Minimal intervention dentistry: part 7. Minimally invasive operative caries management: rationale and techniques

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VERIFIABLE CPD PAPER

IN BRIEF

- Describes minimally invasive operative caries management techniques.
- Highlights the degree to which dental caries should be excavated.
- Suggests removal of grossly softened caries-infected dentine is recommended in most situations along with the placement of a sealed restoration.

PRACTICE

When patients present with cavities causing pain, poor aesthetics and/or functional problems restorations will need to be placed. Minimally invasive caries excavation strategies can be deployed depending on the patient's caries risk, lesion-pulp proximity and vitality, the extent of remaining supra-gingival tooth structure and clinical factors (for example, moisture control, access). Excavation instruments, including burs/handpieces, hand excavators, chemo-mechanical agents and/or air-abrasives limiting caries removal selectively to the more superficial caries-infected dentine and partial removal of caries-affected dentine when required, help create smaller cavities with healthy enamel/dentine margins. Using adhesive restorative materials the operator can, if handling with care, optimise the histological substrate coupled with the applied chemistry of the material so helping to form a durable peripheral seal and bond to aid retention of the restoration as well as arresting the carious process within the remaining tooth structure. Achieving a smooth tooth-restoration interface clinically to aid the cooperative, motivated patient in biofilm removal is an essential pre-requisite to prevent further secondary caries.

INTRODUCTION

The term MI dentistry or 'MID' has been used for many years with several meanings in the dental literature. Minimum(al) intervention dentistry is the holistic patient care philosophy that encompasses the complete patient-dentist team-care approach to managing dental disease by identification and diagnosis (including caries risk assessment), prevention and control, restoration and recall, so educating and empowering the patient to take responsibility for their personal oral health.[1,2] Minimally Invasive Dentistry describes contemporary ultraconservative operative management of cavitated lesions requiring surgical intervention. It does not mean unduly early operative intervention of incipient lesions, which in most cases is unnecessary as more effective and appropriate non-invasive preventive approaches exist. It is the latter definition that will be discussed further in this paper.

MINIMAL INTERVENTION DENTISTRY

1. From 'compulsive' restorative dentistry to rational therapeutic strategies
2. Caries risk assessment in adults
3. Paediatric dental care – prevention and management protocols using caries risk assessment for infants and young children
4. Detection and diagnosis of initial caries lesions
5. Atraumatic restorative treatment (ART) – a minimum intervention and minimally invasive approach for the management of dental caries
6. Caries inhibition by resin infiltration
7. **Minimally invasive operative caries management – rationale and techniques**

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'Golden triangle' of MID

A thorough understanding and appreciation of the interplay between three critical factors is required to achieve success clinically when using a minimally invasive operative caries management strategy (MI OCMS):

1. The histology of the dental substrate being treated
2. The chemistry/handling of the adhesive materials used to restore the cavity
3. Consideration of the practical operative techniques available to excavate caries minimally.

Appreciation of these factors will enable the dental practitioner to embrace the contemporary oral physician's biological approach to operative caries management as opposed to the surgeon's mechanistic efforts of preparing cavities of a pre-determined shape, governed primarily by the properties of the chosen restorative material as opposed to the actual histopathology of the disease process and retention of tooth substance.[3,4]

LESION HISTOLOGY

Enamel caries

Long-term, repeated episodes of bacterial acid demineralisation instigated at a susceptible tooth surface by the residing plaque biofilm results in the growth of subsurface structural porosities, eventually enlarging, if not controlled at the earliest stages by remineralisation/oral hygiene procedures, coalescing and ultimately causing cavitation. Carious enamel with its unsupported prismatic structure is weak under stress from compressive/shear occlusal loads or from tensile shrinkage forces from photo-cured resin-based adhesive materials.[5] If carious enamel is retained at the margin of the cavity and subsequently restored, deficiencies may allow the ingress of plaque biofilm bacteria through micropores within the defective enamel structure - cohesive microleakage. Further complications are associated with the potential of 'secondary' caries developing along defective marginal interfaces where plaque biofilm stagnates, further compromising tooth structure.[3]

Dentine caries

Carious dentine can be subdivided into two histopathological zones:

1. The peripheral caries-infected zone (close to the enamel-dentine junction [EDJ]), irreversibly damaged, necrotic and softened by long standing bacterial contamination and proteolytic denaturation of collagen and acid demineralization of the inorganic component
2. The deeper caries-affected zone, reversibly damaged by virtue of carious process, which has the potential to repair under the correct conditions as the collagen is not denatured.[5-7]

The soft, wet, necrotic nature of caries-infected dentine means it is an inferior chemical and physical substrate for adhesion and seal formation, whereas the potentially repairable caries-affected dentine has been shown to exhibit adequate adhesive bonding potential, especially when surrounded by a periphery of sound dentine and enamel.[8]

It is important to appreciate that using the principles of minimally invasive (MI) dentistry may often lead to less carious dentine excavation overall than past caries excavation rationales based on a mechanistic approach to maximise the retention and physical properties of the restorative material within the cavity.[9] MI cavities will exhibit cut surfaces with different qualities of enamel and dentine histology along the same cavity surface and these tissues will require handling in different ways in order to optimise adhesive bonding. Indeed, clinically delineating between the layers of caries-infected and affected dentine within a lesion is a rather subjective process at present. Caries-infected dentine is sticky and soft to a sharp dental explorer whereas caries-affected dentine is a little more tacky ('scratchy and sticky') in nature and blends to the hard, scratchy consistency of deeper sound dentine.[3] Propylene glycol-based indicator dyes were developed to act as a marker for that carious dentine requiring excavation, but many conflicting studies exist regarding their efficacy in this regard.[10] Latest developments include more specific indicators highlighting the sulphur-containing bacterial products indicative of the increased bacterial load present in caries-infected dentine but these have yet to be validated *in vivo*.

How much dentine caries should be excavated?

The answer to the above question is specific to the individual tooth/lesion, oral cavity, patient and dentist as there are numerous inter-relating co-variables that have to be considered.

Pulp status

The vitality (sensibility) of the pulp must be assessed from the clinical signs and symptoms and suitable investigations (a combination of electrical, thermal and radiographic). Signs of an acute, reversible pulpitis can resolve if the carious process is arrested using a sealed restoration along with effective patient control measures, tipping the histopathological balance from the bacteria in favour of the healing dentine-pulp complex and its acute inflammatory mediators.[5,11].

Lesion depth

Lesion-pulp proximity affects the level of protection afforded to the vital pulp. Indirect pulp protection (capping) conserves caries-affected dentine close to the pulp, minimising the risk of unnecessary pulp exposure, and a suitable material (for example, glass ionomer cement) with anti-bacterial properties as well as bonding and sealing chemically to the remaining dentine affords a potential seal, so permitting rejuvenation of the dentine-pulp complex.[5,12,13]

Extent of viable tooth structure

The functional and aesthetic restorability of the tooth must be assessed. A minimally invasive approach removing only caries-infected dentine will conserve more tooth structure that can help retain and support the definitive sealed restoration. The optimal restorative material is natural tooth substance and smaller cavities are easier to manage for both the dentist and the patient. A reduced surface area of restoration with its margins in cleansable, accessible areas will increase the patient's ability to regularly agitate and remove the plaque biofilm, thus reducing the risk of further onset of caries.

Patient's caries risk assessment

The MI operative caries management strategy (OCMS) relies on close collaboration with successful prevention/control regimes instigated by the patient and the dental team. These can often be linked to the overall risk assessment of the individual patient as a motivated patient has the greater potential to be converted to low caries risk. If these are in place MI restorations have a good chance of medium to long-term success.[14,15] If, however, the caries risk is high in less motivated patients then adhesive restorations may show a reduced long-term survival rate.[16]

Clinical factors

Practical considerations in restoration placement must play a part in deciding whether MI is a feasible option for particular individuals. These may include:

- Suitable access for instrumentation
- Ability to control moisture levels (ideally with rubber dam isolation)
- Appreciation of the final position of the cavity-restoration margin (supra- or subgingival)
- Appropriate handling of adhesive restorative materials by the dental team (for example, ensuring that dentine bonding agent bottle lids are replaced promptly after dispensing to ensure minimal evaporation of any solvent carrier; appropriate ratios of powder: liquid mixed when required etc).

Prospective long-term randomised controlled clinical trials have assessed the validity and efficacy of minimally invasive caries removal with or without indirect pulp capping in terms of restoration longevity and pulp status.[13-15] Systematic analysis of the results has concluded that

Table 1 Tooth-cutting/caries removal technologies, the substrates acted upon and their mechanism of action

Mechanism	Dental substrate affected	Tooth-cutting technology
Mechanical, rotary	Sound or carious enamel and dentine	SS, CS, diamond, TC and plastic burs*
Mechanical, non-rotary	Sound or carious enamel and dentine	Hand instruments (excavators, chisels), air-abrasion, air-polishing**, ultrasonics, sono-abrasion
Chemomechanical	Carious dentine	Caridex™, Carisolv™ gel (amino acid-based), Papacarie® gel (papain-based), pepsin-based solutions/gels
Photo-ablation	Sound or carious enamel and dentine	Lasers
Others	bacteria	Photo-active disinfection (PAD), ozone

Key: SS = stainless steel; CS = carbon steel; TC = tungsten carbide; * = works only on carious dentine; ** = used for stain-removal[3]

as long as there is a suitable patient-dentist team-care approach to maintaining oral health, adhesive sealed restorations placed in ultra-conservative cavity preparations can last well in the functioning oral cavity.[9,12,17] The issue of pulp capping using a separate 'lining' or 'base' material has been reviewed in the literature. In modern day MI OCMS, using adhesive restorative materials, the clinical need of a separate layer of pulp protection has been shown to be unnecessary (apart from the scenario where the pulp may be protected with a thin layer of glass ionomer cement beneath a large amalgam restoration with close pulp proximity).[18]

MATERIALS SCIENCE

A thorough understanding of the clinical relevance of contemporary adhesive dental materials science is required to implement successfully the MI OCMS. The physico-chemical interaction of the relevant dental substrate retained at the cavity surface with the adhesive material must be enhanced by the operator to achieve medium to long-term successful outcomes. The restoration seal is reliant upon the integrity and morphology of mineral (calcium ions, micromechanical undercuts, supported prismatic structure in enamel) and of the collagen nano-matrix/tubular structure in dentine (hybrid zone). The clinical relevance of the individual steps in adhesive bonding (acid etch, primer and bond) have been discussed in an alternative publication.[4] Issues regarding chemical or micro-/nano-mechanical bond mechanisms revolve around the longevity of the seal achieved, which is affected adversely by physico-chemical hydrolysis and potential enzymatic degradation by indigenous, acid-activated dentine matrix metallo-proteinases (MMPs).[4,19-21] Latest in-vitro research indicates the potential use of anti-MMPs in dental adhesives to block the activity of the indigenous MMPs, hence resisting collagen degradation in the carious dentine.[21,22]

MINIMALLY INVASIVE OPERATIVE TECHNIQUES

As can be seen from Table 1, there are several clinical technologies available for cutting teeth and removing caries. Most are not self-selective for caries-infected dentine and involve active discriminatory action from the operator when considering MI OCMS.[23,24] Dentists are highly trained at using dental burs in slow speed or air turbine handpieces as well as hand excavators, and although not self discriminatory in favour of caries-infected dentine, a good operator can still practice MI OCMS effectively using these instruments as illustrated in Figures 1-6.

Ultrasonic and sonic instrumentation use the principle of probe tip oscillation and micro-cavitation to chip away hard dental tissues. Lasers transfer high energy into the tooth through water causing photo-ablation of hard tissues. Great control is required by the operator in order to harness this energy effectively and the effects on the remaining enamel, dentine and pulp continue to be investigated in terms of residual strength and bonding capabilities. A recent systematic review concluded that laser caries removal is not yet a viable general dental practice option for effective caries excavation.[25] Enzymatic (including hypochlorite-, pepsin- and papain-based) solutions have and are being investigated to help further breakdown of collagen in already softened carious dentine in the hope of developing

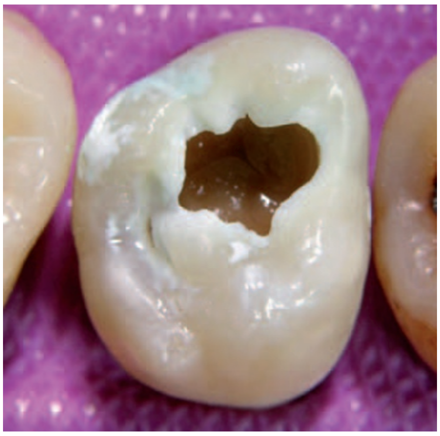

Fig. 1 Cavitated occlusal lesion 17 with demineralised, unsupported peripheral enamel and visible caries-infected dentine. Symptoms were those of an early reversible pulpitis and the pulp was vital to electric pulp testing and ethyl chloride

Fig. 2 Radiograph of 17 showing demineralisation extending into the inner third of dentine towards the pulp. The pulp chamber is clearly visible with a potential bridge of dentine between it and the advancing lesion. There is no proximal cavitation

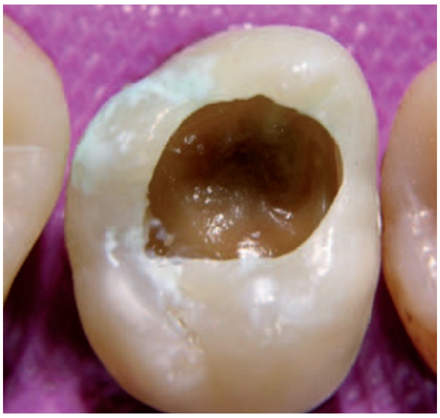

Fig. 3 The peripheral unsupported enamel has been removed using a long tapered diamond bur in a high speed air turbine handpiece and the sound margins lightly bevelled

a more self-limiting technique of removing caries-infected dentine alone.[23] Other chemical methods include photo-activated disinfection (PAD) where tolonium chloride is introduced into the cavity, absorbed by the residual bacteria in the cavity walls and then activated using light of a specific wavelength causing cell lysis, death and ozone (gaseous ozone infused into early lesions causing bacterial death). These technologies currently suffer from a paucity of clinical evidence to validate them for routine clinical use.[26]

Air-abrasion

Air-abrasion is a 68-year-old dental operative technique used for the removal of enamel and dentine during cavity preparation.[27,28] Air abrasion units are capable of minimally invasive tooth preparation using 27 μm aluminium oxide (α-alumina).[24,29,30] However, dentists are used to the parameters of tactile feedback and an appreciation of finite cutting depth when using rotary tooth-cutting techniques, both of which the end-cutting alumina air abrasive jet lacks. This makes the use of alumina air abrasion highly operator-sensitive and requires careful education of clinicians to realise its potential for minimally invasive preparation and the prevention of cavity over-preparation.[31] Studies have been published that characterise the efficacy of alumina air-abrasion and its cutting characteristics on both sound and carious enamel and dentine and collectively these show the technique to be efficient if specific operating parameters (for example, air pressure, powder flow rate and reservoir volume, nozzle diameter and working distance) are regulated judiciously by the operator.[32–35] Clinical studies have indicated good patient acceptance of the technology in terms of the lack of vibration, no heat generation and the reduced need for local analgesia.[36,37]

An important clinical use of air-abrasion is obtaining suitable enamel access in minimally invasive preventive resin restorations. Meticulous cleaning of the occlusal surface before visual examination using a rotary brush or air-polishing is essential for caries detection,[38] followed by the use of a small head dental bur or alumina air-abrasion for the removal of the carious, demineralised enamel. The microscopically roughened enamel surface created by alumina air-abrasion is devoid of weakened prisms and is therefore better adapted for adhesive bonding. However, lack of substrate selectivity and no self-limiting


Fig. 4 The dentine at the periphery has been initially excavated to a depth of caries-affected dentine but flakes of very soft infected dentine remain over the pulpal aspect of the cavity


Fig. 5 The dentine adjacent to the enamel-dentine junction is both scratchy and slightly sticky to a dental probe, indicating it is affected histologically. The peripheral enamel margin is sound histologically


Fig. 6 The final resin composite restoration has been placed and finished to reduce plaque biofilm adherence in the oral cavity

operator feedback when using these operative technologies can result in cavity over-preparation. Innovation in abrasive powder development has resulted in the production of a commercially available bio-active glass powder capable of removing extrinsic dental stain, desensitising

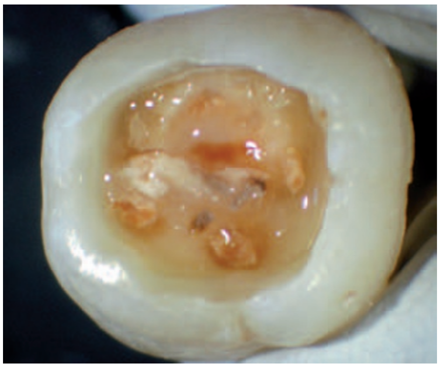
Fig. 7 Cavitated occlusal caries with soft infected dentine evident

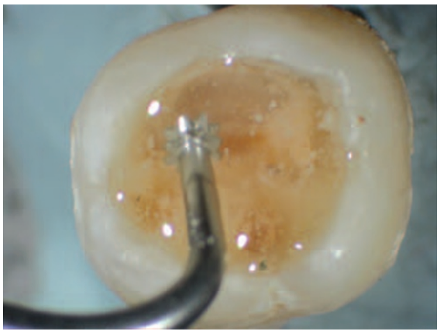
Fig. 8 Initially clear, slightly viscous Carisolv™ gel introduced into the cavity using the mace-tip hand instrument and left for 40 seconds before excavation

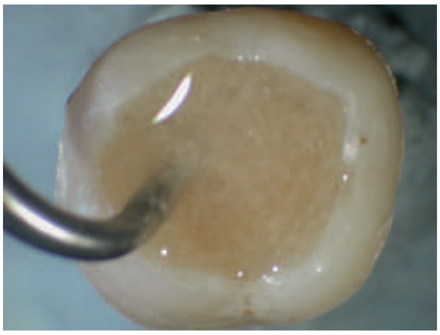
Fig. 9 This process is continued until the gel has a muddy consistency when it is washed out of the cavity and the relative hardness of the remaining cavity walls tested using a sharp dental explorer

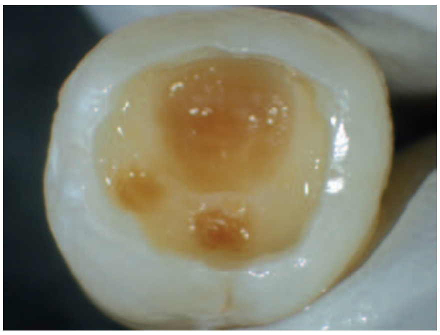
Fig. 10 MI prepared cavity with affected dentine retained over the pulpal aspect of the cavity. The peripheral margins in the case have purposely been excavated to histologically sound dentine to aid the restorative peripheral seal

exposed dentine and exhibiting an intrinsic selectivity towards carious, demineralised enamel and resin composite restorations.[39–41] Research is ongoing into development of a self-selective air-abrasive powder for caries-infected dentine.

Chemo-mechanical caries removal

After the development and subsequent demise of the Caridex™ system in the 1970s, chemo-mechanical caries removal techniques were resurgent with the commercialisation of Carisolv™ gel in the late 1990s. This hypochlorite/amino acid-based gel system assists the MI OCMS with special non-cutting hand instruments offering greater tactile sensitivity to the operator, thus permitting selective infected and affected dentine removal.[23,24] Studies indicated good patient acceptance of this technique.[37] An example of MI caries excavation using Carisolv™ gel is given in Figures 7-10. Developments in chemo-mechanical technology include the laboratory development of pepsin-based gels using specially designed nylon brushes and plastic disposable hand instruments to abrade the softened infected dentine as well as papain-based systems (see Table 1).

CONCLUSIONS

The evidence for the minimally invasive operative caries removal strategy in appropriately selected patients exists. The removal of grossly softened caries-infected dentine is recommended in most situations (except perhaps in a deep lesion overlying the pulp where its vitality assessment leans towards an acute inflammatory response and an adequate clinical seal can be achieved at the periphery of the cavity). Peripheral caries removal should extend to sound dentine where inadequate quantity and quality of enamel remains. It is at this tooth-restoration interface that the peripheral seal is critical to prevent further histopathological progress of the disease. The seal can be achieved using adhesive dental biomaterials that penetrate micro-/nano-mechanically to the mineral and collagenous components of enamel and dentine respectively. With judicious use of contemporary adhesives with their bacteriocidal/static properties, there is little need clinically for a separate lining/base layer to protect the pulp. A thorough understanding of the chemistry of the materials and how they relate to the histology of the tissues is necessary to ensure the best prognosis of a sealed, adhesive restoration.

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1. Mickenautsch S. An introduction to minimum intervention dentistry. *Singapore Dent J* 2005; **27:** 1–6.
2. Doméjean-Orliaguet S, Banerjee A, Gaucher C *et al.* Minimal Intervention Treatment Plan (MITP): practical implementation in general practice. *J Minim Interv Dent* 2009; **2:** 103–123.
3. Banerjee A, Watson T F. *Pickard's manual of operative dentistry.* 9th ed. Oxford: Oxford University Press, 2011.
4. Green D J, Banerjee A. Contemporary adhesive bonding: bridging the gap between research and clinical practice. *Dent Update* 2011; **38:** 439-440, 443–446, 449–450.
5. Banerjee A. A large carious lesion. *In* Odell E W (ed) *Clinical problem solving in dentistry.* 3rd ed. pp 43–48. Edinburgh: Churchill Livingstone, 2010.
6. Ogawa K, Yamashita Y, Ichijo T, Fusayama T. The ultrastructure and hardness of the transparent layer of human carious dentin. *J Dent Res* 1983; **62:** 7–10.
7. Banerjee A, Watson T F, Kidd E A. Dentine caries: take it or leave it? *Dent Update* 2000; **27:** 272–276.
8. Banerjee A, Kellow S, Mannocci F, Cook R J, Watson T F. An in-vitro evaluation of microtensile bond strengths of two adhesive bonding agents to residual dentine after caries removal using three excavation techniques. *J Dent* 2010; **38:** 480–489.
9. Thompson V, Craig R G, Curro F A, Green W S, Ship J A. Treatment of deep carious lesions by complete excavation or partial removal: a critical review. *J Am Dent Assoc* 2008; **139:** 705–712.
10. Van de Rijke J W. Use of dyes in cariology. *Int Dent J* 1991; **41:** 111–116.
11. Hayashi M, Fujitani M, Yamaki C, Momoi Y. Ways of enhancing pulp preservation by stepwise excavation – a systematic review. *J Dent* 2011; **39:** 95–107.
12. Ricketts D N, Kidd E A, Innes N, Clarkson J. Complete or ultraconservative removal of decayed tissue in unfilled teeth. *Cochrane Database Syst Rev* 2006; **3:** CD003808.
13. Bjørndal L, Reit C, Bruun G *et al.* Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy. *Eur J Oral Sci* 2010; **118:** 290–297.
14. Mertz-Fairhurst E J, Curtis J W Jr, Ergle J W, Rueggeberg F A, Adair S M. Ultraconservative and cariostatic sealed restorations: results at year 10. *J Am Dent Assoc* 1998; **129:** 55–66.
15. Maltz M, Oliveira E F, Fontanella V, Carminatti G. Deep caries lesions after incomplete dentine caries removal: 40-month follow-up study. *Caries Res* 2007; **41:** 493–496.
16. Opdam N J, Bronkhorst E M, Loomans B A, Huysmans M C. 12-year survival of composite *vs.* amalgam restorations. *J Dent Res* 2010; **89:** 1063–1067.
17. Ricketts D. Deep or partial caries removal: which is best? *Evid Based Dent* 2008; **9:** 71–72.
18. Hilton T J. Keys to clinical success with pulp capping: a review of the literature. *Oper Dent* 2009; **34:** 615–625.
19. De Munck J, Van Landuyt K, Peumans M *et al.* A critical review of the durability of adhesion to tooth tissue: methods and results. *J Dent Res* 2005; **84:** 118–132.
20. Van Meerbeek B, De Munck J, Van Landuyt K L *et al.* Dental adhesives and adhesive performance. *In* Curtis R, Watson T F (eds) *Dental biomaterials: imaging, testing and modeling.* pp 81–111. Cambridge: Woodhead Publishing, 2008.
21. Breschi L, Martin P, Mazzoni A *et al.* Use of a specific MMP-inhibitor (galardin) for preservation of hybrid layer. *Dent Mater* 2010; **26:** 571–578.
22. Almahdy A, Koller G, Sauro S et al. Effect of MMP inhibitors incorporated within dental adhesives. *J Dent Res* 2012; **91:** 605–611.
23. Banerjee A, Kidd E A, Watson T F. *In vitro* evaluation of five alternative methods of carious dentine excavation. *Caries Res* 2000; **34:** 144–150.
24. Banerjee A, Watson T F, Kidd E A. Dentine caries excavation: a review of current clinical techniques. *Br Dent J* 2000; **188:** 476–482.
25. Jacobsen T, Norlund A, Englund G S, Tranæus S. Application of laser technology for removal of caries: a systematic review of controlled clinical trials. *Acta Odontol Scan* 2011; **69:** 65–74.
26. Azarpazhooh A, Limeback H. The application of ozone in dentistry: a systematic review of literature. *J Dent* 2008; **36:** 104–116.
27. Black R B. Technic for non-mechanical preparations of cavities and prophylaxis. *J Am Dent Assoc* 1945; **32:** 955–965.
28. Black R B. Airbrasion: some fundamentals. *J Am Dent Assoc* 1950; **41:** 701–710.
29. Berry E A 3rd, Eakle W S, Summitt J B. Air abrasion: an old technology reborn. *Compend Contin Educ Dent* 1999; **20:** 751–754, 756, 758–759.
30. Banerjee A, Watson T F. Air abrasion: its uses and abuses. *Dent Update* 2002; **29:** 340–346.
31. Goldstein R E, Parkins F M. Using air-abrasive technology to diagnose and restore pit and fissure caries. *J Am Dent Assoc* 1995; **126:** 761–766.
32. Peruchi C, Santos-Pinto L, Santos-Pinto A, Barbosa e Silva E. Evaluation of cutting parameters produced in primary teeth by an air-abrasion system. *Quintessence Int* 2002; **33:** 279–283.
33. Paolinelis G, Watson T F, Banerjee A. Microhardness as a predictor of sound and carious dentine removal using alumina air abrasion. *Caries Res* 2006; **40:** 292–295.
34. Banerjee A, Uddin M, Paolinelis G, Watson T F. An *in vitro* investigation of the effect of powder reservoir volume on the consistency of alumina powder flow rates in dental air-abrasion devices. *J Dent* 2008; **36:** 224–227.
35. Paolinelis G, Banerjee A, Watson T F. An *in vitro* investigation of the effects of variable operating parameters on alumina air-abrasion cutting characteristics. *Oper Dent* 2009; **34:** 87–92.
36. Epstein S. Analysis of airbrasive procedures in dental practice. *J Am Dent Assoc* 1951; **43:** 578–582.
37. Rafique S, Fiske J, Banerjee A. Clinical trial of an air-abrasion/chemomechanical operative procedure for the restorative treatment of dental patients. *Caries Res* 2003; **37:** 360–364.
38. Strand G V, Raadal M. The efficiency of cleaning fissures with an air-polishing instrument. *Acta Odontol Scand* 1988; **46:** 113–117.
39. Hench L L, Splinter R J, Allen W C, Greenlee T K. Bonding mechanisms at the interface of ceramic prosthetic materials. *J Biomed Mat Res* 1972 **5:** 117–141.
40. Banerjee A, Hajatdoost-Sani M, Farrell S, Thompson I. A clinical evaluation and comparison of bioactive glass and sodium bicarbonate air-polishing powders. *J Dent* 2010; **38:** 475–479.
41. Banerjee A, Thompson I D, Watson T F. Minimally invasive caries removal using bio-active glass air-abrasion. *J Dent* 2011; **39:** 2–7.