Minimally invasive dentistry

CAROL ANNE MURDOCH-KINCH, D.D.S., Ph.D.;
MARY ELLEN McLEAN, D.D.S.

ABSTRACT

Background. During the past few decades, scientific developments in cariology, dental materials and diagnostic systems have changed dentistry's approach to diagnosis and management of dental caries. The authors summarize these developments.

Overview. Dental adhesives and restorative materials, new understanding of the caries process and remineralization, and changes in caries prevlance have catalyzed the evolution in caries management from G.V. Black's "extension for prevention" to "minimally invasive." The authors describe the scientific basis for early diagnosis; a modified classification of caries based on site and size of lesion remineralization; reduction of cariogenic bacteria; and minimally invasive cavity preparation design, techniques and material selection.

Conclusions and Practice Implications. Minimally invasive dentistry is based on advances in science. Emerging technologies will facilitate evolution to primary prevention of caries, though technical, cultural and economic obstacles to full implementation in clinical practice now exist.

"Preservation of a healthy set of natural teeth for each patient should be the objective of every dentist. All work in the health field is aimed basically at conservation of the human body and its function. … The surgeon is so conservative that loss of even a small part of a finger or toe, notwithstanding the fact that the patient will still have nine more, is considered a tragedy. Likewise, loss of even a part of a human tooth should be regarded as a serious injury, never to be considered lightly, and the tooth is certainly worthy of the most careful restoration."[1]

Miles Markley, one of several great leaders in preventive dentistry, summarized in this statement the central concept in the modern approach to the dentist's role in the treatment of dental caries: that the loss of even a part of a human tooth should be considered "a serious injury," and that dentistry's goal should be to preserve healthy, natural tooth structure. His words are perhaps even more relevant today than when he wrote them half a century ago, now that we have the scientific understanding and the means to realize his vision.

Emerging technologies will facilitate evolution to primary prevention of caries, though obstacles to full implementation in clinical practice now exist.

The "minimally invasive" approach to treating dental caries incorporates the dental science of detecting, diagnosing, intercepting and treating dental caries on the microscopic level.[2] This approach to treating dental caries includes many nonsurgical modalities, as well as the key concept that dental caries should be treated as an infectious disease.

It has been known for decades that dental caries is a communicable, infectious disease caused by dental plaque, an oral biofilm, and by exposure to fermentable carbohydrates. Plaque bacteria produce acid in the presence of fermentable carbohydrates. This acid dissolves the calcified component of dental hard tissues, leading to infection and progressive loss of tooth structure, pulpal disease and eventual tooth loss. In the past, dentistry's approach to treating caries has been surgical—removing diseased tissue and replacing it with a dental restorative material. This approach was necessary, given the prevalence of disease, our understanding of the disease process, the limitations of available materials and the lack of proven alternative therapies.

Over time, modern dentistry has evolved to a minimally invasive approach, in which caries is managed as an infectious disease, deferring operative intervention as long as possible. The focus is on maximum conservation of demineralized, noncavitated enamel and dentin. Once control of the infection is achieved, the patient's caries risk status and evidence of lesion demineralization can be monitored over extended periods.[3-5]

Historically, dentists have been hindered in their ability to preserve tooth structure by an incomplete understanding of the caries process and deficiencies in the available restorative materials. Another important limitation, which continues to affect decisions to restore rather than monitor carious lesions over time, is the ability to detect the earliest signs of disease. The accuracy of dental radiographs and visual inspection when used for caries detection is insufficient. Research is ongoing to improve methods of early caries detection to allow us to fully implement new approaches to the management of dental caries.[6] In addition, new caries management protocols have been developed that differentiate between people with different levels of caries risk.[7,8] For any approach to be successful, dentistry must acknowledge that neither fluoride nor the prevention of bacterial microleakage between the tooth and the restoration will be adequate to prevent further caries activity. Dentists must engage and involve patients in the management of their disease. Therefore, all restorative procedures must be carried out only in conjunction with well-understood preventive techniques and patient education.[3-5]

The focus is on maximum conservation of demineralized, noncavitated enamel and dentin.

The development of adhesive dentistry and scientific progress in understanding the nature of caries has enabled dentists to do more than simply remove and replace diseased tissue. “Extension for prevention” has given way to the new paradigm of minimally invasive dentistry, as seen in a refined model of care that has been modified from that described by Tyas and colleagues[5] and includes the following concepts:

- early caries diagnosis;
- the classification of caries depth and progression using radiographs;
- the assessment of individual caries risk (high, moderate, low);
- the reduction of cariogenic bacteria, to decrease the risk of further demineralization and cavitation;
- the arresting of active lesions;
- the remineralization and monitoring of noncavitated arrested lesions;
- the placement of restorations in teeth with cavitated lesions, using minimal cavity designs;
- the repair rather than the replacement of defective restorations;
- assessing disease management outcomes at pre-established intervals.[5]

This article provides an overview of the minimally invasive approach to detecting, diagnosing and treating dental caries by summarizing scientific evidence on caries pathogenesis, early detection, preparation design and material selection.

EARLY DIAGNOSIS

Detection of the carious lesion is only one aspect in the diagnosis of caries. Caries activity—which may be even more important—also must be determined but often is difficult to assess. Caries activity is the process that begins with the presence of attached dental plaque, which leads to demineralization of the underlying tooth structure. It is important to remember that caries activity cannot be determined at one point in time; it must be determined by monitoring the lesion over time. Radiographs and clinical information usually are used to make this determination,[8] though other diagnostic tools are emerging.[3,5,9] Some methods are better for detecting occlusal caries, while others are better for detecting proximal or smooth-surface lesions. These emerging technologies include electrical conductance methods, quantitative laser fluorescence,[10] laser fluorescence,[11] tuned-aperture computed tomography[12-14] and optical coherence tomography.[15,16] There is a clear need for research to increase the accuracy of diagnostic methods. In addition, diagnostic and therapeutic protocols are being developed to aid in treatment decisions based on clinical indicators of caries activity and caries risk.[7,8] Clearly, there is a need to develop site-specific indicators of future caries risk.[5,6,17]

REMINERALIZATION OF EARLY LESIONS AND REDUCTION OF CARIOGENIC BACTERIA

It now is well-recognized that it is possible to arrest and even reverse the mineral loss associated with caries at an early stage, before cavitation takes place. Enamel and dentin demineralization is not a continuous, irreversible process. Through a series of demineralization and remineralization cycles, the tooth alternately loses and gains calcium and phosphate ions, depending on the microenvironment. When the pH is less than 5.5, subsurface enamel or dentin will demineralize. Fluoride enhances the uptake of calcium and phosphate ions and can form fluoroapatite. Fluorapatite demineralizes at a pH less than 4.5, making it more resistant to demineralization from an acid challenge than hydroxylapatite. In early carious lesions, there is subsurface demineralization of the enamel. As caries progresses into dentin, the surface of the enamel eventually cavitates. Once cavitation occurs, it becomes difficult to control plaque accumulation. In areas of difficult access, the plaque also may hinder the availability of calcium, phosphate and fluoride ions, which in turn may decrease the potential for remineralization. Therefore surgical treatment—caries removal and restoration—is indicated for the cavitated lesion.[5]

In the noncavitated lesion, to take advantage of the tooth's capacity to remineralize, one must first alter the oral environment, to tip the balance in favor of remineralization and away from demineralization. This approach includes

- decreasing the frequency of intake of refined carbohydrates;
- ensuring optimum plaque control;
- ensuring optimum salivary flow;
- conducting patient education.

Agents such as chlorhexidine and topical fluorides then can be applied to encourage remineralization. Chlorhexidine acts by reducing the number of cariogenic bacteria. Topical fluorides increase the availability of fluoride ion for remineralization and the formation of fluoroapatite, with its increased resistance to demineralization.[5]

In the noncavitated lesion, to take advantage of the tooth's capacity to remineralize, one must first alter the oral environment.

MINIMUM SURGICAL INTERVENTION OF CAVITATED LESIONS

When surgical treatment is indicated, it should be minimally invasive. Not all dentists agree as to when surgical treatment is indicated. Some dentists favor restoration of early lesions, especially pits and fissures. Minimally invasive techniques such as air abrasion are used to prepare cavities for restoration with adhesive materials. Other dentists favor deferring surgical treatment until there is evidence of cavitation.[17]

Treatment of lesions confined to the inner one-half of enamel and even slightly into dentin generally is not indicated. This approach is justified on the basis that caries progression through the enamel, even in active lesions, is very slow. This is especially true in patients exposed to fluoride. In fact, in some populations, it takes six to eight years for a lesion to progress through enamel. Pitts and Rimmer[18] showed that the percentage of radiographically reversible lesions in the outer one-half of the dentin that have cavitation in the enamel had dropped to 41 percent. By focusing on infection control rather than surgical intervention, it is estimated that this could lead to a 50 percent reduction in restoration placement.[19,20] Dentists spend approximately 70 percent of their time replacing restorations.[5] In a minimally invasive approach, the surgical management of noncavitated, demineralized teeth should be the last resort, especially in patients who have shifted from a high or moderate caries risk to a low caries risk.[3,5]

Cavitation makes plaque control difficult or impossible. Therefore, we must rely on a surgical approach when there is cavitation. Infected tissue is removed and replaced with a suitable restorative material, keeping in mind that nothing can equal natural tooth structure. In addition to removing diseased tissue and replacing functional anatomy, restoration of cavitated lesions facilitates excellent plaque control.[5]

MATERIALS

Adhesive dental materials make it possible to conserve tooth structure using minimally invasive cavity preparations, because adhesive materials do not require the incorporation of mechanical retention features. There are several materials that can be used: glass ionomer cements, or GICs; resin-based composite/dentin bonding agents; and a layered combination of resin-based composites and GICs applied with a technique called lamination.[4,5,7]

Glass ionomer cements. The advantages of GICs include adhesion to tooth and release of fluoride and other ions. They perform well in low-stress areas. GICs release fluoride, calcium and aluminum ions into the tooth and saliva. Also, set glass ionomer is "rechargeable," meaning it can take up fluoride from the environment, which is provided by exposure to fluoride treatments and toothpaste.[21] Theoretically, this fluoride uptake and slow release can have an anticariogenic effect, though clinical studies have not proven it

TABLE

CARIES CLASSIFICATION SYSTEM BASED ON LESION SITE AND SIZE.*

LOCATION	CLASSIFICATION			
	1 = Minimal	2 = Moderate	3 = Advanced	4 = Extensive
Site 1: Pits and Fissures	1.1	1.2	1.3	1.4
Site 2: Proximal Surfaces	2.1	2.2	2.3	2.4
Site 3: Cervical Surfaces	3.1	3.2	3.3	3.4

* Classification system by Mount and Hume.[19]

to be clinically significant.

GICs' disadvantages include technique sensitivity. The handling properties and brittleness of the material can be overcome by adding resin to the material. The resulting resin-modified glass ionomer cements, or RMGICs, are easier to place, are light-cured, and have improved esthetic qualities. However, the introduction of a resin component has the downside of also introducing polymerization shrinkage. GICs and RMGICs are appropriate for cervical restorations,[22] fissure sealants,[23] proximal lesions in anterior permanent teeth[24,25] and proximal lesions in anterior and posterior primary teeth.[26,27]

Resin-based composite/dentin bonding agents. The effective bonding of resin to enamel is a key factor in the selection of these materials. Cavity preparations designed to conserve maximum enamel can eliminate the need for macromechanical retention. Though etching dentin and enamel and formation of a hybrid layer has improved the quality of the bond and the technology is constantly improving, polymerization shrinkage and marginal leakage continue to be a problem when margins are in dentin.[28] Newer flowable resin-based composites have low viscosity and often are used in smaller, preventive resin-type preparations, as well as in class V cavities.[29]

Cavity preparations designed to conserve maximum enamel can eliminate the need for macromechanical retention.

Lamination. The process of lamination, also called the sandwich technique, takes advantage of the physical properties of both the GIC and the resin-based composite. The GIC is placed first because of its adhesion to dentin and fluoride release. Resin-based composite then is laminated over the GIC for the purpose of improved occlusal wear or esthetics.[4,5,8]

MINIMAL CAVITY DESIGNS

Preservation of natural tooth structure should be the guiding factor for the smallest, as well as the largest, cavity. Cavity preparation design and restorative material selection depend on occlusal load and wear factors.[19] It has been proposed that the G.V. Black classification of cavity designs be replaced by a new classification system advocated by Mount and Hume[19] (Table). Traditional cavity preparations were designed at a time when carious lesions usually were diagnosed at a more advanced state than are the incipient lesions dentists detect today. Preparations also were designed for amalgam rather than for adhesive materials, and instrumentation was limited to slow rotary instruments and hand instruments. Technological improvements in high-speed rotary handpieces, bur design, materials and early detection of lesions allow much more conservative preparation designs than those taught in the past.

Another reason that dentists have modified techniques for preparing and restoring teeth is that a traditional approach to the control of caries inevitably leads to a destructive cycle: excessive tooth reduction for a relatively small lesion, followed by restoration replacement and additional loss of tooth structure. Progressive loss of tooth structure and, in some cases, tooth loss are the result of this irreversible cycle.[30,31]

The rationale behind the cavity classification system proposed by Mount and Hume is that it is only necessary to gain access to the lesions and remove areas that are infected and broken down to the point where remineralization is no longer possible. The new classification system is based

Figure 1. Small carious lesion in an enamel pit on distofacial cusp of tooth no. 14. This type of lesion would be restored using a 1.2 minimal preparation (according to the system proposed by Mount and Hume[19]). Photo courtesy of Dr. Dennis Fasbinder, Ann Arbor, Mich.

Figure 2. Stained occlusal grooves in teeth nos. 12 and 13. These lesions would be classified as 1.1 preparations in the minimal preparation classification system (Mount and Hume[19]). Photo courtesy of Dr. Dennis Fasbinder, Ann Arbor, Mich.

Figure 3. Conservative cavity preparations can be used to restore with either amalgam or composite as in teeth nos. 28 through 31.

Figure 4. Tunnel preparation and resin-based composite were used to restore the lesion on the distal of tooth no. 12. Note the minimal restorations and conservation of tooth structure in tooth no. 14.

on site and cavity size[19] (Table). In this new classification system, a 1.1 cavity would be comparable to a preparation for a preventive resin restoration (Figures 1-3).

The profession gradually is embracing these technological advances and, with them, a minimally invasive approach. However, some dentists still find it difficult to change their mind-sets from "extension for prevention" and are continuing to cut large traditional preparations. This apparent lag in adoption of new clinical practices based on scientific evidence is supported by the recent finding that 72 percent of states allowed a lesion confined to enamel to be restored as part of the requirements for clinical board examinations, despite evidence from research regarding appropriate and effective treatment for these early carious lesions.[32]

MINIMAL INTERVENTION TOOTH PREPARATIONS

Preparations with high-speed handpieces. Some modified designs include tunnel and internal preparations for proximal surface lesions (site 2 in Mount and Hume's[19] system). A high-speed handpiece and small burs are used to prepare the cavity.

The tunnel preparation is performed by accessing the carious dentin from the occlusal surface, while preserving the marginal ridge (Figure 4). Tunnel preparations are technically difficult to do because of access and visibility and

Figure 5. Tooth no. 3 before air abrasion and restoration. Note the deep central occlusal pit. Photo courtesy of Dr. James Hamilton, Ann Arbor, Mich.

Figure 6. Tooth no. 3 after preparation with air abrasion. Note the minimal preparation. Photo courtesy of Dr. James Hamilton, Ann Arbor, Mich.

the small amount of tooth structure removed.[4,5,8]

Internal preparations preserve the marginal ridge and the proximal surface enamel.[4,5,8] A recent study showed that after three years, tunnel preparations had better results than did slot class II restorations. After five years, conventional amalgam class II restorations exhibited better survival rates than tunnel or slot preparations.[5]

Minibox or slot preparations involve the removal of the marginal ridge, but do not include the occlusal pits and fissures if caries removal in these areas is not necessary. These cavities may have either a box or a saucer shape and may be restored with resin-based composite or amalgam.[4,5,8] Clinical studies of these conservative restorations have shown 70 percent survival at an average of seven years.[5]

Preparations with air abrasion. Air abrasion is a technique that uses kinetic energy to remove carious tooth structure. A powerful narrow stream of moving aluminum oxide particles is directed against the surface to be cut. When these particles hit the tooth surface, they abrade it, without heat, vibration or noise. The particles exit at the tip of the handpiece, so it is an end-cutting device. Variables that affect speed of cutting include air pressure, particle size, powder flow, the tip's size, the tip's angle and the tip's distance from the tooth.[33] It has been proposed that air abrasion technology can be used to both diagnose early occlusal-surface lesions and treat them with minimal tooth preparation.[2,34] Some authors advocate the use of magnification with this technique.[2,35] The reported advantages of air abrasion include reduced noise, vibration and sensitivity, though these are subjective and vary among patients. Cavity preparations done with air abrasion have more rounded internal contours than those prepared with a handpiece and straight

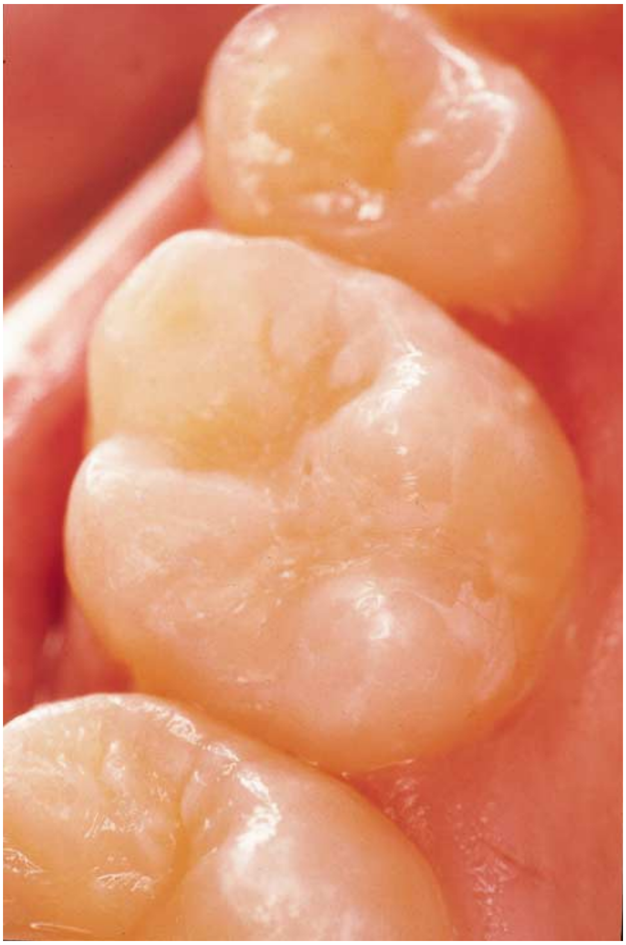

Figure 7. Tooth no. 3 after restoration with composite resin. Photo courtesy of Dr. James Hamilton, Ann Arbor, Mich.

burs. This may increase the longevity of restorations placed because it reduces the incidence of fractures, a consequence of decreased internal stresses as compared with those seen in angular preparations[34-36] (Figures 5-7).

Air abrasion cannot be used for all patients. It should be avoided in cases involving severe dust allergy, asthma, chronic obstructive lung disease, recent extraction or other oral surgery, open wounds, advanced periodontal disease, recent placement of orthodontic appliances and oral abrasions, or subgingival caries removal. Many of these conditions increase the risk of air embolism in the oral soft tissues.[2] Dust control is a challenge, and it necessitates the use of rubber dam and high-volume evacuation.

A randomized controlled clinical study evaluated the efficacy of treating questionable occlusal incipient lesions early, using air abrasion.[34] In the study, investigators randomly assigned 223 teeth with questionable occlusal carious lesions to either a treatment group or a control group. Each tooth in the treatment group was air-abraded and restored with a flowable resin-based composite (Figures 7 and 8). The teeth in both groups were re-examined every six months. After 12 months, two of 113 preventive resin restorations in the treatment group required retreatment. In the control group, only nine of 86 recalled teeth were diagnosed as having caries and were treated. This was fewer than expected. Therefore, the authors concluded that the merit of treating questionable incipient pit and fissure carious lesions had not been demonstrated after 12 months. Long-term studies are in progress, and it remains to be seen whether treating questionable occlusal incipient lesions has any benefit.[34]

Laser cavity preparation. Erbium:yttrium-aluminum garnet lasers and erbium, chromium:yttrium-scandium-gallium-garnet lasers are being used to cut dental hard tissues. These lasers can remove soft caries, as well as hard tissue. Lasers reportedly can allow the dentist to remove caries selectively while maintaining healthy dentin and enamel. They also can be used without anesthetic most of the time. Preparations are similar to those made with air abrasion; adhesive dental materials must be used for restoration. Advantages include no vibration, little noise, no smell and no numbness associated with anesthesia.[36] When dental lasers are used correctly, excessive heat generation and its detrimental effects on dental pulp can be avoided.[33,37,38]

REPAIR VS. REPLACEMENT OF DEFECTIVE RESTORATIONS

It is estimated that worldwide, the replacement of existing restorations accounts for 50 to 71 percent of each general dentist's activities.[5] The replacement of amalgam and resin restorations leads to larger restorations with successively shorter life spans than their predecessors. Reasons for replacing restorations rather than repairing them include several concerns about bond strength to previously placed materials, about residual caries left behind (especially in sites restored by another dentist), and about recurrent caries around the margin of a restoration implying an increased risk of developing caries in other sites, including under existing restorations.

Considering all of these points, plus the fact that caries under well-sealed restorations fails to progress and that caries progresses slowly in

Dr. Murdoch-Kinch is a clinical associate professor, Department of Oral Medicine, Pathology and Oncology, University of Michigan School of Dentistry, 1011 North University Ave., Room 2029, Ann Arbor, Mich. 48109-1078, e-mail "camurdoc@umich.edu". She also is a member of the ADA Council on Scientific Affairs. Address reprint requests to Dr. Murdoch-Kinch.

Dr. McLean is a clinical assistant professor, Department of Cariology, Restorative Sciences and Endodontics, University of Michigan School of Dentistry, Ann Arbor.

most populations, repairing defective restorations rather than replacing them is a valid and more conservative option for treatment. Cavity preparations should ensure independent retention and resistance form for the repair.[5,31] Repair with a GIC may be preferable in cervical areas, because of the potential for fluoride release and GICs' excellent adhesion. The decision to repair rather than replace a restoration always must be based on the patient's risk of developing caries, the professional's judgment of benefits vs. risks and conservative principles of cavity preparation.[5]

DISEASE CONTROL

There is a need to establish clear guidelines on the management of caries as an infectious disease. This component consists of risk assessment and development of a customized treatment plan for the individual patient to include appropriate strategies to modify individual risk. Strategies include bacterial identification and monitoring,[6] diet analysis and modification, use of topical fluorides[39] and use of antimicrobial agents.[40,41] Research is advancing our understanding of oral health disparities and identification of risk factors in members of at-risk populations. Several strategies have potential to reduce caries prevalence in early childhood: increasing access to care, educating patients and their parents and using targeted preventive therapies, including treating the family in hopes of decreasing transmission of virulent *Streptococcus mutans* and other bacterial species from caregiver to child.[42,43] Emerging technologies in this area include caries vaccines[44,45] and bacterial replacement therapy which has been studied in rodents to date.[46] In bacterial replacement therapy, gene manipulation yields a strain of *S. mutans* unable to produce lactic acid through fermentation of carbohydrates. This bacterial strain, JH1140, has been shown to effectively colonize teeth, displace wild-type *S. mutans* and produce less acid and fewer carious lesions than wild-type *S. mutans*. It could be used to prevent dental caries by replacing wild-type *S. mutans* in humans with high caries risk.[46]

THE ISSUE OF REIMBURSEMENT

Reimbursement is another key issue that should be addressed if the profession is to fully embrace the new paradigm of minimally invasive dentistry. Currently, the dentist is paid only if he or she does something; this may create a conflict in the situation where doing nothing is appropriate. The cost-benefit ratio of a minimally invasive approach needs to be analyzed and presented to the public and third-party payers. Reimbursement programs will need to change to encourage practitioners to treat appropriately. The benefits not only will improve the oral health of the public but also will reduce health care costs in the long run and provide satisfaction for dentists, who will know that they have done their best to preserve patients' natural tooth structure.

CONCLUSION

With the development of new dental restorative materials and advances in adhesive dentistry, a better understanding of the caries process and the tooth's potential for remineralization and changes in caries prevalence and progression, the management of dental caries has evolved from G.V. Black's "extension for prevention" to "minimally invasive." This concept includes early detection of lesions; individual caries risk assessment; nonsurgical interventions; and a modified surgical approach that includes delayed restoration, smaller tooth preparations with modified cavity designs and adhesive dental materials and repair rather than replacement of failing restorations. The goal is preservation of natural tooth structure.

Minimally invasive dentistry is based on a large body of scientific evidence that has been summarized and discussed. The future promises further evolution toward a more primary preventive approach, facilitated by emerging technologies for diagnosis, prevention and treatment. However, there are technical, cultural and economic obstacles that must be overcome for this to be fully realized in clinical practice. ■

Although the Practical Science feature is developed in cooperation with the ADA Council on Scientific Affairs and the Division of Science, the opinions expressed in this article are those of the author and do not necessarily reflect the views and positions of the Council, the Division or the Association.

1. Markley M. Restorations of silver amalgam. JADA 1951:43(2): 133-46.

2. Rainey JT. Air abrasion: an emerging standard of care in conservative operative dentistry. Dent Clin North Am 2002;46(2):185-209.
3. Peters MC, McLean ME. Minimally invasive operative care, I: minimal intervention and concepts of minimally invasive cavity preparations. J Adhes Dent 2001:3(1):7-16.
4. Peters MC, McLean ME. Minimally invasive operative care, II: contemporary techniques and materials—an overview. J Adhes Dent 2001;3(1):17-31.
5. Tyas MJ, Anusavice KJ, Frencken JE, Mount GJ. Minimal intervention dentistry: a review. FDI Commission Project 1-97. Int Dent J 2000;50(1):1-12.
6. Murdoch-Kinch CA. Oral medicine: advances in diagnostic procedures. J Calif Dent Assoc 1999;27(10):773-80, 782-4.
7. Benn DK, Clark TD, Dankel DD 2nd, Kostewicz SH. Practical approach to evidence-based management of caries. J Am Coll Dent 1999;66(1):27-35.
8. Summitt JB. Conservative cavity preparations. Dent Clin North Am 2002;46(2):171-84.
9. Tam LE, McComb D. Diagnosis of occlusal caries, Part II: recent diagnostic technologies. J Can Dent Assoc 2001;67(8):459-63.
10. Ando M, van Der Veen MH, Schemehorn BR, Stookey GK. Comparative study to quantify demineralized enamel in deciduous and permanent teeth using laser-and light-induced fluorescence techniques. Caries Res 2001;35:464-70.
11. Sheehy EC, Brailsford SR, Kidd EA, Beighton D, Zoitopoulos L. Comparison between visual examination and a laser fluorescence system for in vivo diagnosis of occlusal caries. Caries Res 2001;35: 421-6.
12. Nair MK, Tyndall DA, Ludlow JB, May K. Tuned aperture computed tomography and detection of recurrent caries. Caries Res 1998;32(1):23-30.
13. Abreu M Jr., Tyndall DA, Platin E, Ludlow JB, Phillips C. Two- and three-dimensional imaging modalities for the detection of caries: a comparison between film, digital radiography and tuned aperture computed tomography (TACT). Dentomaxillofac Radiol 1999;28(3):152-7.
14. Shi XQ, Han P, Welander U, Angmar-Mansson B. Tuned-aperture computed tomography for detection of occlusal caries. Dentomaxillofac Radiol 2001;30(1):45-9.
15. Otis LL, Everett MJ, Sathyam US, Colston BW Jr. Optical coherence tomography: a new imaging technology for dentistry. JADA 2000;131:511-4.
16. Colston BW Jr, Everett MJ, Sathyam US, DaSilva LB, Otis LL. Imaging of the oral cavity using optical coherence tomography. Monogr Oral Sci 2000;17:32-55.
17. Pitts NB. Risk assessment and caries prediction. J Dent Educ 1998;62(10):762-70.
18. Pitts NB, Rimmer PA. An in vivo comparison of radiographic and directly assessed clinical caries status of posterior approximal surfaces in primary and permanent teeth. Caries Res 1992;26:146-52.
19. Mount GJ, Hume WR. A revised classification of carious lesions by site and size. Quintessence Int 1997;28:301-3.
20. Benn DK, Meltzer MI. Will modern caries management reduce restorations in dental practice? J Am Coll Dent 1996;63(3):39-44.
21. Rothwell M, Anstice HM, Pearson GJ. The uptake and release of fluoride by ion-leaching cements after exposure to toothpaste. J Dent 1998;26(7):591-7.
22. Abdalla AI, Alhadainy HA, Garcia-Godoy F. Clinical evaluation of glass ionomers and compomers in Class V carious lesions. Am J Dent 1997:10(1):18-20.
23. Pereira AC, Pardi V, Basting RT, et al. Clinical evaluation of glass ionomers used as fissure sealants: 24-month results. ASDC J Dent Child 2001:68(3):168-74, 150.
24. de Araujo MA, de Araujo RM, Marsilio AL. A retrospective look at esthetic resin composite and glass-ionomer class III restorations: a 2-year clinical evaluation. Quintessence Int 1998;29(2):87-93.
25. van Dijken JW. Longevity of new hybrid restorative materials in class III cavities. Eur J Oral Sci 1999;107(3):215-9.
26. Jang KT, García-Godoy F, Donly KJ, Segura A. Remineralizing effects of glass ionomer restorations on adjacent interproximal caries. ASDC J Dent Child 2001;68(2):125-8, 142.
27. Croll TP, Bar-Zion Y, Segura A, Donly KJ. Clinical performance of resin-modified glass ionomer cement restorations in primary teeth: a retrospective evaluation. JADA 2001;132(8):1110-6.
28. Toledano M, Perdigao J, Osorio R, Osorio E. Effect of dentin deproteinization on microleakage of Class V composite restorations. Oper Dent 2000;25(6):497-504.
29. Manhart J, Chen HY, Mehl A, Weber K, Hickel R. Marginal quality and microleakage of adhesive class V restorations. J Dent 2001;29(2):123-30.
30. Wendt LK, Koch G, Birkhed D. Replacements of restorations in the primary and young permanent dentition. Swed Dent J 1998; 22(4):149-55.
31. Roberts HW, Charlton DG, Murchison DF. Repair of non-carious amalgam margin defects. Oper Dent 2001;26:273-6.
32. Anusavice KJ, Benn DK. Is it time to change state and regional dental licensure board exams in response to evidence from caries research? Crit Rev Oral Biol Med 2001;12(5):368-72.
33. Reyto R. Lasers and air abrasion. New modalities for tooth preparation. Dent Clin North Am 2001;45(1):189-206.
34. Hamilton JC, Dennison JB, Stoffers KW, Welch KB. A clinical evaluation of air-abrasion treatment of questionable carious lesions: a 12-month report. JADA 2001;132:762-9.
35. Friedman MJ, Mora AF, Schmidt R. Microscope-assisted precision dentistry. Compendium 1999;20(8):723-37.
36. Hicks MJ, Parkins FM, Flaitz CM. Kinetic cavity preparation effects on secondary caries formation around resin restorations: a polarized light microscopic in vitro evaluation. ASDC J Dent Child 2001;68(2):115-21, 80, 142.
37. Dostolova T, Jelinkova H, Krejsa O, et al. Dentin and pulp response to Erbium:YAG laser ablation: a preliminary evaluation of human teeth. J Clin Laser Med Surg 1997;15(3):117-21.
38. Glockner K, Rumpler J, Ebeleseder K, Stadtler P. Intrapulpal temperature during preparation with Er:YAG laser compared to the conventional burr: an in vitro study. J Clin Laser Med Surg 1998;16(3):153-7.
39. Marinho VC, Higgins JP, Logan S, Sheiham A. Fluoride gels for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2002;(2):CD002280.
40. Joharji RM, Adenubi JO. Prevention of pit and fissure caries using an antimicrobial varnish: 9 month clinical evaluation. J Dent 2001;29(4):247-54.
41. Alaki SM, Loesche WJ, da Fonesca MA, Feigal RJ, Welch K. Preventing the transfer of *Streptococcus mutans* from primary molars to permanent first molars using chlorhexidine. Pediatr Dent 2002;24(2): 103-8.
42. Skaret E, Milgrom P, Raadal M, Grembowski D. Factors influencing whether low-income mothers have a usual source of dental care. ASDC J Dent Child 2001;68(2):136-9, 142.
43. Mouradian WE. Ethical principles and the delivery of children's oral health care. Ambul Pediatr 2002;2(2 supplement):162-8.
44. Fontana M, Dunipace AJ, Stookey GK, Gregory RL. Intranasal immunization against dental caries with a *Streptococcus mutans*-enriched fimbrial preparation. Clin Diagn Lab Immunol 1999;6(3):405-9.
45. Michalek SM, Katz J, Childers NK. A vaccine against dental caries: an overview. BioDrugs 2001;15(8):501-8.
46. Hillman JD, Brooks TA, Michalek SM, Harmon CC, Snoep JL, van Der Wejden CC. Construction and characterization of an effector strain of *Streptococcus mutans* for replacement therapy of dental caries. Infect Immun 2000;68(2):543-9.