Stephen J Bonsor

Bonded Amalgams and Their Use in Clinical Practice

Abstract: There has been a move in recent years for operative dentists to use the benefits of adhesive technology when placing dental amalgam restorations. This paper describes the potential advantages of the bonded amalgam technique. These benefits include decreased microleakage between the cavity wall and the restorative material. This, in turn, may decrease post-operative sensitivity, pulpal inflammation and the incidence of recurrent caries. Extra retention for the restoration may also be provided and the need for cavities to rely on traditional retention and resistance form may be decreased or even eliminated, thus conserving precious tooth tissue. If the restoration is bonded then flexure during function in teeth may be decreased and, in the case of teeth exhibiting a cracked cusp, this may alleviate or eliminate symptoms. Bonding may also provide support to weakened tooth tissue which otherwise would have to be removed, so rendering cavities more conservative, and may increase the fracture resistance of the tooth. Clinical examples are included to illustrate some of these benefits.

Clinical Relevance: The use of adhesives to bond amalgam to tooth tissue offers potential advantages, although some of the current evidence is equivocal about their routine use.

Dent Update 2011; 38: 222–230

Dental amalgam

Dental amalgam is a mixture of a silver alloy with mercury.[1] It has been used in dentistry since the 1800s[2] and, through scientific investigation, the composition of the constituents of the alloy have been refined to produce a material with today's optimized clinical handling and performance. Traditional amalgam alloys suffered from a lack of strength, exhibited flow and creep and were susceptible to corrosion owing to the presence of the γ2, tin-mercury phase.[2] Furthermore, amalgam on its own does not bond to tooth structure and cannot provide a complete seal or be retained in the tooth without some form of mechanical retention, such as undercuts.[3] More recently, attempts have been made to reduce or even eliminate the γ2 phase by increasing the copper content in the alloy to above 13%.[4] This modification of the setting reaction has resulted in some important changes in the properties of the amalgam, namely:

- A higher compressive strength;
- A more rapid set to full strength;
- A reduction in creep; and
- A reduced susceptibility to corrosion.[2]

This latter point, although a benefit of the newer alloys, can work against the clinician as the corrosion products produced by the γ2 phase in traditional amalgams blocked up the potential gap at the tooth material interface and decreased microleakage.[5,6] The use of another material between the tooth and the amalgam may help to overcome this problem by creating a seal and may also improve the retention of the material.

History of amalgam bonding

Many materials have been employed to fill the amalgam tooth interface and improve retention by bonding. These have included zinc phosphate cement,[7] Copal varnish[8] and polycarboxylate cement.[9] Since the mid 1980s, resin composite adhesives which bond to metal have been used,[10,11] as their bonding potential has been realized to offer considerable advantages. Resin-based composites, either setting by a dual cure[12] or chemical (anaerobic) reaction,[3] have been used for this purpose, as have resin-modified glass polyalkenoate (ionomer) cements.[13–15]

Decreased microleakage
Decreased incidence of recurrent caries
Decreased pulpal inflammation
Decreased post-operative sensitivity
Increased fracture resistance of the tooth
Decreased cuspal deflection
Treatment of cracked cusp
Conservation of tooth tissue
Increased retention

Table 1. The potential benefits of bonding amalgam.

Stephen J Bonsor, BDS(Hons), MSc, FHEA, GDP, The Dental Practice, 21 Rubislaw Terrace, Aberdeen.

Potential benefits

Table 1 lists the potential benefits of bonding amalgam.

Decreased microleakage

Microleakage is 'the passage of bacteria, fluids, molecules or ions between a cavity wall and the material applied to it'.[16] Its clinical relevance is that the passage of bacteria at the tooth restoration interface may cause recurrent caries or pulpal irritation with subsequent pulpal inflammation.[17,18] This could lead to a clinical diagnosis of reversible pulpitis or loss of vitality of the tooth. Operative intervention would then be necessary which, at best, would require a replacement restoration with the cavity inevitably increasing in size[19] or, at worst, endodontics or extraction of the tooth.

Microleakage has been traditionally studied *in vitro* by using a dye leakage model. These studies have shown significantly less microleakage in restorations where either Copal varnish or a resinous material had been applied.[20–23] Other studies have compared resin-lined and varnish-lined amalgams and concluded that bonded amalgam leaked less than varnish-lined restorations.[11,24] The same conclusion was arrived at in an *in vivo* study.[25]

Resin-modified glass ionomer cements have also been advocated for bonding. Two studies in the literature contradict each other, with one[26] concluding that these agents should not be used routinely to control microleakage, as increased dye penetration was observed, and the other[8] concluding that resin-modified glass ionomers could be used successfully as they significantly decreased microleakage.

A study that examined various resin composite adhesive combinations in reducing microleakage[27] concluded that a dentine-bonded system, combined with a high copper amalgam alloy, can provide significant protection against microleakage for up to a year. Interestingly, however, the combination of *Tytin* amalgam (Kerr, Romulus, MI, USA) and *Panavia Ex* (Kuraray, Osaka, Japan) showed a significant increase in microleakage scores compared to the other combinations tested.

The effect of amalgam alloy morphology (namely spherical and admixture varieties) was significant as a reduction in microleakage at the cavity margins was seen in all the adhesive groups tested, except where Copal varnish was used to line cavities.[28] There was no significant difference in total microleakage scores between the alloy types. Bonding using *Amalgambond* and *Disperalloy* (Dentsply/Caulk, Milford DE 19963–0359) and *Amalgambond* and *Tytin* showed significantly less microleakage for the admix alloy (*Disperalloy*) and *Amalgambond* combination.[29]

The importance of a coronal seal in endodontics is well recognized.[30] Great emphasis has therefore been placed on the quality of the definitive restoration after endodontic therapy.[31] In addition, the use of an adhesive system has been promoted to restore endodontically treated teeth (Figure 1) in an attempt to decrease or eliminate microleakage, thus preventing reinfection of the root canal system.[32]

Decreased incidence of recurrent caries

Recurrent or secondary caries can develop between the tooth and the restorative material with time if fermentable carbohydrate ingestion has occurred and the oral conditions are conducive. Three studies have documented secondary caries as the most common reason for replacement of restorations.[33–35] Indeed, marginal microleakage is thought to be a major factor in the development of secondary caries.[5,6,36–39] The development of the ability to bond restorations *in situ* may well improve their marginal integrity. This could in turn retard the progression of caries in this interface. Belcher and Stewart[40] reported a lower incidence of recurrent caries around bonded amalgam restorations after two years of clinical service compared to those placed conventionally.

Decreased post-operative sensitivity

The use of adhesive resins to bond the amalgam to tooth tissue offers the potential to decrease post-operative sensitivity[41] and, whilst laboratory studies have demonstrated that significant reductions in microleakage may be achieved, post-operative sensitivity can only be demonstrated by *in vivo* studies. Most published studies have shown no difference between bonded and conventionally placed amalgam restorations with regards to post-operative sensitivity,[42–44] but one study did show that bonded amalgams were less sensitive up to six months after placement.[45]

Figure 1. An endodontically treated tooth ready for restoration with a bonded amalgam.

Increased fracture resistance of the tooth

It has been reported that root-filled posterior teeth are more susceptible to fracture than teeth with intact pulps. This is mainly due to the removal of (much) tooth structure during the endodontic and restorative procedures,[46,47] but also due to the dehydration of the dentine that occurs following the completion of the endodontic treatment.[48] The use of adhesive techniques, in combination with the definitive amalgam restoration, may therefore afford some support to the weakened tooth and increase the fracture resistance of the tooth.[49]

In vitro studies, to date, show conflicting results. One study[50] reported no significant difference in fracture strength across the experimental groups, and another[51] reported that the

Figure 2. Unsupported enamel remaining on the lingual surface after cavity preparation in a lower left first molar tooth. This cavity is also unretentive so the use of an amalgam adhesive would be indicated if no other methods of auxiliary retention were being employed.

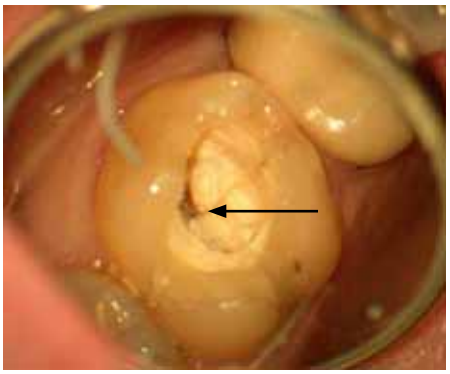

Figure 3. Fracture line extending from the distal marginal ridge onto the cavity floor (marked with an arrow).

Figure 4. A DO cavity prepared to receive a bonded amalgam. The red line illustrates the tooth tissue which would have had to be removed had a traditional technique been employed.

Figure 5. A post-operative view of a bonded amalgam in an unretentive cavity and without the use of auxiliary retention, 14 years after placement.

conventional amalgam group exhibited the weakest resistance to fracture when compared with the groups bonded using amalgam or composite resin, but there was no statistically significant difference between the bonded restorations.

Other *in vitro* studies found no statistical difference in fracture resistance between bonded and non-bonded amalgam restored teeth,[52,53] whilst others have reported variable tooth strengthening of bonded amalgam restorations with different adhesive products,[54,55] and it has also been reported that fracture resistance is markedly increased in bonded amalgam restorations.[56,57]

Unsupported enamel has traditionally been removed when amalgam is planned to restore the tooth, as the material confers no strength to the remaining tooth[3] and this may lead to fracture of the (weak) tooth. If the restoration was bonded *in situ,* then it may obviate the need for tooth tissue removal (Figure 2). Latino, Troendle and Summitt[58] assessed whether a bonded amalgam restoration did actually support unsupported enamel. In this study, no significant difference was detected between the performance of the bonded and conventionally placed (control) amalgam groups. The authors therefore recommended that restorative materials should not be relied upon to support undermined occlusal enamel. In contrast, Franchi *et al*[59] concluded that bonded amalgam appears to be as effective as composite in supporting undermined enamel in terms of resistance to fracture.

The amount of tooth tissue remaining following cavity preparation may have an influence upon the fracture resistance of the tooth. The greater the amount of tooth tissue missing then the greater the risk of fracture. Lindemuth, Hagge and Broome[60] studied bulk fracture strengths of teeth with large and small cavities. The large amalgam restoration group showed no difference in the incidence of bulk fracture between the conventionally placed and those restored with bonded amalgam restorations. However, the small restoration group displayed a significantly greater bulk fracture strength when the restoration was bonded. It was concluded that other factors could also influence fracture resistance.

Decreased cuspal deflection

The ability of the restoration to bond to its surrounding tooth tissue may brace the weakened tooth and decrease its flexion, especially when a large amount of tooth is missing. El-Badrawy found, in an *in vitro* study,[61] that bonding amalgam restorations decreased the cuspal deflection of maxillary premolars and consequently may assist in restoring strength to the tooth.

The challenge of how to deal effectively with cracked cusps is a problem in clinical practice. By utilizing adhesive technology, the flexure around a fracture line may be decreased or even eliminated[62] and the successful treatment of cracked cusp by such an approach has been reported.[63] This is illustrated in Figure 3. A fracture line extends from the distal marginal ridge onto the floor of the cavity and it was treated by bonding the amalgam *in situ* in an attempt to decrease the flexure of the tooth and increase the fracture resistance of the tooth.

Conservation of tooth tissue

In the past, cavity design with mechanical retention was required for traditional amalgam restorations at the expense of healthy tooth tissue.[11] Current techniques aim to remove the minimal amount of diseased tooth tissue necessary and this is facilitated by the use of adhesive technology. Staninec[64] tested bonded amalgams without undercuts against conventionally placed amalgams in undercut cavities, and showed that the bonded group showed a higher resistance to dislodgement and found the bonding technique helped conserve tooth tissue. Setcos *et al*[65] noted that a few 'minimally retentive' conventional restorations were lost early which, when replaced using an adhesive technique, appeared to hold well without the additional mechanical retention. Figure 4 shows a cavity prepared to receive a bonded amalgam restoration. The red line depicts the amount of tooth tissue lost had a traditional cavity been cut.[66]

The use of an adhesive may prevent the needless removal of sound tooth tissue to create traditional resistance and retention form (Figures 2, 4 and 5), or the use of dentine pins with their attendant placement hazards.[67] Summitt *et al*[68] showed that there was no significant difference in failure rate and no difference in the performance of pin-retained amalgam restorations and bonded amalgam restorations at six years.

Longevity of bonded amalgam restorations and the reasons for failure

Most of the published work on restoration longevity relates to conventionally placed amalgams. There is a scarcity of clinical studies on longevity of bonded amalgams and their long-term clinical performance. One double blind study, conducted over a 42-month period, reported that both bonded amalgams and those placed using Copal varnish were free of secondary caries and were rated clinically acceptable.[69]

A double blind study carried out in a general practice in Australia[70] examined amalgam restorations in posterior permanent teeth lined with five resin-based systems (*Scotchbond 2*, *Panavia Ex*, *Amalgambond*, *Amalgambond Plus*, *Geristore*) and a polyamide cavity varnish (*Barrier*) at intervals over periods of up to five years. There were five restoration failures (1.4%) from tooth fracture that involved Class II preparations in molar teeth. These workers were unable to substantiate that bonded amalgam restorations showed fewer failures and marginal deterioration than similar restorations placed in permanent teeth using a cavity varnish lining.

A retrospective study evaluated the longevity of Class I and II amalgam restorations placed in a general practice over a seven-year period. The results showed 182 out of 912 amalgam restorations failed during the observation period. The main reasons for failure were caries (34%), endodontic treatment required (12%) and fracture of the tooth (13%). Life tables calculated from the data revealed a survival for amalgam of 89.6% at 5 years and 79.2% at 10 years. Cox-regression analysis showed a significant effect on the amount of restored surfaces on the survival of the restorations, but no significant effect of operator, material or the combination of material and operator was found.[71]

A similar study carried out in general dental practice comparing and contrasting the longevity of conventionally placed dental amalgam restorations with those placed using either *Panavia Ex* (Kuraray, Okayama, Japan), *Vitrebond* (3M ESPE, Seefeld, Germany) or *Rely X ARC* (3M ESPE) as bonding agents over a ten-year period was recently reported.[72] The results are set out in Table 2. Although conventionally placed amalgam restorations demonstrated a greater longevity than those bonded into place using *Rely X ARC* or *Panavia Ex* at the five-year period mark, there was no statistically significant difference in survival between the restoration types. Interestingly, the bonded amalgam restorations exhibited an acceleration of failure rate around 1000 days post-placement, which suggested a different mode of failure from the conventionally placed group. This author therefore challenges the justification that amalgams, with the greater financial cost to place, should be routinely bonded.

	Conventionally placed	Panavia Ex	Rely X ARC	Vitrebond
Computable sample size	3854	51	1797	5
% Survival at one year	96.29	95.65	97.58	100
% Survival at five years	86.21	76.35	82.59	not computable owing to small sample size

Table 2. Sample size and percentage survival of conventional and amalgams bonded using resinous materials.[72]

Clinical technique

The clinical technique will differ, depending on the adhesive selected to bond the amalgam. As with any procedure, the manufacturer's instructions should be referred to prior to using any product clinically. A previously published paper in this journal by Staninec and Setcos[3] described a clinical technique using *Panavia 21* (Kuraray). However, many clinicians prefer to use a dual-cured resin composite adhesive, such as *Rely X ARC* (3M ESPE). The technique for this adhesive

is as follows:[73]

- After cavity preparation (and placement of a lining material if indicated) a matrix band is placed if required. Inexperienced operators may wish to apply some petroleum jelly VERY sparingly to the inside of the band to prevent inadvertent bonding.
- The cavity floor and walls are etched using 35% phosphoric acid for 15 s before being thoroughly rinsed with water for 10s. They are then blotted dry but care must be taken not to desiccate the tooth tissue.
- Two consecutive coats of *Adper Scotchbond 1 XT* (3M ESPE) adhesive are applied to the enamel and dentine. This material is gently air-dried for 2 s before being light cured for 10 s.
- The *Rely X ARC* cement is mixed for 10 s and applied sparingly to the cavity walls and floor using a brush.
- The triturated amalgam is packed into the cavity.
- The matrix band (if used) is removed and the restoration carved.

Those operators wishing to use a resin-modified glass polyalkenoate (ionomer) cement should firstly complete stage 1 (above). The material should then be mixed as per the manufacturer's instructions and sparingly applied to the cavity walls and floor using a brush. The material should NOT be light cured but the mixed amalgam condensed immediately against the unset cement. Once the cavity has been filled, the matrix band should be removed and the restoration completed.

The choice between bonded amalgam and posterior resin composite

It is true to say that all of the indications and potential benefits for bonding amalgam (Table 1) may also be to posterior resin composite.[74] Indeed, with the use of resin composite increasing,[35,75] as a result of improvements in the materials, the techniques employed to place them and patient demand,[76] some clinicians would postulate that resin composite has superseded the use of amalgam.[77] That said, for various reasons, many practitioners worldwide do still use dental amalgam rather than resin composite and, for them, this paper presents the benefits of bonding amalgam without suggesting whether resin composite or bonded amalgam should be employed in any given situation.

Conclusions

There are many theoretical benefits for employing an adhesive when placing amalgam restorations but much more work is required, ideally with the execution of prospective, randomized, controlled clinical studies, over a long period of time, to determine the longevity and success rate of bonded amalgam restorations.[72,78] The evidence currently available suggests that these restorations may have a place in clinical practice, but the individual merits of each case should be considered prior to use.

References

1. Craig RG. *Dental Materials: Properties and Manipulation* 3rd edn. St Louis, Mo; London: Mosby, 1983.
2. van Noort R. *An Introduction to Dental Materials* 3rd edn. Edinburgh: Mosby, 2007.
3. Staninec M, Setcos JC. Bonded amalgam restorations: current research and clinical procedure. *Dent Update* 2003; **30**: 430–436.
4. Craig RG, Powers JM, eds. *Restorative Dental Materials* 11th edn. St Louis, Mo; London: Mosby, 2002.
5. Pimenta LA, Navarro MF, Consolaro A. Secondary caries around amalgam restorations. *J Prosthet Dent* 1995; **74**: 219–222.
6. Kidd EM. Caries diagnosis within restored teeth. *Oper Dent* 1989; **14**: 149–158.
7. Baldwin H. Cement and amalgam fillings. *Br J Dent Sci* 1897; **40**: 193–234.
8. de Morais PM, Rodrigues Junior AL, Pimenta LA. Quantitative microleakage evaluation around amalgam restorations with different treatments on cavity walls. *Oper Dent* 1999; **24**: 217–222.
9. Zardiackas LD, Stoner GE. Tensile and shear adhesion of amalgam to tooth structure using selective interfacial amalgamation. *Biomaterials* 1983; **4**: 9–13.
10. Shimizu A, Ui T, Kawakami M. Bond strength between amalgam and tooth hard tissues with application of fluoride, glass ionomer cement and adhesive resin cement in various combinations. *Dent Mater J* 1986; **5**: 225–232.
11. Staninec M, Holt M. Bonding of amalgam to tooth structure: tensile adhesion and microleakage tests. *J Prosthet Dent* 1988; **59**: 397–402.
12. Setcos JC, Staninec M, Wilson NH. The development of resin-bonding for amalgam restorations. *Br Dent J* 1999; **186**: 328–332.
13. al-Moayad M, Aboush YE, Elderton RJ. Bonded amalgam restorations: a comparative study of glass-ionomer and resin adhesives. *Br Dent J* 1993; **175**: 363–367.
14. Chen RS, Liu CC, Cheng MR, Lin CP. Bonded amalgam restorations: using a glass-ionomer as an adhesive liner. *Oper Dent* 2000; **25**: 411–417.
15. Ng BP, Hood JA, Purton DG. Effects of sealers and liners on marginal leakage of amalgam and gallium alloy restorations. *Oper Dent* 1998; **23**: 229–235.
16. Kidd EA. Microleakage: a review. *J Dent* 1976; **4**: 199–206.
17. Murray PE, Hafez AA, Smith AJ, Cox CF. Bacterial microleakage and pulp inflammation associated with various restorative materials. *Dent Mater* 2002; **18**: 470–478.
18. Subay RK, Cox CF, Kaya H, Tarim B, Subay AA, Nayir M. Human pulp reaction to dentine bonded amalgam restorations: a histologic study. *J Dent* 2000; **28**: 327–332.
19. Cruickshank EJ, Chadwick RG. Can chemical softening agents minimize cavity enlargement during removal of failed anterior resin composite restorations? *J Oral Rehabil* 1998; **25**: 167–173.
20. Moore DS, Johnson WW, Kaplan I. A comparison of amalgam microleakage with a 4-META liner and copal varnish. *Int J Prosthodont* 1995; **8**: 461–466.
21. Edgren BN, Denehy GE. Microleakage of amalgam restorations using Amalgambond and Copalite. *Am J Dent* 1992; **5**: 296–298.
22. Ben-Amar A, Liberman R, Rothkoff Z, Cardash HS. Long term sealing

properties of Amalgambond under amalgam restorations. *Am J Dent* 1994; **7**: 141–143.
23. Ben-Amar A, Liberman R, Judes H, Nordenberg D. Long-term use of dentine adhesive as an interfacial sealer under Class II amalgam restorations. *J Oral Rehabil* 1990; **17**: 37–42.
24. Sepetcioglu F, Ataman BA. Long-term monitoring of microleakage of cavity varnish and adhesive resin with amalgam. *J Prosthet Dent* 1998; **79**: 136–139.
25. Berry FA, Parker SD, Rice D, Munoz CA. Microleakage of amalgam restorations using dentin bonding system primers. *Am J Dent* 1996; **9**: 174–178.
26. Newman JE Jr, Hondrum SO, Clem DB. Microleakage under amalgam restorations lined with Copalite, Amalgambond Plus, and Vitrebond. *Gen Dent* 1996; **44**: 340–344.
27. Meiers JC, Turner EW. Microleakage of dentin/amalgam alloy bonding agents: results after 1 year. *Oper Dent* 1998; **23**: 30–35.
28. Turner EW, St Germain HA, Meiers JC. Microleakage of dentin-amalgam bonding agents. *Am J Dent* 1995; **8**: 191–196.
29. Saiku JM, St Germain HA Jr, Meiers JC. Microleakage of a dental amalgam alloy bonding agent. *Oper Dent* 1993; **18**: 172–178.
30. Saunders WP, Saunders EM. Coronal leakage as a cause of failure in root-canal therapy: a review. *Endod Dent Traumatol* 1994; **10**: 105–108.
31. Saunders WP, Saunders EM. Assessment of leakage in the restored pulp chamber of endodontically treated multirooted teeth. *Int Endod J* 1990; **23**: 28–33.
32. Howdle MD, Fox K, Youngson CC. An *in vitro* study of coronal microleakage around bonded amalgam coronal-radicular cores in endodontically treated molar teeth. *Quintessence Int* 2002; **33**: 22–29.
33. Qvist J, Qvist V, Mjor IA. Placement and longevity of amalgam restorations in Denmark. *Acta Odontol Scand* 1990; **48**: 297–303.
34. Burke FJ, Cheung SW, Mjor IA, Wilson NH. Restoration longevity and analysis of reasons for the placement and replacement of restorations provided by vocational dental practitioners and their trainers in the United Kingdom. *Quintessence Int* 1999; **30**: 234–242.
35. Burke FJ, Wilson NH, Cheung SW, Mjor IA. Influence of patient factors on age of restorations at failure and reasons for their placement and replacement. *J Dent* 2001; **29**: 317–324.
36. Kidd EA, Silverstone LM. Remineralisation *in vitro* of artificial caries-like lesions produced in relation to amalgam restorations. *Caries Res* 1978; **12**: 238–242.
37. Staninec M, Jow RW, Kircos LT, Hoover CI. *In vitro* caries induction at the tooth-amalgam interface. *Dent Mater* 1988; **4**: 72–76.
38. Torii Y, Staninec M, Kawakami M, Imazato S, Torii M, Tsuchitani Y. Inhibition *in vitro* of caries around amalgam restorations by bonding amalgam to tooth structure. *Oper Dent* 1989; **14**: 142–148.
39. Ben-Amar A, Nordenberg D, Liberman R, Fischer J, Gorfil C. The control of marginal microleakage in amalgam restorations using a dentin adhesive: a pilot study. *Dent Mater* 1987; **3**: 94–96.
40. Belcher MA, Stewart GP. Two-year clinical evaluation of an amalgam adhesive. *J Am Dent Assoc* 1997; **128**: 309–314.
41. Kennington LB, Davis RD, Murchison DF, Langenderfer WR. Short-term clinical evaluation of post-operative sensitivity with bonded amalgams. *Am J Dent* 1998; **11**: 177–180.
42. Mahler DB, Engle JH. Clinical evaluation of amalgam bonding in Class I and II restorations. *J Am Dent Assoc* 2000; **131**: 43–49.
43. Browning WD, Johnson WW, Gregory PN. Postoperative pain following bonded amalgam restorations. *Oper Dent* 1997; **22**: 66–71.
44. Mahler DB, Engle JH, Simms LE, Terkla LG. One-year clinical evaluation of bonded amalgam restorations. *J Am Dent Assoc* 1996; **127**: 345–349.
45. Summitt JB, Burgess JO, Berry TG, Robbins JW, Osborne JW, Haveman CW. The performance of bonded vs. pin-retained complex amalgam restorations: a five-year clinical evaluation. *J Am Dent Assoc* 2001; **132**: 923–931.
46. Oliveira FC, Denehy GE, Boyer DB. Fracture resistance of endodontically prepared teeth using various restorative materials. *J Am Dent Assoc* 1987; **115**: 57–60.
47. Reeh ES, Douglas WH, Messer HH. Stiffness of endodontically-treated teeth related to restoration technique. *J Dent Res* 1989; **68**: 1540–1544.
48. Helfer AR, Melnick S, Schilder H. Determination of the moisture content of vital and pulpless teeth. *Oral Surg Oral Med Oral Path* 1972; **34**: 661–670.
49. Eakle WS, Staninec M, Lacy AM. Effect of bonded amalgam on the fracture resistance of teeth. *J Prosthet Dent* 1992; **68**: 257–260.
50. Steele A, Johnson BR. *In vitro* fracture strength of endodontically treated premolars. *J Endo* 1999; **25**: 6–8.
51. Sagsen B, Aslan B. Effect of bonded restorations on the fracture resistance of root filled teeth. *Int Endod J* 2006; **39**: 900–904.
52. Bonilla E, White SN. Fatigue of resin-bonded amalgam restorations. *Oper Dent* 1996; **21**: 122–126.
53. Santos AC, Meiers JC. Fracture resistance of premolars with MOD amalgam restorations lined with Amalgambond. *Oper Dent* 1994; **19**: 2–6.
54. Oliveira JP, Cochran MA, Moore BK. Influence of bonded amalgam restorations on the fracture strength of teeth. *Oper Dent* 1996; **21**: 110–115.
55. Camacho GB, Goncalves M, Nonaka T, Osorio AB. Fracture strength of restored premolars. *Am J Dent* 2007; **20**: 121–124.
56. Smales RJ, Wetherell JD. Bonded amalgam restorations. *Aust Dent J* 1994; **39**: 128.
57. Christensen GJ. Should you and can you afford to bond amalgams? *J Am Dent Assoc* 1994; **125**: 1381–1382.
58. Latino C, Troendle K, Summitt JB. Support of undermined occlusal enamel provided by restorative materials. *Quintessence Int* 2001; **32**: 287–291.
59. Franchi M, Breschi L, Ruggeri O. Cusp fracture resistance in composite-amalgam combined restorations. *J Dent* 1999; **27**: 47–52.
60. Lindemuth JS, Hagge MS, Broome JS.

Effect of restoration size on fracture resistance of bonded amalgam restorations. *Oper Dent* 2000; **25**: 177–181.
61. el-Badrawy WA. Cuspal deflection of maxillary premolars restored with bonded amalgam. *Oper Dent* 1999; **24**: 337–343.
62. Davis R, Overton JD. Efficacy of bonded and nonbonded amalgam in the treatment of teeth with incomplete fractures. *J Am Dent Assoc* 2000; **131**: 469–478.
63. Bearn DR, Saunders EM, Saunders WP. The bonded amalgam restoration – a review of the literature and report of its use in the treatment of four cases of cracked-tooth syndrome. *Quintessence Int* 1994; **25**: 321–326.
64. Staninec M. Retention of amalgam restorations: undercuts versus bonding. *Quintessence Int* 1989; **20**: 347–351.
65. Setcos JC, Staninec M, Wilson NH. A two-year randomized, controlled clinical evaluation of bonded amalgam restorations. *J Adhes Dent* 1999; **1**: 323–331.
66. Osborne JW, Lopez Howell M, Marshall H. Webb and extension for prevention: a literature review. *Quintessence Int* 1999; **30**: 399–403.
67. Jacobsen P ed. *Restorative Dentistry : An Integrated Approach*. Oxford: Butterworth-Heinemann, 1998.
68. Summitt JB, Burgess JO, Berry TG, Robbins JW, Osborne JW, Haveman CW. Six-year clinical evaluation of bonded and pin-retained complex amalgam restorations. *Oper Dent* 2004; **29**: 261–268.
69. Browning WD, Johnson WW, Gregory PN. Clinical performance of bonded amalgam restorations at 42 months. *J Am Dent Assoc* 2000; **131**: 607–611.
70. Smales RJ, Wetherell JD. Review of bonded amalgam restorations, and assessment in a general practice over five years. *Oper Dent* 2000; **25**: 374–381.
71. Opdam NJ, Bronkhorst EM, Roeters JM, Loomans BA. A retrospective clinical study on longevity of posterior composite and amalgam restorations. *Dent Mater* 2007; **23**: 2–8.
72. Bonsor SJ. *Bonded (Sealed) Amalgam Dental Restorations – Longevity and Clinical Outcome*. MSc thesis: University of Bristol, 2007.
73. 3M ESPE. *3M ESPE Rely X ARC Adhesive Resin Cement System Technical Product Profile*. 1998.
74. Burke FJ, Shortall AC. Successful restoration of load-bearing cavities in posterior teeth with direct-replacement resin-based composite. *Dent Update* 2001; **28**: 388–398.
75. Brown LJ, Wall T, Wassenaar JD. Trends in resin and amalgam usage as recorded on insurance claims submitted by dentists from the early 1990s and 1998. *J Dent Res* 2000; **79:** 461.
76. Reinhardt JW, Capilouto ML. Composite resin esthetic dentistry survey in New England. *J Am Dent Assoc* 1990; **120**: 541–544.
77. Lynch CD, Shortall AC, Stewardson D, Tomson PL, Burke FJ. Teaching posterior composite resin restorations in the United Kingdom and Ireland: consensus views of teachers. *Br Dent J* 2007; **203**: 183–187.
78. Setcos JC, Staninec M, Wilson NH. Bonding of amalgam restorations: existing knowledge and future prospects. *Oper Dent* 2000; **25**: 121–129.