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Trends in Indirect Dentistry: 4. Performance of Adhesive Restorations

Abstract: Restorations which may be bonded to tooth substance hold advantages over traditionally-luted restorations, including reduced requirement for resistance and retention form. There is evidence that adhesive techniques are becoming increasingly used, but is their performance as good as more traditional restorations? This paper reviews the success rates of adhesively-luted indirect restorations, concluding that these require less tooth reduction than non-adhesive restorations, although performance in terms of debond/loss of restoration may not always be as good as in traditional techniques.

Clinical Relevance: The use of adhesive techniques should result in less reduction of tooth substance and may be of value where retention is suboptimal.

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Satisfactory longevity of restorations is central to good dental practice, notwithstanding additional requirements like correct diagnosis, a preventive philosophy, avoidance of unnecessary preparation and caring patient management. The previous paper in this series addressed current luting materials and the means by which indirect restorations may be bonded to tooth substance.[1] In this respect, restorations which are designed to be bonded to tooth substance hold advantages over those in which the luting material simply fills the gap between restoration and tooth. These include:

- Reduced requirement for ideal retention and resistance form which, in turn, should require less preparation of sound tooth substance;
- Sealing dentine with a dentine adhesive, or adhesive luting material, reducing the risk of pulpal irritation and post-operative sensitivity;[1]
- Adhesive restorations may be resin-based or ceramic, ie tooth-coloured.

Disadvantages included, until recently, fewer research data than for conventional restorations, but this is no longer the case.

Dental practitioners in the UK appear to have embraced some aspects of adhesive technology for indirect restorations, with the results of a questionnaire-based study by Hill and co-workers indicating that 88% of respondents provide porcelain veneers for their patients and 68% stating that they provide aesthetic inlays.[2] More recent work by Brunton *et al*. has shown that 64% of the UK dental practitioners who responded to a questionnaire place tooth-coloured inlays, with a majority choosing to prescribe ceramic rather than laboratory composite.[3] It is the purpose of this paper to summarize indirect adhesive techniques which are becoming increasingly available to the clinician and to present information on their longevity by referencing meta-analyses, systematic reviews or long-term or high-number evaluations, rather than quoting large numbers of papers with small numbers of restorations or short evaluation times.

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Indirect adhesive restorations

Resin-retained bridgework

This technique involves the bonding of adhesive 'wing' retainers to the palatal and, in posterior teeth, the occlusal and buccal and/or lingual surfaces of abutment teeth. The pontic is then retained *in situ* by these retainers, with the resin-retained (also termed resin-bonded) bridge being formed in metal-ceramic or, more recently, fibre-reinforced resin-composite materials. Despite the fact that this restorative technique involves only minimal reduction of tooth substance, a thorough history and examination are essential, as with any restoration. In particular, the amount of enamel present and available for bonding to the potential abutment teeth should be assessed, since abutment teeth with large restorations or inadequate amounts of good-quality enamel would be more ideally prepared for crowns for use as retainers for conventional bridges. A further question is whether space is available for the retainers or whether this must be obtained by tooth preparation. Provided that the abutment teeth are of good aesthetics, resin-retained bridges have a good potential for producing restorations of good appearance and reasonable longevity. Readers are referred to recently-published reviews of resin-retained bridges, by Ibbetson in *Dental Update*[4] and by Botelho.[5]

Success rates

A meta-analysis, by Creugers and van't Hof, of clinical papers between 1980 and 1990 on resin-retained bridges, has shown that 74% of the bridges surveyed had survived after 4 years.[6] The only factors analysed were 'type of retention' and 'location of the bridge' because other aspects relating to success were not adequately described in the papers assessed: these two factors were not found to influence success. It could, however, be considered that success rates, today, should be better than those analysed in this study, given the improvements in technique and bridge design since the date of the papers analysed. Creugers and colleagues produced survival data on 166 resin-retained bridges replacing anterior teeth and 37 replacing posterior teeth inserted in 183 patients in 1983 and 1984.[7] Survival analysis at 10 years indicated success rates of 49% to 57% for anterior bridges, and 18% to 37% for bridges replacing posterior teeth. Approximately half of these bridges were of perforated retainer design and half were electrolytically etched. These techniques were abandoned within the past decade because of poor rates of success, in favour of sandblasting the surface of the retaining wings in combination with an adhesive luting material.

In a study with a large number of cases, Djemal and colleagues have assessed the performance of 832 resin-retained bridges and splints provided for 593 patients at the Eastman Dental Hospital, London, between 1978 and 1993.[8] Debonding was the commonest mode of failure among the 27.9% of restorations which had failed, with the age of the restorations which were assessed ranging from one to 16 years. Survival analysis showed that, within the whole sample, there was a 50% probability of a resin-retained restoration in the survey lasting more than 7 years and 10 months. Factors influencing failure were area of coverage by the retainers, the rigidity and resistance form of the restoration, and experience of the operator. Orthodontic movement of abutment teeth prior to bridge placement did not incur additional risk of failure, nor did tooth preparation versus no tooth preparation. Patient satisfaction was high. However, approximately one quarter of the patients with a failed bridge were unaware of its failure. This is a worrying situation, as there is a strong potential for caries to occur, in time, beneath debonded resin-retained bridge retainers. Patients should be strongly advised (a patient information leaflet is a good idea in this respect) to return to their dentist should they become aware of a problem or if the bridge does not 'feel right'.

Hussey and Wilson have shown that retention rates of resin-retained bridges placed in the National Health Service (NHS) in the UK are less than ideal, with almost twice as many bridges de-cementing in one year than were placed.[9] The data therefore pose the question – why are results from hospital-based studies generally positive, but the results from UK NHS general practice less than ideal? It may be that case selection criteria are not so rigorous in general practice, or that there are differences in technique, such as method of isolation. The authors considered this to be a question worthy of further investigation.

Botelho, in his review, has quoted varying retention rates for resin-retained bridges of between 46% at 11 months to 93% at 11 years, and has considered that recent clinical studies are showing promising results over the short to medium term. He also considered that more recent results are better than those from older studies.[5]

Lastly, it is the author's contention that occlusion influences success, at least with anterior resin-retained bridges, with success rates decreasing with increasing overbite on abutment teeth, but few studies have considered the effect of occlusion on the success of resin-retained bridges. Creugers and co-workers[10] considered that occlusal contacts on abutment teeth rather than on the retainers influenced failure, suggesting that retainers be designed to receive occlusal contacts in the intercuspal position, a view which was supported by Crispin.[11] Where overbite is reduced, it is more difficult to ensure that both closed and excursive contacts are maintained on the retainer, which increases the risks that the antagonist will push the abutment out of the framework.

Comparison with conventional fixed bridgework

A meta-analysis of fixed bridgework by Creugers and co-workers estimated survival probabilities for conventionally-retained fixed partial dentures (FPDs) at 90% and 74% at 10 and 15 years, respectively.[12] These results are similar to those presented more recently in another meta-analysis by Scurria *et al*. in which 92% and 75% of the fixed partial dentures (FPDs) analysed had survived at 10 and 15 years, respectively.[13] Failure in this work was defined as removal of the FPD, with no account being taken of pulp death in abutment teeth. In this respect, Cheung and co-workers[14] have reported 11.8% of abutments requiring endodontics within a three year evaluation, and Randow *et al*.[15] reporting endodontic complications in 6.8% of abutments at 6.5 years. In Walton's review of 515 metal-ceramic fixed partial dentures over 15 years, 92% of the fixed partial dentures were known to have survived.[16] Tooth fracture was the most common reason for failure, with loss of retention and caries accounting for a smaller proportion of failures. Four per cent of abutments had required root canal treatment by the time of the 10-year review.

It therefore appears that the success rates, in terms of debonding, of resin-retained bridges when compared with conventional bridges is less good, although papers quoted above have predominantly used techniques which have been superseded because of low success rates. It could be considered that contemporary techniques utilizing sandblasted retainers and adhesive luting materials may produce improved success rates. It could also be considered that complications in resin-retained bridges are less serious than conventional bridges as a result of a b

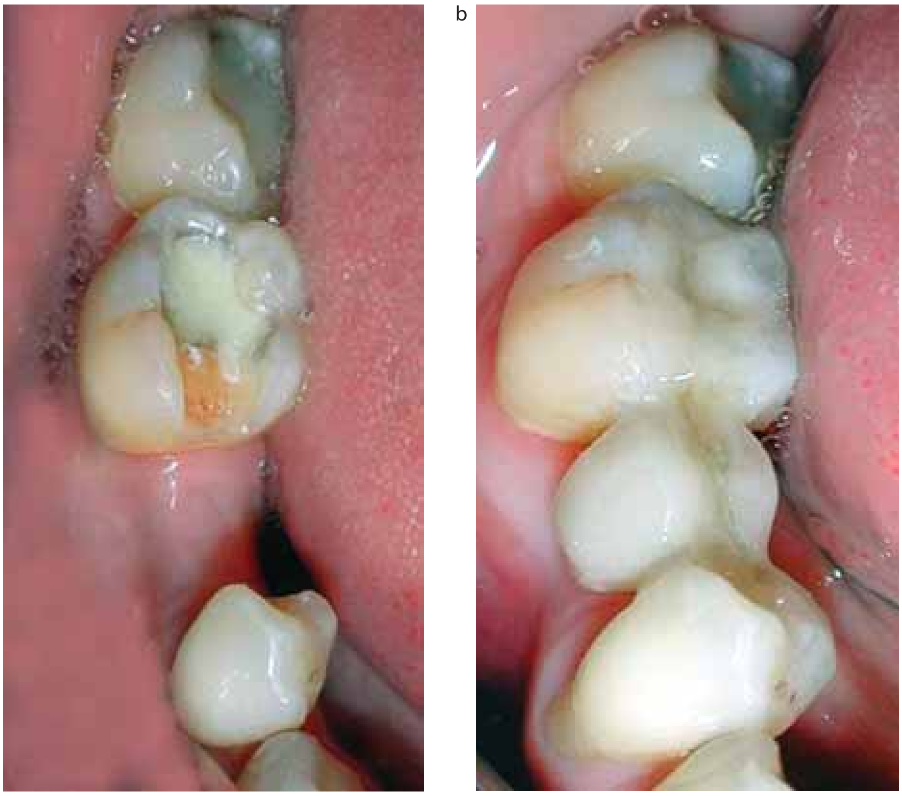

Figure 1. (a) Preparation for resin-retained bridge involved removal of existing restoration from 6/ and wraparound wings at 4/. **(b)** Resin-retained bridge in *Sinfony* (3M ESPE, Seefeld, Germany) with fibre reinforcement, replacing 5/.

the much reduced tooth preparation,[17] although this is difficult to determine as no studies clearly define reasons for failure. The risk of abutment fracture in resin-retained bridges is minimized because of the reduced loss of tooth structure compared with conventional crown preparations. Further research is needed to compare all the factors involved more fully.

Cantilevered resin-retained bridges (CRRBs)

The literature confirms that cantilevered resin-retained bridges are the most successful design. In the studies by Dunne and Millar[18] and Hussey and co-workers,[19] the debond rates were 21% and 17%, respectively, but the percentages of debonds for CRRBs was less than for fixed-fixed resin-retained bridges. Hussey and Linden have evaluated 142 anterior and posterior CRRBs, finding that 12% had debonded with a mean service life of 36 months, but that 96% remained in function.[20] Briggs and colleagues,[21] when evaluating 54 anterior and posterior cantilevered resin-retained bridges, reported a debond rate of 20% and a mean service life of 27 months. More recently, Botelho and co-workers[22] have reported the success rates of 33 CRRBs, with the results indicating a retention rate of 97% at a mean service time of 30 months, including 5 CRRBs which had been *in situ* for 72 or more months. Twenty-one of the abutments in this study had over 20% bone loss and 22 had Grade 1 mobility but, despite this, no tipping or drifting of any of the CRRBs was noted.

It may be concluded that CRRBs have good potential for success, with a number of studies showing higher potential for success than for a fixed-fixed design. However, the studies reflecting better success rates for CRRBs generally employed this design when only single missing anterior teeth were being replaced and the spans were short.

Fibre-reinforced resin-retained bridges

Most recently, resin-retained bridges have been constructed in resin-based materials such as *BelleGlass* (Kerr Mfg Co, Orange, CA, USA) or *Sinfony* (3M ESPE, Seefeld, Germany) with fibre reinforcement (Figure 1). These have the advantages of being tooth-coloured (as opposed to conventional resin-retained bridges which are generally constructed in metal-ceramic, with the retaining wings being unaesthetic), and that the fibre reinforcement may be placed in the areas where strength is required. However, data on the success of these restorations are limited, with Vallitu, in a clinical study of 29 prostheses, suggesting that glass fibre-reinforced resin-retained bridges may be an alternative to cast-metal based resin-retained bridges.[23] Vallitu calculated survival probability of 75% at 63 months for bridges constructed in *Sinfony* (3M ESPE, Seefeld, Germany) or *Triad* (DeTrey Dentsply, Konstanz, Germany) combined with unidirectional or woven bidirectional E-glass fibre reinforcement (*Stick* or *StickNet*: Stick Tech Ltd, Turku, Finland).[23] Two of the frameworks fractured during the time of the study and three became debonded. Three of the failed prostheses were rebonded or repaired *in situ* and, if these were discounted as failures, the mean functional survival rate was 93%. However, the number of patients in the study was low, and the author considered the results as preliminary. Caution is appropriate as the use of resin composite for fixed prostheses has traditionally placed great demands on the ability of the material to provide adequate strength in the connectors.

Porcelain veneers

Porcelain laminate veneers, introduced in the early 1980s, are thin (0.5–1 mm) veneers of ceramic which are bonded to underlying tooth (mainly enamel if the preparation is minimal). This is achieved by etching the enamel and using a light-cure or dual-cure resin composite luting material to bond the veneer to the ceramic fitting surface, which itself has been etched with an acid such as HF to etch the ceramic differentially in order to produce a micromechanically retentive fitting surface. This is a reliable bond and it is the author's opinion that porcelain veneers should not be lost through debonding, unless the clinical and/or laboratory techniques are suboptimal. Gingival response is generally better than

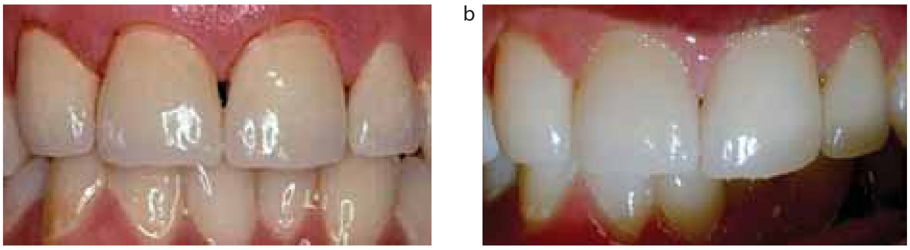

Figure 2. (a) Dentine-bonded crowns at fit appointment at /2, /1, 1/ and 3/ used in the treatment of toothwear, with 3/ being 'literalized' to simulate a lateral incisor tooth. **(b)** Crowns in Figure 2a after 4 years.

for full crowns, although the location of the cervical extension of the restoration in relation to the gingival margin also played an important role.[24] Principal indications are for the improvement of aesthetically poor teeth and for re-aligning teeth with minor imbrications. Porcelain veneers have been considered to biomimetically restore the mechanical behaviour of the crowns of teeth on which they are placed, ie they mimic or recover the biomechanics of the original tooth by means of the restorative material/technique.[25]

Success rates

Despite the minimally invasive technique which should be employed, it should not be assumed that success rates are 100%. In this respect, results of a meta-analysis, by Kreulen and co-workers,[26] which included 15 studies and over 2000 veneer restorations, indicated that the cumulative proportion of survival of porcelain veneers was 92% and that porcelain veneer survival rates were better than those for direct resin composite. However, none of the studies included in the analysis had produced data for more than 3 years.

A literature review by Peumans and co-workers[27] concluded that the adhesive porcelain veneer complex had been proved to be very strong, with optimal bonding being achieved when the preparation was contained in enamel, correct adhesive treatment procedures carried out and a suitable luting composite used. It was also concluded that the maintenance of aesthetics by porcelain veneers was excellent in the medium to long term, the periodontal response good, and that patient satisfaction was high. However, these workers also concluded that the overall, long-term clinical performance was unknown.

Dumfahrt and Schaffer have reported a ten-year evaluation of 191 porcelain veneers, calculating an estimated survival probability of 91% at ten years, with six of the total of seven failures occurring when the veneers were partially bonded to dentine.[28] They reported marginal discoloration in 17% of cases, and concluded that porcelain veneers were a predictable treatment modality. Another long-term (10 years) prospective evaluation of 87 porcelain veneers in 25 patients has been reported by Peumans *et al*.[29] No veneers had been lost and those remaining 'clinically acceptable' decreased from 92% at 5 years to 64% at 10 years, with porcelain fractures and large marginal defects being the principal reasons for failure. Marginal defects were especially noted at locations where the veneer ended on an existing composite restoration and, at such locations, severe marginal discoloration and recurrent caries were frequently observed. Of the restorations deemed to have failed, most were reparable and only 4% required replacement at the 10-year recall. These results are in contrast to those reported by Dunne and Millar in 1993.[30] These workers evaluated 315 porcelain veneers in 96 patients for up to 5 years, with 83% remaining problem-free at the end of the study. Overall, 11% of veneers had failed, either by debonding or because of a defect which necessitated removal, with dental school staff having significantly fewer problem veneers than students or house officers. Increased incidence of problems was noted, as with the previously-quoted study, when veneers were placed on top of existing restorations.

From the results of the studies quoted, and others, it is clear that the success rates of porcelain veneer restorations is by no means 100%, despite the minimally invasive nature of the technique, with veneers placed over existing restorations or on dentine being particularly prone to failure. Cases of 'instant orthodontics' using veneers to re-align imbricated teeth[31,32] should therefore only be undertaken when the patient is fully aware that they are entering the tooth restoration cycle and that the replacement of a failed veneer may be likely to be by a restoration, such as a crown, requiring greater loss of tooth substance. It is also relevant to add that non-intervention methods of tooth whitening, such as home bleaching, rather than veneers, should always be considered first when patients request tooth shade improvement.

Dentine-bonded crowns and inlays

Dentine-bonded crowns

The dentine-bonded crown (Figure 2) is an extension of the principle of a porcelain veneer. It provides the opportunity to restore the tooth with a bonded full coverage restoration that requires relatively small amounts of tooth preparation. It finds its application where both facial and lingual aspects of a tooth require restoration, or where a porcelain veneer is indicated, but the presence of more extensive intra-coronal composite restorations make a veneer less than optimal. In this technique, a crown constructed in an etchable (with HF) ceramic material (Table 1) is bonded to tooth substance by means of a dentine-

Feldspathic porcelain
IPS Empress (Ivoclar, Schaan, Liechtenstein) castable ceramic
Ceramic blocks prepared for CAD-CAM techniques
Hi-Ceram (Vita Zahnfabrik, Bad Sackingen, Germany)

Table 1. Examples of ceramic materials capable of being etched with HF or HCl/HF or HF/HCl/HNO_3 proprietary mixtures to produce a micromechanically retentive fitting surface.

bonding agent placed on the dentine and a dual-cure resin-luting material, which then bonds to the underlying dentine and the ceramic fitting surface.[33] The bond is improved by the treating of the etched ceramic fitting surface with a silane coupling agent.[34]

These crowns hold advantages over metal-ceramic crowns luted in a conventional manner, such as:

- Minimal preparation;
- Good aesthetics;
- Capable of being bonded to minimal tooth substance;
- Reduced risk of pulpal irritation;
- Good peripheral blend;
- Insoluble luting material.

Disadvantages include the more time-consuming nature of their placement as compared with conventional crowns and the lack of long-term clinical data.

Indications include:

- Loss of palatal and/or labial tooth substance, with compromised aesthetics;
- Realignment of moderately displaced teeth;
- Where minimal preparation techniques are appropriate.

Contra-indications include subgingival margins and poor patient motivation.

Success rates of dentine-bonded crowns

Long-term clinical data on dentine-bonded crowns from a variety of sources are sparse and insufficient for the production of a systematic review or meta-analysis. In this respect, Burke and Qualtrough have presented details of the success of 53 crowns at 4.4 years, with all but five of the restorations being intact.[35] Of the restorations deemed to have failed, one had been replaced because of unsightly gingival recession, another because of the fracture of its dentine core, another had a crack which was not noted by the patient and two had been replaced when the patient changed dentist, with the dentist being unable to provide details of the reason for crown replacement. In other words, none of the failures related to the dentine-bonded crown technique *per se*, and no crowns had de-bonded. Patient acceptability was rated as high. More recent data were presented at the British Society for Dental Research in 2004, with dentine-bonded crowns being reported as performing well in the restoration of teeth affected by toothwear, again with nil incidence of de-bonding.[36]

Success rates of tooth-coloured inlays

The dentine-bonded crown concept may be expanded for use with ceramic and resin-based inlays. Hickel and Manhart have assessed the success rates of such inlays by means of a comprehensive survey of the dental literature over a 10-year period to 2000, with annual failure rates being found to range from 0% to 7.5%.[37] It was noted that bulk fracture was a frequent cause of failure of ceramic inlays and that strict case selection, including avoiding the placement of ceramic inlays in bruxers, increased the potential for success. Restorations produced by the CAD-CAM technique were found to have annual failure rates ranging from 0–4.4%.

Individual papers citing either large numbers of restorations or smaller numbers for extended time periods may also provide useful data. The results of a study by Fradeani and Redemagni indicated a survival probability of 95% at 11 years for *Empress* (Ivoclar-Vivadent, Leichtenstein) leucite-reinforced glass-ceramic crowns, but with the majority of the failures being on posterior teeth.[38] Fuzzi and Rapelli examined 183 inlays in 67 patients from time periods of up to 10 years, finding that four inlays failed because of the need for root canal treatment and one because of fracture and estimating a success rate of 97% at 10 years.[39] van Dijken assessed 96 direct resin composite inlays at 11 years, finding that 18% had failed, mainly due to fracture. A higher failure rate in molar teeth than premolar teeth was identified.[40] He compared these data with those of direct-placement composites, finding little difference in rates of success and suggesting that the more time-consuming and expensive inlay technique might not be readily justified.

Hickel and Manhart also included the success rates of composite inlays in their survey, finding that there

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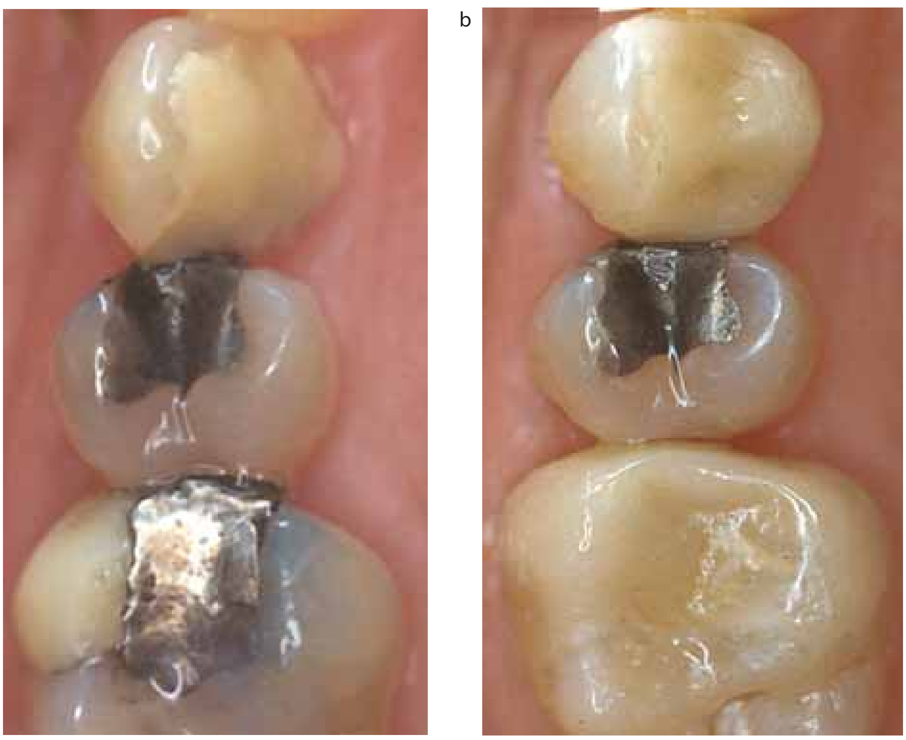

Figure 3. (a) Use of the dentine-bonded crown concept in posterior restorations with extensive partial or complete ceramic coverage: 4/ palatal cusp lost, temporary glass ionomer *in situ*; **(b)** 4 years post-treatment, 4/ restored with MODP ceramic restoration, 6/ has suffered mesial fracture and has been restored with MO ceramic restoration with no innate retention.

were few *in vivo* studies, that annual failure rates ranged from 0–11.8%, and concluding that composite inlays may overcome problems associated with direct placement composite, such as production of correct approximal contour and control of polymerization shrinkage.[37]

van Dijken and colleagues have described the use of the dentine-bonded crown concept in posterior restorations with extensive partial or complete ceramic coverage[41](Figure 3). These workers evaluated 182 restorations in 110 patients over a period of up to seven years. They achieved 100% recall and calculated an overall failure rate of 9.7% (3/31) in non-vital teeth and 6.6% (10/151) in vital teeth.[41] It was considered that the technique reduced the need for traditional full-coverage crowns and the need for pin or post placement, notwithstanding the good aesthetic of the restorations, the reduced destruction of health tooth tissue and the avoidance of endodontic treatment.

In conclusion, dentine-bonded indirect restorations have reasonable potential for success, with bulk fracture being the most frequent cause of failure of ceramic inlays. In this respect, sound clinical advice would appear to be to provide adequate space for sufficient bulk of ceramic. Dentine-bonded crowns, in particular, hold many advantages, including good aesthetics, conservation of tooth structure when compared with tooth preparations for metal-ceramic crowns, and very low incidence of debonding and pulp death.

Adhesive posts

Fibre posts are a recent addition to the clinician's armamentarium: these have been discussed in part 2 of this series.[42] The data on success, although limited in number of papers, includes a large number of restorations, with the results being positive in terms of small numbers of debonded posts and very low incidence of root fracture.[43,44] These have several advantages when compared with conventional metal posts, including:

- Tooth-coloured;
- No risk of corrosion and root darkening;
- Modulus of elasticity similar to dentine, so less traumatic distribution of stresses is possible;

2000/2001	272,982
2001/2002	281,925
2002/2003	304,753

Table 2. Crowns fitted over three years in the General Dental Services.[46-48]

- Capable of adhesive cementation.

Disadvantages include the limited data available on success and the more technique-sensitive placement than conventional posts, though the latter difficulty has been obviated with the introduction of self-adhesive resin-luting materials described in the previous paper in this series.[1] For a full contemporary review of the subject, readers' attention is drawn to the recent paper by Bateman *et al*.[45]

Metal-ceramic versus all-ceramic

Although patients' aesthetic demands appear to have increased over recent years, metal-ceramic (also termed porcelain-fused-to-metal) restorations still form the substantial majority of anterior crowns placed in the UK under NHS terms of service[46-48] (Table 2). In addition to improved metal-ceramic techniques, very thin high gold content substructures have been introduced. These substructures, fabricated by a variety of methods, including capillary action (*Captek*: Precious Chemicals Inc.), may improve the appearance of metal-ceramic crowns by reducing the thickness of the metal substructure and emitting a 'warm' yellow colour through the porcelain. Notwithstanding this, it is generally considered that the optimum aesthetics are achieved by the use of non-metal restorative materials.

Advantages of metal-ceramic restorations include high strength and long history of success.

Disadvantages include:

- Amount of tooth substance removal required leading to significant incidence of pulpal complications and risk of long-term fracture of the dentine core;
- Grey show-through of the metal requires application of opaque/lifeless ceramic (Figure 4);
- Fracture often requires remake;
- Not readily adapted to adhesive technologies;

Figure 4. Contrasting appearance of upper anterior teeth restored with metal-ceramic crowns and lower anterior teeth restored with dentine-bonded, all-ceramic crowns for a patient suffering from bulimia, with extensive tooth substance loss.

- Patient allergy to some constituents of the metal alloy.

Christensen has discussed the principal reasons for the unacceptable aesthetics of metal-ceramic crowns and has laid the blame firmly on the clinician and technician.[49] He considered the unacceptable appearance to be a result of:

- Inadequate tooth reduction, which then allows opaque porcelain and metal to show;
- Technicians' use of external coloration techniques instead of internal pigmentation, which allows crown colour to change after a few years in oral conditions. However, the need for a metal core will always necessitate greater tooth reduction than when the tooth is used as the core, as in the dentine-bonded crown.

It may, however, be considered that recently introduced, high-strength ceramics such as *Procera* (NobelBiocare, Goteborg, Sweden) and *LAVA* (3M ESPE, Seefeld, Germany), which will be described later in this series, may provide the clinician with a greater choice than was previously available when (s)he was looking for a restoration with strength and with good aesthetics. However, these restorations, which still necessitate heavy tooth preparation, are likely to be associated with many of the same biological and mechanical problems as metal-ceramic crowns.

Success rates of CAD-CAM restorations

Computer-aided design and manufacture (CAD-CAM) was introduced to dentistry in 1985 with the original *Cerec* (Siemens AG, Bensheim, Germany) apparatus. There are now a variety of applications, particularly for the most recent versions of the apparatus, as described in the final paper in this series.

Success rates of Cerec *inlays*

There are few long-term data on the success rates of *Cerec* (Siemens AG, Bensheim, Germany) inlays, and those available may not be considered particularly relevant because of the upgrading of the system to *Cerec 3* in recent years. Heymann and co-workers, using the original *Cerec 1* software to produce ceramic inlays, evaluated 42 restorations at 4 years, finding that all were clinically acceptable.[50] All inlays were cemented using a resin-luting material and dentine-bonding agent. Berg and Derand assessed 51 *Cerec* inlays, which had been luted adhesively, after 5 years.[51] They found that three had fractured but that the remainder were functioning satisfactorily. Similar results were obtained by Sjögren and co-workers, who examined 66 class II *Cerec* inlays at 5 years.[52] Three inlays required replacement during the follow-up period, two because of inlay fracture and one because of tooth fracture. The remainder performed well in terms of surface integrity and colour match, while margin integrity was considered excellent in over half of the inlays.

Martin and Jedynakiewicz published a systematic review of *Cerec* ceramic inlays in 1999.[53] Fifteen studies were included, with an overall survival rate of 97% after 4 years. Predominant reasons for failure were fracture of the ceramic, fracture of the supporting tooth and postoperative sensitivity. The authors concluded that the *Cerec* system provided useful restorations with a high success rate.

More recently, Otto and de Nisco examined the performance of 200 *Cerec* inlays after 10 years.[54] These had been luted with a resin cement and adhesive technique. The success rate was 90%, with the principal reason for failure being restoration fracture.

It could be concluded from these studies that *Cerec* inlays have a high potential for success. However, the success rates recorded for *Cerec* do not appear to be higher than for ceramic inlays made either from traditional feldspathic porcelains or the more modern leucite-reinforced ceramics. Nevertheless, it could also be surmised that the improvements in the software and milling system in later versions of the apparatus, and other CAD-CAM developments, could further enhance the clinical results.

Success rates of Procera *crowns*

Procera (NobelBiocare, Goteborg, Sweden) introduced their *AllCeram* concept in 1993, this being a densely sintered core of 99.9% alumina. Using the *Procera* process, an enlarged model of the original die is manufactured. Alumina powder is then compacted on to the enlarged die and then sintered, this process compensating for the 15% to 20% shrinkage of alumina during the sintering process. Feldspathic porcelain is finally fired on to the alumina coping.[55]

Owing to the relatively recent introduction of *Procera AllCeram*, there are few long-term studies. However, Odman and Andersson[56] have evaluated 71 crowns at up to 10 years, with these crowns being luted either with zinc phosphate or glass ionomer cement. The success rate was 92%, with four crowns having fractured, and one noted as having a crack which did not require replacement of the crown. However, 14% of the crowns became loose and were recemented (one twice) and 6% required the placement of a restoration at the crown margin because of a defect. Despite these shortcomings, the authors considered that *Procera AllCeram* crowns were 'an alternative for single-crown restorations'. Oden, the manager of research and development at *Procera*, and co-workers[57] assessed 97 crowns at 5 years, the majority being luted with zinc phosphate cement. Three crowns experienced a fracture through both the veneering porcelain and alumina coping and another two requiring replacement as a result of fracture of the veneering ceramic during the study. One crown required replacement because of recurrent decay. Despite these failures, the authors concluded that *Procera AllCeram* crowns may be used in all areas of the mouth.

A Medline search has failed to identify other long-term evaluations of *Procera AllCeram* crowns. From the data presented, it appears that there is some potential for crown fracture with these restorations. In view of the advantages of resin-luting materials, it would appear prudent to adopt bonding and resin-luting techniques with *Procera*, despite the fact that the fitting surface of these crowns is not micromechanically retentive.

The *Procera* system has also been adapted to produce titanium copings, with favourable results being reported by Lovgren *et al*.[58] However, the advantages of a milled titanium coping are not readily apparent, except when there is a contra-indication to the use of a platinum/palladium alloy used for a traditional metal-ceramic.

Success rates of all-ceramic bridges

The desire to apply the all-ceramic concept to fixed bridgework has always existed, but it has been considered that this is only possible from a mechanical standpoint with the development of new ceramic materials of very high strength.[59] Some short-term clinical trials of all-ceramic bridges have been published, but few long-term data are available.

Sorensen and colleagues, in 1998, published the results of a one-year clinical trial of bridges formed in a lithium disilicate ceramic (*Empress 2*: Ivoclar Williams, Amherst, NY, USA),[60] with the results indicating a catastrophic failure in 6.7% (4 of 61) of units. The authors considered that three of the four restorations that failed had occluso-gingival connector heights that failed to meet the recommended design standards.

Two longer term retrospective studies have been identified, of 18 *In-Ceram Alumina* (Vita Zahnfabrik, Bad Sackingen, Germany) bridges after a mean time of 76 months.[61] Most commonly, these were of two or three units, 64% were cantilevers and 62% involved posterior teeth. Five of the bridges fractured during the observation period, although two of these had suffered external trauma. The authors calculated a cumulative survival rate of 83% after ten years. Von Steyern and colleagues have evaluated 20 posterior three-unit bridges formed in *In-Ceram* after five years.[62] All had bilateral support. Ninety per cent (n=18) were intact after the evaluation period.

Most recently, Suarez and co-workers have assessed the clinical performance of 18 *In-Ceram Zirconia* (Vita Zahnfabrik, Bad Sackingen, Germany) bridges replacing posterior teeth after three years in service.[63] One of the bridges had been lost as a result of root fracture of an abutment tooth, but the remaining bridges were rated as excellent or acceptable. This could be considered to be a promising result.

In conclusion, the results of clinical surveys of all-ceramic bridges are variable, with a number of studies indicating satisfactory results and others reporting success rates which may be considered suboptimal. Recently introduced systems, such as *LAVA* (3M ESPE, Seefeld, Germany) and *Procera Zirconia* (NobelBiocare, Goteborg, Sweden) may provide solutions, but the clinical evaluation of these techniques is still in its early stages.

Conclusion

A wide variety of indirect restorative techniques which use contemporary adhesive technology is now available. These, invariably, require less tooth destruction than conventional non-adhesive techniques. Success rates of adhesive indirect techniques show promise, even if some do not appear to perform as well as traditional techniques when measured in terms of debond/loss of the restoration. However, the reduced tooth substance which is destroyed during preparation of adhesive restorations should reap benefit in terms of reduced pulp death, but the incidence of this may be difficult to determine in the literature. Recently introduced zirconia-based bridgework holds promise as a potential non-metal crown and bridge substructure.

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CPD Answers

1. C,D	6. A, B, C
2. A, D	7. A, C
3. A, C	8. B, C, D
4. B,D	9. C
5. A, C	10. D