathogenesis need to be considered. The thought behind the contemporary (caries) model helps us to understand the underlying causes and associated factors involved in the disease process. A feasible way to detect, assess, and document relevant disease stages as well as the individual's caries risk is warranted. Based on the derived diagnoses, several possible treatments at the tooth as well as the

patient level need to be weighed and explained to the patient before shared decision making can become possible.

Nonetheless, interpretation of current knowledge and diagnostic outcomes as well as the success rate of the various treatment options does not seem to be uniform throughout the world. This is reflected by the radiographic stages at which dentists from various countries intervene invasively in proximal caries. In France, a restoration is inserted by almost 90% of the dentists when the radiograph reveals that the caries extends from the outer enamel up to the dentin-enamel junction.[2] In the United States, fewer dentists seem to restore these lesions that early (40%-75%) but this is still much more often than Scandinavian dentists (<10%).[3-5] It is similarly difficult to choose an appropriate therapy for occlusal and cervical carious lesions (root caries).

In fact, only through longitudinal clinical and radiographic monitoring of the caries progression process of a single caries lesion might the progression of the lesion be forecasted reliably. However, this assumes that:

- the dentist and the patient are convinced that caries is a process that can be arrested, at least in its early stages;
- the patient is compliant with regular checkups;
- caries can be objectively detected, assessed, and documented in order to compare different points in time; and
- the diagnostic findings will be transferred when the patient changes dentists, such that no information is lost.

In addition to the biological, diagnostic, and patient-centered (compliance) limitations, the patient's expectations are also relevant when following the principles of minimum intervention. As discussed before, invasive procedures are frequently viewed by many healthcare providers and by patients as well, as the appropriate method by which to manage the caries process. These procedures are consequently honored, be it psychologically (the dentist who drills is a good dentist, because he or she treats the disease actively) and/or financially. "Wait and watch" noninvasive therapy, which is largely based on self-management, is viewed with a certain amount of skepticism, as are microinvasive procedures. Frequently, the patient and even the dentist are afraid of the uncontrollable, rapid progression of caries lesions in the early stages of the process. In addition, dentists fear leaving microorganisms within the tooth after sealing, caries infiltration, or restoration. These considerations often lead the dentist to intervene prematurely with invasive treatment and to extensively excavate the dentin when preparing the cavity.[6]

The current article aims to provide a concept for everyday practice in order to preserve dental hard tissues by three basic treatment options: noninvasive, microinvasive, and invasive therapy for the various sites of caries as long as possible.

PARADIGM SHIFT IN CARIOLOGY

Medical and dental interventions should be determined by the underlying scientific paradigms that guide our understanding of diseases. Since the mid-20th century, the paradigm of the specific plaque hypothesis led to a focus on specific microorganisms that inoculate our biofilms,[7] which was misinterpreted as an infection, although Koch's postulates for infectious disease never applied for caries. Nonetheless, generations of dentists adjusted their preventive and therapeutic efforts with the aim of eradicating (specific) microbes.

In contrast, the contemporary paradigm relies on the ecological plaque hypothesis that explains caries as a disturbance in the homeostasis of the oral microflora,[8] which is caused by the selective favoring of (potentially) pathogenic microorganisms by a sugar-rich diet. It is assumed that it is not an exogenous infection with pathogenic species that is responsible for caries. Rather, these species are a part of the physiological (endogenous) flora in healthy humans, and only the qualitative and quantitative changes are pathological.[9] The increased consumption of fermentable carbohydrates favors microorganisms that efficiently metabolize these sugars into organic acids (acidogenic) and also tolerate the resultant low pH (aciduric).

A CURRENT CARIES MODEL

The etiology of caries has been described in various models.[10-12] The well-known Venn diagram by Keyes was based on the three essential etiological factors for caries: "bacteria," "tooth," and "sugar,"[10] but for reasons of simplicity other influencing factors were not shown. The model introduced by Fejerskov and Manji,[11] in contrast, shows caries as a multifactorial disease but elucidates the pathogenesis only to a small extent. Recently, we proposed a pathogenesis model of caries based on the ecological plaque hypothesis (Figure 1).[13] According to present understanding, a sugar-rich diet plays a primary role in the etiology and pathogenesis of caries.[14] A greater

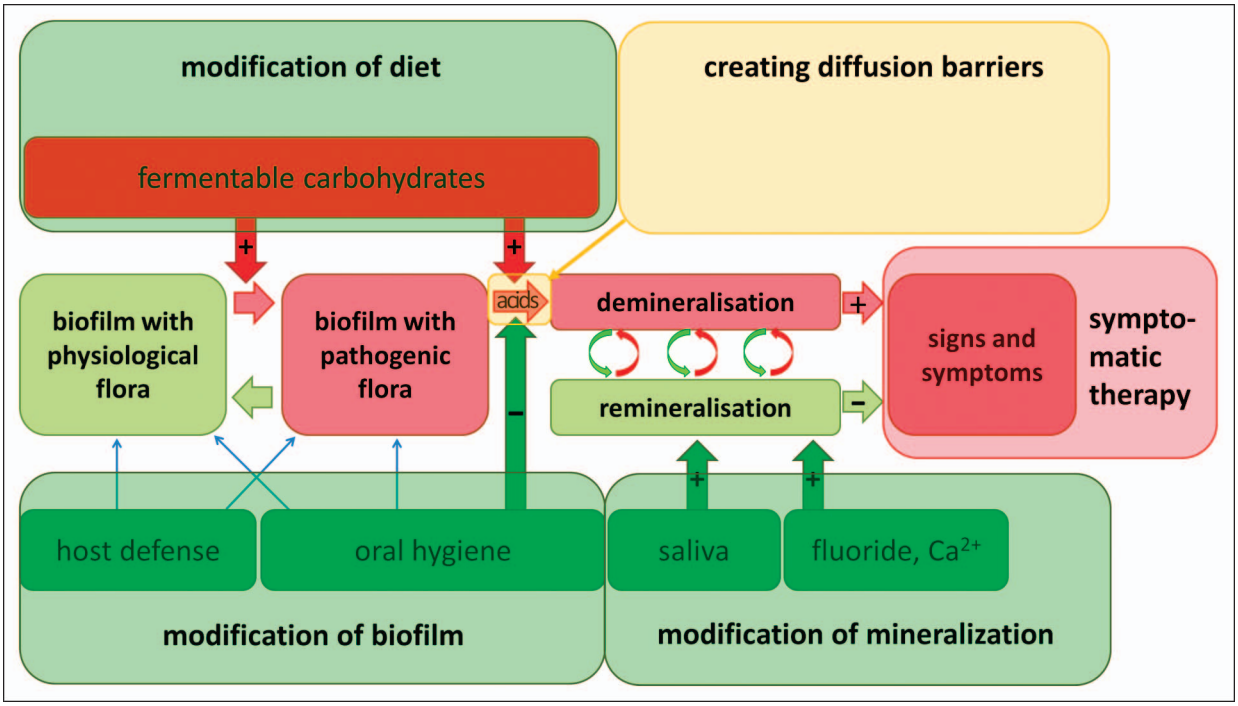


Figure 1. *The pathogenesis of caries (first published in Paris and Meyer-Lueckel[13] and Paris and others[19]). The primary causal pathogenic factor (dark red) for caries is the frequent consumption of fermentable carbohydrates (sugars). This causes an ecological shift in the oral biofilm, with a selection of acidogenic and aciduric species (pathogenic flora). The increased metabolic activity of the biofilm, which is also triggered by sugar consumption, causes the formation of organic acids. This leads to demineralization of dental hard tissues, which consequently results in the characteristic signs and symptoms of caries. On the contrary, there are several protective factors (dark green): the host defense (immune system) and the oral hygiene limit the number of microorganisms. By oral hygiene the biofilm can be completely removed at least locally, and thus acid formation can be avoided. In addition, the components of saliva as well as locally applied fluorides and calcium enhance the remineralization of dental hard tissues, which may alleviate the signs and symptoms of caries. In addition to these (local) direct factors there are several indirect (distant) factors, which only indirectly influence the caries process but may be strongly associated with caries. For simplicity, not all associations are marked. Preventive strategies address the causal factors of the caries process. By creating a diffusion barrier or specifically modifying nutrition, the biofilm, or mineralization, the caries process is altered to inhibit demineralization and promote remineralization. Symptomatic (restorative) therapy is contrastingly restricted to alleviating the clinical signs and symptoms.*

role has been assigned to sugar because caries is a disease of civilizations that consume a greater amount of sugar, which was not the case throughout most of human history.[15] The excessive consumption of fermentable carbohydrates appears to be less physiological or 'normal' than the regular existence of small amounts of potentially cariogenic bacteria in the physiological flora. The frequent consumption of fermentable carbohydrates causes a pathological shift in the oral microflora and promotes acidogenic and aciduric species.[8] Consuming fermentable carbohydrates also causes potentially cariogenic bacteria (eg, *Streptococcus mutans* but also many others) to produce organic acids that demineralize the enamel and dentin. This ultimately causes the characteristic signs and symptoms of caries.

Protective factors also influence the development of caries. Both the host's defenses and the patient's oral hygiene limit the growth and metabolism of the oral biofilm and hence the production of acids. With its buffering properties and minerals, saliva promotes the remineralization of the enamel. The remineralizing effect of saliva can be supported by the application of fluorides and presumably with calcium compounds.[16]

In addition to these local, direct factors, other behavioral and socioeconomic factors are associated with caries, as revealed by epidemiological investigations.[17] However, these only indirectly influence the caries process through the local factors. With the exception of the consumption of fermentable carbohydrates as a pathogenic factor, all of the other factors that locally influence the caries process are shown as protective factors. However, the minimization or elimination of protective factors can have a significant influence on the caries process. For example, the elimination of saliva's protective function in patients with hyposalivation frequently causes caries to progress extremely quickly, even though other factors are scarcely modified.[18] The

risk factors for caries are accordingly increasing the pathogenic factor of fermentable carbohydrates as well as eliminating or reducing protective factors.

According to our present understanding, caries is a multifactorial disease. If and how fast caries develops depends on the complex interrelationships between the various pathogenic and protective factors. If the protective factors predominate, caries does not develop, or existing caries is arrested or healed. However, if the pathogenic factors predominate, the disease progresses.[12] This dynamic character of the caries process enables the disease to be influenced in every stage. Approaches for preventing caries therefore seek to minimize the pathogenic factors and support the protective factors.

CONSEQUENCES OF THE PARADIGM SHIFT IN CARIOLOGY ON THERAPY

The Traditional View: "Drill & Fill"

The "classic" caries therapy was based mainly on invasive interventions. In accordance with the predominating specific plaque hypothesis, for many years the aim of restorative therapy was the complete excavation of all infected tissue and restoration of the resulting defect. Cavity design followed Black's understanding of cavity form[19] that is frequently expressed by the term "extension for prevention." Accordingly, the goal was to prepare a cavity that offers a sufficient degree of retention for the then-available nonadhesive materials (including cement, amalgam, and gold) and thereby to remove "all" carious tissue. The margins of the restoration were to lie in areas of the tooth that are easily accessible to oral hygiene to prevent the formation of adjacent caries. This meant that all occlusal fissures were included and that the proximal box was extended very widely. This philosophy, summarized by the expression "drill & fill," yielded an invasive treatment strategy that was expensive, possibly painful, and, from an epidemiological perspective, resulted in high DMFT values.[6]

A New Philosophy: "Heal & Seal"

According to the ecological plaque hypothesis, the caries process can be arrested if the factors that promote caries are reduced and/or if counteracting protective factors are performed.[20] As described recently,[6] in most cases it takes several years to even a decade for proximal dentin caries to become detectable on a radiograph.[21] Consequently, there exists a considerable amount of time until the "right" moment for (minimally) invasive caries therapy is reached.

If the tooth surface is easily accessible and the patient is compliant, enamel and dentin caries lesions (root caries) can frequently be arrested by noninvasive measures alone. The specific measures that are chosen depend on the frequency of use and the patient's risk of caries. The probability of arresting a caries lesion solely through noninvasive measures decreases as the extent of the caries and cavitation increases. Correspondingly, a caries lesion tends to progress at a greater rate when it has clinically identifiable cavitation,[22] which offers a favorable milieu for microorganisms. Comparable caries-promoting conditions also exist in deep fissures and grooves as well as in the marginal gaps of restorations.

The adhesive filling materials and techniques that have been used for decades enable caries to be treated invasively with less destruction of enamel and dentin than is associated with metal and cements. However, the belief that infected dentin needs to be completely removed remains widespread, although it is becoming increasingly doubtful whether complete removal of bacteria is possible or even necessary, especially since radical caries excavation increases the danger of exposing the pulp,[23] with more pulpal complications as a consequence. With adhesive fillings, the substrate supply to microorganisms deep within the cavity is inhibited, the access of other microorganisms remains blocked, and the remaining microorganisms are sealed in. At the same time, this therapeutic measure (again) enables the patient to clean the related tooth surface. The influence of the dental biofilm, the driving force behind the caries process, is thereby reduced.

A similar condition is achieved by sealing plaque-retentive occlusal tooth surfaces that have an elevated risk of caries. In addition to sealing healthy fissures, in particular when the tooth is erupting, it is also recommended to seal initial caries lesions.[24,25] Noncavitated caries lesions on smooth and proximal surfaces can be sealed[26,27] in principle; however, caries infiltration has certain advantages over sealing in this case.[28,29]

FROM DIAGNOSTICS . . .

As argued in our textbook,[30] before therapy is undertaken, a diagnostic process should be followed thoroughly. First, the signs and symptoms characteristic of caries need to be identified (detection).

Table 1: *Therapeutically Relevant Diagnoses of Caries (Taken from Paris and others[19])*

	Inactive caries *(caries non-progressiva)*	**Sound, but at increased risk**	**Active caries** *(caries progressiva)*		
			early *(superficialis)*	**medium** *(media)*	**late** *(profunda)*
Clinical findings	All ICDAS stages , but inactive	0	ICDAS 1-2 (active)	ICDAS 3-4 (active)	ICDAS 5-6 (active)
Radiographic extension	Mainly E0 E1, E2, D1	0	E0, E1, E2, D1	D1, D2	D2, D3
DIAGNOdent values	Mainly <50	<15	0-40	20-99	n/a
(most likely) Therapy	none	noninvasive or microinvasive		minimally invasive	invasive + pulp preservation or endodontics

This is followed by a precise description of the (severity) stage and activity of caries.[31,32] Several methods can be used to detect and describe caries that will produce both confirmatory as well as contradictory information. The findings are then combined to form a diagnosis, which is used to select a therapy.[33,34] The therapeutic decision involves two elements: whether the disease needs to be treated and which therapy is appropriate.[35]

The art of diagnosing consists of combining the various findings into a diagnosis on which to base the ideal therapy for the patient and his or her disease. The different bits of information that have been collected (findings) are weighted, interpreted, evaluated, and then assembled into a coherent picture for a diagnosis. What is frequently a highly complex clinical situation needs to be simplified and explained using a reasonable number of categories (diagnoses). Thresholds need to be defined for the individual categories that delimit the categories from each other. A variety of systems were developed over time for categorizing clinical and x-ray findings.[36] In our view, it is useful to draw a distinction between active and inactive lesions, since only the former require therapy.[37] In addition, a distinction is frequently made between noncavitated and cavitated lesions, since the former can frequently be treated with noninvasive or microinvasive measures (see below), whereas the latter require restorative therapy, at least in tooth surfaces that are not directly accessible, such as occlusal or proximal surfaces.[38]

Table 1 offers a related categorization of three color-coded diagnoses that will be subsequently used when determining various therapeutic options and findings relating to caries. It should be noted that transitional stages in particular (such as ICADAS 3, 4) cannot be strictly assigned to the various categories. Several parameters should be considered when diagnosing (and determining a therapy for) caries. Furthermore, in the late stages it can be helpful to distinguish caries lesions that only require restorative intervention (media) from those that also require pulp-preserving (eg, stepwise excavation) or endodontic treatment or even extraction (profunda) (taken from Paris and others[19]).

. . . TO THERAPY

Aim of Treatment

One major difference between caries and diseases of other tissues and organs is that the hard substance of the tooth cannot be regenerated (enamel), or it can only be actively regenerated by cells to a slight degree (dentin). “Healing” occurs primarily through mineralization processes in which cells do not directly participate. Remineralization can, however, only occur where there are crystal nuclei. Nonetheless, changes in the surface of the lesions, especially those visible on buccal smooth surfaces, which give

Table 2: *Etiological Targets for Various Therapeutic Strategies*

Target	Intervention	Invasiveness
Biofilm	Mechanical: oral hygiene	Noninvasive
	Chemical: antimicrobials	
	Biological: probiotics ?	
Nutrition	Diet modification	
	Sugar substitution	
Mineralization	Provide substances that promote mineralization: fluoride, calcium compounds	
	Stimulate salivation: chewing gum	
Diffusion	Sealants	Microinvasive
	Infiltration	
Signs and symptoms	Restoration	Minimally invasive

the appearance of remineralization, are at least partially due to surface abrasion and not to the resupply of minerals.[39,40] Caries lesions that do not yet manifest cavitation cannot be completely repaired in the sense of restoring the original contours of the tooth. If the dentin and enamel have been destroyed to the extent of cavitation, the caries process can only be arrested at best. The primary aim of therapy in this case is to restore the tooth's shape and function through restorative measures and thereby allow the patient to regularly remove plaque.[41]

Treatment Approaches

The model of caries presented above (Figure 1) describes the various etiological factors influencing the caries process and, hence, the potential risk factors for caries. In principle, all of the etiological factors for caries are factors that should be considered when developing preventive therapies; however, direct influences are particularly suitable for altering the caries process by modifying nutrition, the biofilm, or mineralization (Table 2). This consideration has given rise to the most frequently used preventive measures for individuals. The common element of all causal strategies is that they do not require invasive treatment of the enamel and dentin and are purely noninvasive. Some therapeutic options, such as sealants or infiltration, only slightly modify the enamel and dentin and are therefore considered microinvasive. Contrastingly, restorative measures are almost always associated with the loss of dentin and enamel and are minimally invasive at best. The term "minimal" expresses the fact that in contrast to the classic rules of preparation defined by GV Black ("extension for prevention"), the restoration of carious defects is confined to the severe parts only, if possible.

The Patient

For a proper treatment decision, not only the disease level of the individual teeth (the stage and activity of caries) but also the patient's risk of caries must be assessed. As described recently, "The majority of the factors contributing to the origin or prevention of caries affect the entire oral cavity and not just individual teeth. Correspondingly caries therapy should include both a local therapy of individual teeth and a therapy that addresses the patient. A systematic caries therapy should address the causal risk factors for the individual patient that were identified when determining the risk of caries. Another consideration when choosing a therapy is patient compliance. Many noninvasive therapeutic options need to be regularly used or require an adjustment of the patient's habits. Therapeutic approaches need to be chosen that are most likely to be pursued by the patient."[19]

Limits of Noninvasive Options

To permanently arrest caries progression by using exclusively noninvasive means, the tooth surface needs to be sufficiently accessible to cleaning. This is largely influenced by the surface cavitation level, the caries extension, and the pathological activity of a cariogenic lesion, which in particular depends on the surface quality.

The degree of surface cavitation correlates somehow with the radiographic extension of the lesion. As a consequence, there is a greater probability that deeper proximal lesions (ie, middle third in dentin) on a radiograph will be clinically cavitated, compared with shallow radiographic (enamel) lesions. However, in order to predict the size of the cavitation and thus the probability of the lesion's progression rate with an acceptable degree of precision, more is needed than an awareness and interpretation of the lesion's radiographic extension. A clinical investigation of the surface with a fine probe should be performed, especially in areas difficult to access visually. Therefore, in particular for proximal surfaces it is useful to know the rate of cavitated lesions of each radiographic lesion extension. As observed after tooth separation, approximately 10% and 30% of proximal caries lesions with a radiographic extension into the inner half of the enamel (E2) and approximately 30% into the outer third of the

dentin (D1) are cavitated, respectively,[42,43] which might be seen as clinically relevant cavitation. However, no standards exist for detecting, assessing, and documenting the different sizes of (micro)cavitation of the surface, of which proximal surfaces are rather difficult to access with adjacent teeth.

When a caries lesion is cavitated, it can be assumed that a potentially cariogenic biofilm has become permanently established. Even if the patient regularly flosses, the biofilm will be difficult to remove and caries progression becomes very likely. Here, the pathological activity of a cariogenic biofilm seems to be increased, followed by a higher probability of the caries lesion to progress. With respect to detecting and assessing the cariogenicity of plaque (biofilm), one problem is that the visit to the dentist only offers a snapshot and that no valid measurements are available. Thus, for the most part, the amount of visible plaque is taken as a surrogate. However, an informed patient tends to be more accurate with plaque removal before visiting the dentist. Thus, the plaque level measured in one appointment may only yield a conditionally representative impression. The frequent establishment of proximal plaque correlates with a tendency of in the adjacent gingiva to bleed. Therefore, increased bleeding of neighboring papilla seems to indicate a higher activity of proximal caries, at least in periodontally healthy patients.[44]

Lesion Progression

The stage in the caries process at which exclusively noninvasive options may be recommended by the dentist to manage caries largely depends on knowledge about the probable speed of the caries progression. As reported in the 1980s and 1990s in Sweden, occlusal lesions requiring invasive treatment established before the age of 12 years and leveled off in late adolescence. Up to 12 years of age, proximal lesions in the posterior region were mainly restricted radiographically to the enamel. In the period of adolescence, new proximal enamel and also dentinal lesions became detectable, adding up to five lesions in mean, either extending radiographically into dentin or being filled at the age of 26 years.[22] According to the study, the median time of proximal caries progression from sound status until it reaches the inner enamel radiographically is approximately six years over the ages of 11 to 22 years. The median radiological progression rate of caries lesions from the enamel-dentin junction (EDJ) into the outer third of dentin (D1) was approximately twice as high as the rate of progression within enamel (Figure 2).

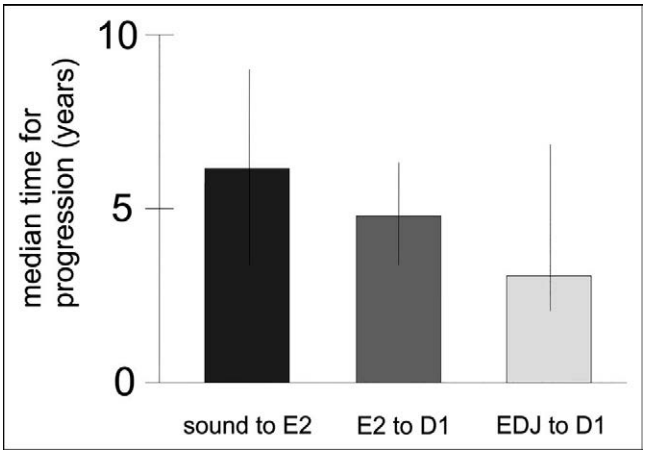


Figure 2. *For an originally sound proximal surface it took about six years in median to establish a caries lesions extending radiographically into the inner half of enamel, as studied in a Swedish cohort in the early 1990s. For a lesion extending into the inner half of the enamel and those up to the enamel-dentin junction it took only five and three years, respectively, to progress into the outer third of the dentin.*[45]

About 10% of the proximal lesions (most presumably in only very few children) progressed within one year from sound to E2 and EDJ to D1, respectively.[45] In conclusion, in most of the patients caries progression is rather low. Occlusal lesions mainly develop shortly after tooth eruption in permanent molars. For proximal lesions, extending radiographically at maximum close to the EDJ noninvasive treatment accompanied by regular monitoring should be favored.

Microinvasive Therapy

In contrast to noninvasive interventions, in the case of microinvasive therapies (ie, fissure sealing and caries infiltration) dental hard tissues are modified in such a way that diffusion barriers are created (eg, with resins). Sealing of occlusal aspects of sound and carious permanent molars is known to be effective in particular in high caries risk fissure and groove systems that can barely be cleaned.[26,46-48] The resin barrier placed onto the surface acts as a diffusion barrier for acids produced in the overlying biofilm; thus, demineralization of the enamel is hampered.

Caries infiltration was introduced as a microinvasive treatment in 2009. After erosion of the surface using 15% hydrochloric acid gel, a low viscous resin, so-called infiltrant is applied onto the caries lesion and penetrates into the lesion pores driven by capillary forces. After three minutes, excess resin is removed from the surface, and the resin inside the lesion pores is light-cured. In this way, the resinous barrier is established inside the lesion, and no

additional sealing, which is in particular difficult to accomplish in proximal areas, is necessary.[49,50] Clinical studies revealed a relative risk reduction of 65%-90% after at maximum three years of followup with regard to the infiltration technique compared with self-applied noninvasive interventions alone. The proximal lesions included were noncavitated and extended radiographically from the inner enamel to the outer third of dentin.[30,51,52] After three years of observation, 46% of the control lesions and 4% of the infiltrated caries lesions had progressed in one of these studies.[52] At present, there are no clinical studies available showing significant clinical effect on postinfiltrated caries progression inhibition for other surfaces. Up until now, fissure caries has not been able to be treated more efficaciously with existing infiltrants compared to sealing alone.[53] In addition to caries inhibition, infiltration of the enamel results in a masking effect of originally whitish caries lesions being used, in particular, for visible vestibular surfaces.[54-56]

Limits to Microinvasive Therapies

To avoid overtreatment, only those caries lesions that are expected to progress and that have not arrested with the use of noninvasive measures, which, for many lesions, cannot be decided at the first dental visit of a patient, should be sealed or infiltrated. However, proximal caries in children (primary molars; four to 10 years of age), adolescents and adults (14 to 35 years of age) manifest a relatively high progression rate,[57] so the danger of overtreatment in this age group is relatively low.[58] For occlusal surfaces of permanent molars, sealing shortly after eruption seems to be most effective.[48] But even established noncavitated occlusal caries lesions can be arrested by sealing if noninvasive treatment alone does not seem to be efficacious enough.[47]

Nonetheless, what is feared far more by many dentists is sealing and infiltrating lesions that are "too deep." This might primarily be related to the concern that the next (invasive treatment–oriented) dentist might argue with the patient that the former (monitoring-oriented) dentist had overlooked a lesion and had not treated it invasively enough. Secondly, this might be due to the misbelief that carious dentin underneath a noncavitated enamel lesion always needs to be removed, since it is infected. In addition, most dentists are experienced in preparing a cavity for a rather shallow proximal caries lesion (ie, extending radiographically up to the enamel dentin junction, but not into dentin), as they were taught that the soft and stained carious dentin histologically extended much deeper (eg, into the middle third of dentin). However, the histological status of the dentin *per se* is no indication for a restoration. As described above, the lesion surface status is the primary factor in determining the therapy. Moreover, noncavitated enamel caries lesions and also underlying carious dentin only contain a few bacteria[59,60] that do not form cariogenic biofilms because of the minimal size of the cavities. It is therefore generally not considered problematic to seal in or infiltrate these areas. This means that when EDJ or D1 lesions are identified on the radiograph and the extent of the caries on the surface is known, one must judge whether the caries can be arrested by noninvasive treatments alone or by infiltration. Only when one has doubt related to the cavitation status might restorative therapy be the right choice.[58]

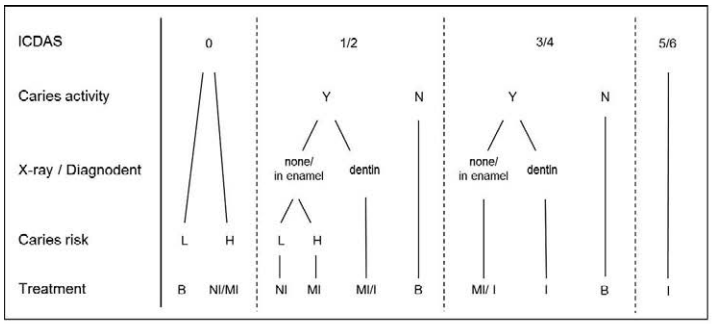
(Minimally) Invasive Therapy

If a proximal or an occlusal lesion is cavitated either into enamel only or into dentin, restorative measures seem to be the best choice. For these, the risks of treating noninvasively or microinvasively alone (ie, caries progression is likely or the tooth gets painful) become greater than the anticipated benefits (ie, protection of sound dental hard tissues, lower costs, and less treatment stress).[61]

In addition to the mechanical, functional, and esthetic aspects, the primary aims of a restoration are to stop disease progression[6,38] and to restore the tooth's ability to be cleaned by the patient by means of plastic reconstruction.[62] Through this process, the heavily diseased parts are removed, but parts being affected only by the caries process are inevitably sealed in, as is the case with microinvasive treatments for noncavitated lesions. Nonetheless, it needs to be remembered that all restorations age over time and will be replaced from time to time by presumably larger restorations.[63] The other articles in this special issue will focus on the material aspects, different techniques, and also repair of restorations.

DECISION TREES AND CHOICE OF THERAPY

To relate the three possible therapies for coronal primary caries (noninvasive, microinvasive, and minimally invasive) to practice, decision trees that can also be employed in the quality management of clinical settings might be helpful in a shared decision-making process.[6] We give two examples, including the most important diagnostic criteria for occlusal and proximal lesions without a prior restoration (Figures 3 and 4). In addition to these decision trees, the most frequent findings and



Explanation of findings for the decision trees

Criterion	Severity	Explanation
Diagnodent caries evaluation (occlusal)	none/ enamel	value <30
	dentin	value ≥30
General risk of caries	low	value <33%*
	high	value ≥33%*
Local risk of caries	low	no anatomical predisposition
	high	anatomical predisposition

*according to caries risk assessment

Figure 3. *Decision tree for caries of occlusal surfaces without a restoration (modified from[6]).*

treatment options ("golden rules") are also described. As said previously, beyond the therapies, on the tooth level the dentist or patient should also pursue patient-related noninvasive interventions according to the caries risk.

Occlusal Surfaces

Whereas it is frequently difficult to diagnose caries in fissures and grooves, the therapy of caries in these locations is relatively easy, since the contour of the cusps and fissures is generally readily accessible. Noninvasive methods, such as controlling the biofilm by mechanical (cross-brushing during eruption) or chemical (chlorhexidine varnish) means or local fluoridation, are used for healthy fissures with an elevated risk of caries and for fissures with early stages of caries. For more severe findings, wither sealing or minimally invasive resin restorations are indicated (Figure 3).[19,38,64]

The following general rules can be applied to this tooth surface:[6]

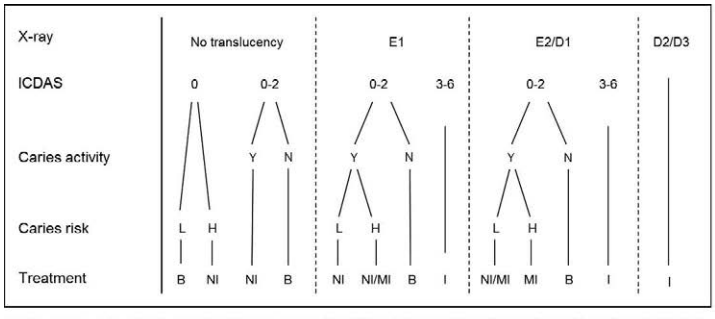
- If the caries is inactive, it should only be monitored and basic prophylaxis reinforced;
- Surfaces categorized as ICDAS 0 and active caries of stages ICDAS 1-2 and occasionally 3 should be treated noninvasively or sealed if there is a higher risk of caries;
- Active caries of stages ICDAS 4-6 should be filled in most cases. If the lesions are very deep, consider removing the caries in stepwise excavation technique or incompletely.

Proximal Surfaces

Given its location below the contact point, proximal caries represents both a diagnostic and therapeutic challenge. Noninvasive methods such as plaque control or local fluoridation are appropriate for healthy tooth surfaces or for surfaces with early forms of caries to prevent or arrest the disease. The control of plaque on proximal surfaces is, however, much more difficult than on other tooth surfaces. The sealing and infiltration of caries are microinvasive measures that can be used to arrest the progress of noncavitated forms of caries. If clinically significant cavitation exists, restorative measures are indicated to restore the ability of the tooth surface to be cleaned. The poor accessibility frequently means that a large amount of enamel and dentin must be removed during the restoration to reach the diseased hard tooth substance (Figure 4).

The following general rules can be applied to this tooth surface:[6]

- In the case of inactive caries of stages ICDAS 1 and 2, basic prophylaxis is sufficient, even given a



Explanation of findings for the decision trees

Criterion	Severity	Explanation
Diagnodent caries evaluation (occlusal)	none/ enamel	value <30
	dentin	value ≥30
General risk of caries	low	value <33%*
	high	value ≥33%*
Local risk of caries	low	no anatomical predisposition
	high	anatomical predisposition

*according to caries risk assessment

Figure 4. *Decision tree for caries of proximal surfaces without a restoration (modified from Meyer-Lueckel and others[6]).*

radiographic extension into the first third of the dentin;
- Active caries of stages ICDAS 1 and 2 with a radiographic extension of E1-E2 should be treated noninvasively (floss, fluoride), if the risk of caries is low;
- Active caries of stages ICDAS 1 and 2 with a radiographic extension of E2-D1 should be infiltrated, if the risk of caries is increased;
- Active caries of stages ICDAS 3-6 should be filled in most cases. If the lesions are very deep, consider removing the caries in a stepwise caries excavation process or incompletely.

Accessible Smooth Surfaces and Anterior Teeth

Oral and buccal smooth surface caries in anterior teeth is less frequent, since oral hygiene can much more easily be established in this area. Here, caries prevalence has decreased over the last decades compared with during the prefluoride era. Nonetheless, with increased plaque retention, as is the case in patients with fixed orthodontic appliances and patients with little oral hygiene, caries lesions are still occurring.[65-68] These lesions are relatively easy to diagnose, and noninvasive measures such as improved plaque control with fluoride toothpaste plus local fluoridation are effective in arresting these caries lesions.[19,64] Only when oral hygiene is difficult to perform (ie, fixed braces) is there a concern that noninvasive measures alone might not be sufficient to avoid caries lesions.

For anterior teeth, esthetic aspects come into play as well. Although an arrested lesion might be a valuable goal form a cariologist's perspective, the unappealing appearance of the "scar" demands further therapies.[69] Nonetheless, the esthetic rehabilitation is most often accompanied by loss of more (eg, microabrasion, composite, or veneers) or less (caries infiltration) additional dental hard tissue.

Root Caries

Today, root caries is found more frequently in older patients with a periodontal attachment loss and exposed dentinal root surfaces.[70,71] Therapy depends on the accessibility of the lesions for oral hygiene. Buccal lesions might even be arrested in cavitated stages by noninvasive therapies (eg, highly fluoridated toothpaste, chlorhexidine, or sodium fluoride varnish).[72] Nonetheless, brownish discolorations of the dentin yield more esthetic treatments, such as adhesive restorations. For proximally located, cavitated root caries lesions, noninvasive therapies are not supposed to be as effective, since plaque removal cannot be accomplished sufficiently. For invasive procedures similar to proximal enamel caries, relatively large amounts of sound dental hard tissues have to be removed to get access to the carious tissues and for restoration placement.

CONCLUSIONS

Minimum interventional treatment of caries involves local treatments at the tooth level as well as addressing the causative factors of the disease on the patient level. Monitoring of caries is essential to assess caries activity and also to support successful treatment outcomes. In addition to minimally invasive interventions, noninvasive and microinvasive options should be a focus of modern cariology in order to preserve dental hard tissues to a greater extent, as has been the case in recent decades.

Note

Parts of this article have been published in sections of the textbook[6,13,19] *Caries Management—Science and Clinical Practices*.[73] Reprinted by permission.

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Regulatory Statement

The preparation of this manuscript was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of RWTH Aachen University in Germany.

Conflict of Interest

HML and SP are appointed as inventors of US and European patents for an infiltration technique for dental caries lesions, held by Charité-Universitätsmedizin Berlin, and receive royalties from DMG, the manufacturer of a product for caries infiltration.

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Criteria for the Replacement of Restorations: Academy of Operative Dentistry European Section

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Clinical Relevance

Restoration replacement is considered to be a last resort, subsequent to excluding the preventively oriented, minimum intervention alternatives of monitoring, refurbishment, and repair.

SUMMARY

The replacement of a restoration is one of the most common procedures in dentistry. However, the criteria for such intervention, excluding catastrophic failure and persistent discomfort and pain, continue to be the subject of considerable debate. The decision-making process remains subjective on the part of the treating clinician, while the evidence base for

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refurbishment and repair rather than replacement for the management of defective and failing restorations continues to grow and strengthen. This article, prepared as an Academy of Operative Dentistry European Section consensus publication, reviews existing criteria for the replacement of restorations and encourages practitioners to shift, if not already doing so, to considering the replacement of a restoration as a last resort rather than as a prudent action to be taken if in any doubt about clinical acceptability. Further research in the area, spanning the risk assessment of defective and failing restorations and new diagnostic tools and processes, together with work to enhance the evidence base of restoration repair *vs* replacement, would be of immense value.

INTRODUCTION

The replacement of a restoration is one of the most common procedures in the clinical practice of dentistry; globally, the annual cost of this activity runs to many millions of euros.[1] It is estimated that as many as 56% of restorations placed by dentists are replacements of existing restorations rather than the treatment of new lesions of caries.[2] The decision of when and how to act in relation to a restoration that has been identified as having a defect that may lead to failure remains problematic given ongoing debate and an ever-expanding evidence base on criteria for intervention. Subjectivity on the part of the operator, influenced by many different confounding factors, has an important influence. An illustrative example of this can be seen from UK and US settings where patients who change dentists are more likely to experience restoration replacement than those who do not.[3-5]

This suggests that practitioners tend to "wait and watch" deteriorating restorations in patients with whom they are familiar, while practitioners who have not seen a patient previously are either more critical of the work of others or more risk averse and tend to intervene to avoid possible future criticism. Alternatively, patients who change dentist for a variety of reasons, such as loss of confidence in their previous dentist, may be reluctant to accept a "wait and watch" approach and request that any suspect restorations be replaced, believing this to be in their best interests. As a result, two distinct patterns of care may be observed in primary care dentistry, one for regular attending patients with stable oral health and another for new patients. Whatever the pattern of care, the best interests of the patient will not be best served by unnecessary intervention.

Criteria for intervention in deteriorating restorations (excluding catastrophic failure, persistent discomfort and pain) and the need to consider applying an alternative restorative approach (Figure 1), continue to be controversial and are changing as the evidence base for refurbishment and repair rather than replacement for the management of defective and failing restorations continues to grow and strengthen.[6] While there are a number of studies that support restoration repair,[7-9] Cochrane systematic reviews in this area have concluded only that there is an absence of relevant high-quality evidence.[10,11] That said, restoration repair offers many advantages when compared to restoration replacement, not least a minimal intervention approach to treatment as well as prolonging restoration longevity.

Reasons for the replacement of asymptomatic direct intracoronal restorations include secondary caries (caries adjacent to restorations [CAR]), fracture, and, for tooth-colored restorations, discoloration, with relatively little variation in frequency of these reasons, regardless of, among other factors, restorative material, geographic location, the different populations of patients, and the experience of clinicians.[2] Reasons for the replacement of indirect intra- and extracoronal restorations have not been studied to the same extent as the reasons for the replacement of direct restorations, but, as with direct restorations, the primary reason for replacement is secondary caries, as diagnosed clinically.[12] The concern arises as to what is and what constitutes secondary caries as diagnosed clinically; this has been shown to vary widely within and between different groups of clinicians, leading to variability in decision making on the sufficiency of restorations in clinical service.[12] This extends to individual clinicians, their familiarity with the patient, and the restorations being examined and depends on the technique and special tests and investigations used to make the diagnostic decisions.[3,4,14] For example, clinicians have been shown to be less likely to replace restorations they placed.[3,4] The use of magnifying aids may also significantly influence decisions to accept or replace restorations.[13] Is the cause of such variability the use of inappropriate criteria, inconsistent application of the criteria, or a consequence of the complex, multifactorial nature of decision making in the assessment of the sufficiency of restorations in clinical service? It is suggested that all three of these factors play a part in the variability

Figure 1: *A case in which the replacement of defective and failing restorations may be indicated to adopt an alternative restorative approach.*

of decision making observed in the everyday practice of operative dentistry. This variability is cause for concern to, in particular, patients, patient consumer groups, and third-party funders of dental care.

This article, prepared as an Academy of Operative Dentistry European Section consensus publication, reviews the development and use of different criteria for the replacement of restorations and explores the ways in which widely applied criteria are changing as the evidence base for refurbishment and repair as an alternative to replacement influences the fate of defective and failing restorations.

CVAR AND RYGE

In an attempt to address the limited availability of data concerning the service life and clinical performance of restorations, a team lead by Dr Gunnar Ryge in 1964 set about the seemingly impossible task of devising a system to quantify the clinical performance of dental restorative materials. Seven years later, Cvar and Ryge published their much-cited paper on criteria for the clinical evaluation of dental restorative materials.[15] This paper was reprinted in 2005, together with a historical note compiled by Bayne and Schmalz.[16] These criteria, generally referred to as the US Public Health Service (USPHS) criteria, not only have had a remarkable impact on clinical dental research[16] but also provide certain criteria for the failure of (need to replace) restorations—the so-called Charlie ratings. These ratings include the following:

- Color match: The mismatch between restoration and adjacent tooth structure is outside the normal range of tooth color, shade, and/or translucency.
- Cavosurface marginal discoloration: Discoloration has penetrated along the margin of the restorative material in a pulpal direction.
- Anatomic form: Sufficient restorative material is missing so as to expose the dentin or base.
- Marginal adaptation: The restoration is mobile, fractured, or missing in part or *in toto*.
- Caries: There is evidence of caries contiguous with the margins of the restoration.

In the late 1970s and 1980s, individuals involved in the clinical evaluation of restorative materials extended ("modified") the so-called USPHS criteria to include assessments of other features of restorations, with the additional criteria including further Charlie ratings. For example, in the clinical trial of Occlusin (ICI Dental, Macclesfield, UK), the largest, multicenter clinical trial of a restorative material ever undertaken, a Charlie rating was included in the methodology for temperature sensitivity, that is, sensitivity to temperature change, typically postoperative sensitivity, extending over a period of more than 2 weeks, considered to be an indication to replace the restoration.[17]

FDI WORLD DENTAL FEDERATION

In 2007/2008, new clinical criteria for the evaluation of direct and indirect restorations were approved by the FDI World Dental Federation and simultaneously announced in three dental journals.[18-20] The criteria were categorized into three groups of parameters: esthetic (four criteria), functional (six criteria), and biological (six criteria). Each criterion could be expressed by one of five scores: three for acceptable and two for nonacceptable (one for repairable and one for replacement). Experience in the use of these criteria led to a number of modifications. In 2010, Hickel and others[21,22] published details of the changes and improvements made to the criteria since 2007. The "clinically poor (replacement necessary)" criteria were detailed as follows:

Esthetic Properties

- Surface luster: Very rough, unacceptable plaque-retentive surface.
- Staining: (a): Surface. (b): Margin. (a): Severe surface staining and/or subsurface staining, generalized or localized, not accessible for intervention. (b): Deep marginal staining, not accessible for intervention.
- Color match and translucency: Unacceptable.
- Esthetic anatomical form: Form is unsatisfactory and/or lost. Repair is not feasible/reasonable.

Functional Properties

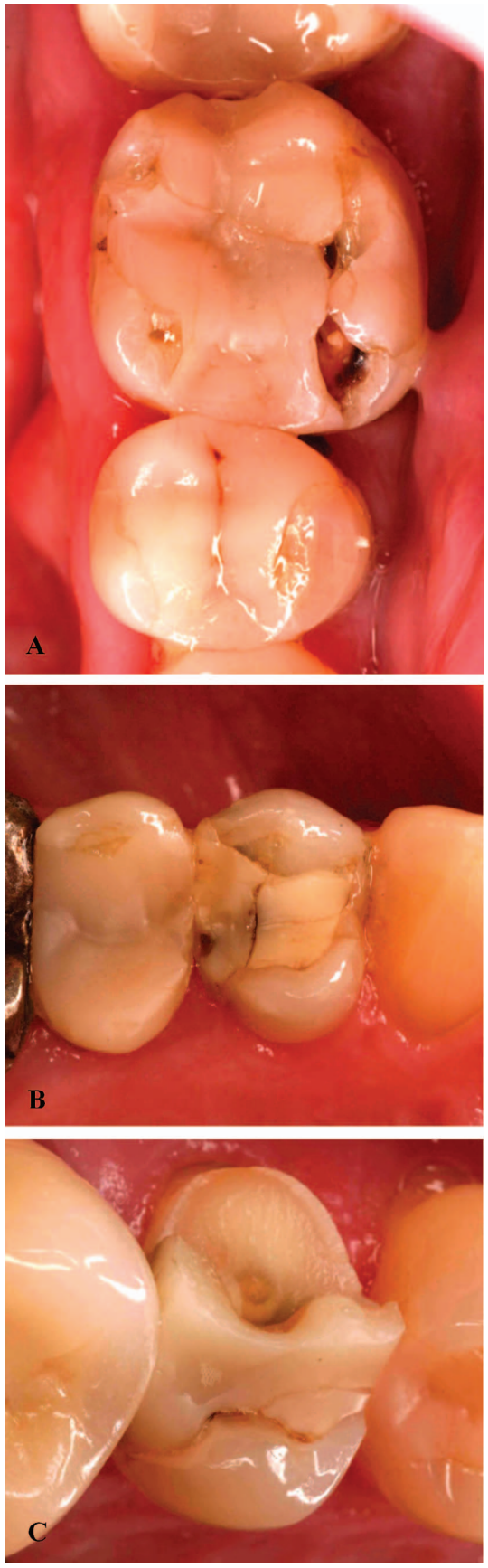
- Fracture of material and retention: (Partial or complete) loss of restoration or multiple fractures.
- Marginal adaptation: Restoration (complete or partial) is loose but *in situ*/generalized major gaps or irregularities.
- Occlusal contour and wear: (a): Qualitatively. (b): Quantitatively. (a): Wear is excessive. (b): Restoration or antagonist >50% of corresponding enamel.
- Approximal anatomical form: (a): Contact point. (b): Contour: (a): Too weak and/or clear damage due to food impaction and/or pain/gingivitis. (b): Insufficient contour.
- Radiographic examination (when applicable): Secondary caries, large gaps, large overhangs/apical pathology/fracture/loss of restoration or tooth.
- Patient's view: Completely dissatisfied and/or adverse effects, including pain.

Biological properties.

- Postoperative (hyper-)sensitivity and tooth vitality: Intense, acute pain or nonvital tooth.Endodontic treatment is necessary, and restoration has to be replaced
- Recurrence of caries (CAR), erosion, abfraction: Deep caries or exposed dentin that is not accessible for repair of restoration.
- Tooth integrity (enamel cracks, tooth fractures): Cusp or tooth fracture.
- Periodontal response (always compared to a reference tooth): Severe/acute gingivitis or periodontitis with or without overhangs, gaps, or inadequate anatomic form.
- Adjacent mucosa: Suspected severe allergic, lichenoid, or toxic reaction
- Oral and general health: Acute/severe local and/or general symptoms.

TRANSLATION INTO CLINICAL PRACTICE

While important in the clinical testing of materials, the USPHS Charlie ratings and the FDI World Dental Federation's "clinically poor (replacement necessary)" criteria have never been promoted let alone adopted as criteria for the replacement of restorations in the everyday clinical practice of dentistry. This has left practitioners making traditional, empirical decisions about the clinical acceptability of restorations in clinical service, with all the variability that this brings. It is suggested that most practitioners practice what they were taught in dental school, typically tempered by experience in clinical practice and acquired skills, developed largely through self-learning, in assessments of risk of failure (need for urgent treatment) before the next time they anticipate the patient returning for routine dental care. For example, if a patient returns every 6 months for a "checkup," then the practitioner questioning the clinical acceptability of a restoration is believed to be more inclined to "wait and see" than to intervene, in particular if he or she placed the restoration and was satisfied with the clinical outcome of preparation and restoration placement and the patient is not expressing any concerns about the comfort, function, viability, or appearance of the restoration. In contrast, the practitioner may decide to intervene and replace the questionable restoration if, for example, the patient is about to set off to some remote location for a prolonged period and will not have access to any dental care or is a poor, irregular dental attendee who last sought routine dental care several years previously and has a history of early restoration failure. A further consideration is traditional, now misguided thinking by patients that a "brand new" replacement restoration rather than a repair would be in their best interests as and when



the dentist needs to do something to a previously filled tooth. This raises the issue of the need for patient education in matters pertaining to the refurbishment and repair of existing restorations. Perhaps, in particular, the term "repair" may convey the wrong message to the patient.

For the practitioner, there are key issues to consider when assessing the sufficiency of existing restorations and making treatment decisions:

1) Is the patient requesting or expecting a replacement restoration? A patient who is dissatisfied with the appearance of a restoration or is experiencing pain, sensitivity, or discomfort associated with, for example, food impaction or sharp edges caused by a fracture of the restoration or remaining tooth tissue may reasonably be expecting operative intervention to resolve the difficulty.
2) Are there lesions or forms of restorations failure present that carry an unacceptable risk to the viability and retention of the tooth if not addressed by some means of intervention? Examples of such lesions and forms of restoration failure are illustrated in Figures 2 and 3.
3) Would intervention, in particular intervention that is unexpected by the patient, cause more harm than benefit, or have any lesions or signs of restoration failure remained unchanged for some time, are they unlikely to progress, and could they reasonably be monitored, subject to the approval of the patient? A clinical case extending over 15 years, illustrating the possibility to monitor rather than intervene, contrary to the wishes of the patient and in the absence of any clinically significant deterioration in the condition of the restorations, is shown in Figure 4. Such cases highlight the possible conflict between patient-centered care and clinical excellence.

REFURBISH OR REPAIR

The situation described above has been confounded in recent years by the development and validation of techniques for the refurbishment and repair of restorations as an alternative to restoration replacement, in particular in patients who are regular

Figure 2. *Some clinical examples of restorations that should be replaced as a consequence of bulk fracture with the probability of further, clinically significant deterioration (A); progressive, pulp-threatening secondary caries and fracture (B); and combined restoration and cusp fracture with loosening of the remaining portion of the restoration (C).*

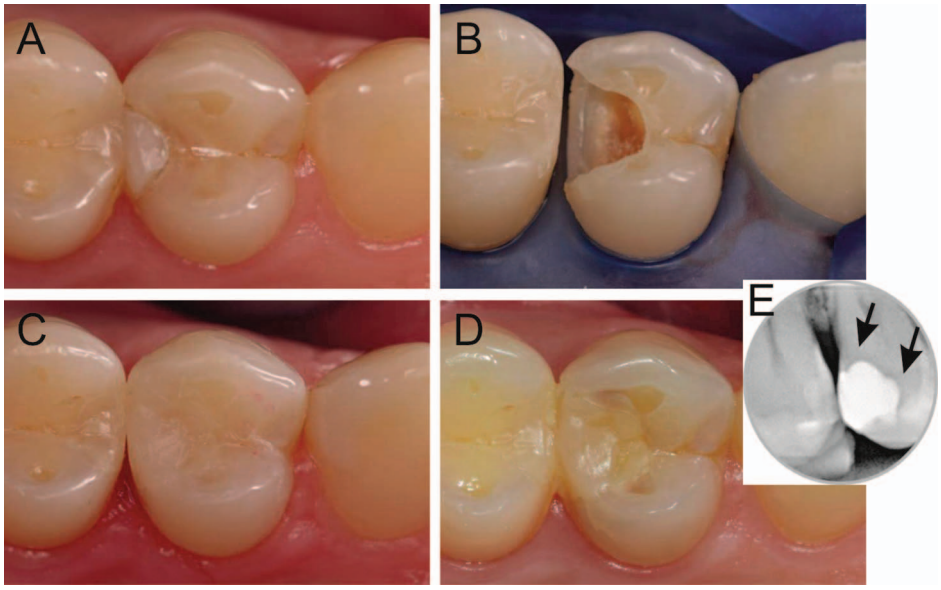


Figure 3. *Treatment decisions for restoration replacement should rely mainly on marginal integrity as assessed clinically rather than radiographically. A decision was made to replace the restoration illustrated (A) following adhesive failure. After complete (enamel and peripheral dentin) and partial (visible as brown area toward the pulp) caries removal (B), a replacement composite restoration was placed (C). Follow-up, five years later (D), revealed intact margins clinically but some wear. The insert of the restored surface in a bitewing radiograph shows proximal-cervical marginal integrity but a radiolucency between the restoration and dentin—the so-called Mach-Band effect. This area should not be (mis)interpreted as caries in need of treatment but rather as a radiographic phenomenon between adjacent areas with different grayscale values. A similar appearance may be observed following ultraconservative caries removal.*

attenders and maintain a good standard of oral health, refurbishment (Figure 5) being considered the correction of the shortcomings of a restoration without damage to the adjacent tooth tissues or the addition of new restorative material and repair (Figure 6) being defined as the correction of a localized defect in a restoration involving the addition of restorative material.[5,23] Developments in this area are such that the option of replacing a defective or failing restoration may, in the foreseeable future, be considered to be indicated only when the possibility of repair has been ruled out. Indications for the repair of restorations have been reported to include[5,23] the following:

- Correction of limited marginal openings and cavomarginal ditching
- Management of localized marginal staining
- Treatment of early lesions of secondary caries
- Repair of fractures that do not threaten the viability of the remaining restoration and tooth tissues
- Chipping of restoration margins
- Management of wear
- Correction of unacceptable esthetics
- Restoration of an endodontic access cavity prepared through an existing restoration

When considering the replacement of a restoration, the wishes of the patient, the risk of causing more harm than benefit, and the possibility of monitoring unsatisfactory but stable situations should be taken into account when considering whether to refurbish or undertake a repair. Again, such decision making may pose conflicts between the provision of clinical excellence and patient-centered care. A recent 10-year follow-up study reporting similar clinical outcomes for repair and replacement, notwithstanding the replacement procedures having inevitably resulted in increases in the size of restorations, included interventions on "bravo" rated restorations, which, in hindsight, can be questioned as unnecessary where monitoring may have been the best form of patient care.[24]

OTHER CONFOUNDING VARIABLES

Other variables that may, in effect, act as criteria in decision-making processes applied to defective and failing restorations include remunerative systems that do not yet include explicit provision for refurbishment or repair as an alternative to restoration replacement and deep-seated, traditional beliefs among certain practitioners and patients that the best approach when faced with a defective or failing restoration is "if in doubt, take it out" (and replace it). The growing body of evidence demonstrating the efficacy of refurbishment and repair,[8-10] where indicated clinically, will hopefully counter such confounding variables sooner rather than later.

THE WAY FORWARD

In the interest of promoting preventively oriented, patient-centered, minimum intervention operative dentistry, it must be recognized that any attempt to define universally applicable, user-friendly, let alone

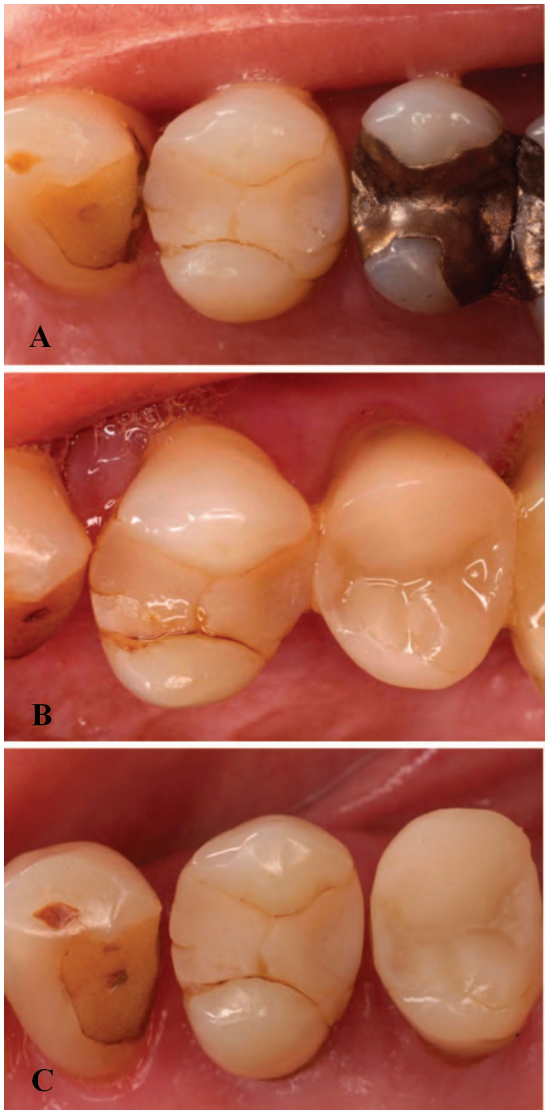


Figure 4. *Illustrations of the upper left quadrant of a female patient, reluctant to have replacement restorations. (A): Distal restoration in canine (more than eight years in clinical service), mesio-occlusal-distal (MOD) composite restoration in the first premolar (three years in service), and an eight-year-old amalgam restoration in the second premolar. The restoration in the first premolar has a Charlie rating for marginal adaptation. (B): Ten years later, the restorations in the canine and first premolar are still in service. There is visible progression of deterioration of the restoration in the first premolar in terms of marginal adaptation, marginal staining, and the extent of the fracture damage mesially; two years previously, the amalgam restoration in the second premolar was replaced, following fracture of the buccal cusp and 16 years in clinical service. (C): A further five years later (i.e., 15 years after Figure 4A was recorded), the restorations in the canine and first premolar are still in service, having served for >23 years and 18 years, respectively. The teeth are migrating as a consequence of progressive periodontal deterioration; however, the restorations were expected to remain in clinical service until extraction was considered to be indicated as a consequence of advanced, progressive periodontitis.*

workable criteria for the replacement of restorations in "frontline" everyday clinical practice will involve compromise, which may disadvantage as many patients as it benefits. The FDI World Dental Federation's "clinically poor (replacement necessary)" criteria provide a list of situations in which restoration replacement should be considered necessary, and, as such, this list provides a useful guide as to when to normally resort to restoration replacement despite the negative effects of such intervention, including enlarged preparation, further weakening of already weakened remaining tooth tissues, and new insult to the dental pulp, all fueling the so-called drill-and-fill restorative death spiral. Building on the refurbish or repair evidence base and the FDI World Dental Federation's "clinically poor (replacement necessary)" criteria, new, forward-looking guidance for restoration replacement in clinical practice may be formulated around the following criteria:

- The restoration has unacceptable qualities, with the probability of further, clinically significant deterioration and/or lesion progression.
- Repair is contraindicated.
- The benefits of replacement outweigh the negative effects and possible harm.
- The prospects for an acceptable clinical outcome are favorable.
- The patient consents.

The range of knowledge, skills, understanding, and experience required to be effective in such patient-centered decision making in operative dentistry must not be underestimated. Indeed, it could be considered to be as much an informed art as a science. It is considered difficult to practice, let alone teach.

Within this guidance, it is should be emphasized that monitoring, refurbishment, or repair should become the "treatment of choice" as the least invasive approach for the management of a deteriorating restoration. When this is not appropriate, replacement should be considered. In applying such guidance, the practitioner, in the ethos of evidence-based practice, should be familiar with best evidence, exercise his or her clinical expertise to the best possible effect, and take account of the views and wishes of the patient, who may need to be educated in the merits of refurbishment and repair over the replacement of defective restorations. Decision making in operative dentistry, past, present and future, cannot be considered an "exact science," in particular, decision making with regard

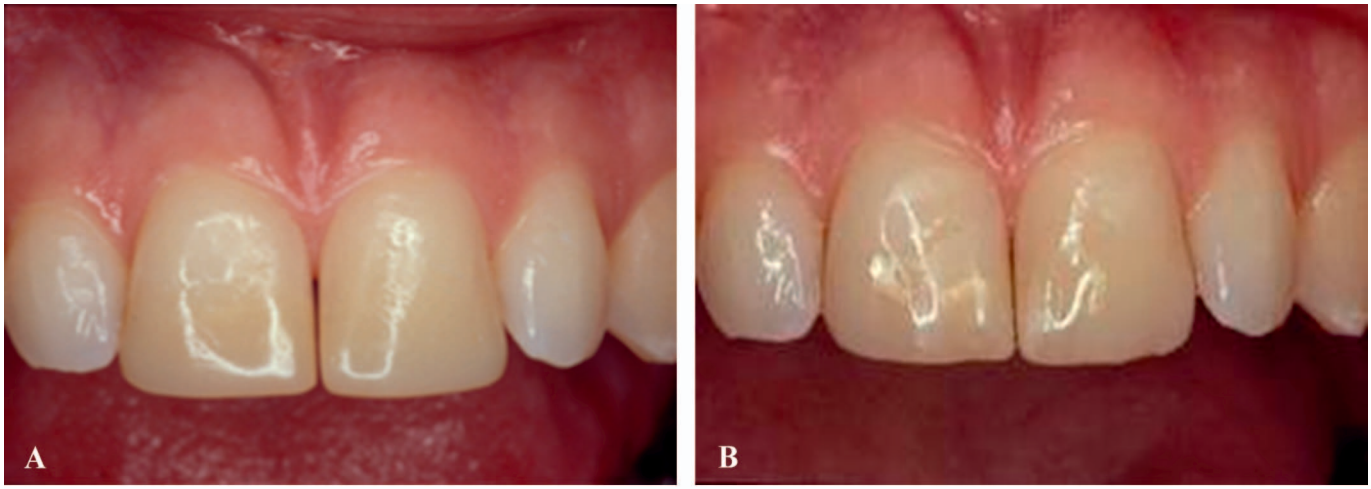


Figure 5. *An example of restoration refurbishment. The patient presented five years after the restoration of his fractured incisors with direct composites, expressing growing concern over the appearance of the restorations (A) and requesting that the restorations be replaced. Following refurbishment (B), the patient decided to retain the restorations and defer any further operative intervention.*

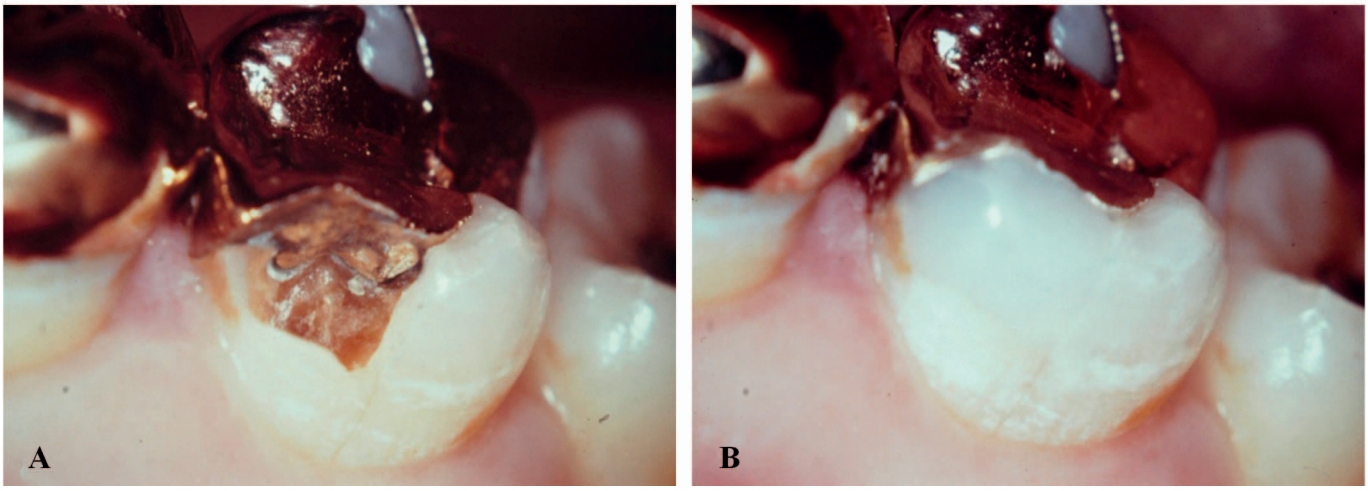


Figure 6. *An example of the repair of a restoration. This older patient presented complaining of sharp edges following the loss of a cusp (A). The cast gold inlay, which had been in clinical service for many years, was firmly retained, and the exposed dentine surface was hard. The decision was taken to carry out a direct composite repair and to subsequently review the need to refurbish (reburnish) the inlay margins away from the repair. The repair was quickly completed without the need for local anesthesia, and the patient was delighted with the outcome.*

to the replacement of restorations, one of the most common procedures in general dental practice.[1] While some practitioners and others, including consumers and funders of oral health care services, may wish decision making in operative dentistry to be driven and possibly dictated by unequivocal "treat" or "no treatment" criteria, this, it is suggested, would not be in the best interests of patients given existing knowledge and understanding of the value and potential of refurbishment and repair techniques. If nothing else, the options, when considering what action to take with respect to an existing restoration with less-than-ideal clinical features should be to monitor, refurbish, repair, or possibly replace, with the reasons for making whatever decision is reached being clearly recorded in the patient's clinical records, ideally together with clinical photographs. The knowledge that this approach is now being widely taught and promoted across the world is viewed as a major step toward the universal adoption of minimum intervention dentistry.[24-28] A major turning point in many countries would be the provision of refurbishment and repair procedures in insurance and third party–funded care programs.

It is acknowledged that further research in the area would be of immense value, for example, research to develop a readily applicable and reproducible scheme to facilitate the risk assessment of defective and failing restorations and investigations

to enhance the evidence base on repair *vs* replacement. Research to develop new diagnostic tools and processes to ascertain the functionality and sufficiency of existing restorations would be of great value also. Such research should run in parallel with research in related areas, such as research on regenerative endodontic procedures.[29]

In the meantime, practitioners who examine existing restorations with the view "if in doubt, take it out" are to be encouraged to adopt the modern mantra of "as a last resort, take it out" and to concurrently apply, as a matter of routine, state-of-the-art criteria, materials, and techniques for the refurbishment and repair of defective restorations.

Conflict of Interest

The authors of this article 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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Extended Resin Composite Restorations: Techniques and Procedures

B Loomans • T Hilton

Clinical Relevance

This article provides an overview of the state of the art of different restorative treatment procedures and techniques needed for placing extended posterior resin composite restorations.

SUMMARY

This article gives an overview of the state of the art of different restorative treatment procedures and techniques needed for placing extended posterior resin composite restorations. Clinical aspects related to the procedure are discussed and reviewed based on the current literature, such as the use of proper adhesive restorative materials, use of liners and bases, moisture control, reconstruction of proximal contacts, extended resin composite restorations, and techniques to address restoring teeth with deep subgingival margins.

INTRODUCTION

Posterior resin composite restorations are now accepted as a reliable, successful, and predictable alternative for direct restoration of posterior teeth.[1-6] Posterior resin restorations offer advantages over traditional amalgam restorations, such as the possibility to use minimally invasive intervention, the ability to bond to the remaining tooth tissues, and the ability to predictably repair defective restorations intraorally.[7] The survival of posterior resin composite restorations is good, and based on reviews it can be concluded that mean annual failure rates vary between 1% and 3%[3,8] and that the main reason for failure for direct resin restorations is (secondary) caries and fracture of the restoration or tooth.[2,5,6,9] In a recently published meta-analysis[10] including 12 longitudinal studies of direct posterior resin composite restorations with at least five years' follow-up, the effects of individual variables (such as patient-, material-, and tooth-related variables) on the survival of posterior resin composite restorations were investigated. It was found that annual failure rates for posterior composite restorations after five and 10 years were 1.8% and 2.4%, respectively, which matches the rates identified in the earlier-mentioned reports. Moreover, the authors found that the individual caries risk and number of restored surfaces play a significant role in restoration survival. Posterior resin composite restorations in patients with a medium or high caries risk had a three times higher risk for failure compared to

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restorations in the low–caries risk patients. Regarding the number of restored surfaces, each additional surface led to an increased risk of failure of 30% to 40%. Another individual risk factor that also has a statistically significant effect on the annual failure rate is bruxism,[11] which may increase the risk of failure by up to four times.

The indication for posterior resin composite in the late 1990s was restricted to small occlusal and occlusoproximal restorations. Nowadays, even large cusp-replacing resin composite restorations[12] and total rehabilitation with resin composite restorations are performed to treat patients with severe tooth wear.[13,14] In addition, a shift in the teaching of posterior resin composites has taken place. While 90% of dental school curricula did not include any didactic teaching of posterior resin composites in the mid-1980s, this rate dropped to 4% or less in the late 1990s and to 0% in the early 2000s. However, 21% of dental schools still did not teach the placement of resin composites in three-surface cavities in permanent molar teeth as of the late 2000s.[15] Interestingly, the authors[13,14] also found that, in the late 1990s, cavity size was no longer mentioned among the five most common contraindications for posterior resin composite placement, but still there is some concern in relation to placement of resin composites in larger cavities (ie, where the buccolingual width of the cavity exceeds one-half of the intercuspal width of the tooth). Overall, it may be concluded that a much wider range of applications involving use of posterior composite restorations is taught than was the case 10-15 years ago.

As a result of this change, dentists today dare to use resin composite materials even for extended restorations and in more complex situations. The skills of the operators have improved, and dentists have gained confidence in placing resin composite restorations even in extended preparations. Therefore, the purpose of this article is to provide an overview of the state of the art of the different restorative treatment procedures and techniques needed for placing extended posterior resin composite restorations.

Adhesives and Composite

From two randomized clinical trials investigating the clinical success of different adhesive bonding systems (three-step etch-and-rinse adhesives and two-step self-etch adhesive) on noncarious cervical lesions, it was found that a highly acceptable clinical performance was achieved for resin composite restorations. From an eight-year clinical study using a mild two-step self-etch adhesive, Clearfil SE Bond (Kuraray, Osaka, Japan), it was shown that selective phosphoric acid etching of the enamel margins had only some minor positive effect on secondary clinical parameters, such as a lower incidence of small marginal defects/discolorations at the enamel side after clinical functioning.[16] Moreover, from a 13-year clinical study[17] using two three-step etch-and rinse adhesives, marginal defects and discolorations were observed at a steadily growing incidence rate, but most were of only a minor extent, such that did not require urgent restoration repair and certainly no restoration replacement. It may be concluded that even after long-term clinical service, three-step etch-and-rinse adhesives and mild two-step self-etch adhesives will result in a clinically acceptable survival rate.

As already reported, from multiple clinical studies, the mean annual failure rate of hybrid resin composite materials in posterior restorations is between 1% and 3%. However, there is little evidence that the varying material properties of the resin composite are a relevant factor in restoration longevity.[18,19] As survival of restorations is mainly dependent on other factors related to the individual patient and operator, improvement in the success of resin composite restorations may indicate that prevention and a conservative approach toward restoration replacement should have higher priority than the material used.

Liners and Bases

For deep preparations, a liner or base of glass ionomer is often placed as a standard procedure for protection of the pulp. A liner or base can be placed in two ways—in an open or a closed sandwich restoration. In a closed sandwich restoration, the dentin is fully covered with a glass ionomer liner but without extending it to the external cavosurface margin. In an open sandwich restoration, the cervical cavosurface margin of only the proximal box is restored with a restorative glass ionomer (Figure 1a-d). The reason for which one uses a liner or base, with a lower modulus of elasticity compared to resin composite (such as glass ionomer or calcium hydroxide), is the stress-absorbing effects of the layer, which could absorb and compensate for polymerization shrinkage stresses and result in less postoperative sensitivity.[20] However, the effect of glass ionomer liners on postoperative sensitivity is equivocal. One study[21] found no statistically significant difference in postoperative sensitivity between the restorative procedures with or without the glass

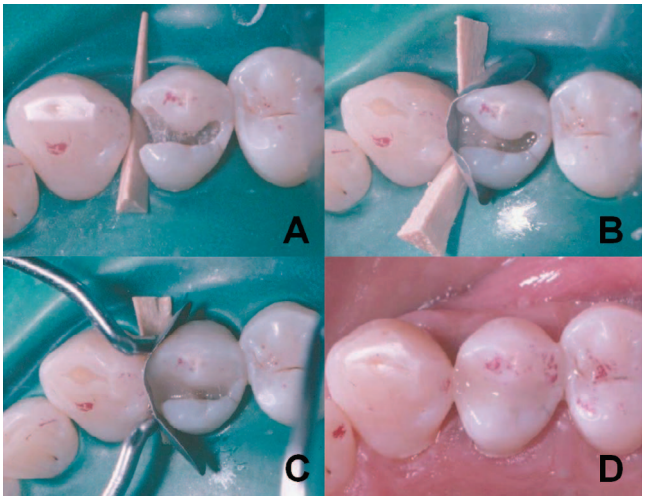

Figure 1. *Open sandwich restoration. (a) MO amalgam with recurrent caries removed. Gingival margin is entirely in dentin. (b) After conditioning of the prepared dentin surfaces, a restorative resin-modified glass ionomer (RMGI) is injected as the first increment into the mesial proximal box. A thin layer of RMGI is also placed as a liner on the pulpal floor. As a result of the lessened abrasion resistance of RMGI compared to composite, the RMGI increment should be maintained apical to the proximal contact so that the contact area is restored with resin composite. (c) Following etching and placement of a three-step etch-and-rinse adhesive on the RMGI and remaining cavity walls, an initial ramped increment of resin composite is placed and cured. (d) Finished restoration.*

ionomer liner, regardless of the adhesive used, while another[22] found that a glass ionomer liner did significantly reduce short-term postoperative sensitivity. In general, postoperative sensitivity in posterior composites is infrequent and tends not to be a substantial problem.[8]

Two studies[1,23] found that restorations placed with a glass ionomer or calcium hydroxide base resulted in an increased risk of failure of the resin composite restoration compared to restorations without a base. However, a recent meta-analysis[10] of 12 studies found no difference in the risk for failure in restorations with or without a liner once the data from a single-practice, retrospective study were excluded from analysis. Likewise, another long-term clinical study[19] found no effect on survival of the resin composite restorations. However, they did find a significant effect on the failure mode of restorations in which a glass ionomer base was placed, as those restorations presented more failures due to fractures. In contrast, a six-year clinical study[24] of extensive Class II open sandwich resin composite restorations demonstrated no difference in restoration failure due to caries vs material fracture.

Against the concern regarding the potential for increased fracture of lined posterior composite restorations must be weighed the potential benefit of enhanced margin integrity with the use of a glass ionomer increment at the dentin gingival margin, particularly in high–caries risk patients. A clinical trial[25] revealed that recurrent caries in Class II composites is eight times more likely adjacent to the gingival margin vs the occlusal margin. Multiple studies[1,2,8,10] have demonstrated caries to be the most common cause of restoration failure, along with fracture. Glass ionomer has repeatedly demonstrated the best marginal adaptation and lowest *in vitro* leakage compared to bonded composite in all cavity classes.[26-29] A relationship between the occurrence of secondary caries and the presence of a glass ionomer base beneath a resin composite restoration could not be proved in two studies.[4,19] In a three-year study[30] of 274 mostly extensive Class II open sandwich restorations in which 43% of the patients were considered caries-risk individuals, only one restoration showed recurrent caries. In this study, two main groups of open sandwich restorations, differing from one another in the thickness of the layer that was placed, were evaluated. In addition, a six-year clinical study[24] of extensive Class II open sandwich composite restorations showed good clinical results, with an annual failure rate of 3%. Unfortunately, in both studies no adhesively placed resin composite restorations absent the use of liner were included, so the relationship between (secondary) caries and the presence of a liner could not be shown in these studies. A three-year study[31] that directly compared the performance of Class II composites restored with either an adhesive-only technique or an open sandwich technique showed equal restoration performance, except for significantly reduced gingival margin demineralization in the open sandwich group.

A possible explanation for the suggestion that the use of a glass ionomer liner or base could result in increased restoration fractures could be the difference in mechanical properties (eg, modulus of elasticity) between the base (calcium hydroxide or glass ionomer) and resin composite materials. This may result in more fatigue of the resin composite restoration and, therefore, in more fractures. Further investigations are needed to study this hypothesis and to shed more insight onto the effect of the individual patient risk factors, such as bruxism and caries risk. Moreover, it is unknown whether the thickness and type of glass ionomer or calcium hydroxide base plays a role in the failure behavior.

Furthermore, as noted above, a liner of glass ionomer would be beneficial in the reduction of

secondary caries because of the presence of fluoride in this material.

MARGINAL ADAPTATION

Obtaining a good cervical cavomargin adaptation of the restoration to the tooth can sometimes be a clinical challenge. Since voids or openings at the margin might result in secondary caries, good adaptation is indispensable.[32] It can sometimes be more difficult to restore a smaller cavity than a larger one. A known technique to fill a preparation is to use a combination of two different viscosities of resin composite. As a first step, a flowable base is placed and polymerized, and secondly, a more viscous resin composite material is placed. When using a high viscous resin composite 'packable' material, it was shown[33] that using an initial increment with a flowable composite reduced the number of porosities at the cervical margin. A modification to this technique is the "snowplow" technique.[34] After inserting a small amount of flowable resin composite in the box, the material is not separately cured, after which the more viscous hybrid composite is inserted into the cavity. Laboratory data indicate that the snowplow technique reduces gingival leakage[35,36] and void formation[34] compared to placing and curing separate layers of flowable followed by viscous composite. During insertion of the resin composite, the flowable composite is pressed against the cavity walls and will be partly pressed out of the cavity. In an *in vitro* assessment of different fill techniques, the use of flowable composite always led to higher percentages of marginal overhangs in bevelled Class II restorations compared to fill techniques using more viscous composites.[37] Therefore, in the process of placing resin composite restorations the use of wedges is indispensable. A proper placement of the wedge will result in a controlled and dry working field, and above all it will provide a good adaptation of the matrix to the cervical area of the tooth and prevent gap formation.

MOISTURE CONTROL

Moisture control is an important prerequisite in order to avoid contamination of the acid-etched surface of the preparation with saliva or blood. It can be obtained with rubber dam or with cotton rolls in combination with aspiration by a saliva ejector. In numerous situations, rubber dam may provide an ideal dry operative field during the whole restorative procedure. However, in some complex clinical situations, rubber dam might even hamper the placement of a restoration and therefore cannot always be used. After reviewing the outcomes of several individual studies comparing the clinical performance of posterior composites placed with and without rubber dam isolation, no clear conclusion can be given. Most studies[23,38-41] reported no statistically significant differences in survival rates or clinical behavior of resin composite restorations placed with cotton rolls and proper aspiration or with rubber dam. On the contrary, a meta-analysis[8] on direct posterior composite restorations found that restorations placed with rubber dam showed fewer material fractures, and this also significantly enhanced overall longevity. A recent meta-analysis[42] found similar findings with Class V restorations, in which resin composites placed with rubber dam isolation demonstrated significantly less restoration loss and marginal discoloration compared to those placed without rubber dam. It might be concluded that the use of rubber dam is not a goal in itself, as the main aim is to obtain a controlled dry working field, but it seems that the use of rubber dam may be the best way to achieve moisture control.

PROXIMAL CONTACT RECONSTRUCTION

The literature provides no clear definition on how tight a contact should be in order for one to consider it to be 'normal.' In most studies contact tightness is qualitatively evaluated by the resistance in passing dental floss through the proximal contact, resulting in the qualifications 'open,' 'weak,' or 'strong.'[43] The intra- as well as the inter-individual variability is very large, and therefore it is not possible to define the 'normal' proximal contact tightness in a quantitative way.[44] To obtain a tight proximal contact with Class II resin composite restorations, the clinical procedure has to compensate for the thickness of the matrix as well as the polymerization shrinkage of the resin composite. One of the techniques recommended to achieve a tight proximal contact with resin composite restorations is the 'pre-wedging' or 'multiple wedging' technique.[45] A wooden wedge is firmly pressed into the interdental space before cavity preparation and is kept in place during preparation. When the restoration is placed, pressure with a hand instrument can also be applied on the inside of the matrix band against the adjacent tooth surface while one is polymerizing the first layer. However, compared to the use of separation rings, the separation obtained with the single insertion pre-wedging technique is negligible.[46] This was also confirmed in several clinical studies[44,47,48] showing that regardless of the type of

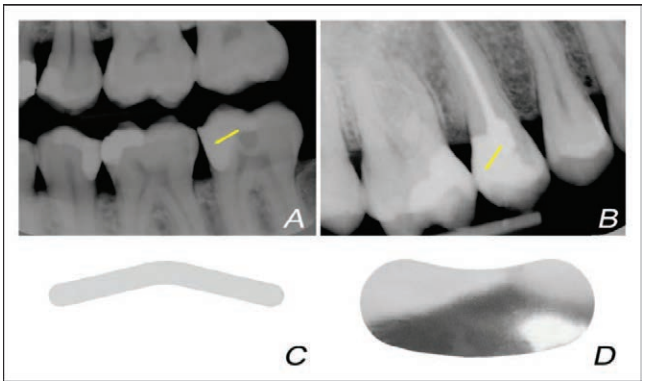

Figure 2. *The use of a flat circumferential matrix may lead to abnormally small or enlarged interproximal areas that are more prone to food impaction. Pre-contoured (sectional) matrix bands may be advantageous, as they result in more anatomically shaped interproximal contours.*

matrix involved, use of separation rings in the reconstruction of proximal contacts of Class II resin composite restorations resulted in significantly tighter and more reliable proximal contacts. Separation can also be significantly enhanced with a multiple wedging technique in which pressure is reapplied to the wedge after initial insertion.[49] Regardless of the pre-wedging technique utilized, wedges also apically displace the interproximal papilla and rubber dam, protecting the gingival tissues and minimizing blood in the operative field. In addition, wedges are still indispensable to obtain a proper cervical adaptation of the matrix to the tooth.

Interestingly, it was also found[50] that the proximal contacts of posterior resin composite restorations were stronger than before treatment began, although this effect tended to diminish after a six-month period, even though the contacts remained tighter than before treatment. Moreover, it was found that those proximal contacts that were weaker than before treatment remained almost unchanged after a six-month period.

In addition to the tightness of the contact, the shape of the proximal contour may also be regarded as an important clinical factor. Use of flat matrix bands without pre-contour will result in abnormal small or enlarged interproximal areas that are more prone to food impaction (Figure 2). Therefore, pre-contoured matrix bands may be advantageous, as they have also been shown[51] to result in improved strength of the marginal ridge of Class II restorations compared to the flat proximal shape.

For 'standard' two- (MO/DO) or three- (MOD) surface restorations, sectional matrix bands in combination with separation rings are the first choice (Figure 3). However, in cases in which the preparation is more extended to the buccal or palatal side, it becomes more difficult to place the sectional matrix bands and separation rings. A possible solution is to divide the restorative procedure into two separate steps using different matrix systems aiming to simplify the cavity design to a standard MO/DO/MOD-cavity design. When the preparation is extended to the buccal or palatal side of the tooth, first a circumferential matrix can be placed to obtain a proper cervical adaptation, allowing application of the adhesive, and to place the resin composite at the buccal or palatal side, without restoring the proximal areas. Now that the preparation is simplified, sectional matrices with separation rings can be placed, after which the restoration is finished.

Preparations with the cervical cavomargin below the cementoenamel junction also present a complex situation. With standard matrix bands (circumferential and sectional) a limited depth can be reached in the cervical area, resulting in an inadequate adaptation of the matrix band to the cervical cavomargin. The use of special matrices may facilitate the restoration of these complex situations, and special matrix bands are available with cervical extensions (eg, Tofflemire matrix band #2 [Produits Dentaire SA, Vevey, Switzerland] or Contact Matrix Subgingival matrices [Danville Materials, San Ramon, CA]). An alternative is the use of the curved matrix (Greater Curve Tofflemire Bands, OH), which enables a good adaptation in the deep cervical areas. After placement of the deepest part of the restoration, this matrix is removed, and a 'standard' matrix band (circumferential or sectional) is placed to finish the second part of the resin composite restoration (Figure 4).

Another option to obtain controlled access to extended and subgingival preparations is a "mini-flap" to provide gingival retraction adjacent to deep cervical areas (Figure 5).[52,53] A mini-flap, so designated because the incision is limited in extent and is typically confined to keratinized tissue, and normally includes a facial and/or lingual marginal incision that extends mesially and distally beyond the area requiring improved access. If needed, vertical releasing incisions can be made to improve tissue retraction while preventing tearing of the gingival tissues. If the incisions do not extend beyond the mucogingival junction, the tissues can usually be replaced without the need for sutures.

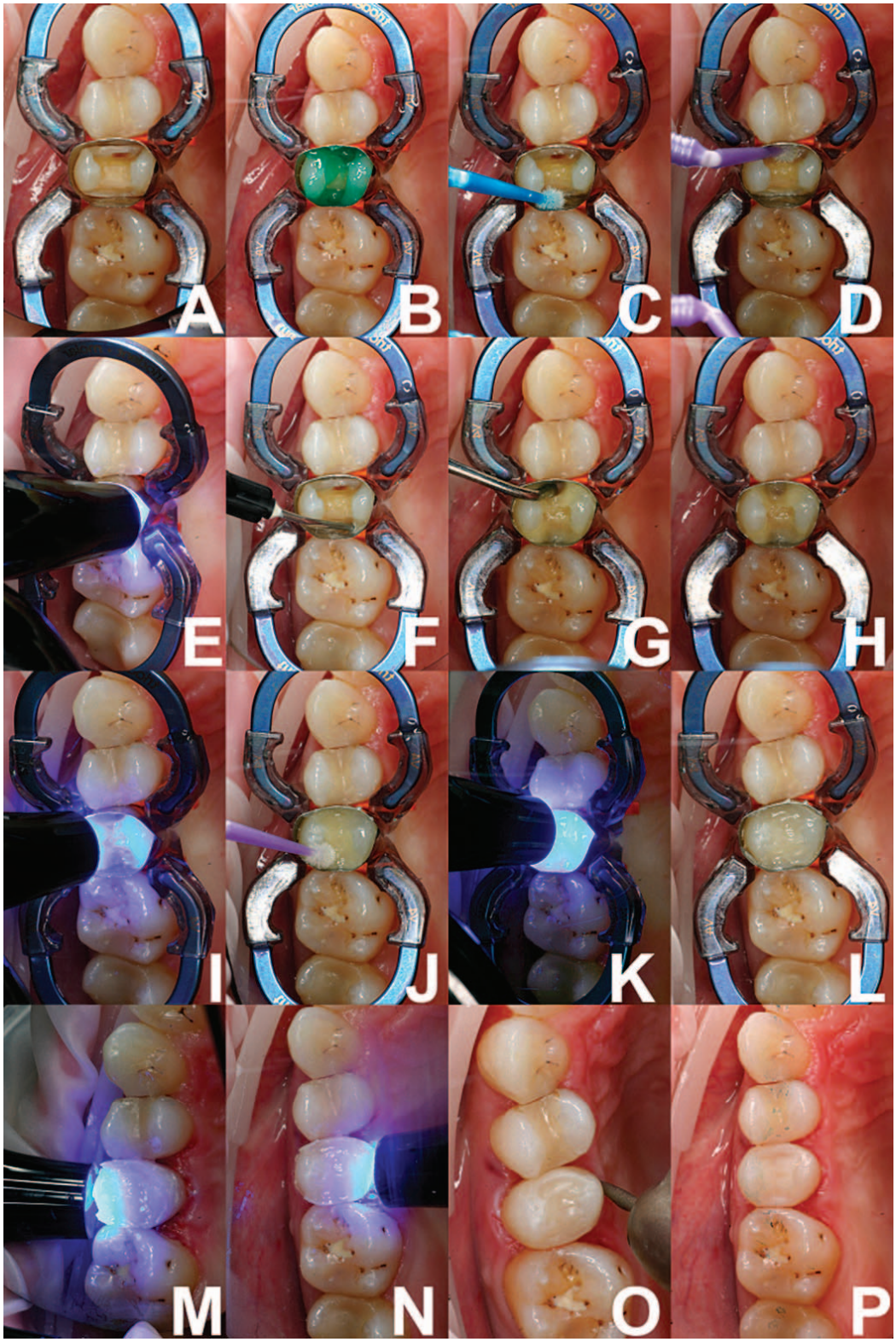

Figure 3. *Procedure of a MOD resin composite restoration using sectional matrices (Contact Matrix System, Danville Materials, San Ramon, CA, USA) in combination with separation rings (V4-Ring Triodent, Katikati, New Zealand). The procedure included a three-step etch-and-rinse technique (Clearfil SA Primer & Photo Bond, Kuraray, Osaka, Japan) and the incremental placement technique of resin composite material (Clearfil Majesty Flow and Clearfil AP-X) using the snowplow technique.*

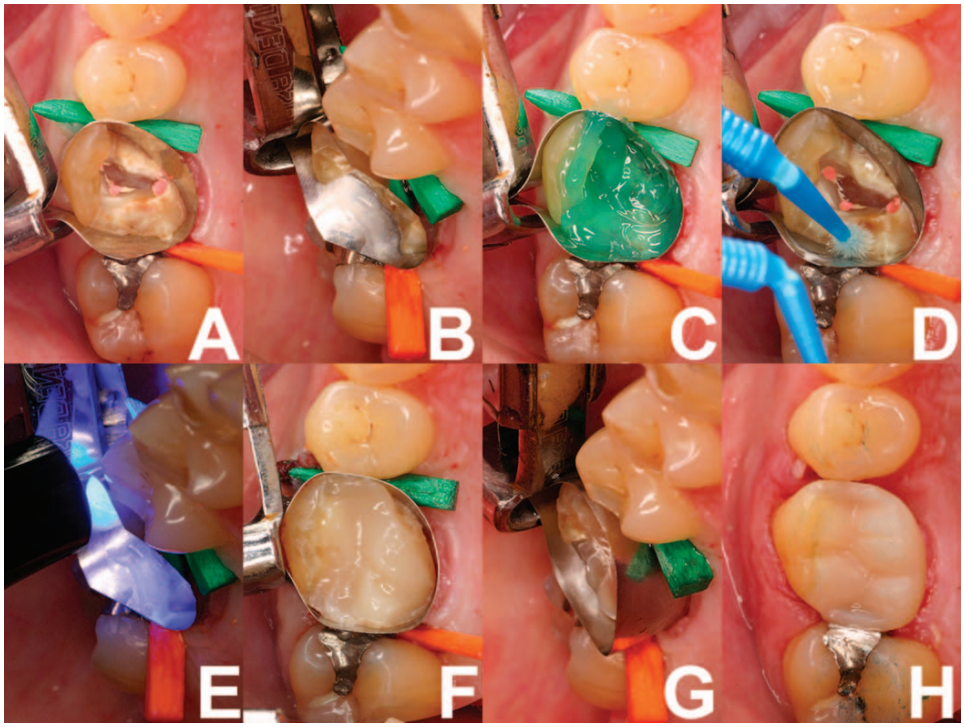

Figure 4. *After preparation, a subgingivally located cavomargin remained. It was decided to restore this preparation in two steps: First, the matrix (Greater Curve Tofflemire Band) secured with wooden wedges was placed. The adhesive procedure was performed, after which the increments of resin composite were applied in the deepest part of the palatal side of the preparation. To obtain an optimal contour of the restoration, the matrix was removed and replaced by a pre-contoured circumferential matrix (Hawe Neos 1001-c, KerrHawe SA, Bioggio, Switzerland). As contamination occurred, the whole adhesive procedure was repeated, and after application of the adhesive the resin composite was applied incrementally and cured. Finally, the restoration was finished and polished.*

DEEP MARGIN ELEVATION

Preferably, cavity margins are located supragingivally, with the margins above the cementoenamel junction (CEJ), but in case of a subgingivally located cavity margin below the CEJ or fractured cusps, traditional techniques are inadequate and are not always applicable. A technique that can be used to facilitate moisture control in these complicated situations is the Deep Margin Elevation or Proximal Box Elevation,[54-56] which offers the possibility of reconstructing step-wise deep proximal margins in order to relocate the cavity margin. The first step is to relocate the cavity margin coronally, after which, in the second step, an indirect restoration can be placed. After relocation of the cervical margin, moisture control is obtained with rubber dam and a controlled placement procedure of an indirect ce-

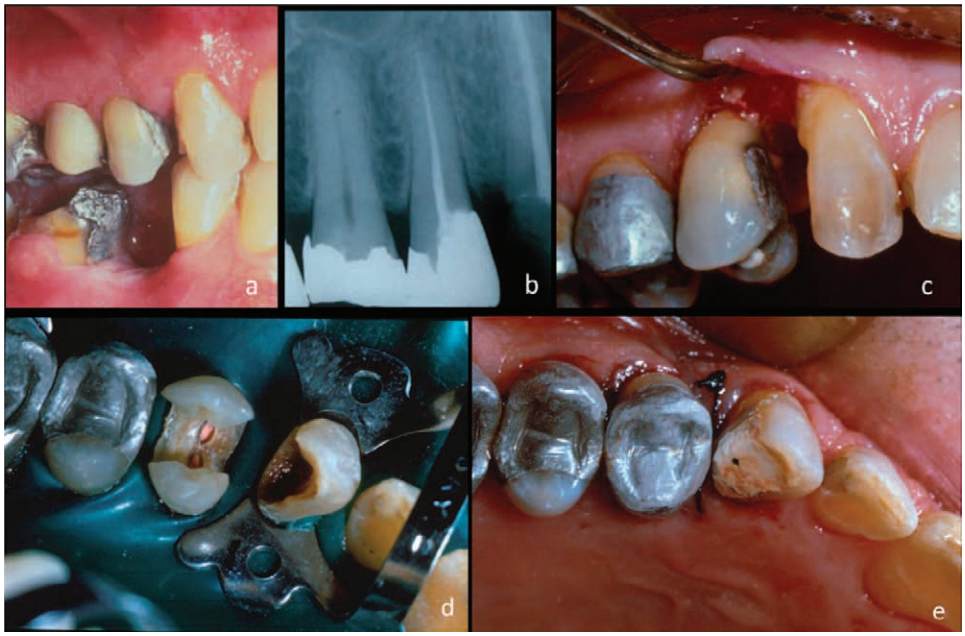

Figure 5. *Mini-flap: (a) Preoperative photo showing tooth #5 MOD amalgam restoration with a deep mesial subgingival margin. Temporary restoration in occlusal surface is where endodontic access was prepared. (b) Radiograph of tooth #5 shows successful endodontic treatment. Mesial margin approximates osseous crest. (c) Facial-lingual mini-flap. Tissue retraction is limited to the keratinized tissue but provides excellent access to mesial restoration margin. (d) Operative field isolated with rubber dam. Note that despite location of deep mesial margin and execution of mini-flap the rubber dam provides complete isolation and accessibility of what once was the deep subgingival margin. (e) Amalgam build-up completed; single suture placed in interdental papilla.*

ramic or resin composite restoration is possible.[57] However, there is some *in vitro* evidence that the proximal box elevation technique may lead to increased gap formation compared to luting the restoration directly to the dentin.[55] Moreover, because of the location and tooth/root morphology of defects requiring consideration for deep margin elevation, moisture control may be difficult or impossible to achieve so as to avoid contamination during bonding procedures. In addition, the reader must be cautioned that there are no clinical studies of even minimal duration demonstrating the viability of this technique.

CLINICAL RECOMMENDATIONS

In the clinical procedure of an extended posterior resin composite restoration, some clinical recommendations may be given:

- Obtain a proper control over the working field by using, ideally, a rubber dam, or if that is not possible, by using cotton rolls with a saliva ejector.
- Use 'gold standard' materials for the adhesive procedure and composite material.
- Sectional matrices in combination with separation rings are the key to success for proximal contact reconstruction in a Class II resin composite restoration.
- Simplify complex and extended cavities into standard cavity design by making use of multiple circumferential and sectional matrix systems.

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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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

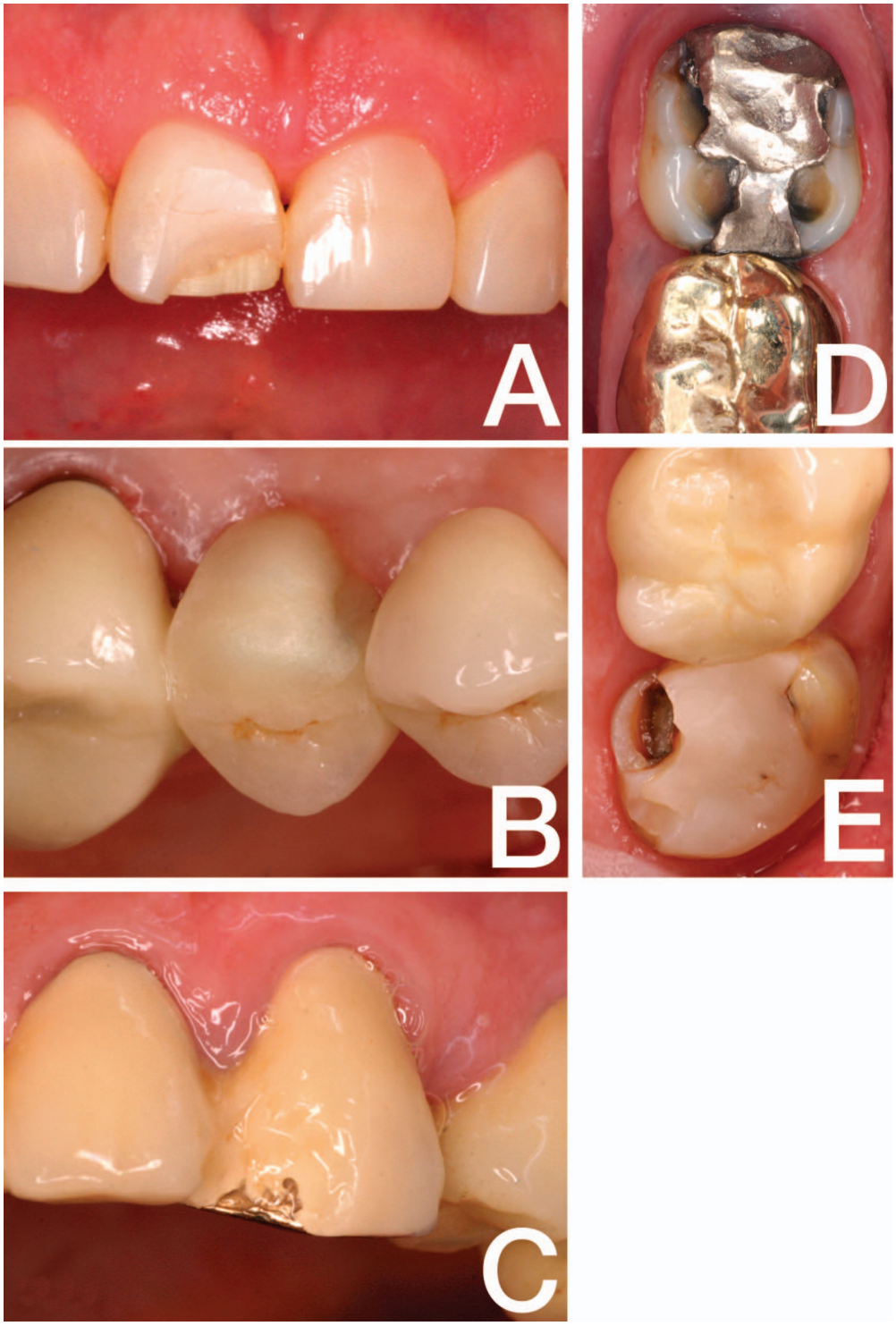

Figure 1. *(a): Cohesive failure of a composite restoration. (b): Cusp fracture next to a large composite restoration. (c): Marginal fractures next to an amalgam restoration. (d): Fracture of a metal-ceramic bridge, exposing framework. (e): Bulk fracture of the veneering ceramic on the pontic of a metal-ceramic 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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Restoration Survival: Revisiting Patients' Risk Factors Through a Systematic Literature Review

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Clinical Relevance

An objective description of patients' factors should become available in clinical studies, since their contribution to restoration survival cannot be ignored and may assist clinical decision making in challenging situations.

SUMMARY

A literature review was conducted to investigate the influence of patient-related factors on restoration survival in posterior permanent teeth as well as to report the methods used to collect these factors. The selection of articles on longitudinal clinical studies investigating the survival of posterior restorations (except full crowns and temporary fillings) and including patient-related factors was performed by applying predefined criteria. The review was organized into two parts, the first describing how patient factors were assessed in the studies (n=45) and the second presenting the statistical significance (n=27) and size of the effect (n=11) of these factors on restoration survival. Patient-related factors mentioned in the studies included age; gender; caries risk; caries activity/severity; decayed, missing, filled teeth; number of restorations; oral hygiene; and bruxism, among others. Sixteen studies included the patient age or age range in the analysis, which was found to be significant in 47% of the studies. Regarding gender, four of 17 reports found a significant effect on survival, showing more failures for men in three studies. The caries risk profile or related variables were included in the analysis of 15 studies, and a significant effect on survival was reported for high-caries-risk individuals (or related variables) in 67% of these studies. Bruxism was also found to influence restora-

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tion survival in three of six studies where this variable was investigated. Some issues were found regarding the reporting of methods used to classify patients according to risk and were thoroughly discussed. In view of the information gathered in this review, the assessment of patient factors along with other variables should become part of clinical studies investigating restoration survival, since several of these factors were shown to influence the failure of restorations, regardless of the material type.

INTRODUCTION

Even though a decrease in the worldwide prevalence of caries has been observed, untreated dental caries in permanent teeth is highly prevalent, affecting about 35% of the world population,[1] especially in posterior teeth. There are several different options to perform posterior restorations, including direct materials (amalgam, composite) and indirect materials (composite, ceramic, metal). The selection, by the clinician, for a particular material and technique to restore posterior teeth may be influenced by the dentist's personal preferences and skills, patient requests and financial resources, and country policies, among others.[2-5] Considering this background information, the decision is ultimately based in the belief of providing the most appropriate and long-lasting treatment according to the patient's needs.

However, the precise indication of the treatment modality, verified through long-term survival of restoration and tooth, is hard to establish based on high-quality evidence.[6] Also, clinical trials investigating the survival of restorations are frequently focused in the comparison of materials or technical procedures,[7-9] while other factors that are crucial for clinical decision making are scarcely examined. The selection of patients to comply with the inclusion/exclusion criteria gives these studies high internal validity but low external validity, making results more difficult to be translated to the daily clinical practice.[10] Regardless of material/technique, in some clinical studies in which patients were not particularly selected for inclusion, it was observed that failures were related to certain patients.[11-14] Patient-related factors such as caries risk and bruxism have been associated with the main reasons for failure for composite resin restorations in posterior teeth[10] and were found to influence restoration survival in retrospective studies.[15,16] Likewise, when examined, patient-related factors seem to negatively affect the survival of other restorative procedures, including ceramic and amalgam restorations.[17-21] Thus, investigations on restoration survival should include patient factors in the analysis to assist with the process of basing clinical decision making on more predictable outcomes and also for patient awareness.

On the other hand, determining the effect of patients and their related variables presents several difficulties. Straightforward variables such as gender; age; and decayed, missing, and filled teeth (DMFT) can be easily collected, whereas others, such as caries risk and bruxism, may heavily depend on the collection method and criteria applied. Therefore, the aims of the present review were to investigate the influence of patient-related factors on restoration survival as well as to report the methods used to collect these factors.

METHODS AND MATERIALS

Search

The search for articles was performed in PubMed/Medline, Scopus, and Cochrane Library databases. The search strategy was constructed by using controlled vocabulary and free terms around the terms *dental restoration*, *amalgam*, *composite resin*, *inlays*, *onlay*, *survival*, *longevity*, *dental restoration failure*, *posterior teeth*, *clinical trial*, *clinical evaluation*, *longitudinal study*, *retrospective study*, and *follow-up*. The search was performed in April 2014, and an automatic update was scheduled in the PubMed database up to the completion of this review, in April 2015.

Eligibility Criteria

For inclusion, full-text articles published in English, with the characteristics presented below, were considered:

- Longitudinal clinical studies, prospective and retrospective
- Posterior permanent teeth
- Direct and indirect restorations, class I, class II, inlay, onlay, overlay, and partial crown
- Amalgam, composite resins (direct and indirect), ceramics
- Three-year minimum follow-up period
- Information regarding patient factors (caries risk, bruxism, DMFT, etc) of the study population, including the criteria applied and/or the effect of patient factors (age, gender, caries risk, bruxism, DMFT, etc) on restoration survival

- Outcome: Cumulative restoration survival (percentage) or annual failure rate (AFR%) or information in text to allow the calculation (number of restorations evaluated and failed/replaced/repaired for a given period of time; life tables)

Studies not presenting the above-mentioned characteristics or presenting different outcome measurements (eg, median survival time) were not considered for this review. Studies presenting the above-mentioned characteristics and also including anterior teeth, primary teeth, post systems, full crowns, or different restorative materials were excluded if the outcome was not reported separately.

Study Selection

All retrieved titles were stored and managed in EndNote X7 software (Thomson Reuters, San Francisco, CA, USA). The articles identified in all databases were screened for duplicates that were automatically excluded. Titles and abstracts were screened by two reviewers (F.H.S., K.C.) independently. If the abstract was missing, the full-text article was subjected to appraisal. Disagreements were identified and discussed until a consensus was reached. References of eligible articles and reviews on restoration survival were hand searched to detect other potential studies of interest, which were screened in the same way.

Evaluation

The articles meeting the inclusion criteria were subjected to critical appraisal, which was carried out by one reviewer (F.H.S.) and checked by another (K.C.). Data were extracted using a pilot-tested table, in duplicate, and included country, clinical setting, study design, follow-up period, number of patients included, drop out, patient-related factors, number of operators, number of restorations originally included and followed, restorative material type, cavity design or number of restored surfaces, tooth, survival/AFR%, factors influencing restoration survival, size of the effect of patient-related variables, and statistical analysis performed. The survival/AFR% was either extracted from the article or calculated by the authors of this review according to information given on live tables or on length of follow-up and number of restorations evaluated and failed. To estimate the mean AFR% of the restorations, the following formula was applied: $(1 - y)z = (1 - x)$, in which y expresses the AFR and x the total failure in z years.[22]

Data Synthesis and Management

Data collection was organized into two separate parts for analysis. First, articles reporting on patient-related factors were searched for the criteria applied to classify the individuals into groups. This information was organized into one table according to the reported patient factors. For the second part, only studies that included patient factors in the analysis of the outcome (restoration survival, failure rate/failure distribution) were selected. Detailed information of these studies was organized into tables, including the significance of all investigated variables and the size of the effect for patient-related variables (when available). Some of the included studies had data on restorations placed in anterior teeth, primary teeth, and full crowns. In such cases, the extraction of data for the present review did not include those samples.

RESULTS

In total, 1048 titles were found in PubMed, 2186 in Scopus, and 40 in Cochrane Library, resulting in 3274 records identified in the databases, of which 366 were duplicates that were removed. After title and abstract screening, 239 full-text articles were assessed for eligibility, resulting in 51 studies included for data extraction. Forty-five articles included the assessment of patient factors and were selected for the first part of the review, and 27 of these studies included the analysis of patient factors in the outcome and qualified for the second part of the review.

Methods to Assess Patient Risk (Part 1)

Studies addressing patient-related factors and the methods used by the authors to assess the individuals are described in Table 1 and included caries risk, caries activity, caries severity, number of restorations, oral hygiene or oral health, salivary parameters and bacterial levels, bruxism/parafunctional habits, erosion, periodontal status, attrition of the tooth structure, and smoking habits. Twenty-six studies reported to have assessed the caries risk of the patients, which was based, in most of the reports, in the present/past caries experience.[15,16,22-33,36,42,43] Objective parameters for defining the caries risk profile were often set according to the number of new caries lesions leading to restorations in a definite period of time. In this sense, a high caries risk was established when one or more new lesions occurred per year in Opdam and others (2010)[22] or two or more in a three-year period in van de Sande and others (2013).[15] In Jokstad and Mjor (1991)[42] and

Table 1: *Description of Methods Presented in the Studies Regarding the Assessment of Patient Factors*

Caries Risk	
Opdam and others (2007),[16] van Dijken (2003),[23] van Dijken (2010),[24] van Dijken and others (1999),[25] van Dijken and Lindberg (2009),[26] van Dijken and Pallesen (2011),[27] van Dijken and Pallesen (2013),[28] van Dijken (2013),[29] van Dijken and Sunnegardh-Gronberg (2005),[30] van Dijken and Sunnegardh-Gronberg (2006),[31] Sjogren and others (2004),[32] Lindberg and others (2007),[33] Andersson-Wenckert and others (2004),[34] Van Dijken and Sunnegardh-Gronberg (2005)[35]	The caries risk for each patient at baseline was estimated by the treating clinician by means of clinical and sociodemographic information routinely available at the annual clinical examinations (eg, incipient caries lesions and former caries history)
Fasbinder and others (2005)[36]	At baseline: number of restorations the patient reported having received in the previous 12 mo; low caries risk, $\leq$1; moderate caries risk, 2 and 3; and high caries risk, $\geq$4
Laegreid and others (2012)[37]	Patient-related factors such as general health; dietary habits; decay, missing, filled teeth; oral hygiene; saliva (quality, quantity); and use of fluoride were measured and given a score according to a predetermined scale and then entered into Cariogram. Then, they were categorized according to severity: very high, high, medium, low, and very low caries risk corresponding to 0%–20%, 29%–40%, 41%–60%, 61%–80%, and 81%–100% chance of avoiding caries.
Opdam and others (2010)[22]	The history of new lesions over the entire period was assessed by the clinician. Patients arriving in the practice with caries lesions but who in subsequent years did not show high caries activity were assessed as "low risk." Patients who continued to show, yearly, one or more new caries lesions during the entire period were assessed as "high risk."
van de Sande and others (2013)[15]	Based on the patient history. In the first 3 y after placement of the restoration, the records were inspected for the presence of a new caries lesion detected from bitewing radiographs and resulting in placement of a restoration. When more than one of these events happened in the three-year period after restoration placement, the patient was assessed as high caries risk. In all other cases, the patient was assessed as low risk.
van Dijken (2000),[13] van Dijken (1991),[38] van Dijken (1994),[39] van Dijken and others (1998),[40] Aberg and others (1994)[41]	Evaluation of six negative factors. Oral hygiene- plaque score or gingival bleeding on more than 30% of the tooth surfaces. Intake of fermentable carbohydrates with a mean of six times or more per day, registered during four days. The presence of more than 2.5×10^5 CFU/mL saliva of *Streptococcus mutans* or 10^5 CFU/mL saliva of lactobacilli. Buffer values of 5.5 or lower and a flow rate of 0.7 mL/min or less. Patients with three or more negative factors were considered at high caries risk.
Caries activity	
Jokstad and Mjor (1991)[42]	Based on the incidence of primary or secondary caries during the first eight years of the trial period. Low caries activity: $\leq$0.5 new restorations per year; high caries activity: $\geq$two new restorations per year.
Nordbo and others (1998)[43]	Based in radiographs and dental records. High activity: >two new lesions per year.
Suni and others (2013)[44]	Patients were divided into caries-active and caries-resistant persons according to their past caries experience in any of the first molars before age eight (caries prone) or after 10 years (caries resistant), with the rest forming an intermedial group.
Caries severity	
Kopperud and others (2012)[45]	Primary caries grades: 1 = radiolucency confined to the outer half and 2 = the inner half of the enamel; 3 = radiolucency confined to the outer third, 4 = to the middle third, or 5 = to the inner third of the dentin
Number of restorations	
Kubo and others (2011)[46]	Retreatment risk: clinical history at the last visit, low (no restorations placed during the past 3 y), medium (one or two restorations placed during the past 3 y), and high (three or more restorations placed during the past 3 y)
Opdam and others (2007),[47] Pallesen and others (2013)[48]	Number of restorations per patient during a defined period of time
Soncini and others (2007)[49]	Number of restorations
Oral hygiene or oral health	
Al-Samhan and others (2010)[50]	The presence of plaque was determined on teeth surfaces by a staining solution. The patients' oral hygiene was determined as good or poor based on their plaque score; 30% or above (note the authors probably meant 30% or below) was considered as having good oral hygiene.

Table 1: *Description of Methods Presented in the Studies Regarding the Assessment of Patient Factors (cont.)*	
Adolphi and others (2007)[51]	Visible plaque was expressed as affected surfaces in percentage
Kopperud and others (2012)[45]	Defined as poor, medium, or good according to the dentist's clinical judgment
Pallesen and Qvist (2003)[52]	Oral hygiene habits were self-reported in interviews
Smales (1993)[53]	Poor oral health: extensive dental plaque, gingivitis, and caries
Salivary parameters; bacterial levels	
Kohler and others (2000)[54]	Saliva sampling: secretion rate and the level of mutans streptococci and lactobacilli. The subjects were divided into four mutans streptococci levels: $<10^5$, $>10^5$–5×10^5, $>5 \times 10^5$–10^6, and $>10^6$ CFU/mL saliva. The lactobacilli levels were divided into three groups: $<10^4$, $>10^4$–10^5, and $>10^5$ CFU/mL saliva.
Rasmusson and others (1998)[55]	Saliva sampling: secretion rate and the level of lactobacilli. The lactobacilli levels were divided into three groups: $<10^4$, $>10^4$–10^5, and $>10^5$ CFU/mL saliva.
Pallesen and Qvist (2003)[52]	At recall visits (2–5 y), secretion rate, pH, and buffer capacity of resting saliva were measured.
Bruxism, parafunctional habits	
Adolphi and others (2007)[51]	Signs of bruxism
Beier and others (2012)[56]	Self-reporting by direct questions and inspection of clinical signs consistent with past bruxism behavior from the presence of clear wear facets caused by clenching, gnashing, and grinding activities of the teeth not interpreted to be a result of masticatory function
Pallesen and Qvist (2003)[52]	Presence of bruxism was self-reported in interviews.
Smales (1993)[53]	Extensive tooth wear (obvious evidence of bruxism)
Smales and Etemadi (2004)[57]	Evidence of parafunction was collected from dental records. Authors stated that occlusal splints were generally made for patients when multiple onlays were placed or parafunctional habits were obvious, as shown by matching facets on extensively worn opposing teeth and the enlargement of masseter muscles.
van de Sande and others (2013)[15]	Self-reporting by six direct questions and clinical signs of bruxism were visually inspected (wear facets, loss of contour, dentin exposure). Patients were classified as having high occlusal stress risk when answered positively on two or more questions and presented at least one of the clinical parameters. In other cases, they were classified as low risk.
van Dijken (2013)[29]	Bruxism was estimated as low or high by the treating clinician by means of clinical signs and history at the annual examinations.
Zimmer and others (2008)[58]	In addition to personal data, the presence of bruxism by wear facets was noted.
Erosion	
Adolphi and others (2007)[51]	Presence of erosion
Periodontal status	
Adolphi and others (2007)[51]	Periodontal health was dichotomized to healthy/nonhealthy; patients with probing depths more than 4 mm were assigned to the "periodontally nonhealthy" group.
Attrition of the tooth structure	
Felden and others (2000)[59]	0 = no attrition; 1 = attrition of enamel, cusps still visible; 2 = dentin is exposed; 3 = occlusal relief is worn away leaving enamel periphery; 4 = crown worn down close to collum dentis. Patients with zero and one degree were summarized as being patients with no attrition; at least one tooth with two, three, and four degrees was summarized as patients with attrition. For each patient, the number of teeth with attrition (degrees two, three, and four) was related to the overall number of teeth scored. This was termed a *percentage of attrition*. Patients were assigned to five groups according to the percentage of attrition.
Smoking habits	
Smales (1993)[53]	Heavy smoking—more than 20 cigarettes a day

Abbreviation: CFU, colony-forming unit.

Nordbo and others (1998),[43] a high caries risk was determined when two or more lesions occurred per year, while in Fasbinder and others (2005),[36] the placement of four or more restorations in the previous year should have been reported by the patient. In several articles, the caries risk was reported to have been estimated by the treating clinician by the evaluation of clinical information regarding incipient caries lesions and former caries histories as well as sociodemographic data.[16,24-35] The study of Laegreid and others (2012)[37] was the only one reporting the use of a caries-risk assessment computer software tool (Cariogram Program[60]) to classify the patients into risk groups. Although not using a specific tool, van Dijken (1991,1994),[38,39] van Dijken and others (1998),[40] Aberg and others

(1994),[41] and Pallesen and Qvist (2003)[52] reported a number of indicators that were taken into account to determine the caries risk, such as oral hygiene, intake of fermentable carbohydrates, salivary microbial counts, salivary flow rates, and buffer values. In these studies, patients presenting three or more out of six negative factors were assessed as high caries risk. Other variables that can be related to the caries risk of the patient were also used, such as DMFT/DFT,[19,45,61] number of total or new restorations per patient,[46-49] caries severity,[45] caries experience at earlier ages,[44] salivary parameters, and microbiologic counts.[54,55]

The assessment of bruxism or parafunctional habits in the study populations was mentioned in nine reports.[15,29,51-53,56-58,62] When stated, the methods used to estimate this condition were based in the examination of clinical signs (eg, wear facets)[15,29,53,56,58] and by self-report questionnaires.[15,52,56]

Gender was investigated in several reports,* as well as was the age or age range of the patients.† A few other patient-related factors were mentioned in the studies with lower frequencies, namely, erosion and periodontal status,[58] attrition,[59] oral health, oral hygiene or plaque levels,[45,51-53,63] socioeconomic status,[49] and smoking habits.[53]

Effect of Patient Risk Factors in Restoration Survival (Part 2)

Characteristics of the Studies—The effect of patient-related variables on survival of restorations, along with other variables, was investigated in 27 studies. General characteristics of the studies are presented in Table 2, and detailed information is presented in Table 3. Studies were grouped according to the restorative material used and included amalgam (six studies),[19,42,53,64,68,69] amalgam and composite resin (three studies),[22,47,49] composite resin (10 studies),‡ sandwich restorations (two studies),[16,34] and ceramics (six studies).[56-58,62,65,66] Most studies (21) were undertaken in European countries, and 52% (14) were prospective trials. Regarding the clinical setting, 10 studies were undertaken in private clinics, seven in faculty clinics, five in public dental health facilities, one in a dental school, one in the dental clinic of a defense agency, and two in more than one type of clinical facility. The quality/failure of restorations was assessed with the criteria for the clinical evaluation of dental restorative materials for use by the United States Public Health Service (USPHS), or modified USPHS (11), the standards of quality of dental care used by the Californian Dental Association (1), clinical history extracted from patients' files (5), other predefined clinical criteria (4), and the association of methods (6), for example, by using the Fédération Dentaire Internacionale clinical criteria for the evaluation of restorations and the clinical history. The restorations were placed in both premolar and molar teeth in most of the investigations (23), filling small, moderate, and extensive cavities. One study included practically only premolar teeth (98%),[48] and three others included exclusively molars (Table 2).[37,68,69]

The follow-up times are presented in Tables 2 and 3. The first refers to the maximum period to which restorations were followed, and in Table 3, the follow-up is given according to the period used in the survival analysis (survival%; AFR%) in the original article or the period was selected by the authors of this review, taking into account the number of restorations remaining in life tables in one case.[53]

Regarding the size of the studies (Table 3), two were large prospective trials undertaken in public dental health centers, with high numbers of patients (1873[45] and 2881[48]), restorations (3286[45] and 4355[48]), and operators (27[45] and 115[48]) involved. The dropout of patients ranged from 0[49] up to 41%,[42] and in most prospective studies, dropouts varied between 8 and 22%.[34,46,54,58,61,62,64,65] Concerning the age group of the participating patients, several studies (21) had a wide age range. The studies of Roberts and Sherriff (1990),[69] Soncini and others (2007),[49] and Pallesen and others (2013)[48] included only children[49] or children and adolescents.[48,69]

Effect—Regarding the statistical method in the studies, information was retrieved concerning the use of univariate or multivariate data analysis (Table 4). Statistical significance of all investigated variables (yes/no) in each study is shown in Table 4. The size of the effect (odds ratio/hazard ratio) for patient-related variables is displayed in Table 5 from available studies.

Sixteen studies included the patient age or age range in the analysis, which was found to be significant in 47% (seven) of the studies.[42,45,48,50,53,67,68] Pallesen and others (2013)[48] investigated several variables influencing the survival of class I and II composite restorations in a

* References 15, 16, 19, 42, 45-50, 56, 60, 62-67.

† References 15, 16, 19, 37, 42, 44-50, 53, 54, 65, 67-70.

‡ References 15, 37, 45, 46, 48, 50, 54, 61, 63, 67.

Table 2: *General Characteristics of Selected Studies According to the Investigated Materials*

	Country	Clinical Setting	Study Design	Time	Evaluation	Cavity	Teeth
Amalgam							
Gilthorpe and others (2002)[19]	UK	Defense Dental Agency	R O Historical cohort	16	Clinical history	Class I, II and complex	PM, M
Gruythuysen and others (1996)[64]	NL	Faculty Practice	P E Cohort	15	Defined clinical criteria	Conservative class II	PM, M
Jokstad and Mjor (1991)[42]	DK, FI, NO, SE	Private, public dental health, and faculty practice	P E Cohort	10	USPHS	Class II	PM, M
Plasmans and others (1998)[68]	NL	Faculty practice	P E RCT	9	Defined clinical criteria, clinical history	Class II, cusp coverage $\geq$1	M
Roberts and Sherriff (1990)[69]	UK	Private practice	P O Cohort	5	USPHS	Class I and II	M
Smales (1993)[53]	AU	Dental hospital	P E Cohort	15	Defined clinical criteria	Class I and II	PM, M
Amalgam/composite resin							
Opdam and others (2010)[22]	NL	Private practice	R O Historical cohort	12	Clinical history	Large class II	PM, M
Opdam and others (2007)[47]	NL	Private practice	R O Historical cohort	10	Clinical history	Class I and II	PM, M
Soncini and others (2007)[49]	US	Nonprofit health centers	P E RCT	5	Clinical criteria	Small, medium, large	PM, M
Composite resin							
Al-Samhan and others (2010)[50]	KW	Dental school	R O Historical cohort	3	USPHS	Class I and II	PM, M
Baldissera and others (2013)[63]	BR	Private practice	R O Historical cohort	20	Clinical history, FDI	Class I and II	PM, M
Bottenberg and others (2009)[67]	BE	Faculty practice	P E RCT	5	USPHS-m	Class II	PM, M
Kohler and others (2000)[54]	SE	Public dental health	P E Cohort	5	USPHS	Class II	PM, M
Kopperud and others (2012)[45]	NO	Public dental health	P E Cohort (PBR)	5	Clinical criteria	Saucer-shaped and class II	PM, M
Kubo and others (2011)[46]	JP	Faculty practice	R O Historical cohort	10	Clinical history, USPHS-m	Class I and II	PM, M
Laegreid and others (2012)[37]	NO	Faculty practice	P E Cohort	3	USPHS-m	Extensive class II	M
Lundin (1990)[61]	SE	Public dental health	P E Cohort	3	USPHS	Small or moderate class II	PM
Pallesen and others (2013)[48]	DL	Public dental health	P O Cohort (PBR)	8	USPHS-m	Class I and II	PM, M
van de Sande and others (2013)[15]	BR	Private practice	R O Historical cohort	18	Clinical history, FDI	Class I and II	PM, M
Composite resin/closed sandwich							
Opdam and others (2007)[16]	NL	Private practice	R O Historical cohort	9	Clinical history	Class II	PM, M
Open sandwich							
Andersson-Wenckert and others (2004)[34]	SE	Two dental clinics	P E Cohort	6	USPHS-m	Extensive class II	PM, M
Ceramic							
Beier and others (2012)[56]	AT	Faculty practice	R O Historical cohort	21	USPHS-m	Inlay/onlay	PM, M
Otto and Schneider (2008)[65]	CH	Private practice	P O Cohort	17	Clinical history, USPHS-m	Inlay/onlay	PM, M
Schulz and others (2003)[66]	SE	Private practice	R O Historical cohort	9	CDA	Inlay	PM, M
Smales and Etemadi (2004)[57]	AU	Private practice	R O Historical cohort	6	Clinical history	Onlay	PM, M
van Dijken and Hasselrot (2010)[62]	SE	Public dental health, faculty practice	P O Cohort	15	USPHS-m	Partial crown	PM, M
Zimmer and others (2008)[58]	DE	Private practice	R O Historical cohort	10	Clinical history, defined clinical criteria	Class I and II	PM, M

Abbreviations: CDA, Californian Dental Association evaluation criteria; E, experimental; FDI, Fédération Dentaire Internacionale evaluation criteria; M, molar; PM, premolar; O, observational; P, prostective; PBR, practice-based research; R, retrospective; RCT, randomized controlled trial; USPHS, United States Public Health Service evaluation criteria; USPHS-m, modified USPHS.

Table 3: *Information Regarding the Size of Selected Studies, Patients' Age, Survival (%), and Annual Failure Rate (AFR%)*[a]

	Patients (P)	P Dropout, %	P Age Range	P Mean Age, y	Restorations (R)	R at Last Recall	Operators	Time[b]	Survival, %	AFR%
Amalgam										
Gilthorpe and others (2002)[19]	200	NA	24-31	28	4712	NA	—	12.5	50	5.4
Gruythuysen and others (1996)[64]	183	21	15-40	23	1529	1213	3	15	82	1.3
Jokstad and Mjor (1991)[42]	210	41	8-71	28	468	256	7	10	81	2.1
Plasmans and others (1998)[68]	130	3	17-54	32	300	291	3	8.3	88	1.5
Roberts and Sherriff (1990)[69c]	—	—	5-20	—	652	NA	1	5	78	4.9
Smales (1993)[53c]	105[d]	—	<20->41	—	582	—	1	5	95	1.0
Amalgam[A]/Composite resin[CR]										
Opdam and others (2010)[22]	273	NA	22-77	48	1949	NA	1	12	75[A]; 81[CR]	1.7[CR]; 2.4[A]
Opdam and others (2007)[47]	621	NA	—	—	2867	NA	2	10	79[A]; 82[CR]	1.9[CR]; 2.3[A]
Soncini and others (2007)[49c]	399	0	6-10	8	1262	1262	6	5	85[CR]; 89[A]	2.3[A]; 3.2[CR]
Composite resin										
Al-Samhan and others (2010)[50]	139	NA	13-78	29	432	NA	—	3	95	1.7
Baldissera and others (2013)[63c]	79	NA	24-87	51	374	NA	1	17	66; 95	0.3; 2.5
Bottenberg and others (2009)[67]	32	27	19-56	38	132	77	3	5	81	4.1
Kohler and others (2000)[54]	45	8	11-63	26	63	51	3	5	72	6.3
Kopperud and others (2012)[45e]	1873	29	6-57	15	3286	2396	27	5	88	2.9
Kubo and others (2011)[46f]	77	9	8-82	57	170	155	1	10	58; 90	1.1; 5.2
Laegreid and others (2012)[37]	74	1	31-80	50	74	73	2	3	88	4.2
Lundin (1990)[61]	213	12	14-75	33	242	214	24	3	93	2.2
Pallesen and others (2013)[48]	2881	—	5-18	14	4355	—	115	8	84	2.0
van de Sande and others (2013)[15]	44	NA	25-71	47	306	NA	1	15	70	2.3
Composite resin[CR]/Sandwich[S]										
Opdam and others (2007)[16]	248	NA	18-80	—	458	NA	2	9	71[S]; 88[CR]	1.4[CR]; 3.8[S]
Open sandwich										
Andersson-Wenckert and others (2004)[34]	151	18	14-80	44	268	220	3	6	83	3.2
Ceramic										
Beier and others (2012)[56]	120	—	14-72	46	547	—	2	12	90; 92	0.7; 0.9
Otto and Schneider (2008)[65]	108	18	17-75	37	200	187	1	17	89	0.7
Schulz and others (2003)[66]	52	2	28-79	54	109	107	1	7	85	2.3
Smales and Etemadi (2004)[57]	50	NA	15->51	—	97	NA	2	6	61; 62	6.3; 6.7
van Dijken and Hasselrot (2010)[62c]	121[d]	10	26-81	52	117	—	4	15	66; 82	1.3; 2.8
Zimmer and others (2008)[58]	95	22	22-65	44	308	226	1	10	86	1.4

Abbreviations: AFR%, annual failure rate; NA, not applicable, retrospective studies.
[a] *Underlined information (survival and AFR) represents numbers that were calculated by the authors of this review, using data provided in the article.*
[b] *Follow-up time with regard to survival/AFR analysis.*
[c] *Numbers presented here are only for the variables of interest (excluding anterior teeth, primary teeth, and full crowns). In two studies, the number of patients for the variables of interest could not be determined.*
[d] *Total number of patients involved in the trial is presented.*
[e] *The study included amalgam (4.6%), but the analysis was performed only for resin composite restorations (81.5%), and therefore the extracted data relate to resin composite.*
[f] *Only one operator was included in the analysis, and therefore the extracted data relate to him.*

large sample of children/adolescents. The study reported that among the patient-related factors, only the age range influenced the results, with adolescents showing a hazard ratio of 0.43 compared with younger children (5-11 years; Tables 4 and 5).[48] Also, in Kopperud and others (2012),[45] younger patients at baseline influenced negatively the survival of composite restorations. When age was categorized into over/under 30 years, no effect on composite restoration survival was found in van de Sande and others

(2013),[15] but lower survival rates for amalgam restorations were observed for patients older than 30 years in Plasmans and others (1998).[68] Two studies also reported lower survival rates in patients older than 41[53] and 45 years[50] when compared with other age groups. In this last study, the hazard ratios for patients younger than 15 years and older than 45 years were not significantly different.[50]

Regarding gender, 23.5% (four of 17) reports found a significant effect on survival, showing more failures for men in three studies[37,62,64] and for women in one.[50]

The caries risk profile or related variables (DMFT, number of restorations, and caries severity or activity) was present in the analysis of 15 studies, and a significant effect on survival was reported for high-caries-risk individuals (or related variables) in 66.7% (10) of these studies.[§] These studies included amalgam,[19,22,42,47,49] resin composite,[15,22,45,47-49,54] and sandwich[16,34] restorations. For individuals classified as having high caries risk, the hazard ratio ranged from 2.45 to 4.40 compared with low-risk individuals.[15,16,34] Kubo and others (2011)[46] evaluated the retreatment risk and did not find a significant effect on survival for class I and II composite restorations. In the study by Kopperud and others (2012),[45] no effect of caries severity on survival of class II composite restorations was found, but a higher DMFT score was significantly related to lower restoration survival. The study by Laegreid and others (2012),[37] in which the Cariogram Program was used to estimate the caries risk, reported no effect on survival of extensive composite restorations according to different risk profiles. Also, Lundin (1990)[61] reported that no correlation was found when caries experience (DFT) and failure rates were compared between different composites.

The effect of bruxism or parafunctional habits was significant in three of six reports in which this factor was investigated. Studies reporting a significant effect included amalgam,[53] resin composite,[15] and partial-crown ceramic restorations.[62] Patients presenting high caries risk and bruxism were found to present a hazard ratio of 8.31 compared with low-risk patients in van de Sande and others (2013).[15] The other three studies reported no effect of this variable on survival of inlay/onlay ceramic restorations.[56,57,62]

Bottenberg and others (2009)[67] analyzed the patient as a factor and found a significant contribution of this variable on general failures of composite restorations. Patient oral hygiene had a significant effect on survival of composite restorations in the study of Al-Samhan and others (2010),[50] but the effect of this variable was not significant in the study of Kopperud and others (2012),[45] and neither was oral health significant in the survival of amalgam restorations, as reported by Smales (1993).[53]

§ References 15, 16, 19, 22, 25, 38, 47, 49, 51, 53.

DISCUSSION

The survival of restorations may be affected by a number of variables, and therefore, the inclusion of known factors as well as potential factors into analysis is crucial to determine treatment alternatives and prognosis, according to specific conditions at the tooth level and patients' needs at an individual level. As seen by the dates of the included studies, 10 were published from 2010 on and 11 between 2002 and 2009. So even though previous studies[42,53,61,64,68,69] had reported an influence of patient factors in the survival of restorations, increased attention in research took longer to take place. Yet, as seen in the results of this review, it became clear that there is a lack of standardized methods to assess patient-related factors. Even in studies in which these factors were investigated, there was no uniformity on clinical parameters used, and the description of cutoff points was frequently missing or vague. This is likely due to the difficulty of establishing the relationship between etiological factors and clinical signs and the diagnosis for several conditions in the dental field. Since several factors were addressed in the studies, each holding its own particularities, the discussion is presented under topics, as follows.

Caries

In the caries disease process, multiple risk indicators/predictors may be needed to establish a graded risk status and future caries prediction.[71] Certainly, the collection of several variables is important to correctly identify risk indicators in each patient, guiding preventive and treatment strategies at the individual level.[72] Nonetheless, when investigating restoration survival, the use of simplified measures may provide a good estimate of the disease activity when the restoration is placed and in follow-up evaluations. Visible cavitation or caries into dentin identified by radiographic examination was shown to significantly correlate with several caries risk factors.[73] Caries lesions leading to restorations within a three-year period was one of the correlated items,[73] which is similar to the criteria applied in some of the included studies reporting a significant influence on restora-

Table 4: *Statistical Significance (Yes^{+}/No^{-}) of the Investigated Variables on Restoration Survival and the Statistical Method Applied (ie, Univariate [U] or Multivariate [M] Analysis)*[a]

	Patient factors				
	Age	**Gender**	**Caries**[b]	**Bruxism**	**Others**[c]
Amalgam					
Gilthorpe and others (2002)[19]	−	−	+[d]		
Gruythuysen and others (1996)[64]		+			
Jokstad and Mjor (1991)[42]	+		+		
Plasmans and others (1998)[68]	+				
Roberts and Sherriff (1990)[69]	−				
Smales (1993)[53]	+			+	−
Amalgam/composite resin					
Opdam and others (2010)[22]			+		
Opdam and others (2007)[47]	−	−	+[f]		
Soncini and others (2007)[49]	−	−	+[f]		
Composite resin					
Al-Samhan and others (2010)[50]	+	+			+
Baldissera and others (2013)[63]		−			
Bottenberg and others (2009)[67]	+	−			+
Kohler and others (2000)[54]			+		
Kopperud and others (2012)[45]	+	−	+[d-h]		−
Kubo and others (2011)[46]	−	−	−[f]		
Laegreid and others (2012)[37]	−	+	−		
Lundin (1990)[61]			−[d]		
Pallesen and others (2013)[48]	+	−	−[f]		
van de Sande and others (2013)[15]	−	−	+	+	
Composite resin/sandwich					
Opdam and others (2007)[16]	−	−	+		
Open sandwich					
Andersson-Wenckert and others (2004)[34]			+		
Ceramic					
Beier and others (2012)[56]		−		−	
Otto and Schneider (2008)[65]	−	−			
Schulz and others (2003)[66]		+			
Smales and Etemadi (2004)[57]				−	
van Dijken and Hasselrot (2010)[62]		+		+	
Zimmer and others (2008)[58]				−	
+	*7*	*5*	*10*	*3*	*2*
−	*9*	*12*	*5*	*3*	*3*
Total	*16*	*17*	*15*	*6*	*5*

[a] *The effect for factors presented here are only for the variables of interest (excluding anterior teeth, primary teeth, and full crowns).*
[b] *Caries and other caries-related variables.*
[c] *Others: oral hygiene, Al-Samhan and others (2010)[50] and Kopperud and others (2012)[45]; patient as a factor, Bottenberg and others (2009)[67]; heavy smoking and poor oral health, Smales (1993).[53]*
[d] *Decayed, missing, filled teeth.*
[e] *Number of dentists per patient.*
[f] *Number of restorations per patient.*
[g] *In the three-year analysis.*
[h] *Caries severity.*
[i] *Adhesive system.*
[age] *Age of the operator.*

Table 4: *Statistical Significance (Yes^{+}/No^{-}) of the Investigated Variables on Restoration Survival and the Statistical Method Applied (ie, Univariate [U] or Multivariate [M] Analysis)[a] (ext.)*

	Local Factors					Material	Operator	Statistics
	Tooth	Endodontics	Jaw	Cavity	Technique			
Amalgam								
Gilthorpe and others (2002)[19]	+	+	−	+	−		+[e]	M
Gruythuysen and others (1996)[64]	−		−	+		−	+	U
Jokstad and Mjor (1991)[42]	−		−	−		−	−	M
Plasmans and others (1998)[68]	−		−	−	−	−	−	U
Roberts and Sherriff (1990)[69]				−				U
Smales (1993)[53]				−		−		M
Amalgam/composite resin								
Opdam and others (2010)[22]	−			+		+		U
Opdam and others (2007)[47]				+		−	−	M
Soncini and others (2007)[49]				+		−		M
Composite resin								
Al-Samhan and others (2010)[50]	−		−	−		−	−	M
Baldissera and others (2013)[63]	−		−	+		+		M
Bottenberg and others (2009)[67]						−		U
Kohler and others (2000)[54]	−		−	−	+		−[g]	U
Kopperud and others (2012)[45]	−			+		+	−	M
Kubo and others (2011)[46]	−			+		−[i]		M
Laegreid and others (2012)[37]				−				M
Lundin (1990)[61]						−		
Pallesen and others (2013)[48]	+		+	+	+	−	−[age]	M
van de Sande and others (2013)[15]	+	+	+	−		−		M
Composite resin/sandwich								
Opdam and others (2007)[16]	+			+	+		+	M
Open sandwich								
Andersson-Wenckert and others (2004)[34]				−	−			M
Ceramic								
Beier and others (2012)[56]	−	+		−				U
Otto and Schneider (2008)[65]	+		−	−				U
Schulz and others (2003)[66]	+							U
Smales and Etemadi (2004)[57]					−		−	U
van Dijken and Hasselrot (2010)[62]	−	+	−		-	+[j]		M
Zimmer and others (2008)[58]		−		−		−		M
+	*6*	*4*	*2*	*10*	*2*	*4*	*4*	
−	*11*	*1*	*9*	*12*	*5*	*13*	*8*	
Total	*17*	*5*	*11*	*22*	*7*	*17*	*12*	

tion survival.[15,22,42] Although the included studies reported different methods and cutoff points (Table 1), most of them were able to show an influence of caries-related variables on restoration failure (Table 4). Decayed, missing, filled teeth–surfaces (DMFT-S), representing past caries experience, has been used as a predictor variable and has shown that higher caries experience in the past correlates with caries increment.[74] Also, individuals presenting a higher level of caries disease (component D from the DMFT index) at the age 15 were more likely to have failed restorations when they were 24 years old.[75] Three of the included studies have used DMFT/DFT, and two reported a significant effect on restoration survival.[19,45] The other study reported that no correlation was found for DFT and failure rates, but the statistical method was not described in the article. In addition, most of the patients were dental students, which could have influenced the results.[61] For studies on restoration survival, the use of cumulative scores as a single

Table 5: *Statistical significance (P) and Hazard Ratio (HR)/Odds Ratio (OR) of Patients' Risk Factors Assessed in the Studies*

	Factor	HR/OR	95% CI	*P*
	Age, y			
Al-Samhan and others (2010)[50]	≤15 (≥45)	0.529	0.089-3.161	0.079
	16-30 (≥45)	0.444	0.225-0.877	0.019
	31-45 (≥45)	0.408	0.173-0.963	0.041
Gilthorpe and others (2002)[19]	Years	0.99	0.98-1.00	0.072
Kopperud and others (2012)[45]	6-12 (13-19)	1.63	1.09-2.44	0.02
	20-57 (13-19)	0.05	0.01-0.40	<0.01
Pallesen and others (2013)[48]	12-19 (5-11)	0.43	0.36-0.52	<0.0001
van de Sande and others (2013)[15]	≥31 (≤30)	0.97	0.54-1.75	0.938
	Gender			
Al-Samhan and others (2010)[50]	F (M)	2.982	1.178-7.540	0.021
Baldissera and others (2013)[63]	F (M)	1.05	0.41-2.71	0.910
Gilthorpe and others (2002)[19]	M (F)	0.89	0.62-1.30	0.556
Kopperud and others (2012)[45]	M (F)	1.33	0.95-1.85	0.09
Laegreid and others (2012)[37]	M (F)	8.7	—	0.022
Pallesen and others (2013)[48]	M (F)	0.92	0.75-1.12	0.40
van de Sande and others (2013)[15]	F (M)	1.35	0.72-2.53	0.347
van Dijken and Hasselrot (2010)[62]	M (F)	1.959	1.00-3.84	0.050
	Oral hygiene			
Al-Samhan and others (2010)[50]	Poor (good)	9.046	1.021-19.751	0.014
Kopperud and others (2012)[45]	Medium/poor (good)	1.31	0.90-1.90	0.15
	Caries risk			
Andersson-Wenckert and others (2004)[34]	High (low)	2.85	1.35-6.02	0.001
Opdam and others (2007)[16]	High (low)	2.45	1.55-3.88	<0.001
van de Sande and others (2013)[15]	High (low)	4.40	2.33-8.30	<0.001
	Caries severity			
Kopperud and others (2012)[45]	Primary caries grade 4 and 5 and replacement (primary caries grade 3)	1.04	0.72-1.52	0.82
	DMFT			
Gilthorpe and others (2002)[19]	DMFT	1.02	1.01-1.04	0.009
Kopperud and others (2012)[45]	DMFT	1.06	1.02-1.10	0.01
	Restorations			
Opdam and others (2007)[47]	Number of restorations	0.91[a]	0.86-0.95	<0.001
Pallesen and others (2013)[48]	1 (≥2)	0.94	0.78-1.13	0.51
	Bruxism			
van de Sande and others (2013)[15]	Yes (no)	2.78	1.39-5.59	<0.001
van Dijken and Hasselrot (2010)[62]	No (yes)	0.38	0.19-0.77	0.007
van de Sande and others (2013)[15]	High caries risk and bruxism (no risk)	8.31	4.40-15.66	<0.001

Abbreviation: DMFT, decayed, missing, filled teeth.
[a] *Estimate coefficient from Cox regression model estimated with the bootstrap technique.*

indicator may overestimate the caries risk. The increment in DMFS/DFS on a given interval of time should also be given, because it would be comparable to new restorations and cavitated lesions as reported in other studies.

Identifying high-caries-risk patients when the restoration is placed may provide a good estimate of individuals at higher risk of restoration failure.[76] A large retrospective cohort study, with seven years of follow-up, showed that high-caries-risk patients developed more primary dentin lesions as well as secondary caries compared with patients classified as no/low risk at baseline. At baseline, the most marked differences between these groups were the number of dentin lesions (0.45 for low risk vs 3.1 for high risk) and secondary caries (0.07 for low risk vs 1.0 for high risk).[74]

Oral health and oral hygiene were evaluated in three studies,[45,53,50] and one reported a significant contribution of this variable in restoration survival.[50] Although individuals presenting a high level of biofilm accumulation throughout life may be more prone to oral health problems in adult life, as reported in a birth cohort study,[77] other variables should be jointly evaluated when investigating restoration survival. Still, the observation of biofilm accumulation and gingival bleeding indexes during the follow-up of patients is essential to observe their compliance to treatment.

Another variable investigated in the studies and included in the present review was the number of restorations per patient (regardless of the reason for placement) at a given period of time. Individuals with more restorations were shown to experience more failures than individuals with fewer restorations in two reports,[47,49] but this variable was not significantly related with restoration survival in two other studies.[46,48] In this sense, considering all the above-mentioned reasoning, registering the number of cavitated caries lesions, dentin caries from radiographic evaluations, or interventions due to caries within a two- to three-year period seems a straightforward method to identify patients at high risk.[72]

Bruxism and Occlusal Loading

The general mechanisms—friction, corrosion, and stress[78]—that can affect sound tooth structures in the form of noncarious tooth surface lesions may also affect restorations. Tooth wear and bruxism are multifactorial conditions, sometimes overlapping each other because mixed mechanisms may be involved.[79] For both, physiologic and pathologic distinctions should be identified, since bruxism habits may be seen as a normal activity,[80,81] and tooth wear is part of a normal physiologic process.[82,83] The assessment of these conditions usually takes into account objective clinical evaluation and subjective self-reported information.[83,84]

Most of the studies included in the present review, assessing bruxism, have not objectively stated the cutoff points applied to determine the condition. Thus, a direct comparison of methods is not feasible. Among the studies evaluating ceramics, no significant effect on the failure rates for inlay/onlay restorations was found.[56-58] However, for extensive partial crowns, a significant effect for bruxism was shown in restoration survival.[62] Regarding other materials, only two studies have investigated the effect of bruxism, and in both cases, this variable significantly influenced the survival of amalgam[53] and composite[15] restorations. Other reports were found presenting information regarding bruxism behavior only in the discussion of the results, where more failures were seen in bruxing patients.[41,59,65]

A review on bruxism prevalence in adults showed that several flaws in the studies were related to the lack of valid criteria to diagnose this condition.[85] A grading system was proposed by Lobbezoo and others (2013)[86] in which bruxism should be registered as "possible," "probable," or "definite." These distinctions should be made according to the assessment strategy, namely, solely by means of self-report information with questionnaires (possible), by the use of questionnaires and clinical evaluation (probable), and, for a definite diagnosis, by the use of both preceding evaluations plus an electromyographic recording (awake bruxism) or polysomnography (sleep bruxism).[86] These distinctions seem useful for the awareness of clinicians and researchers that bruxism may be under- or overestimated, especially when only one method is applied.[87] In addition to this grading system, the severity of bruxism should be part of the assessments.[85] Questionnaires designed with this purpose should include response options other than simply "yes" or "no," such as proposed by Liu and others (2014)[88] for tooth wear assessment, in which "mostly," "sometimes," and "never" were included. As a fourth response option, "not aware" could also be added. For the clinical evaluation, specifically concerning the intraoral examination, indexes should be used to grade the severity of clinical signs.

In addition, little is known about the effect of high occlusal loads and stress concentration on tooth surface loss and on restorations, except that several mechanisms may be involved.[79] *In vitro* studies on occlusal load frequently focus on abfraction on premolar teeth, and stress concentration in the cervical area was shown to slightly increase when an occlusal restoration is present.[89] Probably the cavity configuration as well as the axis and force of applied loads will generate distinct stresses on different teeth. Material properties,[90] the occlusal load, and the cavity type[91] were shown to influence stress concentration patterns. This might be particularly relevant for restorations placed in patients presenting high occlusal stress risk, due to bruxism, parafunctional habits, heavy occlusal loading, or severe tooth wear. Hence, for practical reasons, the measurement of clinical signs regardless of the name of the condition seems advisable when investigating restoration survival.

Ideally, assessment strategies developed with this purpose should be appropriate for use in research trials but specially by practicing dentists.Factors taking long periods to influence restoration survival are probably more suitable for practice-based research in which patients are usually not particularly selected, as seen in several of the studies included in the present review. With time, moderate to severe conditions will be identified by the patient and/or the clinician during routine dental appointments and should be clearly distinguished in clinical files. For example, the degree of attrition of the tooth structure as reported by Felden and others (2000)[59] may serve to measure tooth structure loss regardless of the etiological factor(s).

Gender and Age

Few studies have found a significant influence of gender on survival of restorations, and this variable is probably related to others. Men, in general, may have stronger bite forces than women,[92] which could contribute to more failures due to fatigue of the material or bonding interfaces, leading to fracture and debonding and increased failure rates. As discussed by Schulz and others (2003),[66] the combination of a patient effect, such as unfavorable loading, and an inadequate material dimension may have contributed to a higher failure rate in men observed in their study. The presence of bruxism and parafunctional habits may overcome the influence of gender, and therefore gender should not be an isolated variable when evaluating restoration survival. In addition, women are more concerned with their health and they attend dental services more regularly.[93] Such an aspect is important because it has been demonstrated that individuals having regular dentist visitations during the life course may exhibit better oral health outcomes.[94]

The same line of reasoning may be valid when considering the influence of age on restoration survival. Other factors, such as caries risk in younger individuals[42] or more complex restorations and greater tooth structure loss after several restorative interventions in older individuals, may superimpose the effect of age. Pallesen and others (2013)[48] observed, among children and adolescents, a higher intervention rate for younger individuals at baseline. The authors discussed that findings could be related to differences in caries risk and the more difficult cooperation of younger children during treatment procedures. So although age may present a significant effect, polarized for the very young and more mature patients,[45,48,50] the analysis of the contribution of age on restoration survival, as it is for gender, should not be seen under an isolated perspective.

Other Patient-Related Variables

Socioeconomic status and educational level may also influence restoration survival,[75] but no longitudinal evaluations investigating the effect of socioeconomic vulnerability were found. Although Soncini and others (2007)[49] characterized the participants according to ethnicity, household income, and educational level of the caregiver, this information was used primarily to verify the equal distribution of the materials (amalgam and resin composite) for each of the displayed characteristics. It is also mentioned that the statistical model was adjusted for some patient factors if they were statistically significant or changed the effect (10% or more) of the restoration material. Since for permanent teeth, the model was adjusted only for number of restorations in the mouth, the other factors (age, sex, and socioeconomic status) presumably did not influence restoration survival. However, the collection and reporting of these data are of importance because they provide the characterization of the sample population. In fact, when evaluating the survival of restorations in specialized private practices, a more favorable environment may be displayed because patients with a higher socioeconomic background usually attend these facilities,[63,95] especially considering countries where the dental health system does not rely on public coverage.[96] Thus, a better general and oral health may be expected, with lower chance of failure, and restoration survival may be overestimated for the general population, where individuals with different economic backgrounds are included.[10]

Statistical Analysis

One important point to be raised when investigating patient risk factors for longevity of restorations is the use of appropriate statistical analysis. Generally, a descriptive analysis of interest variables is recommended, followed by the analysis of associations between each evaluated patient factor and failure of restorations, often called univariate analysis. From the 27 selected studies, 10 have analyzed factors associated with longevity of restorations only in a univariate way (Table 4). This strategy does not consider the complex interrelationships that exist between all covariates investigated. For example, it is well established in the literature that dental caries is a multifactorial condition, affected by socioeconomic, behavioral, and tooth factors, among others.

In this way, to investigate the real effect of caries on longevity of restorations, it is strongly recommended to adjust its effect by other variables that are associated with both caries and longevity of restorations, which can act as confounders of this association, using multivariate methods. An increasing tendency to improve the quality of the analysis using multivariate models is observed among included studies. Another aspect that requires attention when patient factors are investigated is data organization. Most of articles on longevity of restorations considered that all variables are at the same level of organization, ignoring the complex nature of dental studies, where variables from surfaces/teeth/patients are analyzed together. Generally, more than one restoration is evaluated per patient. In this case, the assumption of independence between observations (restorations) leads to errors in data analysis and interpretation of results. Restorations are clustered within patients. This means that an important correlation exists between restorations of the same patient. The use of methods that ignore this correlation may lead to incorrect results, increasing the probability of rejection of the null hypothesis (ie, finding statistically significant results when none are present in the data).[97] This problem is present in most of articles that use a survival analysis approach, by conventional Cox regression models. To deal with data organization, multilevel models are the appropriate method that adjusts the results by correlation existing between restorations from the same patient.[75] Recent studies on longevity of restorations have used Cox regression models with shared frailty to investigate patient risk factors.[15,63] These models for survival analysis are analogous to multilevel regression models with random effects and consider the intragroup correlation being recommended for future studies.

Final Considerations

The selection of patients for particular treatment alternatives is often restricted to certain risk profiles. Recommendations for restorative techniques according to patient-related conditions are made, regardless of sound evidence to support the clinical decision.[98] Interestingly, the methods used to estimate the risk, meaning the criteria applied for patient inclusion/exclusion, are frequently missing, and the description for patient exclusion is often limited to "poor oral hygiene" or "patients with bruxism were excluded." While in retrospective evaluations, investigators may be limited to work with information available in the clinical records, in prospective studies, the characterization of the sample population (by means of indexes, self-reported information, and cutoff points) should be far more complete and available for the reader, even if data will be presented only descriptively. A recent report reinforced the need to use guidelines when reporting clinical studies, to increase the completeness and transparency of biomedical research. Inadequate reporting of research may lead to wasted research resources, increasing the risk for publication inaccuracy or biased data, with implications for health care decisions.[99]

A survey among general dentists in Kuwait showed that the dentist's choice regarding direct restorative materials is influenced by factors such as oral hygiene, numbers of restorations in the mouth, and cavity size.[2] However, no strong evidence exists to support the use of a particular material for either situation.[100] Material choice seems to be related to dentists' preference, country, and cultural trends.[5,101-104] Future investigations should deal with individuals' particularities and risk factors, assisting the clinical decision making for materials and techniques in challenging situations.

It is noteworthy that studies evaluating the survival of restorations have been mostly focused on the comparison between materials, including a very restricted group of patients. Aiming for studies more easily translated to daily clinical practice, investigations including patients with different socioeconomic and education backgrounds, with different levels of caries and occlusal stress, should be encouraged. Another interesting approach would be to set new prospective studies on longevity of dental restorations recruiting only volunteers/patients at high risk, considering that these risk situations would be the utmost challenge for the restorations. Also, since the events experienced during the life course may affect a series of oral health outcomes in other periods of life,[105] they should be considered during the design and evaluation of studies reporting the longevity of posterior restorations. Considerable time in clinical practice is spent on replacing failed restorations,[106] with a high cost for the individuals and for health systems.[107,108] Restorations are replaced/repaired, and in the near future, they tend to fail again,[109,110] because the dentist is treating the consequences instead of the causes for failures.[74] Therefore, the investigation of factors related to patients is crucial to change their current status, increase the survival of restorative procedures, and cut costs.

CONCLUSIONS

Within the limits of the information collected in the current review, some conclusions and recommendations can be made:

1. The assessment of patient factors along with other variables should become part of clinical studies investigating restoration survival, since several of these factors were shown to influence the failure of restorations, regardless of the material type.
2. Several studies lacked detailed information regarding the method used to classify patients. A full description should be clearly stated together with the cutoff points applied, so the sample population from different studies can be compared. More importantly, with the characterization of population, results from clinical studies may be interpreted according to individual particularities and not only in relation to materials and cavity variables.
3. For caries risk assessment, simplified methods based in caries activity were presented and seem appropriate for use in restoration survival analysis. The collection of this information is available in periodic radiographic examinations and in clinical files where the reason for intervention is registered. The higher hazard ratio found for restoration failure in caries-active individuals may assist the clinician to inform their patients toward adherence to treatment.
4. Few studies were found investigating the role of bruxism/parafunctional habits on restoration survival, and different results were reported. Improvement in methods for the assessment of patients under high occlusal stress risk is needed. The association of self-reported information and clinical indexes is encouraged, and the severity of the condition should be distinguished objectively.
5. For data analysis, multivariate models should be used, and when available, several restorations should be included per patient, since risk factors related to the individual may be masked when only one restoration is selected.

Regulatory Statement

This study was conducted in accordance with all the provisions of the human subjects oversight committee guidelines and policies of Federal University of Pelotas in Brazil.

Conflict of Interest

The authors 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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Professional Variability in Decision Making in Modern Dentistry: A Pilot Study

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Clinical Relevance

This pilot study highlights that a considerable proportion of variation in dental decision making is independently attributable to provider-specific factors. These results emphasize the continuing challenges of the limited availability of robust scientific evidence, limited implementation of and adherence to clinical guidelines, as well as habitually anchored rather than evidence-informed clinical decision-making routines.

SUMMARY

Dental treatment planning is usually expected to take account of the individual patient's clinical risks and benefits. Ideally, the therapeutic choice for each and every patient should be based on adequate clinical diagnostics and risk assessment that facilitates stabilization of the patient's clinical condition as well as prevents further oral impairment. However, identification of the most suitable approach tends to become more and more challenging as the number of therapeutic alternatives continues to increase due to medical innovation. In this study, the challenge of decision making in modern dentistry is illustrated using the example of bounded edentulous spaces. Many therapeutic alternatives exist for such clinical scenarios, including a noninvasive monitoring approach, minimally invasive tooth recontouring, orthodontic and prosthodontic treatment, and implant placement. The findings of this pilot study highlight the utmost relevance of incorporating individual patients' needs and risks into clinical treatment planning and providing appropriate guidelines.

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INTRODUCTION

A widespread belief among patients is that treatment decisions first and foremost depend on the patient's disease. This perception seems to be based on the assumption that for each and every clinical condition there is unambiguous evidence about the effectiveness of alternative therapies and that this information is the most authoritative criterion when treatments are recommended and undertaken by

Table 1: *Questionnaire Form*

Treatment Recommendation for Bounded Edentulous Spaces (BES) Resulting From Missing Lower First Molars
( ) Orthodontic treatment to correct tippings in the left side
( ) Orthodontic treatment to correct tippings in the right side
( ) Orthodontic treatment to correct tippings in both sides
( ) Tooth extraction(s) before orthodontic treatment. If any, please state where: _____
( ) Bridge-work in the left mandible
( ) Bridge-work in the right mandible
( ) Bridge-work in both sides of the mandible
( ) Implant in the left mandible
( ) Implant in the right mandible
( ) Implants in both sides of the mandible
( ) Closing the BES by means of tooth re-contouring in the left side
( ) Closing the BES by means of tooth re-contouring in the right side
( ) Closing the BES by means of tooth re-contouring in both sides
( ) Monitoring (no immediate treatment)
( ) Other suggestion(s); if any, please state: _____
NB: Form provided to respondents after description of the scenario; because different treatment alternatives can be combined into sequential treatment approaches, respondents could give multiple treatment recommendations.

medical providers. However, this may not always be the case in dentistry.

The supposed wonderland of perfect information may be obscured by the fact that available evidence about treatment alternatives is often very limited, and, thus, no clear treatment guidelines exist. One such clinical scenario refers to single posterior bounded edentulous spaces (BES). Such conditions do not just make up a few rare cases; their treatment has been reported to account for about 7% of annual dental expenses.[1,2] Treatment of BES is likely to be of continuing relevance as the population ages, and it has been suggested that despite a general decline in complete edentulism throughout the past decades, the frequency of partial edentulism has remained relatively stable.[3] In terms of treatment, it has often been argued that a missing tooth should be replaced to avoid arch collapse as a result of movement of adjacent and unopposed teeth.[4,5] However, a recent systematic review suggests that occlusal changes in BES after tooth loss are often limited; therefore, tooth replacement should not necessarily be regarded as the mainstay of therapy.[6] Given the absence of clear treatment guidelines for BES, however, dentists' recommendations may vary with respect to parameters that do not solely relate to patient characteristics.

First, many dentists may believe they have no option but to abide by information that has been passed from colleague to colleague. And as dentists may specialize in one or another subdiscipline, each of which may favor different lines of action, treatment recommendations may vary considerably across disciplines. For example, this sort of variation has previously been reported for treatment of periodontally compromised teeth, and different dental practice scopes have frequently been observed to be associated with different treatment preferences.[7-10] Second, the active dental profession comprises recently graduated dentists and dentists with decades of treatment experience. Yet, depending on the level of knowledge and experience, treatment recommendations may vary. Differences in levels of competency may also vary between dental students at different stages of education.[11-15] Third, the settings within which dentists work may differ. Many providers are self-employed and bear the cost risk of a small or medium-sized business. Other providers are employed (eg, in public institutions like a university hospital). Previous evidence, for example, suggests that different reimbursement arrangements can influence treatment decisions.[16-18] This may be another reason why treatment recommendations may depend on factors that do not solely relate to a patient's clinical condition.

So far, little information exists about the extent to which such dentist-related factors influence treatment recommendations for BES. Therefore, the purpose of the present study was to explore the extent to which treatment recommendations vary among dentists with different levels of experience, different fields of specialization, and different work settings.

METHODS

Survey Design and Administration

Using a standardized questionnaire form (Table 1 and a clinical vignette case for characterizing a clinical decision scenario (described in the next section), an anonymous survey about treatment recommendations was conducted among dentists and students of the dental clinics at the University of Heidelberg and among dentists working in private practices in June and July 2010. After the clinical vignette was presented by one person in a standard slide-show format to all lecture-attending respondents, the form was completed by dentists affiliated with the departments of prosthodontics (n=24; response rate=100%), conservative dentist-

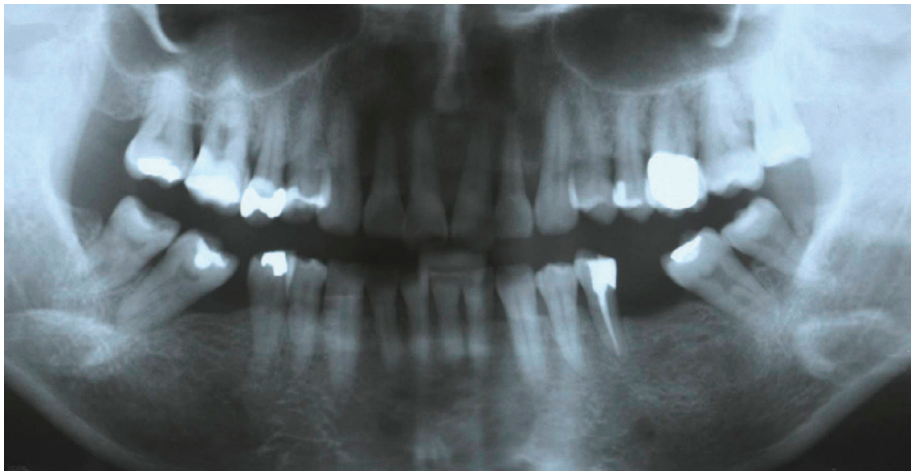

Figure 1. *Orthopantomogram.*

ry (n=20; response rate=91%), maxillofacial surgery (n=17; response rate=71%), and orthodontics (n=10; response rate=91%). The survey was also completed by students in the first (n=57; response rate=90%) and third year (n=31; response rate-84%) of clinical training who had already completed the preclinical years of education. The form was also completed by private practitioners who attended a lecture that was part of a training course for dentists specializing in endodontics (Gesellschaft fur Endodontie Bonn e.V.) (n=55; response rate-92%). The survey was conducted anonymously by all respondents. No time limit was set for filling out the questionnaire.

Clinical Vignette Case

The vignette described a previously reported case of a 59-year-old woman who is seeking advice regarding missing lower first molars in both sides of the lower jaw.[19] The patient has been missing these teeth since childhood for reasons unknown, has no treatment preferences (neither for nor against tooth replacement nor any other type of therapy), and is willing to follow any recommendation given by the dentist. The dental condition has been stable for many years, and the patient has had no recent or current signs of discomfort; pain; or esthetic, functional, or other limitation. The patient is described as health conscious and very cooperative. An orthopantomogram, pictures of the clinical situation, and diagnostic plaster models were provided (Figures 1 through 6). The full description of the presented clinical vignette case is shown in Table 2.

Statistical Analysis

For both sides of the lower jaw, the proportion of respondents recommending various treatment alternatives was computed. Response categories indi-

Figure 2. *Clinical situation (overview).*

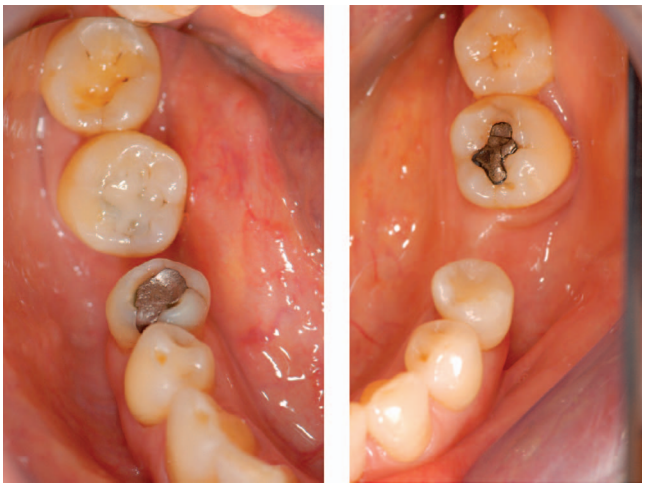

Figure 3. *Close-up view of bounded edentulous spaces in both sides of the lower arch.*

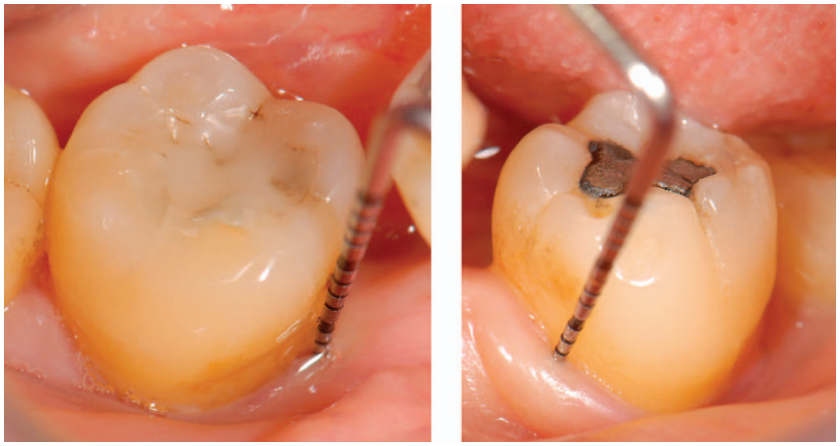

Figure 4. *Close-up view of mesial pocket probing at the second lower right molar (left picture) and the second lower left molar (right picture).*

cating identical treatment within both mandibular sides were recorded such that the according recommendation was imputed to the separate categories for both left and right side. We used χ^2 tests ($p<0.05$) to detect statistically significant differences in treatment recommendations between (1) University hospital dentists, dentists working in private practice, and students; (2) clinical practitioners within different university departments; and (3) students in different years of clinical education. Statistical analysis was performed by one scientist (SL) who was not involved in conceptualizing and carrying out the survey and was, thus, independent and blinded with respect to the data-generating process. All data analyses were carried out with the software package STATA/SE 12.0 (StataCorp, College Station, Texas).

RESULTS

Descriptive Statistics

Table 3 shows the frequency of different treatment approaches as recommended by clinical practitioners, private practitioners, and dental students. Bridgework (left) was most frequently recommended by students in their first year. Bridgework (right) was chosen most often by respondents from the prosthodontics department. Implant placement (left) was most frequently recommended by students in their first year. Implant placement (right) was chosen most often by respondents from the maxillofacial department. Tooth recontouring (ie, direct composite buildups to close gaps)[20] was most frequently recommended by students in their first

Figure 5. *Occluded models (anterior and lateral).*

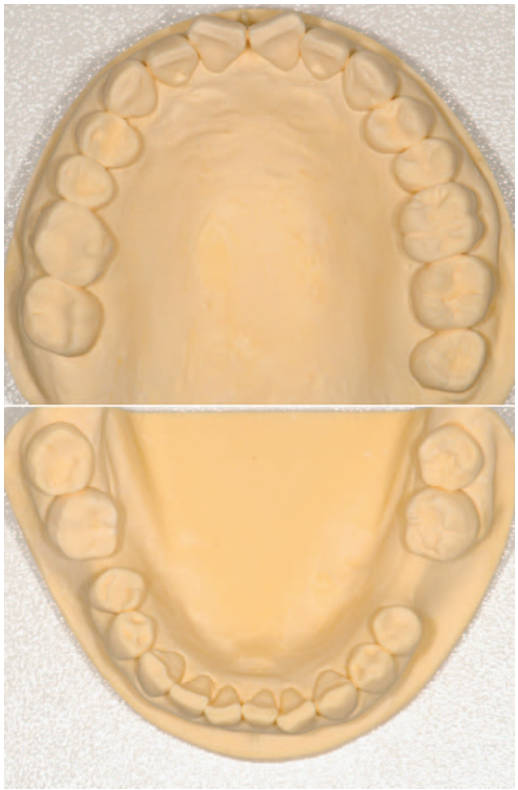

Figure 6. *Occlusal view of models.*

Table 2: *Case Characteristics of the Clinical Vignette*
• Both lower first molars have been missing since childhood for reasons unknown
• Dental condition has been stable for many years
• No recent or current discomfort/pain
• No aesthetic, functional, or other limitations
• No hereditary disposition known for diseases of the oral cavity
• Regular intake of medication against hypertension; no other acute/chronic systemic diseases
• Patient is a non-smoker
• Social anamnesis: the patient is married and homemaker
• No financial or time constraints for treatment
• The patient brushes her teeth 2-3 time per day using a fluoridated toothpaste; interdental cleaning includes tooth floss and individually adjusted interdental brushes; for cooking, she uses fluoridated salt
• No complications during or in response to earlier endodontic, periodontal and restorative dental treatment
• No pathologic abnormalities detectable, neither within nor outside the oral cavity
• Complete dentition with missing upper right wisdom tooth and missing lower first molars
• No carious lesions detectable; normal signs of erosion, abrasion, and attrition; no traumatic abnormalities
• Sufficient direct and indirect dental restorations
• Endodontically treated lower left second premolar; all other teeth exhibit positive vitality
• No discoloration or excessive movability of teeth
• All teeth respond negative to percussion
• No current periodontal treatment need (pocket probing depths of 1-3 mm in general; no bleeding on probing; previously treated and stable furcation involvement (grade 2) at both upper first molars; gingival recessions at some teeth, particularly at the upper right first molar
• Myofunctional examination revealed no need for according therapy
• Both remaining lower second molars are tipped into mesial direction, particularly on the right side
• Mesio-distal extension of the mesial BES is ca 7 mm on the left side and ca. 2 mm on the right side; only slight elongation of upper first molars with no indication of deficient contacts with antagonizing teeth
• Neutral to slightly distal toothing in the left canine and premolar region; distal toothing in the right canine and premolar region in the extent of about one premolar; mesial shift of the dental midline in the lower jaw; crossbite between lower right wisdom tooth and second upper right molar

clinical year. Orthodontic treatment was suggested most often by respondents from the maxillofacial department. Among University hospital dentists, a monitoring-only approach was most frequently recommended by dentists from the conservative dentistry department, followed by dentists from the prosthodontics, orthodontics, and maxillofacial departments (see Figure 7).

Testing for Statistical Significance

Table 4 shows χ^2 statistics from tests for differences in treatment recommendations among hos-

Table 3: *Frequency (Standard Error) of Treatment Recommendations for Bounded Edentulous Spaces*

	University Hospital					Dental Students	
	Conservative	**Prosthodontics**	**Surgery**	**Orthodontics**	**Private Practice**	**First Year**	**Third Year**
Bridgework left	0.00 (0.00)	0.04 (0.04)	0.06 (0.06)	0.20 (0.13)	0.20 (0.05)	0.28 (0.06)	0.26 (0.08)
Bridgework right	0.00 (0.00)	0.04 (0.04)	0.00 (0.00)	0.00 (0.00)	0.05 (0.03)	0.04 (0.02)	0.00 (0.00)
Implant left	0.30 (0.11)	0.38 (0.10)	0.82 (0.10)	0.30 (0.15)	0.31 (0.06)	0.89 (0.04)	0.52 (0.09)
Implant right	0.00 (0.00)	0.00 (0.00)	0.24 (0.11)	0.00 (0.00)	0.02 (0.02)	0.11 (0.04)	0.03 (0.03)
Recontouring left	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (0.02)	0.00 (0.00)
Recontouring right	0.30 (0.11)	0.21 (0.08)	0.29 (0.11)	0.60 (0.16)	0.18 (0.05)	0.79 (0.05)	0.52 (0.09)
Orthodontic left	0.00 (0.00)	0.00 (0.00)	0.24 (0.11)	0.10 (0.10)	0.04 (0.03)	0.21 (0.05)	0.03 (0.03)
Orthodontic right	0.00 (0.00)	0.00 (0.00)	0.29 (0.11)	0.00 (0.00)	0.07 (0.03)	0.14 (0.05)	0.10 (0.05)
Monitoring only	0.65 (0.11)	0.46 (0.10)	0.18 (0.10)	0.30 (0.15)	0.35 (0.07)	0.00 (0.00)	0.29 (0.08)
n	20	24	17	10	54	57	31

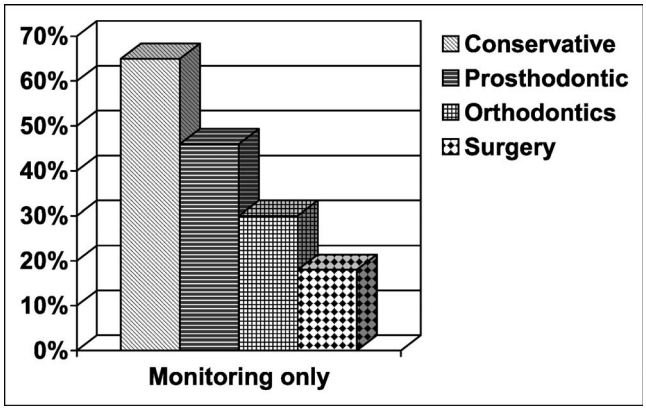

Figure 7. *Proportion of University hospital dentists recommending a monitoring approach for the described clinical scenario of bounded edentulous spaces.*

pital practitioners, private practitioners, and students. When comparing University hospital dentists with students, treatment with bridgework (left), implant placement (left), and recontouring (right) were found to be recommended significantly more often by students, whereas a monitoring approach was recommended significantly more often by dentists working in the clinics. When comparing dentists working in the clinics with private practitioners, treatment with bridgework (left) was recommended significantly more often by private practitioners. When comparing private practitioners with students, treatment with implant placement (left), recontouring (right), and orthodontic treatment (left) were recommended significantly more often by students, whereas a monitoring approach was recommended significantly more often by private practitioners.

Table 5 shows χ^2 statistics from tests for differences in treatment recommendations among dentists from different departments within the university hospital. No significant difference was found between the conservative dentistry and the prosthodontics departments. When comparing dentists working in the conservative dentistry department with their colleagues working in the maxillofacial department, implant placement and orthodontic treatment were recommended significantly more often in the maxillofacial department, whereas a monitoring approach was recommended significantly more often in the conservative dentistry department. When comparing dentists working in the conservative dentistry department with their colleagues working in the orthodontics department, bridgework (left) was recommended significantly more often by the orthodontists. When comparing dentists working in the prosthodontics department with their colleagues working in the maxillofacial department, implant placement and orthodontic treatment were recommended significantly more often in the maxillofacial department, whereas a monitoring approach was recommended significantly more often in the conservative dentistry department. When comparing dentists working in the prosthodontics department with their colleagues working in the orthodontics department, recontouring (right) was recommended significantly more often by the orthodontists. When comparing dentists working in the maxillofacial department with their colleagues working in the orthodontics department, implant placement (left) was recommended significantly less often by the orthodontists.

Table 4: *The χ^2 Statistics From Tests for Differences in Treatment Recommendations Between Dentists in University Hospital, Dentists in Private Practice, and Dental Students*

	Clinics vs Students	Clinics vs Private Practice	Private Practice vs Students
Bridgework left	*12.68*[a,b]	*6.10*[a,c]	0.97
Bridgework right	0.16	1.65	1.02
Implant left	*16.14*[a,b]	2.62	*28.57*[a,d]
Implant right	0.33	1.18	2.41
Recontouring left	1.63	Not applicable	1.27
Recontouring right	*23.14*[a,b]	2.68	*35.40*[a,d]
Orthodontic left	2.34	0.69	*4.47*[a,d]
Orthodontic right	1.29	0.00	0.99
Monitoring only	*22.01*[a,e]	0.98	*28.57*[a,f]

[a] *Italic values indicate statistically significant difference at the 5% level.*
[b] *Treatment was recommended significantly more often by students than by dentists.*
[c] *Treatment was recommended significantly more often by private practice than university hospital.*
[d] *Treatment was recommended significantly more often by students than by dentists.*
[e] *Treatment was recommended significantly more often by dentists than by students.*
[f] *Treatment was recommended significantly more often by private practice.*

Table 5: *The χ^2 Statistics From Tests for Differences in Treatment Recommendations Among Dentists From Different Departments Within the University Hospital*

	Conservative vs Prosthodontics	Conservative vs Surgery	Conservative vs Orthodontics	Prosthodontics vs Surgery	Prosthodontics vs Orthodontics	Surgery vs Orthodontics
Bridgework left	0.85	1.21	*4.29*[a,b]	0.06	2.20	1.27
Bridgework right	0.85	—	—	0.73	0.43	—
Implant left	0.27	*10.14*[a,c]	0.00	*8.13*[a,d]	0.17	7.0[a,e]
Implant right	—	*5.28*[a,c]	—	*6.26*[a,d]	—	2.76
Recontouring left	—	—	—	—	—	—
Recontouring right	0.49	0.00	2.50	0.40	*4.95*[a,f]	2.44
Orthodontic left	—	*5.28*[a,c]	2.07	*6.26*[a,d]	2.47	0.76
Orthodontic right	—	*6.80*[a,c]	—	*8.04*[a,d]	—	3.61
Monitoring only	0.10	*7.69*[a,g]	0.71	*6.87*[a,h]	0.38	2.44

[a] *Italic values indicate statistically significant difference at the 5% level.*
[b] *Treatment was recommended significantly more often in the orthodontics department than the surgery departments.*
[c] *Treatment was recommended significantly more often in the surgery department than the conservative dentistry department.*
[d] *Treatment was recommended significantly more often in the surgery department than the prosthodontics department.*
[e] *Treatment was recommended significantly more often in the surgery department than the orthodontics department.*
[f] *Treatment was recommended significantly more often in the orthodontics department than the prosthodontics department.*
[g] *Treatment was recommended significantly more often in the conservative dentistry department than the surgery department.*
[h] *Treatment was recommended significantly more often in the prosthodontics department than the surgery department.*

As shown in Table 6, implant placement (left), recontouring (right), and orthodontic treatment (left) were recommended significantly more often by students in their first clinical year, whereas a monitoring approach was recommended significantly more often by students in their third clinical year.

DISCUSSION

The present study revealed substantial variability regarding treatment recommendations with respect to dentists' level of experience, area of specialization, and institutional setting in which they work. First, our findings appear to give evidence for a tendency toward less invasive treatment being recommended with increasing level of treatment experience. Dental students were more likely to recommend implant placement (left) and recontouring (right) than practicing dentists. Students were also more likely to recommend bridgework than clinical practitioners and more likely to recommend orthodontic treatment than private practitioners (left). Dentists were more likely to recommend monitoring than students. Among students, implant placement (left), recontouring (right), and orthodontic treatment (left) were recommended more often by students in their first year, whereas monitoring was recommended more often by students in their third year. It should be noted tooth recontouring is a specific component of the first-year curriculum.

Table 6: *The χ^2 Statistics From Tests for Differences in Treatment Recommendations Between Students in Different Years of Clinical Coursework*

	Third-Year Students vs First-Year Students
Bridgework left	0.05
Bridgework right	1.11
Implant left	*15.84*[a,b]
Implant right	1.46
Recontouring left	1.11
Recontouring right	*7.05*[a,b]
Orthodontic left	*5.07*[a,b]
Orthodontic right	0.35
Monitoring only	*20.28*[a,c]

[a] *Italic values indicate statistically significant difference at the 5% level.*
[b] *Treatment was recommended significantly more often by first-year students than by third-year students.*
[c] *Treatment was recommended significantly more often by third-year students than by first-year students.*

Second, it seems that the area of dentists' specialization also has a considerable impact on the type of recommended treatment. Although no differences were detected between the conservative dentistry and prosthodontics department, dentists in the maxillofacial department were more likely to recommend implant and orthodontic treatment but less likely to recommend monitoring compared with colleagues from the prosthodontics and conservative dentistry departments. Orthodontists were more likely to recommend bridgework (left) than conservative dentists, more likely to recommend recontouring (right) than prosthodontists, and less likely to recommend implants (left) than colleagues from the maxillofacial department.

Third, our findings also hint at the relevance of settings in which dentists work. In particular,

bridgework (left) was recommended more often by dentists working in private practice than by University hospital dentists. It may be tempting to speculate whether such a difference in treatment recommendations may be attributable to different financial incentives for private and clinical practitioners, yet identification of such a link was outside the scope of the present study.

Given that, to date, treatment guidelines for BES are not fully conclusive; the observed variations may not appear completely unexpected.[21] Nevertheless, the extent of differences among various groups of respondents seems remarkable. As there was also great variation within different groups of respondents, this may hint at further uncertainties about which treatment approach would be the most adequate for BES. Unquestionably, the currently existing knowledge regarding clinical management of BES is insufficient to judge any of the proposed treatment approaches as entirely right or wrong. However, for clinical scenarios characterized by stable BES without any limitations perceived by the patient, previous evidence suggests that it is unlikely that the patient will incur a high risk of adverse health consequences if a monitoring approach is taken rather than immediate tooth replacement.[6] In order to establish more differentiated treatment guidelines for BES that facilitate more patient-centered treatment decisions in the future, however, more research is needed that examines the potential of monitoring approaches. Moreover, there is a need for better understanding about how dental professionals change their clinical practice and about reviewing dental education programs because reviewing clinical guidelines alone may not necessarily lead to rapid implementation of altered therapeutic approaches.[22]

As with any other pilot study, the present investigation has its limitations. First, no tailored sample-size planning or other specific sampling procedures could be applied. Some of the variation in the reported results could have been influenced by an unfitted sample size or by sample selection bias. Second, the present study could not control for other potentially relevant covariates, such as, for example, a different age composition of self-employed dentists and their colleagues working in hospital. This could be relevant because it may complicate the distinction between age-related effects of experience and effects of different practice settings (private practice vs hospital). Third, the sample for private practitioners was recruited from dentists having a specific interest in endodontics and thus may not be considered representative of the entire professional community.

Nevertheless, the findings of the present study uniquely quantify the extent of intraprofessional variability in treatment recommendations as regards BES. The fact that the treatment patients receive seems to be strongly influenced by provider characteristics that do not directly relate to the patients' clinical condition may be a challenge. Patients usually seek treatment advice from dentists because of their supposed expert knowledge with regard to the necessity of clinical intervention and which treatment approach, if any, is the most clinically adequate. However, if the existing clinical evidence about therapeutic alternatives is unclear, it seems not unlikely that dentists seek to justify treatment approaches in the way in which they are most comfortable. This is not to say that dentists would only act in their own interest and would not respect the patient preferences, but if it is impossible to differentiate between the clinical appropriateness of two therapeutic alternatives and, thus, both are clinically justifiable, it seems plausible that providers prefer the one that best accommodates their own skill. Based on the supposed expert advice, patients may then shape their treatment preferences accordingly. Ultimately, however, this implies that one specific treatment is chosen over several others despite no evidence of better clinical effectiveness. This may not only raise concerns of inefficient resource use (if providers prefer more expensive treatments) but also of inconsistencies within the dental profession (if patients with identical clinical conditions receive largely different treatment recommendations).

All in all, the present study gives novel evidence for considerable intraprofessional variability in dental treatment recommendations for BES with respect to dentists' level of experience, area of specialization, and institutional setting in which they work. The extent of the observed variations seems highly remarkable. Treatment guidelines and dental education programs should thus be reviewed. Moreover, future randomized controlled clinical research examining the effectiveness of monitoring approaches will be helpful to further the development of more differentiated treatment guidelines for BES. In addition, more detailed investigations of factors relevant for dentists when making clinical decisions could take particular advantage of state-of-the art experimental techniques used in the behavioral sciences, such as discrete choice experiments.

Disclaimer

This study was solely funded through the authors' institutions. No external funding was received.

Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee guidelines and policies of Heidelberg University. The approval code for this study is 07/07/2011.

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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Restoration of Severely Compromised Teeth With Modern Operative Techniques

M Lenhard

Clinical Relevance

The cases show that composites may be a valid alternative to indirect restorations.

SUMMARY

This case report illustrates how to restore severely compromised teeth with direct composite restorations. The size of the restorations presented is often considered by dentists as being a contraindication for direct composites. Hence, the technique is explained step by step, addressing the crucial points.

CASE 1

A 47-year-old male patient presented himself with an insufficient restoration on a first lower molar, displaying a fractured lingual cavity wall and multiple cracks in the buccal wall (Figure 1). The adjacent teeth were restored with old amalgam restorations that showed wear and small cracks in the restoration surfaces. However, these teeth were free of secondary caries, and the restorations were functionally intact.

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It was decided to replace the defective amalgam restoration on the first molar by a direct composite restoration and to keep monitoring the restorations on the adjacent teeth.

Clinical studies indicate that even large composite restorations including cusp replacements will perform clinically very well, provided the decisive steps in the clinical protocol are addressed adequately.[1-3]

Recently, every major dental manufacturer introduced a bulk-fill composite to facilitate the clinical protocol for direct composite restorations by allowing the operators to place layers of a thickness of 4 mm, thereby reducing the total number of layers that are needed to fill the cavity completely. At present, research confirms that these materials can be applied successfully with respect to the advocated layer thickness[4-7] without significantly compromising the marginal quality of the restorations[8-10] or survival rates.[11]

The downside of these materials is that they are quite translucent and no dark colors are available. Darker colors or higher opacity would counteract the polymerization of thick layers. Hence, the high translucency and rather light colors of bulk-fill materials may result in a certain optical mismatch to the surrounding dental hard tissues.

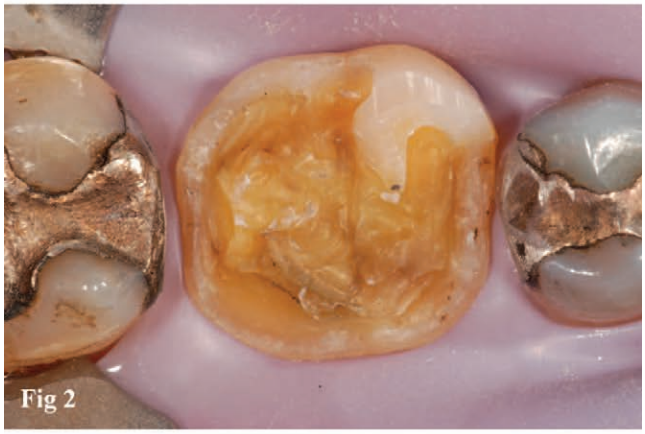

Figure 1. *Initial situation: The lingual cavity wall of a lower first molar was fractured. The buccal cusps displayed multiple cracks. The adjacent teeth showed old amalgam restorations with wear and small cracks in the restoration surfaces and marginal staining. However, these teeth were free of secondary caries and the restorations were functionally intact.*

Figure 2. *During preparation the distobuccal cusp came off. The remaining mesiobuccal cusp was reduced by approximately 1.5 mm.*

Figure 3. *The adhesive protocol included a selective enamel etching for 30 seconds and the application of a two-bottle self-etch adhesive. (AdheSE, Ivoclar Vivadent, Schaan, Liechtenstein).*

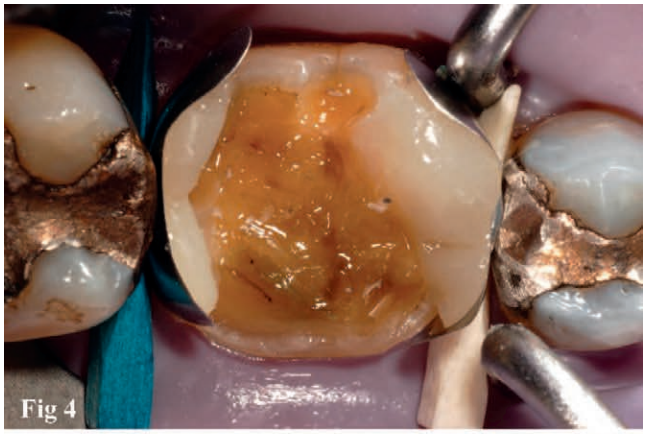

Figure 4. *After the application of sectional matrices (Composi-Tight, Garrison Dental Solutions, Spring Lake, MI, USA), the tooth was built up with a bulk-fill composite (Tetric EvoCeram Bulk-Fill, Ivoclar Vivadent), starting with the interproximal walls.*

Figure 5. *Third and fourth increment built up the buccal and lingual cavity walls.*

Figure 6. *The last two increments finished the occlusal part of the restoration.*

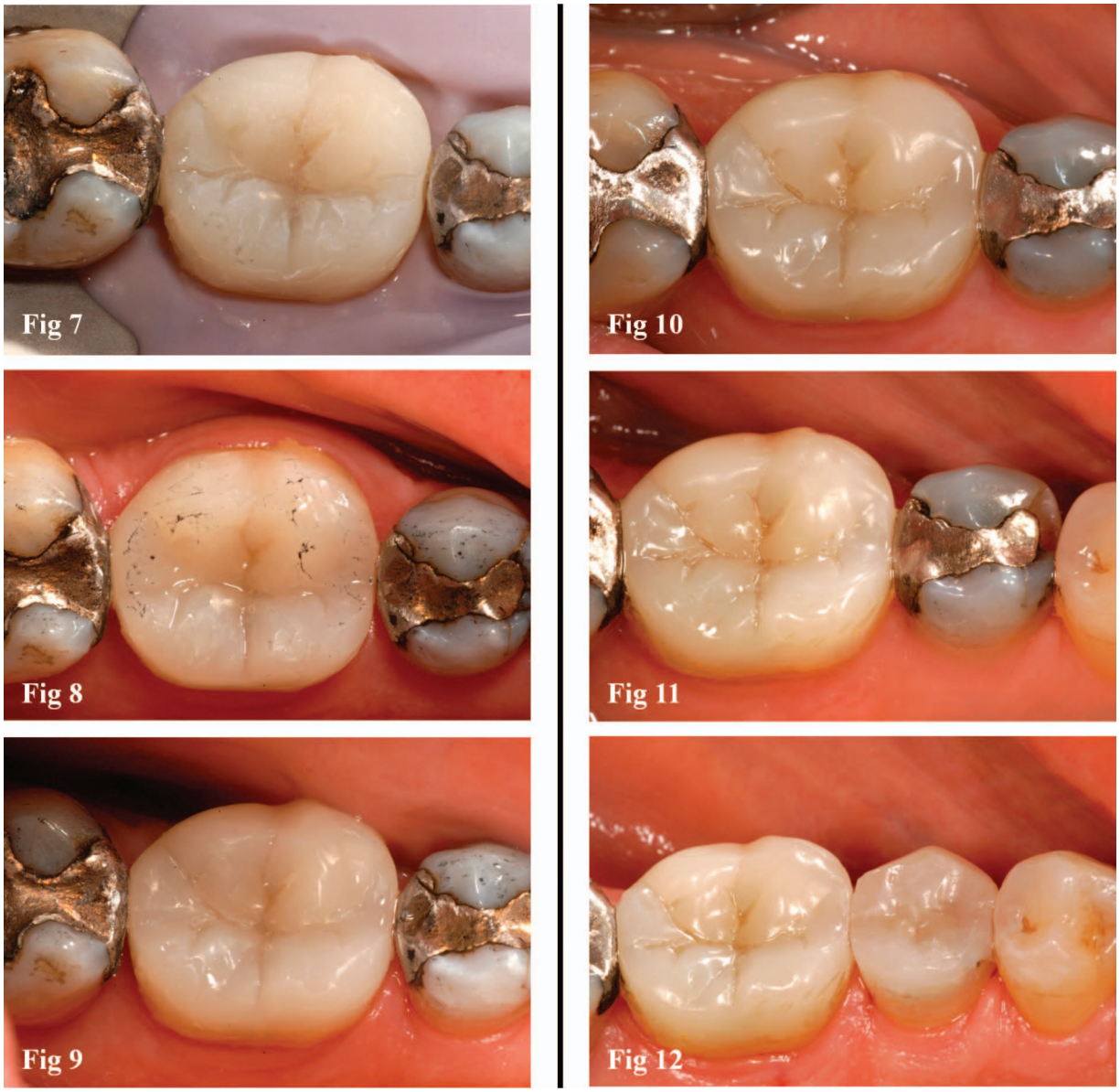

Figure 7. *Fine-grit diamonds and flexible polishing discs were used to adjust the shape of the restoration.*

Figure 8. *Situation after adjusting the occlusion.*

Figure 9. *Finished restoration.*

Figure 10. *Situation three years postoperative. The restoration looked virtually unchanged. The adjacent old amalgam restorations were still in service.*

Figure 11. *Shortly after, the mesial cavity wall of the adjacent premolar fractured.*

Figure 12. *Situation after replacement of the old amalgam restoration with a bulk-fill composite-restoration including the buccal and lingual cusps of the premolar.*

However, it has to be stated that in posterior restorations this mismatch is hardly visible to the patient and therefore should not be overly emphasized.

After the placement of a rubber dam, the old amalgam was removed. During the preparation, the distobuccal cusp chipped as a consequence of the multiple cracks. The finished preparation displayed three missing cusps and the mesiobuccal cusp being reduced by 1.5 mm (Figure 2). Interproximal cervical margins were beveled using oscillating instruments (SonicFlex, No. 58 and 59, KaVo, Biberach, Germany).[12] All remaining enamel margins were beveled[13] and finished with a fine-grit (40-μ) diamond to remove microcracks caused by the preparation.[14]

The preparation was followed by selective enamel etching for 30 seconds and the application of a two-step self-etch adhesive (Figure 3).[15] A sectional matrix was applied and the tooth was built up with six increments of a sculptable bulk-fill material (Figures 4-6). Each increment was light cured with a broad spectrum LED curing light (Bluephase G2, Ivoclar Vivadent, Schaan, Liechtenstein) for 20 seconds at 1200 mW/cm^2.

Light curing should be considered as one of the most critical steps in the clinical protocol of composite restorations. The most common reason for failure of composite restorations is the fracture of the restoration itself.[16] One of the factors contributing to this is very likely that the energy dose applied by the operators to cure the composite is often inadequate,[17,18] whereas the clinical performance is linked to the degree of polymerization.[18,19]

After the layering, the occlusion was adjusted and the restoration polished (Figures 7-9).

At the three-year recall (Figure 10), the restoration appeared to be virtually unchanged. The adjacent amalgam restorations were still in service. However, shortly after, the mesial wall of the adjacent premolar fractured (Figure 11), and the restoration was replaced again by a bulk-fill restoration including both cusps (Figure 12).

The case illustrates that dental resin composites can be used successfully even for large, cusp-replacing restorations. It further emphasizes the importance of a conservative approach to the replacement of "nonideal" restorations. When the patient presented himself with the fractured molar, the adjacent teeth were restored with amalgam restorations that showed wear, stained margins, and, on the premolar, even small cracks in the enamel and the restoration. However, these teeth were caries free and without any functional problems. Hence, the decision to monitor these restorations slowed down the cycle of redentistry for the premolar by three years, and even more so for the second molar, because this restoration is still in place.

Figure 13. *Initial situation.*

The decision to replace an old restoration is subjective, especially for restorations that were not placed by the current operator but another dentist, often leading to early replacement of functional restorations or, in other words, overtreatment.[19] Therefore, dentists should concentrate on preserving the health of the tooth and the functionality of existing restorations rather than exhaust the esthetic possibilities of modern materials at the cost of premature redentistry.

CASE 2

A 69-year-old female patient came to the clinic with a fractured upper right lateral incisor (Figure 13). The clinical records showed that the patient only saw a dentist erratically, when a restoration fractured or she suffered from dental pain. Her oral hygiene was moderate, and several old restorations showed signs of wear and marginal staining or disintegration; however, no active carious lesions were present.

The fractured lateral was free of caries and vital. The patient asked for a cost-effective, functional solution to the problem. The stained margins on the other anterior teeth were of no esthetic concern to the patient.

It was decided to restore the tooth with a direct composite buildup at the same appointment.


Fig 14


Fig 18


Fig 15


Fig 19


Fig 16


Fig 20


Fig 17


Fig 21

Figure 22. *Final situation, one week postoperative. The restoration had a natural appearance, displaying an incisal translucency and a halo effect.*

Figure 23. *One-year recall: The restoration showed excellent physical and optical stability. The stained restorations on the adjacent teeth were still in place and functional.*

After preparation, the enamel was selectively etched for 30 seconds, followed by the application of a two-bottle self-etch adhesive.

When no silicone key is available, the easiest way of building up an anterior tooth is the "finger-tip technique," where the index finger is used as an oral matrix on which to adapt the composite (Figure 14).[21,22] However, it has to be kept in mind that gloves do not prevent the penetration of dental monomers.[23,24] Hence, touching the uncured adhesive and composite can lead to direct skin contact with the monomers. Research has shown that the prevalence of allergic reactions of dental staff to monomers is rather high, with the most common allergen being 2-hydroxyethyl methacrylate.[25]

However, the penetration of monomers through dental gloves does not take place immediately. Depending on solvent of adhesive and type of gloves, breakthrough times were shown to be from 2.8 to 30 minutes, with nitrile gloves generally being better than latex gloves.[26] Therefore, it should be possible to use this technique without any risk by simply exchanging the glove after completing the finger-tip technique.

Modern composites allow rather simple anatomical layering techniques. The clinical crown in the

←

Figure 14. *Finger-tip technique: The finger serves as an oral matrix, allowing to easily build up the oral wall. For this first layer of composite, an enamel color must be chosen (Empress Direct, enamel A4, Ivoclar Vivadent, Schaan, Liechtenstein). The layer should be kept as thin as possible (<1 mm). When done right, the finger-tip technique allows excess-free layering and brings the incisal edge into the right position. This way, later adjustments on the oral aspect of the restorations are minimized.*

Figure 15. *The polymerized first layer.*

Figure 16. *After the first layer was polymerized, a matrix was wrapped around and a wedge was placed. The finger then tightly adapted the matrix to the oral aspect of the first layer.*

Figure 17. *The mesial increment was placed, again using an enamel shade.*

Figure 18. *After repeating this technique likewise for the distal interproximal increment, the matrix and the wedges were removed.*

Figure 19. *The next step was the application of a dentin shade. This layer is decisive for the final translucency of the restorations. As with natural dentin, composite dentin shades are more opaque than enamel shades. Hence, the thicker the dentin layer that is placed, the more opaque the restoration will be. At the same time, lightness of the restoration will be increased because the opaque dentin shade will optically block out the dark background (the oral cavity) and reflect more incoming light. The key to success in anterior restorations is matching translucency. As a general guideline, for older patients, lower amounts of dentin shade are used because natural teeth become more translucent with age.*

Figure 20. *Finally, the oral aspect was covered with a layer of enamel shade.*

Figure 21. *The surface was polished with flexible discs (Sof-Lex Discs, 3M Espe, St Paul, MN, USA) and a one-step silicon polisher (OptraPol NG, Ivoclar Vivadent).*

present case was built up with just five layers (Figures 15-21) with a nano-hybrid composite, using an enamel shade and a dentin shade.

One week postoperative (Figure 22) and at the one-year recall, the restoration showed excellent stability and a harmonic integration (Figure 23).

The direct approach successfully addressed the needs of the patient without having to compromise on esthetics. Even though esthetics was not of concern to the patient, dentists should always try to achieve an ideal optical integration in the anterior section, especially given that this goal is quite easy to achieve with direct composite buildups.

Regulatory Statement

This study was conducted in Etzwilen, Switzerland, at the author's private practice.

Conflict of Interest

The author of this manuscript certifies that he has 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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Case Report: A Predictable Technique to Establish Occlusal Contact in Extensive Direct Composite Resin Restorations: The DSO-Technique

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JJM Roeters • BAC Loomans • MC DNJM Huysmans

Clinical Relevance

This technique enables the dentist to restore teeth in occlusion with direct composites in a predictable and minimally invasive way.

SUMMARY

This paper describes the application technique of direct shaping by occlusion (DSO) for large composite restorations including the entire occlusal surface. For this technique, matrix bands and wedges are inserted without interference with antagonists in the desired occlusion. The final increment of soft-composite resin is shaped by letting the patient occlude on the uncured composite. Due to the nature of the technique, special care has to be taken for moisture control and handling of contamination. The procedure, advantages, and limitations of the technique are discussed.

PURPOSE

Direct composite resin restorations have been shown to be suitable to provide a solution in a wide variety of indications with long-lasting results.[1-6] Even in total rehabilitations of severely worn dentitions, direct composites have been shown to be successful[7-9] on a

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medium to long term (5-10 years) and sometimes even preferred over indirect full-ceramic restorations.[10] However, the direct restoration of teeth with extensive defects is a demanding procedure for most clinicians, especially when a new occlusion has to be established. Some dentists use moulds fabricated from a wax-up by the dental technician to apply the resin composite to the teeth.[10,11] Recently, in this journal a technique was described to restore severely worn teeth with direct composite pairwise in order to establish interocclusal relationship.[12] However, making proper restorations in the desired shape and in good occlusion is time-consuming and requires special skills from the dentist.

Frequently, indirect restorations are chosen in such a situation,[13-16] but even when these indirect restorations are made in a minimally invasive way,[16] costs are extensive and not affordable for most patients. Direct composite has the advantage of combining reasonable cost and proven longevity even in severely damaged dentitions.[7,8] Moreover, it can be applied in a minimally invasive way offering possibilities for future restorative options in a dynamic way.[11,12,17,18]

The aim of this paper is to describe a technique facilitating occlusal rehabilitation on a mid-long term basis at limited costs. The technique was introduced in a Dutch language paper.[19] Its clinical effectiveness has been established as restorations made according to this technique have been shown to have a favorable longevity.[7]

DESCRIPTION OF THE TECHNIQUE

The essential part of the technique is that to establish occlusion, the final increment of composite resin covering the occlusal surface is left uncured when the patient is asked to occlude and keep the teeth in occlusion, while the composite resin is cured from the buccal side (DSO = direct shaping by occlusion). By coating the antagonist with a thin layer of Vaseline, bonding and sticking of the composite will be avoided when cured. The technique facilitates the shaping of a restoration that includes the entire occlusal surface. In the following case presentations, the technique will be described in further detail.

CASE 1

A 41-year-old man with severe tooth wear was referred to the clinic of the dental school in Nijmegen. The anamnesis revealed that bruxism was the reason for the wear. The patient complained about the esthetic appearance related to the reduced size of his teeth. During the informed consent, it was decided to start a restorative treatment including a complete build-up of all anterior and posterior teeth in increased vertical dimension of occlusion (VDO). Furthermore, he was advised to wear a night guard for protection after the rehabilitation was completed.

Before starting the restorative treatment, individual stone casts were mounted in an articulator in maximal occlusion, and the desired VDO (+5 mm) was determined by the operator, carefully considering the necessary interocclusal space in posterior and anterior teeth. To transfer the new vertical dimension into the mouth, polyvinyl siloxane stops were made in the molar region of the casts (Figure 1A). The new VDO was checked in the mouth (Figure 1B).

In this case, the reconstruction started with direct composite resin build-ups of the mandibular anterior teeth, which is not relevant for the DSO technique as shown. Preparation of all involved teeth was limited to a bevel ground on the sharp edges of enamel, when present. In the cases where retention of the restoration could be at risk because available tooth substance is limited or applied heavy shear forces are expected, some resistance form can be created by grinding seats or grooves. When the mandibular anterior teeth were shaped and finished, attention was paid to have sufficient space left between the restored mandibular incisors and the unrestored maxillary anterior teeth with stops *in situ* in order to allow restoration of their palatal surfaces. After finishing and polishing the mandibular anterior teeth, a metal matrix band (Tofflemire) was inserted from the palatal side of a central maxillary incisor and secured with wooden wedges. Before placement of the matrix, the estimated height of the metal was adjusted with scissors. After placement, the matrix band was adjusted once more using a high-speed diamond bur. Finally, the matrix was checked in occlusion on the stops in increased VDO as there should be no interference between matrix and antagonists (Figure 1C). Although it was intentional that no rubber dam was applied, appropriate moisture control was achieved using cotton rolls, suction device, and proper matrix-wedge placement while a dental nurse facilitated the procedure at chair side.

Applying a three-step etch-and-rinse adhesive (Clearfil Photo Bond, SA primer) according to the manufacturer's instructions started the restorative procedure. Then, a small amount of flowable composite was injected into the cervical area and left uncured to act as lubricant and to improve adaptation of the restorative material (snow-plough technique).[20] This

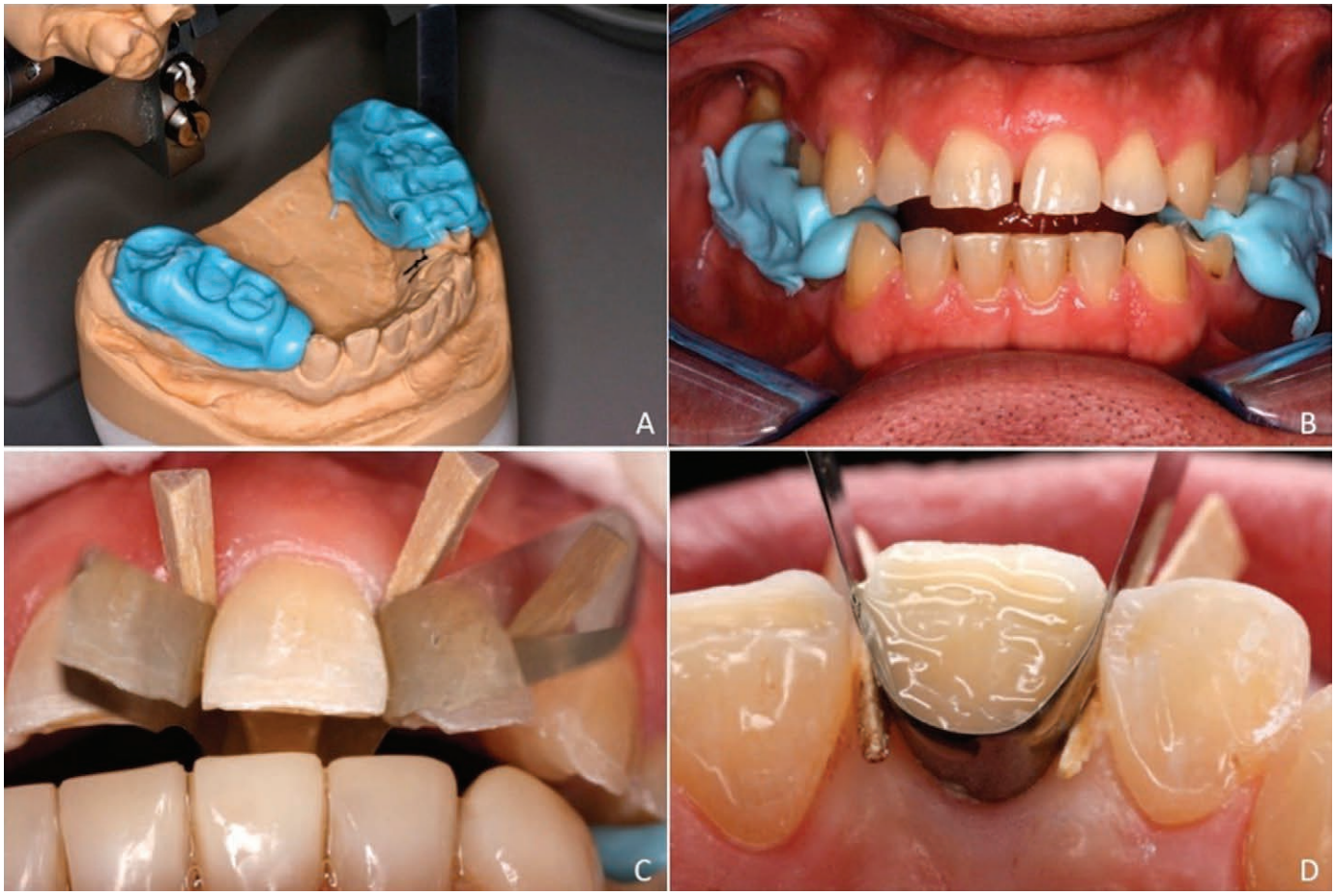

Figure 1. *(A): Stops made on the mounted casts for transferring the desired VDO into the mouth. (B): Checking new VDO in the mouth. (C): Vestibular view of matrix band secured with wedges enabling full closure in the occlusal stops. (D): Palatal view of the tooth with matrix band and wedges after the application of the first layer of composite, which is cured normally. The correct placement of matrix and wedges will result in adequate moisture control.*

was immediately followed by the first cervical layer of hybrid composite (Clearfil AP-X) that was applied and cured for 20 seconds, while care was taken that this layer was placed up to a level 1 mm below the matrix (Figure 1D). Subsequently, the final layer of the hybrid composite was inserted covering the entire surface inside the matrix. The thickness of this final layer was estimated to be sufficient for the antagonistic teeth to make a clear impression in the uncured composite. This layer was left uncured, while the antagonistic tooth was coated with a thin film of Vaseline. Hence, the suction device was removed, and the patient was asked to close the mouth into the stops and keep the teeth in occlusion (without biting with force) resulting in a direct shaping of the palatal surface by the antagonist (DSO). Then, with the jaws closed in the increased VDO stops, the composite was cured from the buccal side (Figure 2A). After curing for at least 40 seconds with a powerful curing-light unit (>1000 mw/cm^2), the patient was asked to open the mouth, and the composite was additionally cured from the occlusal direction (20 seconds), and once more from the lingual side after removal of the metal matrix (20 seconds). In this case, the vestibular surface was subsequently restored with a direct veneer using an anterior composite (Empress Direct), resulting in the first tooth to be finished (before polishing) (Figure 2B). Figure 2C shows the shape of the finished antagonist contact area on the palatal surface. Note that occlusion was checked and all interferences in eccentric direction were removed before the second tooth was restored. Figure 2D shows the application of the matrix on the second tooth and the first layer of uncured flowable composite resin applied before injection of the hybrid material using the snow-plough technique.[20] All maxillary anterior teeth were reconstructed in a similar way, while the posterior stops were kept *in situ* during closing in order to have identical maximal occlusion. Every tooth was adjusted in occlusion to

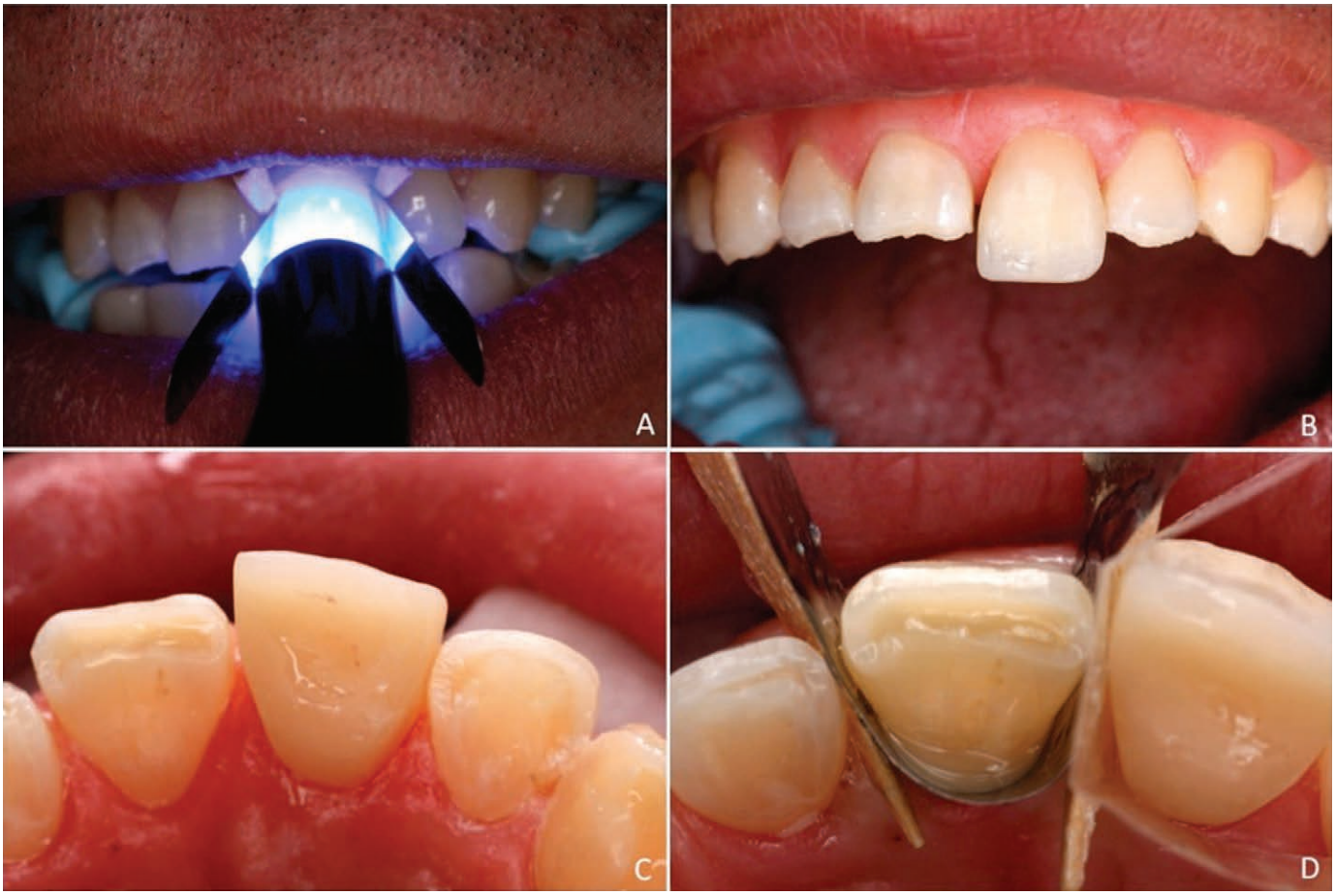

Figure 2. *(A): Polymerization of the last layer of composite resin in occlusion (DSO). (B,C): First tooth finished before final polishing. Compare the size with the contra lateral incisor. (D): Matrix* in situ *and application of a thin layer of flowable composite in the cervical area of the second tooth (snow-plough technique).*

the already built-up and finished teeth, and eccentric interferences were removed before treating the subsequent tooth. After removing interferences in lateral excursions on all incisors, the palatal surfaces of the canine teeth were adjusted so that a canine guidance was achieved.

Once the reconstruction of the maxillary anterior teeth was completed using the DSO technique, all teeth were polished. Figure 3A through C shows the result with the anterior teeth restored in increased VDO. This was the end of the first treatment session (4 hours), and the patient was sent home for a week.

The next procedure to restore posterior teeth was as follows:

1. maxillary first premolars were built up in the estimated Curve of Spee in line with the maxillary canines (Figure 3D);
2. mandibular first premolars were restored using the DSO technique (Figure 3D);
3. mandibular posterior teeth were built up in the estimated right plane prior to restoring the maxillary antagonists (Figure 3E,F); and
4. maxillary second premolars and molars were restored using the DSO technique (Figure 4A through D).

For this part of the treatment, two treatment sessions of four hours were required. As with the anterior teeth, the occlusal surfaces were finished and interferences in lateral excursions were removed using fine-grit diamond burs, aiming at contact in occlusion and preserving canine guidance.

All teeth were polished and finished using abrasive discs and silicone tips (Figure 5A through C).

CASE 2

A 45-year-old woman was referred to the clinic with a bridge that repetitively had been dislodged. At the time the patient was seen, the bridge had been

Figure 3. *(A): Maxillary anterior teeth. (B): Mandibular anterior teeth. (C): First session completed. All anterior teeth restored, allowing reduced but stabilized occlusion including canine guidance. (D): Second session started with the first premolars being restored. Right arch. (E): Left arch, including mandibular posterior teeth restored. (F): Mandibular teeth are restored according to the Curve of Spee.*

recemented three months earlier, and again the premolar-abutment tooth showed a dislodged crown (Figure 6A through C). The etiology was identified as bruxism, mainly by clenching the teeth. It was decided to remove the mesial part of the bridge and replace it with a direct composite crown to see if this solution would function on the mid-long term basis. It was agreed to decide later whether a new crown

Figure 4. *(A): In the first molar, the existing amalgam restoration was removed, a matrix band placed using a Tofflemire device and secured with wedges. It was verified that the patient was able to close in the desired VDO without interference. (B): The final layer of composite resin inserted on the occlusal surface left uncured. It is important to have excess of material to achieve an imprint of the opposing tooth. (C): Polymerization of the material after closing in occlusion (DSO technique). The Tofflemire device has been removed and the matrix-band was "opened" to have better access for the curing light. (D): First maxillary molar immediately after opening the mouth, after the final curing.*

had to be made and if the diastema had to be closed again, probably with an implant-supported crown. After informed consent, the mesial part of the bridge was removed (Figure 6D). The core proved to be suitable for a direct composite build-up. This was done using the DSO technique.

First, moisture control was achieved using cotton rolls placed buccally and lingually and inserting a suction device. Due to the healthy condition of the gingiva and the absence of inflamed tissue prone to bleeding, it was decided to do the adhesive procedure without a matrix placed. After the adhesive procedure using a two-step self-etching adhesive (Clearfil SE Bond), a partial metal matrix band was placed, using the operator's finger to control the position on the lingual surface in the gingival sulcus (Figure 7A). Subsequently, a layer of hybrid composite was inserted in the matrix, shaped, and cured (Figure 7B). Then, the matrix was removed and the buccal cervical surface was built up in the same way (Figure 7C). Subsequently, another partial metal matrix band was placed mesially and secured with a wedge and a separation ring to establish proximal contact (Figure 8A,B). When the mesial, buccal, and lingual surfaces were built up and cured properly, the occlusion was checked after removal of cotton rolls and suction device. It showed that the first build-up interfered in maximal occlusion resulting in the composite to be reduced with a high-speed diamond bur (Figure 8C).

Figure 5. *(A) Maxillary jaw: restorations finished and polished. (B): Mandibular jaw: restorations finished and polished. (C): Maxillary anterior teeth after polishing and finishing the restorations.*

Hence, a Tofflemire matrix band was applied. A high-speed diamond bur was used to reduce the metal matrix so that no interference with antagonistic teeth remained when closing the mouth in maximal occlusion. No separation ring was required at this point because the proximal contact was already constructed in the first step. Then again, moisture control was achieved by cotton roll and suction device isolation. The adhesive procedure was repeated by applying phosphoric acid, rinsing, and applying the adhesive. Finally, the occlusal part of the restoration was restored using the DSO technique (Figure 9A through D).

Figure 10 (A through D) shows the case completed and follow-up after six months.

List of Materials

- Clearfil AP-X (Kuraray, Osaka, Japan);
- Clearfil Majesty Flow (Kuraray, Osaka, Japan);
- IPS Empress Direct (Ivoclar Vivadent, Schaan, Liechtenstein);
- Clearfil Photo Bond, SA Primer, (Kuraray, Osaka, Japan);
- Phosphoric acid 35% (DMG, Hamburg, Germany);
- Clearfil SE Bond (Kuraray, Osaka, Japan);
- Sof-Lex pop-on polishing discs (3M ESPE, St Paul, MN, USA);
- Silicone tips (Cosmedent, Chicago, IL, USA);
- Tofflemire matrix system and bands (Henry Schein, Melville, NY, USA); and
- Partial matrix bands (Palodent, Dentsply, Konstanz, Germany)

Figure 6. *(A,B,C): A bridge from tooth 35 to 37 has failed repetitively by dislodgment of the mesial abutment tooth. (D): Core visualization of the premolar after the mesial abutment crown and pontic were removed.*

Potential Problems

The presented technique is a relatively inexpensive alternative for placing extensive restorations in occlusion and can be applied in several situations, including cases that require increased vertical dimension. Clinical long-term results for restorations placed in increased VDO using this technique are limited to one retrospective analysis showing good results on a mid-long term basis.[7] More evidence on the survival of resin composite restorations when patients with severe tooth wear are restored in increased VDO is limited to two other studies,[8,21] including one that shows unfavorable outcome after three years when a microfilled composite was used.[21] However, clinical studies on restorative treatment of patients in increased VDO with indirect techniques are absent, and evidence is limited to case reports.[10,16,22] Although some clinical evidence is present that this technique is working in clinical dentistry, long-term results are still questionable, and some concerns that might arise must be addressed.

Figure 7. *(A): Adaptation of the partial matrix band in the gingival sulcus controlled by finger pressure. Composite resin being inserted from the preloaded tip. (B): First layer of composite cured. (C): Premolar after applying the buccal portion of composite.*

Moisture Control

For the DSO technique, moisture control cannot be achieved by placing a rubber dam because this would prevent the patient from biting in occlusion. The authors are aware of the often-stated recommendation to use a rubber dam when an adhesive restoration is placed, but want to make a statement for the applied moisture control using cotton rolls, also based on the available scientific evidence. There are some clinical studies showing that regarding

Figure 8. *(A) Band, ring, and wedge located mesially. (B,C): Vestibular and occlusal view after reducing the composite to remove interferences in occlusion.*

sealant retention and adhesive bridge retention, rubber dam plays a positive role in success rates,[23,24] but a 10-year study comparing clinical survival of posterior composite restorations placed either with cotton rolls or with a rubber dam isolation method showed no differences in clinical outcome.[25] Moreover, several long-term clinical survival studies on posterior composite restorations placed without a rubber dam show good results.[4,26,27] Even when cervical outlines of class II restorations placed without a rubber dam extended below the dentin enamel junction, ending in dentin, no increase in secondary caries rates could be observed compared to restorations ending proximally in enamel.[28] This indicates that the placement of a rubber dam is not mandatory to have good results when placing posterior composite restorations.

However, with the DSO technique, patients are asked to articulate into uncured composite, which may compromise the quality of the restoration. The authors consider the following prerequisites as most important for a successful DSO technique.

1. Avoid, when possible, building up mandibular molars with this technique, as these teeth are the most difficult for maintaining moisture control. Moreover, in normal class I relation, maxillary molar teeth offer better opportunities to place the matrix and matrix device without interference with antagonists, and a better access for the curing light is possible.
2. Keep the period of closing in occlusion and possible moisture contamination as short as possible: remove suction when Vaseline is applied and the last uncured layer of composite is in shape. This means that when saliva is contaminating the area, it only comes in contact with uncured composite that is pressed in the palatal direction due to the closing in occlusion, and this material has to be removed anyway during shaping and finishing. Therefore, when properly applied, contamination will not compromise the result.
3. Whenever contamination occurs with saliva, it is recommended to repeat the adhesive procedure[29,30] after reestablishing moisture control. When, after the DSO technique, additional layers of composite should be applied, which is not normal but may be the case, we recommend removal of composite contaminated with Vaseline with a high-speed bur and repeating the adhesive procedure after reestablishing moisture control. So when applied properly, moisture control is no problem with the DSO technique, though the authors admit that, especially with lack of specific skills, it can be a potential weakness.

Restoring in Increased VDO

Although often a splint is recommended to test the increased VDO,[16] a recent review was not conclusive on the necessity of wearing a splint in advance when increased VDO was included in the treatment plan.[31] That review paper concluded that restoration in increased vertical dimension can be done safely up to 5 mm. Moreover, the increased vertical dimension as applied in direct composite offers possibilities for adjustment of the occlusion; therefore, we are not recommending to use a splint in advance for these direct build-ups and, as the clinical report shows, no problems with the adjusted VDO were found.[7] The method of positioning the occlusion by means of the stops offers the possibility to mount casts in central

Figure 9. *(A): Final layer of uncured composite resin. (B): Polymerization with Tofflemire in position and the mouth closed. Note the Vaseline applied on the antagonistic tooth. (C): Occlusal view immediately after the final polymerization. (D): Restoration finished and polished.*

occlusion as well as central relation, and guides the patient's jaw in a reproducible position every time when closing the mouth. After opening the occlusion, many interferences still exist when patients make excentric movements or between central relation and central occlusion that need careful adjustment. It is important to do these adjustments after every new tooth is built up, so that before starting to build up a next tooth, central occlusion and lateral excursions are well established.

Moreover, as direct composite is used to create increased vertical dimension, this can be considered

Figure 10. *(A): Case completed. Vestibular view during occlusion. (B): Vestibular view during opening mouth. (C): Occlusal view after the conclusion of the case. (D): Six-month follow-up.*

as "adjustable" if vertical dimension apparently is too high after a certain time. However, within the considerable experience that we have with the technique, we never have had a case where, after building up the occlusion, the vertical dimension had to be decreased in a following session due to complaints from the patient.

SUMMARY OF ADVANTAGES AND DISADVANTAGES (OR LIMITATIONS)

The DSO technique offers a possibility to restore teeth with direct composite in occlusion, especially in clinically complicated cases like replacing existing crowns or rehabilitations in increased vertical dimension. It is a relatively inexpensive technique that offers also the possibility to make mid-long term temporary restorations when large rehabilitations are to be done and new occlusal situations have to be tested. Especially for the restoration of severe tooth - wear cases, the technique has proven itself as successful on a mid-long term basis.

However, the technique demands certain experience and skills of the operator as anatomic form and occlusal patterns are made manually. Moreover, certain skills of the dental team in moisture control are necessary as the technique is not possible with a rubber dam in place. For less experienced dentists, wax-up models and moulds[11] may offer alternative options to do these extensive cases.

CONCLUSION

This newly presented technique can be a good choice to restore teeth with extensive tissue loss at relatively low cost. The technique has been proven successful for the treatment of severe tooth wear in increased VDO and is minimally invasive. It can also be used to make direct full coverage restorations in occlusion. Therefore, it can be a good option to restore teeth on the short- and middle long-term.

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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