The Scientific Basis for the Teaching and Practice of Conservative Operative Dentistry

Dorothy McComb BDS., MScD., FRCD(C)

Dorothy McComb
Restorative Dentistry
Rm 352C
124, Edward St.
Toronto, Ontario,
Canada. M5G 1G6
d.mccomb@utoronto.ca

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Conservative Operative Dentistry.

A major area of controversy in dentistry is the operative-restorative intervention decision. This decision is a significant one as the action is irreversible and submits the tooth to a lifetime of re-restoration. Such a decision assumes that an active carious lesion is indeed present and that no other more conservative therapy is possible to effect a successful outcome. The issue requires reconciling the documented low sensitivity of current diagnostic procedures, particularly for fissure caries, with an understanding of the need for high diagnostic specificity, to ensure that sound teeth are not inadvertently included. It also requires substantive current knowledge of the variable nature of the caries process, disease etiology and the concept of individual risk. The current lack of consensus within the dental community concerning diagnosis and treatment decisions for early carious lesions has led to different practitioner philosophies based on personal experience and opinion. These range from a uniform concept of surgical investigation and restoration of all suspicious areas, including very early tooth changes, to a more prudent, individualised, disease-orientated and preventive approach. Decision-making principles that will help effect a considered patient-specific decision will be addressed elsewhere at this conference . This paper proceeds from the decision to initiate operative intervention, while acknowledging the significance of that decision.

Once a carious lesion requires operative intervention, to halt the caries process and restore lost tooth structure, what form should that intervention take and what factors are involved in providing maximum longevity of the resulting restoration and tooth? Traditional cavity preparation includes varying degrees of "extension for prevention" in an attempt to remove caries-prone tooth structure adjacent to new restorations. The high rates of re-restoration performed in clinical practice, largely due to a diagnosis of recurrent caries, would seem to cast doubt on the effectiveness of this concept. Further, the re-restoration cycle significantly weakens teeth, can result in additional pulpal pathology, increases the need for extra-coronal coverage and, in some cases, can ultimately cause premature loss of teeth. In more recent years, the traditional concepts of extension for prevention have been challenged. Although conservative cavity preparations are taught routinely in many dental schools, traditional restorations are still prevalent in general practice, even in the younger population. This paper looks at the evidence concerning the outcomes of newer conservative operative interventions and attempts to assess information concerning the relationship between cavity preparation extension and restoration survival.

Two specific questions were formulated**:**

Question 1:

Does cavity preparation outline form affect the longevity of dental restorations in restored crowns of permanent teeth? and

Question 2:

Does cavity preparation outline form affect the longevity of restorations in restored crowns of primary molars?

The search strategy was developed in concert with a consultant (PF Anderson, Dentistry Library, University of Michigan). A Medline/Embase search resulted in 995/92 (total 1187) references for the permanent dentition and 169/116 (total 285) for the primary dentition. All abstracts were reviewed for relevance to the topic by the author and a final database of 54 (permanent) and 44 (primary) references were studied further. Articles were also retrieved from references cited in the literature obtained. Articles used had to be human clinical studies involving outcomes of intra-coronal restorative intervention, with particular reference to conservative operative strategies. The clinical research on specific conservative operative treatments in permanent teeth was also reviewed and assessed by a second reviewer (Dr P.R. Walshaw, B.D.S., M.Sc. Assistant Professor, Clinical Sciences, Faculty of Dentistry, University of Toronto) and appropriate references included in three systematic review tables. These specific studies, plus other appropriate clinical research resulting from the search strategy, were examined further for evidence of the factors involved in restoration failure. The quality and nature of the literature was highly variable. Heterogeneity included operator variables (public health service, private practice, specialist, faculty and student operators), patient variables (age, sampling, sample size, caries risk, concomitant preventive treatment etc), material variables and study duration which was often minimal.

I The Permanent Dentition

Conservative Cavity Preparation

Traditional operative dentistry involves standardised preparations which utilise differing degrees of "convenience form" (access to caries through sound tooth structure) and "extension for prevention" (attempts to place cavity margins in less caries-susceptible tooth locations) which can further reduce the structural integrity of teeth. It is generally accepted that restorations address the replacement of diseased tooth structure but do not address the causative disease process and have a finite life-span. Dentists currently spend more time treating further disease progression around existing restorations, and replacing deficient restorations, than the treatment of initial disease. This cycle increases the need for more extensive extra-coronal restorations and the likelihood of endodontic treatment and is the major negative consequence of initial restorative therapy. In recent years more conservative forms of operative intervention have been recommended which concentrate more specifically on removal of carious dentine and preservation of as much sound tooth structure as possible. Three specific techniques are 1) the proximal "tunnel" restoration, 2) the proximal-only ("box", "saucer" or "slot") restoration and 3) the preventive resin restoration. What is the evidence for the performance of these relatively new procedures and how do they compare in terms of longevity and causes of failure?

1) The Proximal "Tunnel" Restoration

The "tunnel" concept, which accesses proximal dentinal caries through a sound mesial or distal occlusal pit, was described in 1984 (Hunt) to preserve the overlying proximal marginal ridge and maintain greater tooth integrity. This access has the theoretical potential to preserve not only the structural transverse marginal ridge, which maintains bucco-lingual tooth integrity, but also much of the outer proximal tooth surface. The preparation involves no "extension for prevention" but has been promoted for use in conjunction with fluoride-releasing glass ionomer cements, in order to provide compensatory caries-inhibition. A further possible advantage is less risk of iatrogenic damage to the adjacent tooth. Two types of completed tunnel preparations are possible 1) the "partial" tunnel with little or no external perforation, sometimes sparing removal of suface demineralised enamel and 2) the "total" tunnel" where the approximal enamel has been perforated, with or without residual demineralised enamel.

A total of 9 clinical trials in permanent teeth and 2 in primary teeth through the 1990's resulted from the search strategy. Almost all utilised a glass-ionomer-cermet cement as the restorative material. The clinical studies often were incomplete with regard to controls, patient data, particularly caries-activity, and many operator/examiner details, making definitive comparisons and analysis difficult. Definition of failure also differed from study to study. However, all of the studies, excluding two clinical reports (Hunt 1984, Knight, 1992) have been included in the evidence table because, in concert, considerable information can still be obtained. (Table 1).

Clinical reports from early usage (Hunt 1984, Knight 1992) and the first clinical trial (Svanberg, 1992) utilized small numbers of glass ionomer restorations and indicated the technique to be promising. Larger clinical studies encountered higher failure rates. Use of a metal cermet glass ionomer (Ketac Silver) gave little evidence of recurrent caries inhibition in the vast majority of studies and the most frequent causes of restoration failure reported were marginal ridge fracture and recurrent decay. A high proportion of marginal ridge fractures was associated with more extensive tunnel preparations. Designed to provide caries inhibition, glass ionomer materials are relatively weak and provide little structural tooth reinforcement. Bonded composites, which could have provided greater structural integrity, have not been studied in tunnel situations. Amalgam controls were included in only three trials. In two of these there were no amalgam failures over 2years (Wilkie et al) and 5 years (Lumley and Fisher, 1995) but in one, involving caries-active adolescents, there was a 17% incidence of recurrent decay over 3 years (Svanberg, 1992). Traditional Class 2 composite restorations were significantly superior to GI tunnels in one trial (Wilkie et al, 1993). The longest clinical study (7years) reported a 50% survival time of 6 years (Hasselrot, 1998) for the tunnel restoration and 2 recent multi-operator trials provided evidence of very high rates of associated caries (up to 41-45%) as early as 3 years. (Strand et al 1996; Nordbro et al.1997; Pilebro et al 1999). Residual caries, recurrent caries and progression of remaining demineralised enamel were all factors cited in failure causes, emphasizing the high caries risk of the interproximal area. The presence of a glass ionomer was unable to overcome the caries challenge in a large number of cases.

Many studies utilising baseline radiographs reported evidence of inadequate initial caries removal. (Hasselrot 1993, 1998; Strand et al 1996; Pilebro et al 1999). This was presumably due to the blind approach provided by the limited access. The effectiveness of caries removal by the partial tunnel preparation has also been examined in vitro. Residual caries was present in 26% of cases and was operator dependent. (Strand et al, 1994). Visibility was only improved by enlarging the occlusal access, reducing the conservative nature of the technique and weakening the overlying ridge (Knight 1992). The technique is clearly more difficult to execute than the traditional approach. Low restoration survival was associated with the limited preparation extension, especially where demineralised proximal enamel was left, in order to avoid cavitation of the proximal surface (Strand et al 1996; Nordbo et al, 1997; Pilebro et al 1999; Pyk et al, 1999). The low effectiveness reported reveals the difficulties involved with arresting caries in the caries-prone proximal contact area. Additional preventive treatment, and patient compliance with caries prevention, is essential to avoid continuation of the primary caries process and early re-treatment. Further, due to the lack of direct vision, the extent of remaining demineralised enamel is not known. It has been stated that the technique is not indicated for caries-active patients (Strand et al, 1996; Nordbo et al, 1997).

Evidence of caries inhibition on adjacent proximal surfaces was reported in one early controlled clinical trial (Svanberg, 1992). This was purported to be due to caries-inhibition from the presence of the glass ionomer at the adjacent contact. A possible confounding factor, however, is the fact that traditional proximal cavity preparation introduces the danger of iatrogenic bur damage to the adjacent tooth. Such surface damage has been shown to be commonplace following routine Class 2 preparations and is associated with the development of subsequent new primary caries (Qvist et al 1992).

The tunnel technique is limited to treatment of early dentinal decay, often prior to enamel cavitation with the “partial” or “incomplete” tunnel. As cavitation is becoming accepted as the minimum stage defining the necessity for operative intervention, the technique has increasingly limited usage. It involves removal of alternative sound tooth structure to gain access and does not guarantee structural maintenance of the overlying marginal ridge, Marginal ridge fracture is more likely with the “total” tunnel and with increased size of the preparation. Operator, material and patient factors are all particularly important. The tunnel technique cannot be recommended for routine use. The low effectiveness reported argues in favour of a more direct approach to proximal dentinal caries with concomitant removal of adjacent demineralised tooth structure. The results of the systematic review also reveal the difficulties involved in arresting proximal caries and support the removal of peripheral, extensively demineralised enamel within the caries-prone proximal contact area, adjacent to, and continuous with, the original cavitation site.

2) The Proximal “Box-only” Restoration

Traditional Class 2 cavity preparation for the treatment of proximal caries involves both a proximal and occlusal portion. Changes to this approach have been recommended where only the proximal tooth structure is carious. Although such “box-only” or “slot” preparations for amalgam were introduced in 1973 (Almquist) and “adhesive slot” preparations for resin composite in 1978 (Simonsen), such conservative restorations are still relatively rare in general dental practice.

Only 3 clinical studies in permanent teeth resulted from the literature search. Two involved adhesive proximal slot restorations with resin composite, each providing publications at two different time periods, up to 5-years (Kreulen et al. 1995, 1998) and 10-years (Nordbro et al.

1993, 1998). All five publications have been tabulated (Table 2). No failures were recorded for 68 composite box-only restorations over 5 years. Although the rounded adhesive slot preparation was considered somewhat difficult to accomplish, the treatment time for these conservative restorations was less than that for a conventional 2-surface composite, but longer than an equivalent amalgam restoration. Technical deficiencies were noted on baseline radiographs with cervical deficiencies (13%), voids (9%) and dentinal radiolucencies (1.5%) (Kreulen et al, 1995) but these did not lead to actual restoration failure over the five year duration. The former are common material handling difficulties with resin composite. The results advocate monitoring of such deficiencies rather than automatic restoration replacement. The 10-year success rate for composite proximal "saucer" preparations was 68.6% (Nordbo et al, 1998). Half of the failures were due to recurrent decay and half were considered technique related. Recurrent caries, when present, occurred only at the gingival margin, not bucco-lingually, justifying the minimal lateral and occlusal extension. Loss of retention did not occur. One clinical trial of "tunnel" restorations included a small number of control silver amalgam proximal slot restorations. No failures were recorded for these over a period of 5-7 years (Lumley & Fisher 1995). The available clinical trials in permanent teeth provide evidence that the proximal slot-only restoration is a viable treatment option, providing similar or better longevity compared to conventional Class 2 composite or amalgam restorations, combined with greater tooth preservation. The technique was superior to "tunnel" restorations, likely due to improved operator visibility, but also possibly due to removal of all demineralised enamel.

Despite the absence of significant supportive evidence the technique makes common sense for the post-fluoride dentition and is standard teaching in many dental faculties. The proximal slot concept eliminates the significant tooth weakening produced from automatic inclusion of the occlusal surface. However, while advocating the abolition of occlusal preparation solely for "extension for prevention", an accurate diagnosis of the condition of the occlusal fissures is essential.

Gingival Margin Location

Gingival extension of Class 2 restorations, whether traditional or box-only design, is of particular interest. The vast majority of recurrent decay occurs in the gingival proximal location (Mjor, 1985; Klausner et al 1987). The "extension for prevention" concept suggests that subgingivally placed margins reduce the risk of secondary caries, but the evidence for this comes from the pre-fluoride era. The need for appropriate location of the gingival proximal margin has been shown to be important in a rare study which examined the relationship between proximal cavity design and recurrent caries in children 9-13 years of age living in an area with sub-optimal fluoridation (Otto and Rule, 1988). Three consecutive years of radiographs, of Class II restorations on permanent first molars, were selected and divided into short, intermediate and long with regard to the length of the proximal portion. Relationship to the marginal ridge and cemento-enamel junction were used to categorise each restoration. Restorations with gingival margins which did not clear the contact area (i.e. short) had a significantly higher rate of caries at all time intervals over a 2-year period. Although there was a trend for "long" to have less recurrent caries than "intermediate" at each of the three time intervals, the difference was not statistically significant. Another study of cavity design versus failure in Class 2 amalgam restorations over 8-10 years concluded that secondary caries was primarily associated with gingival cavity design features on the proximal surface (Jokstad, Mjor 1991b). These included narrow gingival extension, possibly leaving areas of demineralized enamel in a caries-prone location. As a "self-cleansing" location for the gingival margin of proximal restorations is impossible, good patient home-care is essential. There is thus some evidence that overly conservative gingival extension increases the risk of recurrent caries in the absence of good patient compliance.

3) The Preventive Resin Restoration

The Preventive Resin Restoration (PRR) is a conservative occlusal restoration which involves replacement of discrete areas of carious tooth structure with resin composite followed by use of an overlying fissure sealant instead of traditional Class 1 "extension for prevention" (Simonsen 1977).

A total of 18 clinical studies have been published over the period 1978-1999, of which 15 were prospective and 3 retrospective investigations. The studies tend to suffer from lack of information concerning study design, including many operator and patient factors, and poor presentation of data. Success rates are not easily comparable from study to study as the definition of failure was variously reported as actual presence of caries or, alternatively, loss of sealant. Nonetheless a systematic review table has been produced (Table 3). All the clinical studies show generally favourable outcomes, however all universally report total, or partial, loss of the sealant as a major problem. The comparison of data is compounded by the practice of replacing deficient areas of fissure sealant during the trial period. In one study, sealant was only replaced a) if there was a risk of further caries with partially intact sealant, b) if the missing zone showed staining and decalcification or c) if the patient was in a high risk group (Gray et al 1999). Three studies performed a direct comparison with silver amalgam (Azhdari et al 1979; Welbury et al 1990 and Cloyd et al 1997) The PRR was at least as successful as amalgam in two of the trials, up to 5 years, with the added advantage of preservation of sound tooth structure. Sealant failure was a significant problem in the other (Cloyd et al) which led to an occurrence of 8.1% recurrent caries whereas no amalgam failures were recorded over the 3 years. No occlusal caries was reported with intact sealants in any of the clinical studies, though many did not utilize radiographs at recalls. All cases of occlusal caries, up to 24% at 9 years (Houpt et al 1994), were associated with sealant failure, though the incidence of sealant failure was significantly higher than the presence of caries. Loss of sealant was increased over glass ionomer restorative materials (Gray & Paterson 1994; Kilpatrick et al. 96) and larger areas of composite restoration (Gray,1999).

In a different, but significantly related type of study, the ability of sealed composite restorations to halt the radiographically-observed progress of frank carious dentine over a period of 10 years has been reported (Mertz-Fairhurst et al 1998). This provides some welcome reassurance concerning inadvertent sealing of incipient dentinal caries under fissure sealants and has positive implications for the conservative treatment of deep carious dentine in the vicinity of the pulp. The apparent arrest of frank, extensive dentinal carious lesions under sealed “restorations” however, requires further study. Rudolphy et al (1997) have monitored progression of radiolucencies under amalgam restorations over a 6-year period. Of 30 radiolucencies, 18 enlarged and 12 remained the same. The authors used radiographs only, without clinical examination, and therefore do not know the integrity of the overlying restoration, but clearly caries progressed in many cases. The facts that a) micro-organisms are reduced, but not eliminated, in residual caries under resin and glass ionomer (Weerheijm et al, 1993) and b) that mutans streptococci persist after 2 years in residual caries under the majority of amalgam and glass ionomer restorations (Weerheijm et al 1999), suggest that complete removal of active, infected carious dentine is still advisable once operative therapy is indicated. However, the implications are profound for more conservative clinical decisions with respect to both early occlusal decay, to avoid operative intervention, and deep decay, to avoid pulpal exposure and the need for endodontic therapy. This area of cariology deserves further study.

In summary, the Preventive Resin Restoration is a predictable and effective conservative treatment for localised areas of occlusal decay. The weak link in the P. R. R. is the overlying fissure sealant, which requires regular monitoring, maintainance and additions over the years. As the sealant takes the place of “extension for prevention” for the caries-prone occlusal pits and grooves, it is an integral part of the restoration. The success and longevity of Preventive Resin Restorations are therefore dependent on the retention of the overlying sealant. Loss of sealant has variously been reported from 13-70% in the studies reviewed. Studies to analyse causes of failure and improved success for such an important preventive technique are required, including improved chemical or mechanical methods of fissure debridement and/or conditioning to improve sealant retention and longevity (Futtatsuki et al, 1995). Further, improved diagnostic procedures are urgent for occlusal caries to allow dentists to use this technique with confidence, removing the fear of missed areas of decay without traditional fissure removal. Improved diagnostic sensitivity would also discourage the use of operative intervention to check for the presence of occlusal caries in the absence of overt signs.

Factors involved in Restoration Failure

Secondary caries is the most frequently cited reason for restoration failure or replacement, followed by fractured restorations. Reasons for replacement are related to many clinical variables which have traditionally been grouped under Patient, Operator and Material Factors. A systematic review of dental restoration longevity (Downer et al 1999) has provided strong indication of both patient (age and caries activity) and operator factors. This review of operative interventions also reveals strong evidence for the influence of patient factors involved in restoration failure. High caries activity by bacterial assay and salivary flow rates (Bentley et al, 1990; Kohler et al 2000), poor oral hygiene and plaque index (PI) scores (Goldberg et al, 1981; Eriksen et al 1986;) and incidence of new primary or secondary caries (Jokstad and Mjor, 1991a and b) are all common factors determining the frequency of restoration replacement. Material effects and operator skills are important, but recurrent caries would seem to be more of a patient caries management challenge than a restorative problem in the permanent dentition.

This systematic review of conservative intervention has revealed that conservatism per se does not guarantee increased restoration longevity. All restorations are vulnerable to caries recurrence, material failures and technical deficiencies. Indeed, misguided conservatism in some cases may accelerate restoration demise due to the extreme technical difficulties involved and particular materials recommended. This is evidenced by the poor effectiveness of the tunnel restoration for the treatment of proximal caries. On the other hand, more successful conservative strategies, such as the preventive resin and proximal slot restorations, which provide equivalent longevity to traditional restorations should enhance tooth longevity over larger-sized restorations, due to the initial reduction in tooth structure removal. There is, as yet, no hard evidence of increased tooth longevity due to the use of proven conservative operative strategies but it makes sense. Support of such successful conservative strategies, utilised where operative intervention is absolutely indicated, in no way supports the concept of operative intervention for diagnostic purposes. The best restoration is one that never has to be placed.

II The Primary Dentition

The final database of 44 relevant references involving the primary dentition was examined with respect to the formulated question concerning the effect of preparation outline form on the longevity of restorations. The vast majority of clinical research on the primary dentition involved relatively short-term comparisons of dental materials, particularly newer proprietary materials, as they enter the market-place. This reflects the generally low restoration longevity in the primary dentition and the continuing search for a longer-lasting restorative solution. Little research has been conducted on determination of the fundamental factors involved in primary restoration failure and no specific clinical research focussed on the issue of appropriate outline form. Salient conclusions resulting from the review of clinical studies in the primary dentition is included in this portion of the report.

Two studies involving tunnel preparations in primary teeth resulted from the search. Poor performance was documented (Hasselrot et al 1993; de Freitas et al 1994) (Table 4) and the technique cannot be recommended. Only one consistent conservative restorative strategy was revealed from the search, that of addressing proximal caries without definitive occlusal extension. Twelve references involved this type of conservative restoration, variously called “box-only”, “minimal preparation” or “slice” and the results of these have been summarised in a systematic review table (Table 5). Glass ionomer restorative materials figured prominently in this conservative strategy and almost all clinical studies involving glass ionomer materials in the posterior primary dentition involved proximal-only caries removal and restoration. For completeness, the few other clinical studies of glass ionomer performance in primary molars are included. The first 4 references in Table 5 involve glass ionomer-type materials in traditional Class 2 restorations in comparison with silver amalgam. The remaining references in the table all involve box-only proximal restorations, with the last 3 involving poly-acid-modified-composites or "compomers" - a relatively new class of dental materials.

Primary restoration Longevity

Longevity of restorations is very low in the primary dentition (Wendt, 1998). The teeth are small, the dimensions are thin, the patient is often uncooperative and compliance with preventive measures is difficult to achieve. Generally, the earlier the age at restoration, the lower the longevity (Wong & Day, 1990; Holland et al, 1986) The re-restoration cycle is thus more frequent in the primary dentition resulting in further loss of tooth structure and high likelihood of pulpal involvement. Although primary posterior teeth only need to last several years in the mouth, caries management and restorative care is problematic in the caries-prone child patient. Premature tooth loss through failed restorative care can be traumatic to the patient and may require space-maintainance to avoid loss of arch space and subsequent local malocclusion.

Silver amalgam has been the most commonly used material and is the gold standard for comparative studies. However, the clinical performance of silver amalgam in primary teeth has been variously reported from 8% (Ostlund et al, 1992) to 50% (Qvist et al 1986) failures over 2-3 years. Walls et al (1988) reported 40% failure over 2 years, Donly et al (1999) 29.4% over 3 years, Derkson et al (1983) 17% over 2years. In contrast, Roberts and Sherriff (1990) reported a low 14.7% replacement rate over 10 years and a mean estimated survival time greater than 7.5 years. Many different operator and patient factors are involved in such variable restoration replacement figures but clearly the life-span of multi-surface amalgam restorations is generally much shorter in the deciduous than the permanent dentition. A similar situation exists for composite restorations. The predicted life-span of re-restorations is even shorter (Holland et al 1986). Qvist et al (1986) found that the major reasons for replacement of restorations in the primary dentition were fracture or total loss. There is thus a continuing search, to the present day, for improved materials as a restorative solution to caries management.

Conservative Proximal-Only Primary Molar Restorations

As with the permanent dentition traditional Class 2 cavity preparation in primary molars involves an occusal and proximal section joined at an "isthmus". This design is a legacy from the pre-fluoride era where occlusal and proximal surfaces were invariably both carious. There is also a widely held belief amongst clinicians that an occlusal "dovetail" is necessary for retention of the proximal box portion, even when no caries is present in the occlusal fissures (Forsten & Karjalainen (1989). Occlusal forces during eating tend to separate the proximal portion from the occlusal. The isthmus, being the narrowest, thinnest section has a high fracture rate, particularly in the primary dentition. Silver amalgam is a relatively brittle material, particularly in the thin sections associated with primary teeth. In recent years the "box-only" concept has been suggested for primary molars to conserve tooth structure, reduce operative effects on the dental pulp and to increase restoration longevity by eliminating the vulnerable isthmus. Interestingly, although this concept was first introduced in the permanent dentition for silver amalgam, no clinical studies resulted from the search involving silver amalgam proximal "box-only" restorations in the primary dentition.

Soon after the introduction of glass ionomer cements in 1975 the material was recommended for small proximal lesions in primary molars. The largest number of clinical trials involving proximal-only restorations used conventional glass ionomers, particular a commercial form with inclusion of sintered silver particles (Ketac-Silver), and later a few studies reported on the performance of a resin-modified glass ionomer. More recently a few short-term trials using “compomers” and resin composites in “box-only” restorations have been reported in the literature (Table 5).

A significant omission in many of the trials is the presence of a control amalgam, or resin composite, traditional restoration. The varying success rates reported with these more established materials reveal the significant operator and/or patient factors involved in restoration failure, which must be controlled in any clinical trial. The results of the uncontrolled studies are therefore difficult to compare and only generalised conclusions can be made. The research reports often do not provide adequate information concerning the type of patients, the reliability of the examiners, the experience of the operators, nor the handling of the results. Drop outs and exfoliated teeth are factored differently from study to study which affects the reported rate of success. Invariably the studies are very short term, often only 1-2 years in length. Only screening of inadequate and ineffective treatment strategies is possible in the short clinical trials.

Material effects dominate the performance of primary molar restorations. Glass ionomers provided consistently poor results, generally due to their strength limitations. High failure rates were recorded for the use of conventional glass ionomer materials in traditional Class 2 restorations from 37% (Qvist et al 1997) to 60% (Ostlund et al, 1992) over 3 years. Failure rates for silver amalgam in the same studies were 18% and 8% over the same time period. In a similar one-year controlled clinical trial, a 40% failure was recorded for a conventional glass ionomer containing sintered silver (Hung & Richardson 1990). All the silver amalgam restorations remained in service at one year. Almost all glass ionomer failures involved isthmus fracture and loss of the restoration. Clearly the weak and brittle mechanical nature of conventional glass ionomers is totally unsuitable for restorations involving an isthmus.

Even in proximal box-only restorations, conventional-type glass ionomers provided poor performance, from failure rates of 23% at 1 year (Forsten et al, 1989) to 54% at 3 years (Holst , 1996), for a GI containing sintered silver, and failure rates of 16% at 1 year (Forsten et al, 1989) to 39.6% at 3 years (Attwood et al, 1994) for conventional GI cements. There is some evidence of better performance in slot preparations from Andersson-Wenckert et al (1995) but equally poor performance in others (Forsten et al 1989). Failures involved mostly fracture, bond breakdown and total loss of restoration. Recurrent caries was recorded in association with a significant proportion of failed restorations. The material Ketac-Silver showed a high failure rate with (Ostlund et al 1992) and without (Kilpatrick et al; Espelid et al, 1999) an isthmus. Due to the high failure rates it has been stated that conventional glass ionomers are not suitable for the permanent restoration of primary molars (Kilpatrick et al, 1995). They may be useful as a short-term solution only for Class 1 restorations (Attwood, 1994).

These deleterious material effects therefore overwhelmed the assessment of the conservative preparation per se on tooth longevity, pulpal response and recurrent caries. The minimal preparation may even have increased failure rates due to mechanical limitations, as many restorations failed due to fracture and/or lack of retention (Welbury et al, 1991; Kilpatrick et al 1995; Holst, 1996). There was obviously an erroneous belief that the relatively low bond strengths demonstrated in vitro for these materials were adequate to provide retention under dynamic occlusal stresses. No mechanical retention was provided in most studies.

Better results have been reported for resin-modified glass ionomer materials in proximal box-only restorations. A low 2% failure rate over 3 years in proximal box-only restorations has been reported in a recent study (Espelid et al, 1999). However, a failure rate of 26.7% in traditional Class 2 (Donly et al, 1999) and 19.8% in “saucer” preparations over 3 years

(Folkesson et al 1999) have also been recorded. In the latter study, restoration loss and fracture were the major reasons for failure, suggesting inadequate retention in the slot preparation. Knowledge of any material's physical and mechanical limitations are critical for success. Analysis of the proximal surfaces of exfoliated teeth showed significantly less peripheral proximal demineralisation in association with the resin modified glass ionomer (Donly et al, 1999). This review did not encompass a systematic look at caries inhibition by fluoridated restorative materials but some studies reported evidence of such (Donly et al, 1999; Qvist et al, 1997; Derkson, 1989). Qvist concluded, however, that conventional glass ionomer is not an appropriate alternative to amalgam in primary teeth, as the decreased need for restorative treatment of adjacent surfaces cannot compensate for the many restoration fractures.

Similar improved, but varying, results are reported for the newer acid-modified composite materials or "compomers" in conservative proximal restorations. In the four studies using box-only preparations (Table 5), failure rates were 2.3% (Marks et al, 1999) and 9.7% (Marks et al, 2000) at 1 year, all satisfactory at 2 years (Mass et al, 1999) and 20% failures at 2 years (Andersson-Wenckert et al, 1997) in a multi-centre field trial. Correlation of recurrent caries with individual caries activity was not statistically significant in the latter study and failures were due to loss of retention, often in combination with caries. This may be indicative of true "secondary" caries (i.e that which is secondary to the milieu created by a failed restoration) in contrast with recurrent caries (i.e. that which is a recurrence of the primary disease around an otherwise sound restoration). Of note is the fact that the far more successful box-only restorations in the trial by Mass et al (1999) included proximal grooves to prevent proximal displacement during function.

In summary, frequency of restoration replacement is high in the younger populations and highest in the primary dentition (Wendt et al 1998). Both recurrent caries and material failures figure prominently in primary dentition studies. Whereas there is minor evidence for caries susceptibility as a factor in primary restoration failure, there is strong evidence for age at time of treatment and the size of the restoration (Wong & Day, 1990). Material influences are far more pronounced, with survival times highest for stainless steel crowns (Braff, 1975; Roberts and Sherriff, 1990; Dawson et al, 1991, Einwag and Dunninger, 1996;) and lowest for conventional glass ionomer in posterior restorations. (Papathanasiou et al. 1994; Kilpatrick 1993). A recent systematic review of stainless steel crowns in the deciduous dentition confirms the greater longevity and reduced re-treatment needs compared with amalgam restorations (Randall et al, 2000).

In summary, pursuit of conservative operative procedures in the primary dentition has not been uniformly successful to date. Material and technical failures for intra-coronal restorative therapy figure prominently in the paedodontic literature. Improved alternative therapeutic strategies are required. Initial trials of "non-traumatic" methods of treating caries in deciduous teeth have been reported using stannous fluoride and/or silver diamine fluoride alone or in combination with minimal cavity preparation and restoration with composite resin. (McDonald and Sheiham, 1994). Cariostasis over a period of 18months was reported in 95% of teeth that received minimal cavity preparation, involving incomplete caries removal, use of fluoride and restoration with composite resin over the residual soft caries. This research parallels somewhat the 10 year results by Mertz-Fairhurst (1998) for the permanent dentition. The results from the primary dentition are short-term only and further research in this area is necessary.

FUTURE RESEARCH DIRECTIONS

1) Urgent need for improved diagnostic accuracy for caries status of occlusal surfaces to allow appropriate preventive/operative therapy, to prevent the use of operative techniques for investigation of caries status and to allow greater clinician confidence in the use of fissure sealants and preventive resin restorations.

2) Analysis of the factors involved in fissure sealant failure and development of methods and/or materials to improve longevity.

3) Clarification of the operator, patient and material factors involved in restoration failure, with a view to improved restoration longevity and dentist decision-making

4) Mechanisms of alternative caries therapy including dentinal cariostasis in situ and further clinical trials of novel cariostatic operative therapies.

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Table 1. The Proximal "Tunnel" Restoration. Clinical Studies.

Year	Author	Study Design	Country, Sample	Sampling	Study Period	Subjects	Restorations
1992	Svanberg	I (small)	Sweden Public Health Clinic	Volunteers (caries- active)	3yrs	18 (13-16yrs)	18 tunnel (Ketac Silver) 18 amalgam
1995	Lumley et al	II-1	UK Dental Faculty	Any suitable patients	5yrs	25 (19-45yrs)	33 tunnel (GI + KS) 14 amalgam proximal slots
1999	Pilebro et al	II-3	Sweden Mixed, PHS plus Faculty	Multicentre All tunnels 1992-93	3yrs	272 (10-74yrs) Mean 19yr	374 (Ketac Silver)
1999	Pyk et al	II-3	Sweden P.Health Clinic	All tunnels 1987-93	2yrs	142 Mean 19yr	242 tunnel (87% K.Silver, 13% GI)
1998	Hasselrot et al	II-3	Sweden. General Practice	All tunnels 1988-90	7yrs	193 young adult	267 tunnel (Ketac Silver)
1998	Holst et al	II-3	Sweden P.Health Service	Any suitable patients	3yrs	Not given	322 (Ketac Silver) 170 molars 145 bicuspid
1997	Nordbro et al	II-3	Norway P.Health Service	Any suitable patients	3-4yr	Not given	302 tunnel (Ketac Silver)
1996	Strand et al	II-3	Norway. General practive	Any outer third dent. caries	3yrs	117 (10-30yrs)	230 tunnel (Ketac Silver)
1993	Wilkie et al	II-3	Australia Dental Faculty	Volunteer patients	2yr	26 23 ‹ 40yrs 3 › 40yrs	42 tunnel (Ketac Silver) 44 Class 2 amalgam

Table 1 (cont.) The Proximal "Tunnel" Restoration. Clinical Studies.

Year	Author	Criteria	Examiners	Other	Nos. Lost	Findings
1992	Svanberg	Clinical Radiographic Stone casts	1 dentist No details		Not stated	Tunnel - 5.5% marg.fracture, 0% rec.caries. Sig. reduced adjacent proximal caries. Amalgam 17% rec. caries
1995	Lumley et al	Clinical Radiographic	2 authors No details	Bicuspids, mes. 1st molar only	None	3yrs, all satisfactory. 5yrs: Tunnel - 21% failure (15% rec.caries, 6% fractured ridge) Amalgam - 0% failure
1999	Pilebro et al	Clinical radiographic	Clinical: Each dentist. Radiographic: 2 examiners	12 dentists	18.4%	8% residual caries 20% replacements at 3 yrs (41% untreated progression, 14% ridge fract, 3% rec.caries)
1999	Pyk et al	Clinical Radiographic		Life-table method	Not given	15.7% failures (9.5% rec. caries, 4.2% ridge fracture.)
1998	Hasselrot et al	Clinical Radiographic	1 dentist/ examiner. No details	Tunnels: Partial 87% Total 13%	57%	50% failure at 6yrs. (41% ridge fracture, 40% rec. caries, 19% enamel cavitation.)
1998	Holst et al	USPHS Radiographic	Clinicians Trained & calibrated	Partial & total tunnels	16%	15.7% failures (7.3% 1yr, 3.2% 2yr, 5.2% 3yr) Rec. caries 8%, fracture 6%
1997	Nordbro et al	Clinical Radiographic	Not given	Tunnels: Partial 215 Total 87	Not given	28% ridge fracture. 45% of rest rec. caries. Total tunnel better than partial tunnel
1996	Strand et al	Clinical Radiographic	2 clinical + 2 radiographic Consensus		30%	54% failures: 16% rec.caries, 14% ridge fracture, 24% progression of residual demin. enamel.
1993	Wilkie et al	Clinical radiographic Colour photo Replica casts	Clinical - 2 dentists. Indirect - 1 Kappa .48-.86	Rubber dam. 55% partial tunnel	Not given	KS material problems 48% (voids, defects, wear) Rec caries & ridge fracture 0% Am 100% Comp 91% success

Table 2. Proximal-Only Restorations. Clinical Studies.

Year	Authors	Study Design	Country, Sampling Source	Sampling Method	Study Period	Number Subjects	Number Restorations
1993	Nordbo et al	II-3	Norway Public Dental Service	Volunteers. Incipient proximal-only	3yr	37 Adolescents (13-17yrs)	43 Composite "Slots"
1998	Nordbo et al (cont.)	II-3	As above	As above	10yr (Mean 7.2yrs)	As above	51 Composite "Slots"
1995	Kreulen et al	II-3	Netherlands	Class 2 trial patients with proximal-only caries	2yr	48 (22.2±5.6yr)	68 Composite "Box-only"
1998	Kreulen et al (cont)	II-3	As above	As above	5yr	As above	As above
1995	Lumley et al	II-1	UK Dental School Patients	Over 18yrs Early dentinal	Minimum 5yr	14 (19-45yrs)	14 Amalgam Box-only

Table 2(cont.) Proximal-only restorations. Clinical Studies

Year	Authors	Assessment Criteria	Examiner Training/ Reliability	Other	Subjects Lost	Findings
1993	Nordbo et al	Blind basis. USPHS Clinical Radiographic Replicas	P.Health Dentists + first author. R-not given		9.3%	18.8% failure at 3yrs. Causes: Recurrent caries & Technical (voids etc)
1998	Nordbo et al (cont)	As above	As above		As above	30% failure at 9.6yrs. Recurrent caries 50% (Often related to high caries risk patients.) Technical 50%
1995	Kreulen et al	USPHS Clinical Radiographic Replicas	2 observers Kappa .87 (inter)		None	No failures, but technical deficiencies noted in 14-35%
1998	Kreulen et al (cont)	As above	As above	Abstract only	2%	No clinical failures. Treatment time longer than amalgam.(30%)
1995	Lumley et al	Clinical and Radiographic	Not given	Controls in tunnel trial	None	No failures at 5 yrs. Superior to GI tunnels -21% failure

Table 3. The Preventive Resin Restoration. Clinical Studies.

Year	Author	Study Design	Country, Sampling	Sampling Method	Study Period	Number Subjects	Restorations
1998	Mertz-Fairhurst et al	I	US, Dental Faculty	Faculty patients - volunteers	10yrs	123 (8-52yrs)	156 cariostatic PRR vs 77 amalgamS/ 79 amalgamUS
1990	Welbury et al	I	UK, Dental School	Attending Patients. Paired lesions	5yr	126 (6-18yrs)	174 PRR 174 Amalgam
1992	Cloyd et al	II-1	US, Dental Faculty	Faculty patients - early caries	3yr	38 (8-35yrs)	74 PRR vs 52 Amalgam
1979	Azhdari et al	II-1	US	Not given	18mths	Not given	130 PRR vs 116 Amalgam
1980	Simonsen	II-1	US Medical Centre	Not given	3yr	123 (6-8yrs)	88 Sealant only 73 PRR enamel 71 PRR dentine
1978	Raadal	II-1	Norway Faculty Pedo clinic	Attending patients	30mths	281 (5-7yrs)	647 Sealant only 249 PRR enamel
1996	King et al	II-2	Hong Kong Faculty	Retrospective All attending 1990-1993	16.5mth (6-39m)	351	532 PRR
1996	Walker et al	II-2	US Faculty	Retrospective audit	up to 6.5yrs (1.1y)	Not given (6-18yrs)	5185 PRR
1992	Roth et al	II-2	US Faculty pediatric clinic	Retrospective chart audit	27mths (7-71m)	64	100 PRR
1999	Gray et al	II-3	UK Dental School	Attending patients	2yr	164 (mean 23.9yrs)	164 GI-PRR 49% 2nd molars
1996	Kilpatrick et al	II-3	UK Dental School	At least 2 early caries	1.5yr (.5-2yr)	67	80 PRR 80 GI-PRR
1995	Gray et al	II-3	UK Comm Services	Attending patients with early caries	2yrs	Not given (6-16yrs)	115 PRR-enamel 163 PRR dentine
1994	Gray et al	II-3	As above	As above	1yr	Not given (10.6yrs)	128 GI-PRR
1994	Houpt et al	II-3	US/ Israel Faculties	Attending patients	9yrs	110 (6-14yrs)	332 PRR
1993	Stadtler	II-3	Austria faculty	Not given	5yrs	Not given	292 PRR 242 Sealant
1992	Granath et al	II-3	Sweden Faculty	Not given	2yrs	111	87 PRR 48 Class 1 Comp

Table 3 cont. The Preventive Resin Restoration. Clinical Studies.

Year	Author	Criteria	Examiners	Other	Nos. Lost	Findings
1998	Mertz-Fairhurst et al	USPHS (mod) radiographs	2-calibrated	4-celled design	5-8%	Arrest of caries (radiographic) in sealed restorations. 75-84% loss of sealant. Longevity: Am(S)>CariostaticC(S)=Am(US)
1990	Welbury et al	USPHS (mod)	2-calibrated & tested		37.4%	Failures: 10%Am, 7.3%PRR but PRR-50% sealant loss. Projected survival similar
1992	Cloyd et al	USPHS	2-examiners (independent)	2dentists Am/PRR	7-10%	No amalgam failures. PRR- 8.1% caries, all due to sealant loss
1979	Azhdari et al	Clinical	Not given		Not given	No differences at 1yr 14% PRR sealant loss
1980	Simonsen	Clinical Radiographs	Author (No details)		14%	No caries. 97-100% sealant retention, but deterioration requiring additions
1978	Raadal	Clinical Radiographs	Author (no details)	staff and students	24% lost	25% sealant/17%PRR failures. Loss of sealant main cause No caries under intact sealant
1996	King et al	USPHS	1 examiner Kappa (0.54-1.0)		Not given	97.7% caries free, however only 28.4% complete sealant
1996	Walker et al	Restoration replacement	N/A	School Database	N/A	16.8% replacements - 13.1% sealant loss (incl. 6.9% caries) and 3.7% proximal caries.
1992	Roth & Conry	USPHS	2-calibrated (67-98%)	Multiple operators	Not given	26% loss of sealant requiring treatment. 4% caries, always with sealant loss
1999	Gray	USPHS	2-examiners consensus		8.1%	All PRR present. Sealant loss 31-33%. More sealant loss from GI causing crevices.
1996	Kilpatrick et al	Clinical	Not given	1operator	17.5%	No failures. Sealant loss: 21.5% C-PRR 40.9% GI-PRR
1998	Gray & Paterson	Clinical	3-examiners Consensus	14 dentists	42%	90.5% adequate. 9.5% need replaced. 41.5% required additional sealant.
1994	Gray & Paterson	Clinical			23%	7.1% caries. 62% GI-PRR required additional sealant.
1994	Houpt et al	Clinical	1-examiner (no details)	1operator/ examiner	76.2%	24% caries. 20-25% sealant loss. No caries with intact sealant.
1993	Stadtler	Clinical	Not given	No detail	Not given	94.3% survival. Total (5.7%) partial (22.8%) sealant loss
1992	Granath et al	USPHS	5-calibrated (80% inter-)	Student operators	28%	3.4% PRR failure. (caries 1.1%)

Table 4. Tunnel Restorations in Primary Teeth. Clinical Studies

Year	Author	Study Design	Country Sample	Sampling Method	Study Period	Number Subjects	Restorations
1993	Hasselrot et al	II-3	Sweden General Practice	Retrospective analysis All inserted 1988-90	3.5yrs	Not given	36 primary
1994	de Freitas et al	II-3	Brazil Faculty	Exfoliation expected 6m-1y	1yr	20 children	66 composite

Table 4 (cont.) Tunnel Restorations in Primary Teeth

Year	Author	Criteria	Examiners	Other	Nos. Lost	Findings
1993	Hasselrot et al	Clinical Radiographic	1 dentist No details		42%	Failures 90.5% 84% ridge fracture 10% cavitation enamel 21% recurrent caries
1994	de Freitas et al	Clinical Radiographic Direct after exfoliation	3 examiners	Direct no correlation with radiographs	6m - 9.1% 1y - 54.5%	marginal caries 35% (residual or recurrent? - noted on exfoliated teeth) Ridge fracture 3%

Table 5. Glass Ionomer Type Restorations and Modified Cavity Preparations

Year	Author	Design	Country, Sample	Study Period	Number Subjects	Restorations
1999	Donly et al	II-1	US Faculty, No details	3yrs	40 (6-9yrs)	40 amalgam 40 RMGI (Vit) Traditional Class 2
1997	Qvist et al	II-1	Denmark Pub.Health Service	3yrs	666 (3-13yrs)	543 amalgam 515 GI (KF) 79% Class 2 trad.
1992	Ostlund et al	II-1	Sweden Pub. Health Service	3yrs	50 (4-6yrs)	25 amalgam 25 composite 25 conv GI (Chem) Traditional Class 2
1990	Hung & Richardson	II-1	Canada, No details	1yr	22 (5-7yrs)	33 amalgam 40 GI (KS) Traditional Class 2
1999	Espelid et al	II-1	Norway Pub. Health Service	3yrs	43 (5-11yrs)	49 GI (KS) 49 RMGI (Vit) Proximal box-only
1995	Kilpatrick et al	II-1	UK Faculty	18mth	37 (5-11yrs)	46 GI (KS) 46 GI (KF) Proximal box-only
1995	Andersson-Wenckert et al	II-1	Sweden Pub. Health Service	3yrs	25 (6-10yrs)	28 GI (Chem) - slot 28 GI (Chem) - traditional Class 2
1991	Welbury et al	II-1	UK Faculty Child clinic	5yrs	76 (5-11yr)	119 amalgam (trad) 119 GI (KF) Minimal prep.
1989	Forsten et al	II-3	Finland Pub.Health Clinic	1yr	Not given	207 GI (KF and KS) traditional and slot preparations
2000	Marks et al	II-3	Netherlands Faculty	1yr	43 (mn 6.6yr)	53 GI (KM) 52 Compomer (Dyr) Box-only
1999	Folkesson et al	II-3	Sweden Pub.Health Service	3yrs	85 (4-12yrs)	174 RMGI (Vitremer) Class 2, of which 167 are “saucer” Included caries-risk
1996	Holst	II-3	Sweden Pedo clinic All in 4mths	3yrs	48 (4-7yrs)	172 GI (KS) Class 2, proximal “slice”
1994	Attwood et al	II-3	UK Pub.Health Service	3yrs	Not given	635 GI (Chemfil) “caries-free only prep”. 360 Class 2
1999	Marks et al	II-1	Netherlands faculty	1yr	52 (mn 6.9y)	53 box Comp (Dyr) 61 trad Am Cl 2
1999	Mass et al	II-3	Israel Private Practice	up to 2yrs	42 (3-11yrs)	44 amalgam 63 Compomer (Dyr) Box-only (grooves)
1997	Andersson Wenckert et al	II-3	Sweden Pub Health	2yrs	79 (5-12)	159 Comp (Dyr) 91% box-only

Table 5 (cont). Glass Ionomer Restorations and Modified Cavity Preparations

Year	Author	Criteria	Examiners	Other	Nos. Lost	Findings

1999	Donly et al	USPHSmod Direct exam: (exfoliated)	No details	1 dentist	52.5%	Am - 29.4% failures RMGI - 26.7% failures (Less prox. demineralisation)
1997	Qvist et al	Clinical	No details. ? same PHS dentists	14 dentists	39% lost + exfoliated	Am - 18% failures GI -37% failures (loss, fractures) Rec. caries (2% vs 0%) & adjacent new caries (21% vs 12%) lower for GI
1992	Ostlund et al	USPHS	Same 2 clinicians	2 dentists	None	Am - 8% failures Composite - 16% failures GI - 60% failures (fractured isthmus)
1990	Hung et al	USPHS mod.	1 independ. No details	Half mouth design	None	Am - 100% success GI (KS) - 40% failure (isthmus fracture)
1999	Espelid et al	USPHS Replicas	2 clinicians (trained)		46%	RMGI - 2.0% failures GI (KS) - 26.5% failures (defects and caries)
1995	Kilpatrick et al	USPHS mod.	Clinician / examiner	1 operator	None	GI (KS) 41.3% - failures GI (KF) - 23.9% failures Both loss / bond breakdown
1995	Andersson-Wenckert et al	USPHS	No details	2 dentists	62.5% includes exfol-n	Traditional 32% failures (6) Slot 23% failures (5) ? not significant
1991	Welbury et al	USPHS mod.	1 clin. 1-2yr 1 clin. 3-5yr Concord 89%	2 dentists	16.8%	Am - 26.5% failures GI (KF) - 32.8% failures (fracture/loss/rec. caries)
1989	Forsten et al	Clinical	No details	4 dentists	3.8%	GI (KS) - 23% failures GI (KF) - 16% failures Traditional and slot same
2000	Marks et al	USPHS mod. Radiographs	2 trained and calibrated Kappa 0.94)	Comp- less time	36.2%	GI (KM) - 8.3% failure Compomer -9.7% failure (Both rec. caries & fracture)
1999	Folkesson et al	USPHS mod.	6 trained dentists. 2 per restoration	insert. by 6 dentists	39%	1yr - 8.1%, 2yr - 11.7% 3yr - 19.8% failures (9.4% loss, 8.2% caries, 4.7% fracture, 3.5% comb)
1996	Holst	USPHS mod. Some rads	36 PHS dentists	1 clinician	30.8%	1yr - 34%, 2yr - 44%. 3yr - 54% failures (mostly loss or fracture - 8% caries)
1994	Attwood et al	Clinical	2 calibrated	6 PHS dentists	43.5%	1yr - 23.4%, 3yrs - 39.6% failures. Mostly total loss, only 5.3% recurrent caries
1999	Marks et al	USPHS Radiographs	1 trained Rads (2 calib)	Split mouth	8.8%	Am 1.6%, Dyract 2.3% failures (plus cervical radiolucencies)
1999	Mass et al	USPHS Radiographs	Clin-Operator/ examiner Rads -2		Less than 1/3 each recall	All satisfactory. Minor defects present only.
1997	Andersson-Wenckert	USPHS mod	2 calibrated dentists	Multi-centre	34%	Dyr. 20% failures (Loss of retention with caries)