Ceramic Inlays: A Case Presentation and Lessons Learned from the Literature

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ABSTRACT

Ceramic dental restorative materials offer an esthetic alternative to dental amalgam or gold. There is uncertainty relative to the longevity of ceramic inlay restorations. Recently published long-term research studies reveal general clinical performance trends. These trends are discussed while presenting a ceramic inlay case. Successful clinical use of ceramic inlay materials is absolutely dependent on the creation of an uncompromised adhesive tooth/ceramic interface. Ceramic inlay restorations perform well in terms of long-term retention, color match, and anatomic contour stability. These restorations all experience limited margin deterioration that does not predispose to marginal discoloration or secondary caries. Patients rarely suffer from postoperative sensitivity secondary to ceramic inlay placement.

Ceramic inlays fail predominantly as a result of crack propagation from material flaws leading to bulk fracture. Some superficial ceramic defects may be repaired with composite resin. Internal material flaws are minimized by industrial production of indirect pressable glass-ceramic materials or ceramic blocks designed for computer-aided design/computer-assisted manufacturing (CAD/CAM). External surface flaws are limited by careful polishing techniques. Strategic placement of ceramic inlays in teeth that are not subject to heavy occlusal loading will result in more predictable long-term performance. Preparation design to prevent flexure of ceramic inlay materials is essential.

CLINICAL SIGNIFICANCE

Use of ceramic inlays to restore defects in posterior teeth requires careful attention to detail. Placement of ceramic inlay materials in high-stress areas may result in less predictable long-term performance. Ceramic inlays are advantageous for restoring moderately sized defects when optimal control of restoration contours and esthetics is desired.

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INTRODUCTION

The ultimate goal of dental medicine is the prevention of dental disease. When this goal is not achieved, the focus shifts toward the correction of dental disease, which in the case of dental caries is achieved with restorative materials that perform like tooth structure. The introduction of tooth-colored restorations made from composite resin or ceramic has solved many of the esthetic concerns that patients have expressed over silver amalgams or gold alloys. These materials depend on an adhesive interface between the restoration and the remaining

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tooth structure, and are therefore subject to the durability of that interface. In addition to dependence on an adhesive interface, these restorative materials have unique characteristics that must be considered when restoring stress-bearing areas of the oral cavity.

Enamel, as a substrate, is minimally variable from patient to patient and tooth to tooth. The durability of the adhesive interface with enamel is very predictable. Dentin, however, as a substrate varies greatly within each tooth and from patient to patient. Hence, the adhesive attachment to dentin is not as predictable. Tooth-colored restorative systems are, therefore, technique sensitive and require greater attention to detail than restorative systems that do not require an adhesive interface. It is incumbent upon the dentist to understand this variability and create the conditions necessary for a successful adhesive bond to both enamel and dentin.

Current tooth-colored restorations made of composite resin perform much like amalgams when attention to detail is maintained.[1] Less is known about the clinical performance of tooth-colored ceramic restorations. Ceramic restorations, in general, fail from cyclic loading, material flexure, and subsequent propagation of fractures inherent in the ceramic material and on the external surface.[2,3] Conventional sintered feldspathic porcelain inlays are prone to fracture, and methods to reinforce the porcelain have been developed. Industrial production of ceramic blocks for CAD/CAM helps minimize the inclusion of internal flaws in the ceramic.[3] Ceramics that have an increase in the crystalline phase of the ceramic have greater resistance to fracture.[2] One strategy to limit fracture propagation is to increase the leucite crystal content in the feldspathic porcelain (IPS Empress and ProCAD, Ivoclar Vivadent, Amherst, NY, USA). In these products, larger leucite crystals interrupt fractures that form in the amorphous phase and resist fracture propagation. Another method is to heat-treat leucite-reinforced ceramic such that the leucite crystals begin to convert into the sanidine crystal polymorph of feldspar (Vita Mark II, Vita Zahnfabrik, Brea, CA, USA). Upon cooling, the sanidine crystals contract more than the original leucite crystals, resulting in a net compressive force in the ceramic block with a resultant increased resistance to fracture propagation.[4]

Research has been undertaken to assess how well dental restorative materials perform over time. Comparing the various clinical studies of these materials has proven to be difficult because of a lack of standardization. The need for standardization led to the development of the much-used United States Public Health Service (USPHS) criteria to allow consistent assessment of the various clinical parameters that define how these materials perform over time. A key ingredient to successful standardization is the calibration of the researcher(s) conducting the study.[5] Short-term studies of ceramic inlay performance have been carefully evaluated, and a need for improved study design quality was observed.[6]

This decade has seen the publication of clinical research on ceramic inlay restorative materials with evaluation times ranging from 8 to 15+ years. The goal of these studies has been to identify the long-term clinical performance. Modified USPHS criteria have frequently been employed in these various long-term clinical research reports (randomized clinical trials, controlled clinical trials, and case reports).[7–12] The type and level of calibration of the examiners has rarely been reported.[8,10] Most of the published long-term clinical evaluation of ceramic inlays are case series studies.[7,9,11,12] Studies with a greater amount of control lack strength because of low sample size[8,10] or uneven sample population (either male/female ratios or premolar/molar ratios).[8–10] In all the published studies evaluated in this article, the specific patient sex (male or female) and type of restored tooth (premolar or molar) where the restoration failed are not reported.[7–12] Even so, the diligent work of the various researchers provides valuable information to the dental clinician when treatment planning with ceramic inlays. General performance trends can be assessed in terms of retention, color match, marginal discoloration (interfacial staining), recurrent caries, wear (loss of anatomical form or contour), marginal adaption (integrity), postoperative sensitivity, or other failures. The goal of this case presentation is to highlight the strengths and weaknesses of ceramic inlay restorative materials and discuss how case selection and preparation design may increase predictability.

CASE REPORT

A 26-year-old female patient presented in early 2007 with a moderately sized fractured mesio-occluso-lingual (MOL) dental amalgam in an asymptomatic, vital first maxillary molar (Figure 1). This molar had received an occluso-lingual (OL) amalgam in 1991, followed by a mesio-occlusal (MO) amalgam in 1993. The OL amalgam was found to be defective in 1998 and was replaced. Options of another amalgam, a composite, or a ceramic inlay were discussed in terms esthetics and predictable longevity. The patient's desires were to restore the tooth with a ceramic tooth-colored material. Patient demographics are among the first characteristics to consider when considering use of ceramic inlay restorative materials. Long-term studies suggest that ceramic inlays perform better in females than in males.[7,12] Assessment of tooth vitality and an accurate pulp diagnosis are important steps, as one long-term study reported the greatly reduced survival of ceramic inlays in nonvital molar teeth.[11] Excessive occlusal wear was not detected. There was no evidence of parafunctional habits. Long-term case series studies suggest that the use of ceramic inlays in patients with bruxism or clenching may result in a greatly reduced restoration life span.[7,9,12] If this had been a mesio-occluso-distal (MOD) amalgam, replacement with an MOD ceramic inlay may not have been the most predictable option. Long-term studies suggest that MOD ceramic

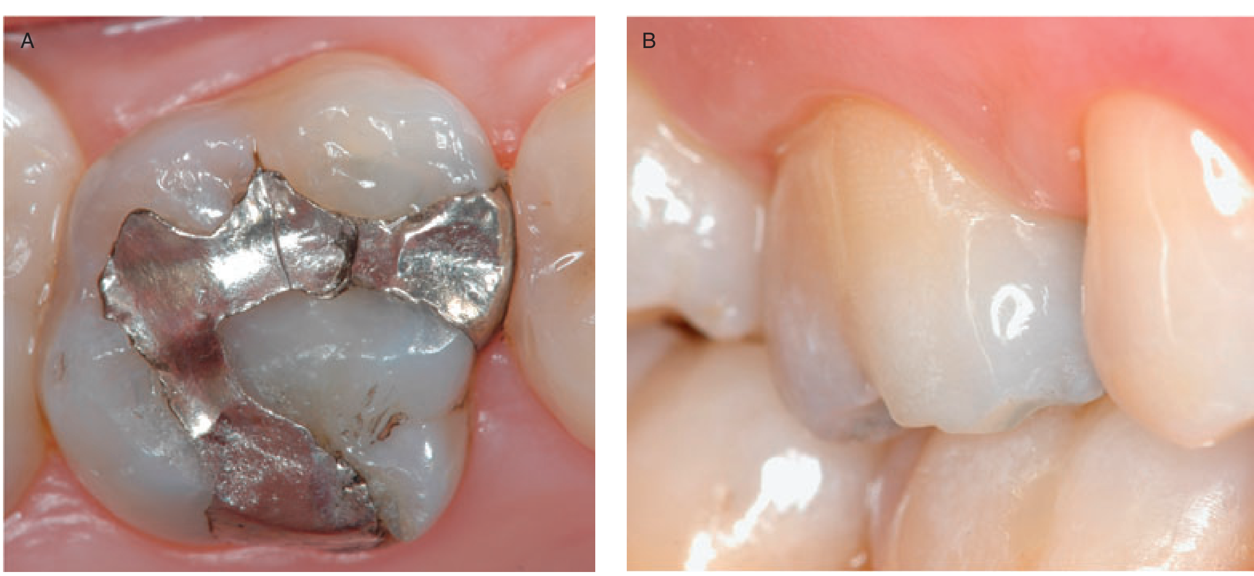

Figure 1. A fractured MOL amalgam in the maxillary right first molar (A). Common esthetic clinical presentation of the first maxillary molar restored with amalgam (B).

Figure 2. A bitewing radiograph revealing thin amalgam in the approximate area of fracture. The interproximal box is likely to retain enamel along the apical cavosurface margin. The anticipated interproximal space likely will not require excessive unsupported ceramic.

inlays in molars do not perform as well as other restoration configurations.[7,10–12] The reason for this is unknown.

Evaluation of the current restoration and an associated bitewing radiograph revealed fracture development in the isthmus area where the restoration was thin (Figures 1 and 2). Ceramic restorations are subject to fracture propagation during flexure. Preparation design to allow for the necessary bulk for rigidity becomes essential.[7,9,12] It is generally accepted that the thickness of the ceramic material be ~2 mm in stress-bearing areas to limit flexure under loading.[13,14] In addition to thickness of ceramic, tooth structure support of the ceramic increases resistance to fracture, especially in interproximal areas where the ceramic material has to extend to make adjacent tooth contact.[9] In this case, the interproximal distance between the molar and premolar was normal, and the anticipated support of the ceramic marginal ridge was adequate (Figures 1 and 2).

Creation of an adhesive bond to tooth structure requires that the tooth be isolated from saliva, gingival crevicular fluid, and blood while preventing dentin dehydration. There has been considerable debate over whether rubber dam isolation provides greater restoration predictability than cotton roll isolation. No long-term ceramic inlay study directly compared the two isolation methods and controlled for all other variables. The overall restoration longevity reported in long-term studies does not appear to be adversely affected by the type of isolation technique.[7,9,10,12] Not all studies reported the type of isolation used.[8,11] Proper isolation, in any form, cannot be overemphasized. Rubber dam isolation may well provide increased operating field control while careful attention is given to each procedural step (Figure 3).

Removal of the fractured restoration allows evaluation of the current extent of tooth destruction (Figure 3). Removal of the remains of a pin in the lingual preparation extension was not indicated. In this case, avoidance of narrow isthmus areas and thin ceramic required increasing the dimensions of the preparation (Figure 4). Design of the new ceramic restoration allowed for ease of draw during try-in and fitting. This limited the likelihood of binding and inadvertent restoration fracture before cementation. All transitions were gradualized to limit the potential for areas of stress concentration. The preparation draw, although adequate for fitting, also retained enough parallelism to provide protection from excessive stress on the micromechanical adhesive bond between the restoration and the tooth (Figure 5). Retention of ceramic inlays has rarely been

Figure 3. Isolation with rubber dam and removal of defective restoration to assess the size of the cavitation. Narrow isthmus areas that would prevent adequate porcelain thickness were identified (a, b, and c).

Figure 4. Divergent walls were created and cavosurface margins adjusted to allow maximum bulk of ceramic at the interface. Clearance with the adjacent tooth was established to allow interproximal finishing. Margins were maintained in enamel for maximum bond predictability.

reported as a concern, provided that appropriate attention is given to isolation and establishment of the adhesive interface.[15]

The preparation design will also need to be modified to allow for ceramic bulk at the margins (Figures 4 and 5). Ceramic inlays develop a self-limiting loss of marginal integrity at the cavosurface adhesive interface over time.[7–9,11,12] Long-term studies report no increase in caries as a result of the marginal deterioration.[7–10,12] Three of these studies utilized radiographs to assess for caries in interproximal areas that may be difficult to detect clinically.[8,10,12]

Ease of isolation and greater predictability of enamel bonding dictates the placement of ceramic restoration margins in enamel whenever possible (Figure 4). It has been unclear whether gingival margins placed in dentin are more prone to recurrent caries. Long-term studies of ceramic inlays report no associated increase in caries when margins are placed on dentin.[7–10,12] The potential adverse effects of polymerization shrinkage are minimized because of the thin cement layer. Therefore, it may be that the bond to the dentin is relatively more protected than it would be if direct composite were used.

A CEREC 3D system (Sirona, The Dental Company, Charlotte, NC, USA) was used to generate the MOL inlay for this individual. Every attempt to ensure a small marginal gap was made (Figure 6). It is now possible to consistently have ceramic inlays with marginal gaps less than 100 micrometers (μm). Early CAD/CAM systems created marginal gaps of 150 μm or more. Long-term studies with various CAD/CAM and pressed glass-ceramic systems report no detected adverse effects at the marginal interface, even with larger marginal gaps.[7,9–12]

The restoration occlusal anatomy was adjusted to recreate appropriate

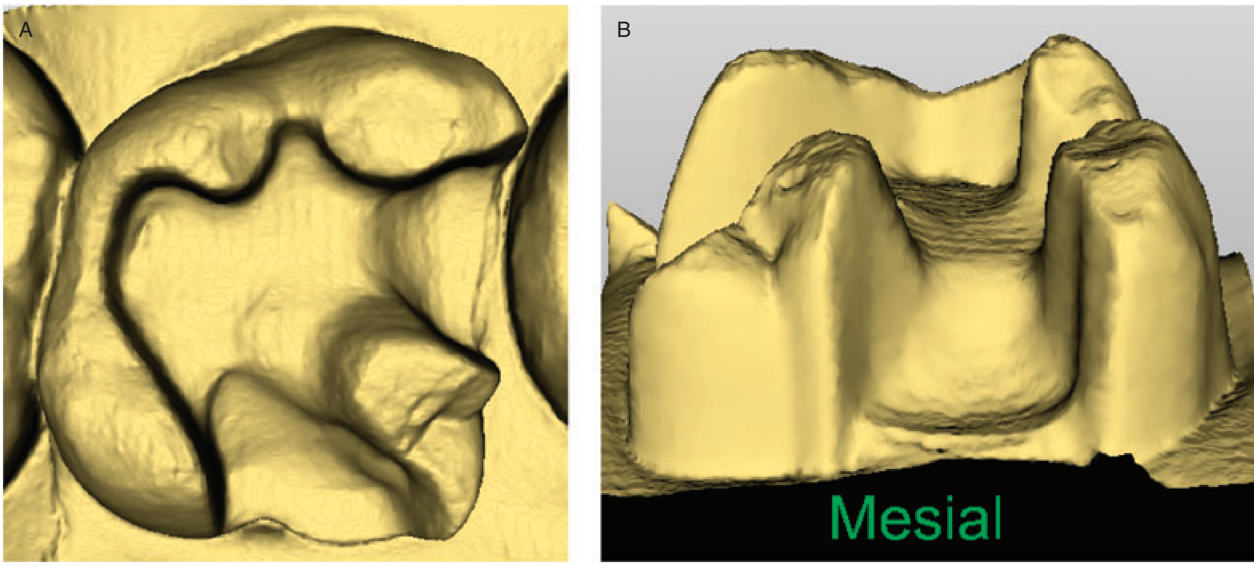

Figure 5. Images (A and B) used during ceramic inlay computer-assisted design (CEREC 3D). Sharp transitions have been removed to limit areas of stress concentration. The wall divergence was designed to allow fitting, retention form, and protection of the adhesive interface.

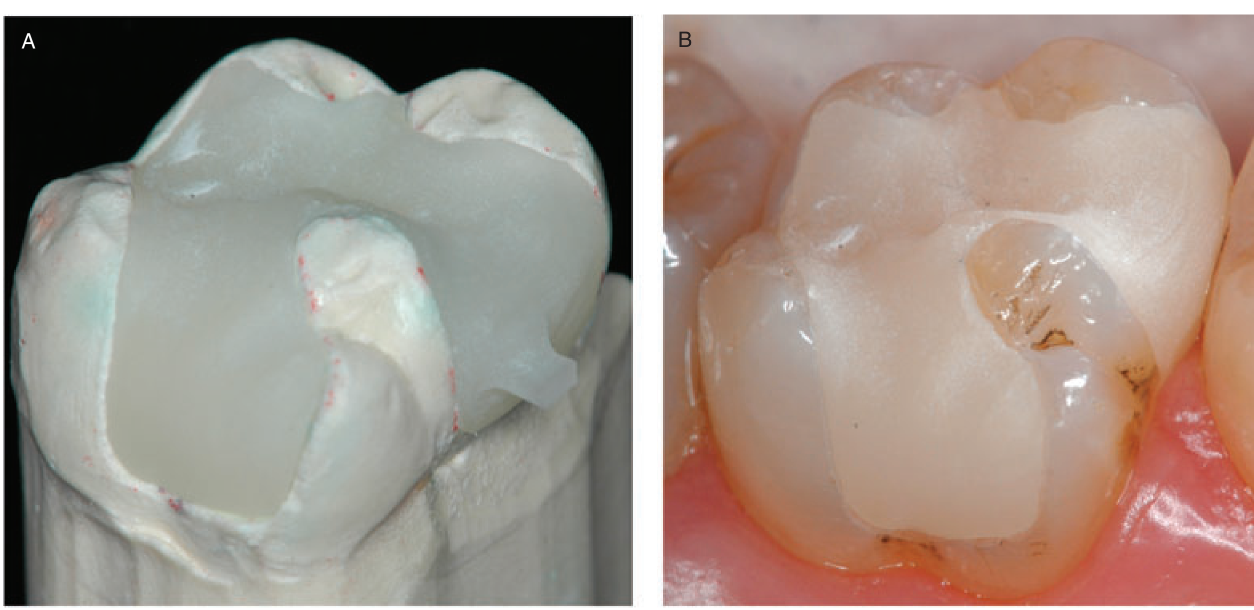

Figure 6. The CAD/CAM unit generated a ceramic inlay with satisfactory fit of a dental stone die (A) as well as fit in the upper maxillary first molar (B). Slight submargination was present at the lingual margin.

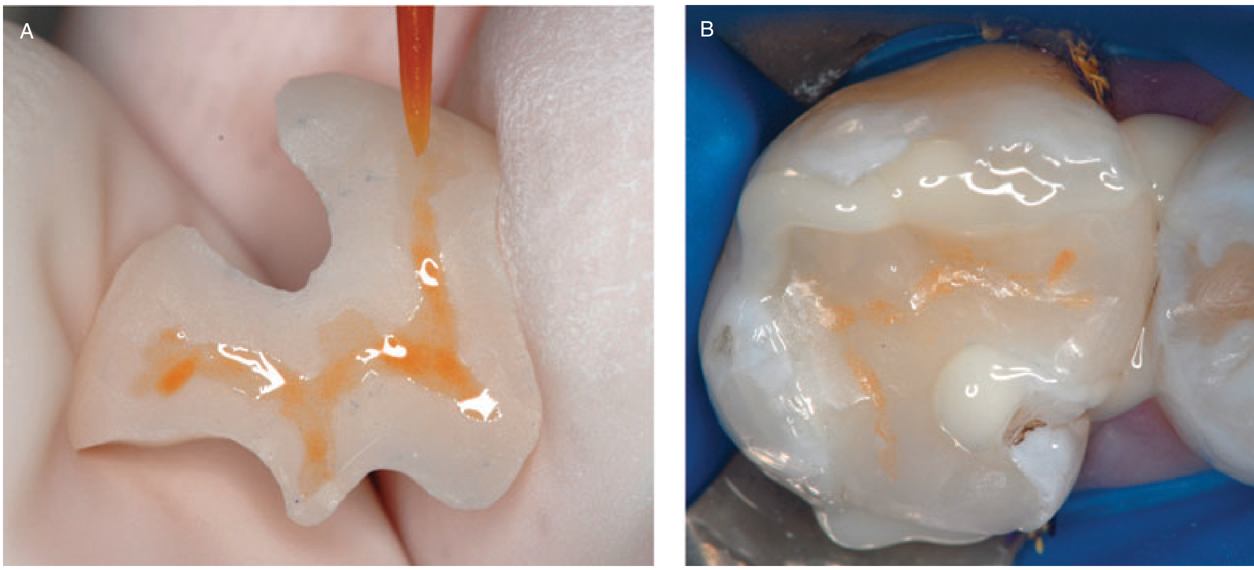

Figure 7. Staining and glazing of ceramic inlays is optional but can aid in the elimination of surface flaws that may predispose the inlay to fracture (A). An image of the ceramic inlay immediately after initial seating (B). Predictable clinical performance depends on the establishment of the adhesive interface.

cuspal inclines and marginal ridge heights. Surface characterization was added in the process of glazing (Figure 7A). The Vita Mark II inlay was etched with 9% hydrofluoric acid and treated with fresh silane. A light-emitting diode curing light (DEMI, sdsKERR, Orange, CA, USA) was used for all light-curing steps. The adhesive interface was created by closely following the manufacturer's instructions included with the 3M ESPE Rely-X ARC (St. Paul, MN, USA) adhesive resin cement system (Figure 7B). This system includes the 3M ESPE Scotchbond etchant and the Adper Single Bond Plus Adhesive. GLUMA Desensitizer (Heraeus Kulzer, South Bend, IN, USA) was applied to the dentin for 30 seconds, between the etch-and-bond steps, and excess fluid was evaporated with a light airstream. The restoration was completely seated with controlled pressure using a ball burnisher. Excess cement was immediately removed with caution as to not remove cement from the margin interface. Initial light-curing was accomplished while maintaining controlled seating pressure on the inlay. Careful compliance with the manufacturer's instructions for use of any particular adhesive system cannot be overemphasized. Long-term studies reported the use of various luting systems, but no strong statements can be made with regard to relative adhesive cement effectiveness.[7–12] The occlusion was checked and adjusted after cementation to limit potential flaw propagation.

Careful attention to the placement of even functional stops on the occlusal surface, which are in addition to natural tooth functional stops, will limit excessive cyclic loading of the ceramic material. Once the occlusion is perfected, careful attention to surface polishing becomes essential (Figure 8). Areas that are adjusted with rotary instrumentation are more prone to develop marginal ridge or bulk fractures.[9] Removal of surface defects/flaws (which increase the likelihood of ceramic fracture) cannot be overemphasized.[2,9] The final polish is accomplished with rubber instruments, followed by

Figure 8. The adjustment of the occlusal contacts allows shared, even loading of the natural tooth and the ceramic inlay.

diamond paste.[16] Loss of anatomic contour from restoration wear does not appear to be a long-term concern.[7–9,12] None of the long-term studies evaluated wear of the opposing surfaces. The ceramic surface texture gradually becomes more rough and pitted over the long term but rarely becomes a clinical concern.[7–10,12]

A 1-month follow-up examination of this individual revealed no post-operative sensitivity associated with the new ceramic restoration. Long-term studies report that the various amounts of postoperative sensitivity experienced were rarely a substantial patient concern.[7,9,10,11] Ceramic inlay materials are very esthetic and can return the appearance of a restored tooth to near normal (Figure 9). A 1-year follow-up evaluation reveals ongoing achievement of esthetics, good clinical parameters, and no radiographic concerns (Figure 10). Long-term studies report that the color mismatch over time gradually becomes more pronounced, but this did not present an esthetic concern for the patients.[7–10,12]

All long-term clinical reports of ceramic inlays find that ceramic fracture is the primary mode of failure.[7–12] Many times, the fractured area can be repaired with composite resin.[12] No carefully controlled studies have been accomplished that allow comparison of the performance of pressed glass-ceramic inlays with CAD/CAM-produced ceramic inlays. Analysis of the various long-term studies reveals that, in general, ceramic inlays have greater longevity in premolars than in molars.[7,8,11,12] Careful thought should be given to the level of anticipated cyclic loading before choosing a ceramic inlay to restore any particular tooth. Clinical detection of bulk fracture is not always possible, and this may have inflated the survival probabilities reported in the various long-term studies.[17] Identification and interpretation of the relative severity of ceramic fracture and need for intervention may be highly subjective.[11] Within the limitations of these studies, reported survival probabilities that range between 75 and 92% at 15+ years indicate that ceramic inlay restorations are fairly predictable when used as indicated.[11,12]

Treatment planning discussions must inform patients of the strengths and weaknesses of this particular restorative material. Specific attention to indications and relative contraindications, along with sensitivity to the technical demands of creating an adhesive interface, will increase the likelihood of providing a highly esthetic and predictable ceramic inlay restoration (Table 1).

CONCLUSIONS

Ceramic inlays are a highly esthetic restorative option. Their use should be limited to vital teeth that are not under heavy occlusal loading. Attention to detail in every step is a prerequisite to long-term success. Establishment of an excellent adhesive interface, an adequate ceramic thickness, and a highly polished

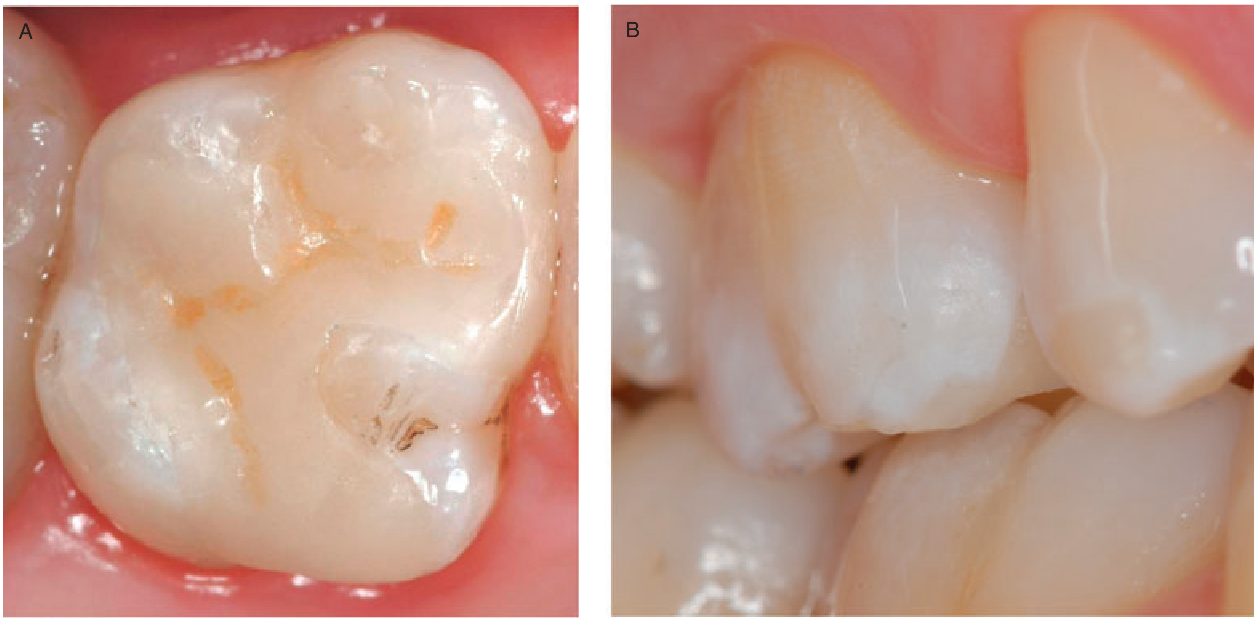

*Figure 9. One-month follow-up images (*A *and* B*) revealing optimal esthetic and functional clinical performance of the ceramic inlay restoration.*

*Figure 10. One-year follow-up image revealing optimal clinical performance (*A*). One-year follow-up bitewing radiograph with normal radiographic appearance (*B*).*

TABLE 1. SEVENTEEN LESSONS ON CERAMIC INLAY USE.

1. Ceramic inlays perform better in females than in males over time.[7,12]
2. Ceramic inlays do not survive well in nonvital molar teeth.[11]
3. Ceramic inlays do not survive well in patients with bruxism or clenching.[7,9,12]
4. MOD ceramic inlays in molars do not perform as well as other restoration configurations.[7,10–12]
5. Preparation design for ceramic inlay restorations must allow ~2-mm material thickness in stress-bearing areas to limit flexure under loading.[2, 3,7,9,12–14]
6. Overcontour of ceramic to close large interproximal areas may predispose to early failure.[9]
7. Absolute isolation is essential. Use whatever method works best.[7,9,10,12]
8. Careful attention to adhesive technique and preparation design will help insure predictable retention of ceramic inlays.[7–12,15]
9. Ceramic inlays develop a self-limiting loss of marginal integrity at the cavosurface adhesive interface over time.[7–9,11,12]
10. Ceramic inlay marginal deterioration does not appear to increase likelihood of caries.[7–10,12]
11. Subgingival ceramic inlay margins has not been associated with an increase in recurrent caries.[7–10,12]
12. The size of the marginal gap of ceramic inlays fabricated using various CAD/CAM and pressed glass-ceramic systems has not been reported to have an adverse effect on restoration longevity.[7,9–12]
13. Surface flaws of ceramic inlays must be carefully removed (by polishing) to avoid crack propagation that may lead to marginal ridge or bulk fractures.[9]
14. Ceramic inlays maintain anatomic contour over time.[7–9,12]
15. Ceramic inlays gradually develop rough and pitted surface texture over time.[7–10,12]
16. Fracture is the primary mode of failure of ceramic inlays.[7–12]
17. Premolar ceramic inlays have more longevity than molar ceramic inlays.[7,8,10,12]

restoration surface helps to prevent fracture propagation and failure. When used in the correct circumstances, ceramic inlays may offer an attractive alternative to nontooth-colored restorative materials.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are included in this article.

REFERENCES

1. Opdam N, Bronkhorst E, Roeters J, Loomans B. A retrospective clinical study on longevity of posterior composite and amalgam restorations. Dent Mater 2007;23:2–8.
2. Seghi RR, Denry IL, Rosensteil SF. Relative fracture toughness and hardness of new dental ceramics. J Prosthet Dent 1995;74:145–50.
3. Thompson JY, Bayne SC, Heymann HO. Mechanical properties of a new mica-based machinable glass ceramic for CAD/CAM restorations. J Prosthet Dent 1996;76:619–23.
4. Mackert JR, Twiggs SW, Williams AL. High-temperature x-ray diffraction measurement of sanidine thermal expansion. J Dent Res 2000;79:1590–5.
5. Bayne SC, Schmalz G. Reprinting the classic article on USPHS evaluation methods for measuring the clinical research performance of restorative materials. Clin Oral Investig 2005;9:209–14.
6. Hayashi M, Wilson NHF, Yeung CA, Worthington HV. Systematic review of ceramic inlays. Clin Oral Investig 2003;7:8–19.
7. Otto T, De Nisco S. Computer-aided direct ceramic restorations: a 10-year prospective clinical study of CEREC CAD/CAM inlays and onlays. Int J Prosthodont 2002;15:122–8.
8. Sjogren G, Molin M, van Dijken JWV. A 10-year prospective evaluation of CAD/CAM-manufactured (CEREC) ceramic inlays cemented with a chemically cured or dual-cured resin composite. Int J Prosthodont 2002;17:241–6.
9. Kramer N, Frankenberger R. Clinical performance of bonded leucite-reinforced glass ceramic inlays and onlays after eight years. Dent Mater 2005;21:262–71.
10. Thordrup M, Isidor F, Horsted-Bindslev P. A prospective clinical study of indirect and direct composite and ceramic inlays: ten-year results. Quintessence Int 2006;37:139–44.
11. Reiss B. Clinical results of CEREC inlays in a dental practice over a period of 18 years. Int J Comput Dent 2006;9:11–22.
12. Otto T, Schneider D. Long-term clinical results of chairside CEREC CAD/CAM inlays and onlays: a case series. Int J Prosthodont 2008;21:53–9.
13. Prakki A, Cilli R, Da Costa AU, et al. Effect of resin luting film thickness on fracture resistance of a ceramic cemented to dentin. J Prosthodont 2007;16:172–8.

14. Federlin M, Krifka S, Herpich M, et al. Partial ceramic crowns: influence of ceramic thickness, preparation design and luting material on fracture resistance and marginal integrity in vitro. Oper Dent 2007;32:251–60.

15. Molin MK, Karlsson SLA. Randomized 5-year clinical evaluation of 3 ceramic inlay systems. Int J Prosthodont 2000;13:194–200.

16. Sasahara RM, Ribeiro Fda C, Cesar PF, Yoshimura HN. Oper Dent 2006;31(5):577–83.

17. Clinical Research Associates. CEREC 20th anniversary—is it time to buy in-office CAD-CAM? CRA Foundation Newsletter 2006;30:1–4.

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