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Air abrasion: an emerging standard of care in conservative operative dentistry

J. Tim Rainey, DDS*

Texas Institute for Advanced Dental Studies, Box 173, 606 Osage Street, Refugio, TX 78377, USA

Microdentistry versus macrodentistry

Macrodentistry is the dentistry that we, as dentists, have been trained to practice. The basic concepts and techniques of macrodentistry, which were developed when electricity in dental offices was the rare exception rather than the norm, have been practiced virtually unaltered for more than a century.

In the past few years, the emerging techniques of operative dentistry dedicated to minimal invasion and minimal sacrifice of sound tooth structure have been explored and documented [1], and they have become part of mainstream dentistry. As new techniques emerge and are adapted into dental disciplines, the usual intent and purpose of the original technology often change in the course of adaptation. Microdentistry, the dental science of diagnosing, intercepting, and treating dental decay on the microscopic level, is now emerging as an operative tool in science-based microdentistry. Air abrasion is an old dental technology that is finding a new place in modern, science-based dentistry. Air abrasion has been redefined from the original applications of the 1950s [2], when dental education was dedicated to preserving the dogma and theories of operative techniques focusing on extension for prevention [3], and it is likewise being again redefined as micro air abrasion when applied on the microscopic level.

In the late 1940s and early 1950s, Dr. Robert B. Black [4] developed air-abrasion instruments and techniques applicable to the dental philosophy of his time. Black investigated methods of tooth preparation that would eliminate the trauma and discomfort associated with rotary instruments [5]. His works and investigations resulted in the original air-abrasion unit, the

* Corresponding author.
E-mail address: jtimrainey@tiads.com (J.T. Rainey).

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S.S. White AirDent unit (SSWhite, Lakewood, NJ). Building on Black's knowledge and experience, dentistry has begun a paradigm shift from the old G.V. Black principles of extension for prevention [6] formulated at the turn of the century, to ultraconservative techniques of preservation of tooth structure available through the emerging new discipline of microdentistry.

Compared with principles of traditional operative dentistry formulated at the end of the 19th century [7], the principles of microdentistry are amazingly simple. Whereas the adjuncts of traditional operative dentistry as currently taught are centered on diagnosing and treating decay in the late stages [8], the adjuncts of microdentistry are centered on early diagnosis and intervention. Traditionally, dentists are taught how to cut healthy tooth structure, in effect amputating sound tooth structure around a diagnosed carious lesion for access, removal, and prevention of caries, principles that have been strongly questioned for decades [9]. The role of air abrasion in microdentistry is not to amputate sound tooth structure but to preserve as much as possible of the structural integrity of the sound tooth structure remaining around a lesion.

The physics of a microabrasive air stream and rotary instrumentation represent two entirely different forms of energy and have entirely different results. Rotary instrumentation is a form of mechanical energy. Air abrasion is a form of kinetic energy. Rotary instrumentation functions to remove tooth structure indiscriminately, primarily by lateral application of force. Air abrasion tends to operate linearly, but air abrasion also can follow unsound tooth structure, turning at more than 90° angles as carious lesions are encountered and deflecting the abrasive air stream toward hypocalcific structures.

Learning to use air abrasion

There are three essential tools the microdentist relies on when using micro air abrasion: first, the dentist must have good magnification to diagnose, to see, and to perform microdentistry accurately. The next tool of the microdentist is caries-detection dye, which is used to follow the progress of the caries-removal process. Third, the dentist must have an air-abrasion unit that is reasonably adjustable and responsive.

After assembling the proper tools of air abrasion, there are several methods the dentist can use to become familiar with the effects of the physics of air abrasion before beginning to use air abrasion in the mouth. The simple exercise of cutting a disposable, rear-surface mirror helps the dentist prove to him- or herself that air abrasion will cut and helps the dentist become familiar with the effects of air abrasion.

The unit performs a cutting action by impinging sharp-edged powder particles against a surface. A cylindrical powder/air stream converges from the nozzle for a short distance (approximately 0.5–1.6 mm) and then diverges into a cone shape. The point of maximum convergence provides the maximum effect. The dentist should hold the air-abrasion tip approximately 1 mm perpendicular from the glass surface of a disposable, rear-surface mirror. With a medium adjustment of powder delivery and air pressure, one can depress the pedal to activate the abrasive stream.

There will be a slight hesitation in effect, because the cutting dynamics must first cavitate the surface of the mirror. The practitioner should hold the tip completely steady and continue the cut. As the cut in the mirror progresses, the cavitation will appear as a double cone: the cut on the surface will be reflected by the rear surface of the mirror. As the cut progresses, the two cones will grow in size and converge. When they finally converge, there will be a single cone-shaped hole through the glass of the mirror. One should make several of these cone-shaped cuts.

Next, attempt to cut a circle in the mirror. Initiate a cut, and then slowly draw a circle. Notice that it is impossible to cut a uniform trench. There will be a series of valleys and hills as the cutting dynamics follow the path of least resistance (cutting a cone) then jump over the edge of the cone and initiate another cone-shaped depression. Next, experiment with different nozzles, flow rates, and pressures. Small holes and cuts with straight walls are made with the nozzle at close distances. As the nozzle moves vertically away from the work, the hole diameter or width of cut increases, with the walls becoming cone shaped. The best distance and angle for various cuts can be determined with a few practice trials. To obtain sharp definition (as in precise cutting), the nozzle-tip distance should be kept to a minimum of 0.8 mm, and one should use the smallest-diameter, 0.011-inch (0.28-mm) nozzle.

After observing and mastering the use of air abrasion to cut the hard mirror surface, which is similar to smooth surface enamel in cutting characteristics, the dentist is now ready to begin to understand the anatomy of teeth before moving on to operating on extracted teeth.

Comprehending the difference between rotary instrumentation and micro air abrasion merely requires basic, elementary application of high school-level physics. The damage to the tooth done by a surgical carbide bur is completely indiscriminate, depending on the guidance of the operator. The mechanical energy of a rotary bur indiscriminately destroys anything it touches while it microfractures the surrounding enamel [10], something that cannot be done with the aluminum oxide commonly used with micro air abrasion. Traditionally, dentists have "cut teeth" with the best tool invented to do so, the high-speed drill. This is a key paradigm shift, moving beyond the concept of cutting teeth. Some aspects of technique in air abrasion are counterintuitive to those learned with the high-speed drill. The purpose of rotary instrumentation is to destroy anything the bur touches, which includes indiscriminate destruction of sound tooth structure, causing pain and requiring needle injections of anesthesia. Conversely, the use of air abrasion as a cutting instrument is discouraged.

In minimizing the invasiveness of procedures and promoting early microscopic detection of decay, the focus is on the conservation of tooth structure, which is of value to the patient. The purpose of microabrasion in microdentistry is to remove unsound tooth structure, maintaining the natural structural integrity of the tooth. The goal of micro air abrasion is to allow the dentist to remove unsound tooth structure discriminately. Kinetic energy, applied in the form of micro air abrasion, follows the path of least resistance, seeking out unsound tooth structure and exposing the underlying decay. Micro air abrasion is the microdentist's choice in maximizing tooth structure conservation.

The science and anatomy

As an adjunct to microdentistry, air abrasion is now supported in the literature [11] as an accepted alternative to traditional rotary instrumentation [12]. The basic principle of microdentistry is to identify the decay [13] on the microscopic level and then remove only the decay and the unsound tooth structure.

By isolating and removing the decayed tooth structure while leaving the healthy tooth structure intact, the pain and discomfort associated with the traditional use of the needle and drill can indeed be avoided [14]. Because micro air abrasion allows the dentist to preserve healthy tooth structure while avoiding impingement on vital tooth structure, most early-intervention procedures can be performed without anesthesia [15–17]. In fact, the use of anesthesia is rare enough that the routine use of anesthesia in micro air abrasion would be outside the standard of care.

In many studies, the two things most disliked about dentistry are the use of the needle [18] and drill [19]. The new technology and associated new techniques of air abrasion often eliminate the need for the high-speed drill and local anesthesia [20]. Using an airjet delivering microabrasives to a focal point smaller than the usual drill to conservatively remove tooth structure and decay, air abrasion eliminates objectional heat, sound, and vibrations associated with high-speed instrumentation. An additional benefit is the elimination of the recognized side effect of microfracture and microcrazing of the enamel margins [21] and enamel in general initiated by the high-speed turbine [22]. It is also not necessary to destroy important structural components when using microabrasion-assisted microbonding techniques.

For the dentist to implement microdentistry, it is first necessary to understand the anatomy and structures of the teeth. Because most traditional operative dentistry concerns the repair of posterior teeth, understanding these anatomic structures of the posterior teeth allows the dentist to further refine the skills and techniques necessary for the successful implementation of microdentistry into practice.

Anatomy

The subocclusal oblique transverse ridge of the mandibular molars

The use of air abrasion in microdentistry techniques has led to the identification of a previously unreported structure in mandibular molars [23], best described as a subocclusal oblique transverse ridge. This structure, dubbed the "Rainey Ridge" after its discoverer, is part of an occlusal web of enamel that is also apparent in the maxillary molars [24].

A salient feature of the ridge, because it underlies the anatomic landmark commonly referred to as the central "fossa," is its interconnection of the distolingual cusp and the mesiobuccal cusp. This finding is contrary to conventional academic teachings on tooth anatomy, which commonly refer to the central fossa area as the "central pit." It has been shown that the so-called central pit area is actually an area of intact enamel [25] that is a slight rise rather than a "fossa."

The subocclusal oblique transverse ridge (Fig. 1) is part of a coronal web of interconnected enamel that is defined and separated by fissures. When maintained intact, the web system contributes to the structural integrity of posterior teeth [26].

The identification of the Rainey Ridge calls into question certain assumptions about dental anatomy that have been passed on without adequate scrutiny. There is increasing evidence that the structural design of cavity preparations has been based on a misunderstanding of tooth anatomy.

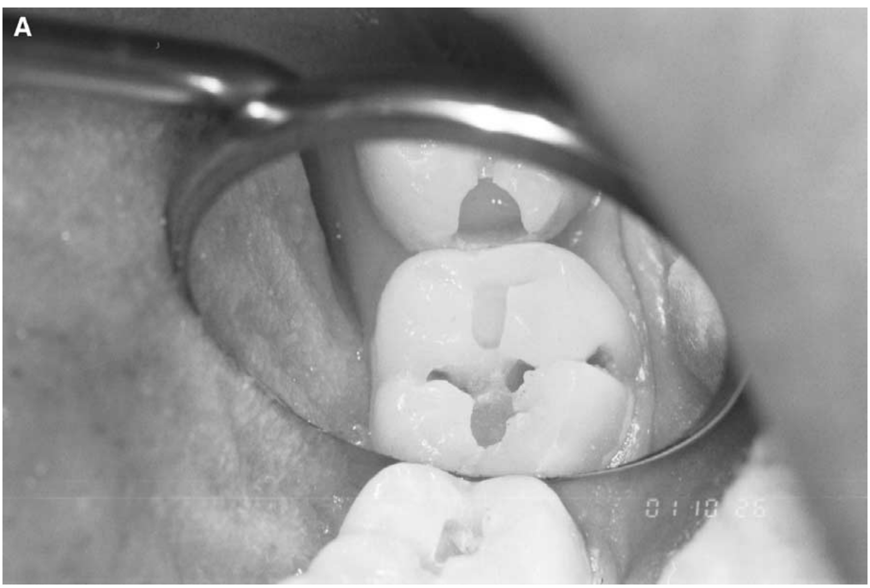

Fig. 1. The sub-occlusal oblique transverse ridge of the mandibular second molar.

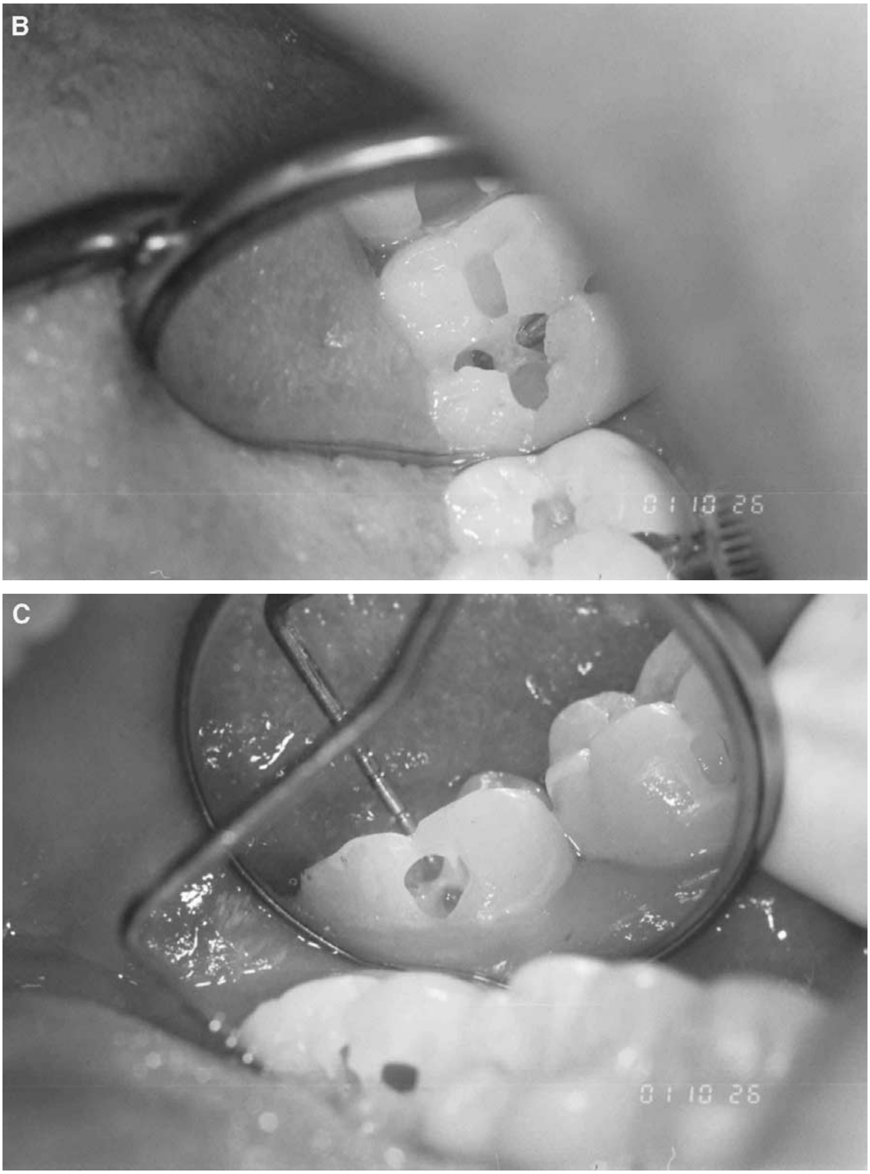

Fig. 1 (*continued*)

Dentistry's understanding of tooth anatomy has been based on unsound assumptions which, in turn, were based on outdated and incorrect macroscopic techniques, principles, and drawings handed down from previous centuries. The current accepted standards of operative procedures and cavity designs are based on these antiquated assumptions and are simply and unquestionably wrong. Dentistry has likewise presented a simplistic model of the microscopic characteristics of fissure anatomy that is also wrong (Figs. 2 and 3). It is now recognized that fissures in teeth are complex structures, with areas of subsurface restrictions, hypocalcification, and restrictions within the fissure that can effectively hide areas of subsurface hypocalcification that may be the genesis of decay.

Air abrasion has an unparalleled ability to expose and allow the exploration of the hypocalcified internal characteristic of occlusal fissures. Unsound fissures are the focal point of the genesis of new decay. The highly selective, discriminate elimination of the hypocalcification and early caries of the pit, fissure, and groove system of the upper and lower molars by air abrasion allows for the easy removal of unsound tooth structure and the subsequent identification and preservation of sound tooth structure.

The presence of the ridge is important when preparing teeth for ultraconservative dentistry. These structures explain the greater resistance to fracture of teeth without prepared cavities [27]. Cavity preparation design therefore should be based on the anatomy of the occlusal surface with the optimal conservative approach.

Air abrasion eliminates the needless destruction of sound tooth structure associated with traditional restorative techniques while leaving the tooth ideally conditioned [28] for the beneficial caries-inhibiting and strengthening

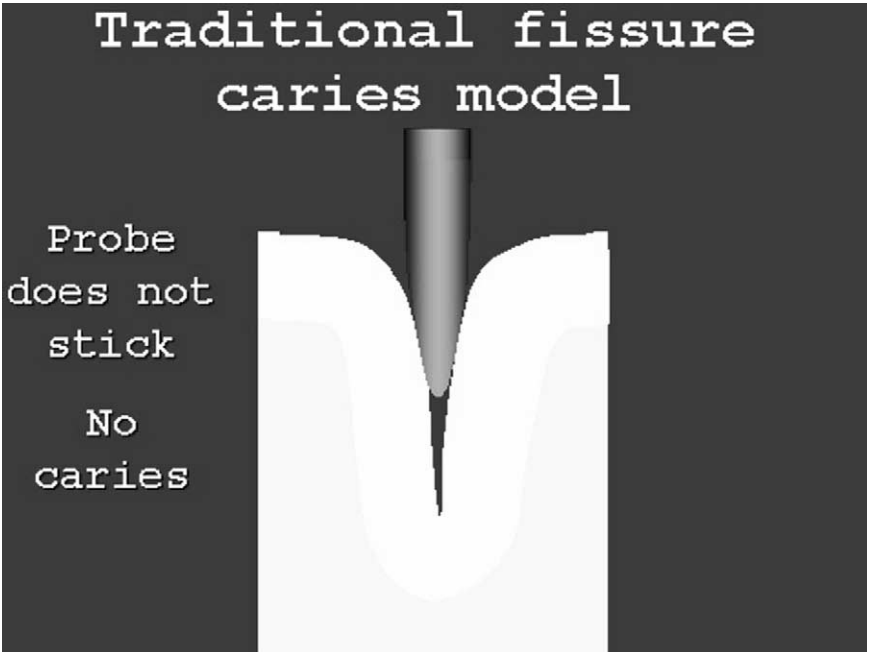

Fig. 2. Old fissure model.

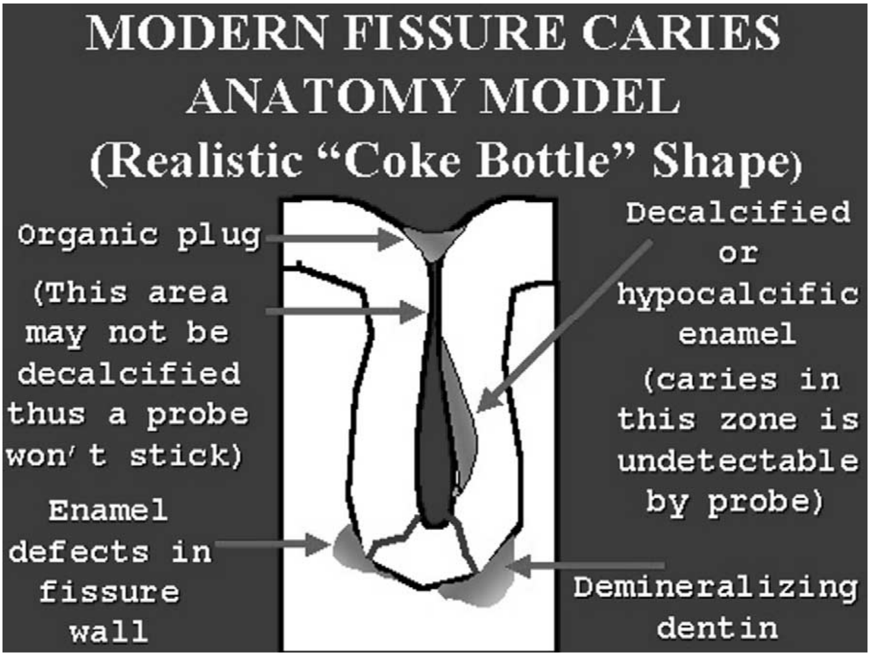

Fig. 3. Fissure anatomy model.

properties of bonded restorations, with the added benefit that anesthetic is often unnecessary.

Diagnosis

Decay

Early and accurate diagnosis of decay is a basic principle of microdentistry. Decay begins on the microscopic level; therefore, any effective treatment planning must address decay on this level. The decay process must be understood first before the student can proceed.

In no other area of medicine does the practitioner wait for visual verification of a disease process before intervening. To wait means ignoring the technological and scientific advances of the 20th century, and, more importantly for the patient, it means the irreversible loss of tooth structure.

The emphasis in modern medicine is now predominately preventive. Our physician colleagues do not hesitate to vaccinate or alter the patient's potential susceptibility to disease. Would it be improper *not* to vaccinate a child against typhoid fever? Then why do we wait for undeniable visual or tactile evidence of tooth structure loss before intervening in the disease process of caries and the resultant cavitation? In dentistry the standard of care has always been "wait and see." To wait and then see predictable and interceptable destruction of healthy tooth structure means that the structural integrity of the tooth may have been compromised by the subsequent restorative processes [29]. All of the tools needed for early intervention and repair are easily and readily available—caries-detection dyes, magnification, and micro air abrasion.

Since the advent of "modern dentistry" more than 100 years ago, the pattern of dental decay in the West has shown an overall decline in the incidence of visually discernible caries [30], leading to dilemmas in diagnosis [31] owing to demographic factors such as diet, hygiene, overall health and longevity, and the introduction of antibiotics and fluoridation. Ominously, Canadian studies recently have detected an upward trend in caries for the first time in recorded Canadian history [32]. These changing patterns have encouraged researchers to reevaluate traditional models of decay [33]. Visual detection, probing, and radiographs [34] have been discounted as inaccurate methods of decay detection.

Decay begins on the microscopic level. The naked eye can only diagnose lesions that have already reached the macro level, at which point a significant amount of tooth structure has been destroyed unnecessarily. G.V. Black, in his later years, recognized the difficulty of accurately diagnosing decay and advocated early intervention: "A sharp explorer should be used with some pressure and if a very slight pull is required to remove it, the pit should be marked for restoration even if there are no signs of decay" [35].

The case for caries-detecting dye

Caries-detecting dye (CARIES DETECT DYE) is an essential component of microdentistry, both in the diagnostic and the operative phase. Used in conjunction with magnification, caries-detecting dye enhances the dentist's ability to diagnose unsound tooth structure and caries [36] on the microscopic level, often permitting preventive, minimally invasive restorations rather than destructive full-scale macro fillings.

Current caries-detecting dye is organic and nontoxic. There are several approved dyes on the market. By staining the infected, irreversibly denatured, unremineralizable dentin, caries-detecting dye is an effective aid to early diagnosis. The diagnosing ability of dye can conserve healthy tooth structure by keeping preparations to a minimal size. Only stained material needs to be removed, and the use of dye ensures that the preparation is caries free before restoring the tooth.

Early caries is characterized by a disruption of the tooth structure in the form of increased hypomineralization. These often microscopic disruptions are demonstrated clearly by increased dye absorption through decalcified tooth structure, beginning with the enamel.

Caries-detection dye is more than just a diagnostic tool; it is also an operative guide, because the staining indicates the pathway of carious lesions.

It is used before, during, and after any operative procedure. Cavity preparation can now be limited to affected tooth structure; sound dentin and enamel do not need to be removed. By concentrating on unsound tooth structure, pain associated with operative procedures involving vital dentin is minimized.

Laser caries diagnosis

The introduction of laser caries diagnosis with DIAGNOdent (Kavo America, Lake Zurich, IL) has finally given the profession a means of quantifying caries. Laser diagnosis is effective for pit-and-fissure caries [37] as well as smooth surface caries and for examining restoration and crown margins.

A 680-mn diode laser is used. The laser is directed into the fissures through a fiberoptic tip that has a central optic bundle to transmit the light and an outer peripheral fiberoptic ring to return the reflected light to the unit. Sound tooth structure causes no change in the frequency of the reflected laser light. Changes that occur in enamel and dentin as a result of caries cause a change in the reflected laser light. The changes are quantified by the unit to provide both a digital read-out of peak and instantaneous values and an audible alarm. Several studies have given consistent results for diagnosing occlusal caries in excess of 90% [38]. Compared with the conventional diagnostic model of mirror, probe, and X-rays, which achieves accuracy as low as 25% for early pit-and-fissure caries, dentistry now has a tool that is complementary to the concepts of microdentistry. Many of the fissures that produce high readings are unstained and contain no obvious plaque or organic plug. These fissures can be immediately charted for restoration. The fissures that contain organic plugs or debris giving a high reading can be specifically cleaned with sodium bicarbonate prophylaxis, then reassessed with the DIAGNOdent that has been calibrated to the specific tooth.

The sodium bicarbonate prophylaxis is also considered a key tool in the air-abrasive microdentistry armamentarium. It prepares the tooth for the successful application of caries-detecting dye and allows easy diagnosis.

The first studies on diagnosing decay with caries-detection dye were performed on extracted teeth, as are most studies involving human teeth. The oral cavity is a constantly changing environment. In real life, if the patient consumes a meal or snack heavily laden with dietary oils, a pathogenic fissure may be obscured by the sealing effect of the dietary oil, giving a false-negative reading when using caries-detection dye.

The powerful scouring action of the pressurized water and sodium bicarbonate solution effectively removes from the tooth surface soft plaque and oils and loose organic plugs from the pit-and-fissure system of the posterior teeth. Removing superficial debris and oil allows the dentist to diagnose more accurately.

Micro air abrasion works by delivering a stream of microscopic aluminum oxide abrasives through a tiny nozzle under air pressure. (The standard 27-μm abrasive is three-fourths the size of a human hair.) The cutting speed is comparable to that of rotary instruments, but the heat, pressure, vibration, and noise are eliminated, making most preparations possible without the use of an anesthetic (Tables 1 and 2).

The case for ultraconservative preparations

The unique advantage of air abrasion is its ability to produce extremely conservative preparations. The less one does to a tooth, the more likely it is that the tooth and restoration will last a lifetime. Moreover, smaller restorations tend to last longer. G.V. Black (rather than R.B. Black, the father of

Table 1
Comparing micro air abrasion to the high-speed drill

High-speed drill	Micro air abrasion
Rotary bur known to cause microfractures	No known potential for microfractures
Potential for indiscriminate destruction of tooth structure	Increased accuracy in the hands of an experienced practitioner; efficient, conservative removal of affected tooth structure only
The dentist is forced to destroy sound tooth structure to accommodate the size and shape of the rotary dental bur	Extremely small preparations are possible
Heat, vibration, bone-conducted noise all contribute to patient discomfort	Heatless, vibrationless, minimal sound; patient apprehension greatly diminished
Pain generated usually requires anesthetic	Anesthetic rarely needed
Pinpoint production of static electricity	Static electricity is dissipated over a large surface area

Table 2
Value of the air-abrasive microdentistry system

	Benefits to			
Advantages	Dentist	Practice	Staff	Patients
Reduced need for anesthetic (no needles)	✓	✓	✓	✓
Reduced patient apprehension	✓	✓	✓	✓
Rapid cutting (efficient, effective)	✓	✓		✓
Precise (controlled cutting, pinpoint accuracy)	✓	✓		✓
Less heat, noise, and vibration	✓	✓	✓	✓
Better bonds (increased bond strength to all materials)	✓	✓	✓	✓
Can work in all four quadrants within the same appointment, increasing office efficiency	✓	✓	✓	✓
Minimally invasive access conserves and preserves sound tooth structure	✓	✓		✓

air abrasion), being the first to propose an organized, logical approach to dental treatment, has been credited as the father of modern dentistry [6]. First outlined in 1891, his approach of "extension for prevention," advocating the removal of tooth structure to accommodate filling material, is still being taught today in most dental institutions as the "current standard of care."

Based on what might have been sound judgment for the late 1800s, the extension-for-prevention approach has not assimilated the immense scientific and demographic changes that have occurred during the past century of dental practice and has been questioned repeatedly in the literature [39]. Studies have shown conclusively that the amount of tooth structure removed during initial operative procedures bears an inverse correlation to the longevity of the resulting restoration and the strength of the remaining tooth structure. The less tooth removed during initial procedures, the longer the life span of the resulting restoration.

Air abrasion presents a scientific, repeatable method of diagnosis and a compatible treatment modality. Combined with microabrasion techniques, treatment planning results in minimum destruction of sound tooth structure. The combination of caries-detection dye as an initial diagnostic aid and microabrasion techniques can and does conserve enormous amounts of tooth structure compared with conventional operative techniques (Table 3).

It has long been recognized that trauma from the high-speed drill and thermal expansion of amalgam fillings result in tooth fractures. Studies have shown conclusively that all prepared teeth are more susceptible to fracture than unprepared teeth. The most influential factor in reducing tooth strength was found to be the width of the occlusal portion of the preparation. Also, it has been shown that the repair-replacement-repair cycle leads to larger restorations that may necessitate crowns or crowns and endodontic treatment [40]. Tooth fracture, often attributed to aging, is the result of overextended cavity designs. Long-term amalgam restorations result in multiple enamel fractures and cusp failures [41].

Studies also show that the use of the high-speed drill can cause microfractures in the cavity wall. When teeth prepared with high-speed rotary instruments are viewed under scanning electron microscopes, cavity walls exhibit

Table 3
Comaprison between conventional "extension for prevention" dentistry and microdentistry

Extension for prevention	Microdentistry
Rotary drill	Air abrasion
Deep, angular cavity preparation designed to retain filling material	Remove only affected tooth material
Amalgam fillings	Adhesive-bonded restorations
Rudimentary understanding of tooth structure	New recognition of key anatomic structural features of teeth

areas of cracks, crazes, and microchips. In contrast, teeth prepared with micro air abrasion consistently reveal no such pattern.

Preparations achieved with air abrasion exhibit uniform roughness of enamel without the sharp internal line angles characteristic of drill preparations. A preponderance of evidence suggests that air-abrasion technology has the potential to prepare both dentin and enamel bonding surfaces to provide a superior bond strength to other materials.

Bonded restorations

When air-abrasion technology was first introduced 40 years ago, restoration was still based on mechanical principles of retention of filling material. Today, there are many adhesive restorative materials available that complement a conservative approach to cavity preparation. The materials used in microrestorative procedures should have adhesive properties compatible with enamel or dentin, or when bonding to both, an optimal compromise.

The adhesive restorative materials of choice include the following:

Glass ionomers
- Autocures
- Light cures (resin-modified light cured glass ionomers)

Compomers

Composites
- Flowables
- Flowable/stackables
- Stackables
- Anterior microfills
- Posterior microfills or hybrid
- Condensables (nonshrinkables)

All of these materials are inherently compatible and can be used in different combinations; treatment options can be auto, dual, or light cured. Each material has a wide, overlapping range of use. The aspiring microdentist must acquaint him- or herself with these materials.

Air-abrasive tools, techniques, and procedures

Considerations for using air-abrasive technology in tooth preparation

Refinement and mastery of the beginning and advanced techniques of air abrasion in human tooth structure take time, practice, and further learning. The principles for working in vitro are identical to those when working in vivo. Begin by experimentation with extracted teeth. Start your learning curve by experimenting with numerous extracted teeth. The early learning curve is best mastered by using caries-detection dye and extracted teeth that have few, if any, visible occlusal carious defects.

A setting of 80 psi or less with 27-μm particle size and a 0.014-inch tip is comfortable and adequate for starting most procedures.

1. Clean the surface of the extracted tooth and place caries-detection dye. Any areas that have been penetrated by the caries-detection dye will be explored.
2. Place the nozzle at a right angle *and no more than 1 mm* to the surface to be treated. Practice tracing out the path of the grooves, pits, and fissures that will be followed with the kinetic air stream. *Do not move back and forth at random*. Progress methodically from one end of the tooth to the other.
3. Start with a 3-second burst at 80 psi designed to trace out the grooves, pits, and fissures of the occlusal surface of any molar. The burst should be interrupted over areas of sound enamel, such as the isthmus separating the mesial and distal pits of mandibular molars and the oblique ridges of maxillary molars. Do *not* attempt to remove sound tooth structure or connect fissures through sound tooth structure. To do so weakens the structural integrity of the tooth, takes up valuable time, and totally defeats the purpose of microdentistry.
4. Observe and diagnose the cleaned pit and fissures for any remaining decay or missed pits and fissures. Use short, controlled bursts to remove the last signs of any stain in the fissures. Note any exposed dentin.
5. Observe and diagnose again for decay into the dentin. If no decay is present, the tooth is ready to be restored.
6. Continue with a setting of 80 psi or lower and 27-μm particle size for dentin/decay removal if decay is present. As penetration into the tooth becomes deeper, use shorter bursts and less air pressure for patient comfort. Mentally map out any areas of suspected decay. Start with the least-affected area first. Use short, controlled bursts to remove any stained dentin or decay.
7. Stop frequently and observe any exposed dentin or decay into the dentin.
8. Refine the preparation appropriately.

After mastering the procedure outside of the mouth, the practitioner is now ready to repeat the procedure in the mouth.

Select the easiest cases first, preferably lower teeth with minimal decay. From the patient's perspective, air abrasion is generally well tolerated. Most procedures can be performed without the use of local anesthetic. Typically, there will be a sharp learning curve as the dentist discovers that significant amounts of decay are often undetected in otherwise seemingly intact teeth [42]. If discomfort is encountered in deeper preparations, the use of smaller particle size and lower pressure is more comfortable for the patient. The smaller tip sizes are also more effective for decay removal.

One aspect of microdentistry that the author discusses with the patient before treatment is the amount of powder that ends up in the mouth. The dentist can make light of the powder: "You'll feel like you swallowed some of the beach"; "Congratulations, you made it through a Desert Storm." The spray is minimized by placing a wet 2-inch by 2-inch gauze square on the tongue, replacing it as necessary.

In implementing micro air abrasion, approach the applications with the intent to remove unsound tooth structure. Traditionally, practitioners have "cut teeth" with the best tool invented to accomplish this, the high-speed drill. When incorporating air abrasion, it is essential to understand a few basic concepts. Practice, then, makes perfect.

Several systems that enhance the dentist's ability to discriminate against unsound tooth structure are now undergoing extensive trials. For example, researchers in Japan have conducted extensive studies using "soft" abrasives to remove caries selectively. These adjuncts to conventional micro air abrasion are designed to allow the dentist to discriminate easily and selectively against unsound tooth structure during microprocedures, leaving sound tooth structure unaffected.

These new tools, selective abrasives, new delivery systems, caries-detection dyes, digital radiography, remineralization enhancement procedures, laser cavitation devices, and other turn-of-the-21st-century technologies will complete the revolution in diagnosis and treatment of occlusal caries.

Cutting rate

The order of ease in the cutting of tooth structure is (1) hypocalcified enamel of the pit, fissures, and grooves; (2) enamel; (3) dentin; and (4) caries. The cutting rate (removal of material) increases as the nozzle approaches the tooth surface more closely. The cutting rate also may be varied by adjusting the powder flow or airflow using different pressure settings and powders and by changing the nozzle diameter. With experience, the dentist will find a comfortable balance between cutting rate and control of powder flow. Most preparation procedures can be easily accomplished with approximately 40 to 60 psi and 2.5 g/min powder flow. Sensitivity is dependent on many factors, especially air pressure, powder flow, and dwell time. A setting of 80 psi seems to be the threshold for sensitivity. Many practitioners find that a maximum setting of 60 psi with a flow rate of 1.8 to 2.5 g/min is optimal for most procedures, without any sensitivity. Pulsing the stream with the foot pedal also helps to decrease dwell time and sensitivity. Enamel cuts more slowly than dentin, so although it may take 1 to 2 minutes to complete a class I preparation on a molar, it may take 5 seconds to complete a class V preparation on a premolar.

Soft, carious dentin absorbs and scatters the particle stream; one must be aware of where the tip and stream are aimed into the tooth. The use of a small (one-quarter or one-half) round bur is recommended for soft decay.

Increased powder flow and air pressure increase cutting rate but may also increase patient discomfort or sensitivity.

Selecting machines

Continuous mode without exhaust

Several machines provide a continuous flow of abrasive particles. They work in an on/off mode. Because of the extended amount of time it then takes for bleed-off to occur through the nozzle, the machines will effectively cut for several seconds after power is cut off. The practitioner should avoid these machines; imagine using a high-speed handpiece that will not stop for several seconds after one's foot is removed from the pedal. This is not acceptable in macrodentistry procedures and is even less tolerable in microdentistry procedures. For this reason, the continuous mode without exhaust is recommended only for extraoral procedures, such as preparing crowns for cementation.

Generally, continuous cutting creates a stable air pattern with resulting vortices within a preparation, and can, in effect, change the rules, by effectively causing peripheral collateral damage to sound tooth structure and increased hydraulic pressure within the dentinal tubules. The result is pain. It also may cut areas within the preparation without the operator's anticipation. The dentist has a tendency to stop short of a completed preparation, one in which all decay is removed. Failure to resort to short incremental cuts in deeper cavities also lowers the temperature of the tooth below the pain threshold; one must remember to tap the pedal.

Continuous mode with exhaust

The exhaust feature prevents the problems experienced with bleed-off through the handpiece after the dentist deactivates the pedal. When cutting in deeper cavities, short incremental cuts are favorable. The incremental cutting allows for escape of trapped air during the lulls between the bursts of air, leveraging the cutting efficiency of the much lighter 27-μm particle favored for deeper preparations. If a continuous, uninterrupted air stream flow is used, the 27-μm particles do not carry enough kinetic energy to penetrate against the exhaust air stream.

Directing the particle stream

The particle stream exits the end of the tip, making it an end-cutting device. For cutting efficiency, it is best to hold the nozzle tip at a 30° to 608 angle (rather than the side-cutting angle of 908 necessary with a bur) approximately 1 to 3 mm from the surface one wants to modify. This nozzle position will direct the flow of particles away from the field instead of deflecting back into the oncoming stream. Scatter is also reduced. Never direct the particle stream into an open pulp chamber or into the sulcus because it can create an air embolism.

Patient comfort

The use of micro air abrasion for most procedures can generally be well tolerated by patients without a local anesthetic. The most important variable in patient discomfort is the depth of the preparation. With deeper penetration into vital dentin, patients are more likely to report sensations of coldness or pain.

Approximately 50% of patients will feel no sensation or slight cold sensations. The other 50% may find it somewhat uncomfortable, although most of these patients will choose not to have local anesthetic. A small percentage of preparations will require anesthesia (approximately 10%). As the dentist gains more experience, the percentage of successful completions without discomfort will increase through crystallization of clinical experience, which will allow prediction of which teeth are most likely to be badly damaged by decay, enough to cause operative hypersensitivity.

When the dentist has extensive experience, he or she will wish to add the parallel water-stream technique and, when available, the parallel water-stream device to his or her armamentarium. This technique dramatically increases the depth and extent of the operative capabilities of microabrasion in unanesthetized teeth. By flooding the cavity and pinpointing the decay through the flooded field, the collateral damage caused by the exhausting abrasive air stream is cushioned and virtually eliminated. Warm water should be used to maximize patient comfort. The reduction of stimulation and cutting of vital dentin allow the operator to concentrate the abrasive beam on the caries, which desiccates the caries and subsequently allows the abrasive stream to remove the caries selectively.

The following section addresses sensitivity related to air pressure, particle size, powder flow (to a lesser degree), and dwell time (i.e., less is better). Lowering the air pressure and using a smaller particle size result in less sensitivity.

Sensitivity

The dentist should introduce the procedure to his or her patients and inform them that they may or may not feel any sensation, but they should let the practitioner know if they have any discomfort and want an anesthetic. It should be explained that about half of patients do not experience any sensation and about half do. For the half who do, however, few choose to have anesthesia. One can reduce sensitivity for a patient by decreasing air pressure and cutting slower, pulsing the foot pedal, and taking more time.

When patients experience discomfort the first question often is, "Is it going to get worse?" If one can assure them that it generally does not, one will be able to manage them through the procedure without anesthesia. A note of caution is that the patients who do feel this technology will not report discomfort until the dentist is working in the pulp. Be cautious; stop, look, and examine the procedure.

Most cavity preparations take between 30 seconds to 1.5 minutes. For longer procedures, some patients may experience discomfort from dryness and may wish to have their mouths rinsed with the water syringe and evacuated with the saliva ejector. As with any other cavity preparation procedure, a conventional saliva ejector should be positioned in the patient's mouth to collect the saliva and rinse water. Substituting a high-volume intraoral evacuator, for example, the Den-Vac Loop evacuator (Dentivac Loop, Portland, OR), for the standard saliva ejector is of great benefit, particularly early on in the learning curve. Have the dental assistant place the evacuation system in close proximity to the operative site. For additional powder control, a 4×4 gauze may be placed in the operative field.

Stream intensity, or particle flow rate (g/min), is variable from 0 to 8 g/min. A good standard is approximately 2 g/min. Higher levels may cause patient discomfort, and as particles reach certain levels of concentration, speed and effectiveness of cutting are compromised. Although the particle stream may seem to be cutting more efficiently, the quality of patient comfort is compromised at higher flow rate settings.

Air pressure

The dentist should always use the lowest air pressure necessary to perform a procedure. One must particularly exercise caution when using air pressures higher than 80 psi. Air pressure has a direct relationship to patient discomfort. Emphysema (or air emboli, air trapped in tissue) is a possible complication of all dental treatment, including air abrasion. The following conditions represent contraindications to air-abrasive treatment:

1. Severe dust allergy
2. Asthma
3. Chronic pulmonary disease
4. Recent extraction
5. Oral surgery
6. Any open wound, lesion, or sore, or sutures in the mouth
7. Recent periodontal surgery or advanced periodontal disease with a compromised periodontal attachment
8. Recent placement of orthodontic appliances with resulting oral abrasions
9. Subgingival caries removal
10. Any condition that would place the patient at greater risk for emphysema by using compressed air in the mouth

Nozzle diameter

Begin with the end in mind. Specialty nozzles should not be used on tooth structure until the dentist is experienced and familiar with air-abrasion technology. Several nozzle designs are available. At first, there will be little need for different nozzles. As the dentist gains experience, just as several different burs are necessary when preparing teeth the traditional way, several types of tips are necessary with air-abrasive techniques.

Nozzles range in diameter from 0.011 to 0.032 inch and are available in 458, 678, and 908 angles. Select a nozzle that is suitable for the procedure. The larger the nozzle, the larger the hole it creates. To remove large lesions and existing restorations, use a 0.018-inch nozzle. For most small lesions, a 0.014-inch nozzle is recommended. For precise cutting, diagnosis of occlusal pits and fissures, small class II and III lesions, or refining class IV and V restorations, use a 0.011-inch nozzle.

Choose an angulation that provides the best access. Most preparations can be performed with a 458 nozzle, but 678 or 908 nozzles allow better access to maxillary molar occlusal surfaces and lingual surfaces of maxillary anterior teeth. Most clinicians use the 458, 0.014-inch nozzle for most procedures.

In the advanced, experienced practice, the dentist will link the tool to the cavity he or she wants to create, or the limitations of the working surface: for a wide, cone-shaped cavity, use the 0.018-inch nozzle; for a narrow, deep cavity with nearly vertical walls, use the 0.011-inch nozzle.

The geometry also changes with the distance of the nozzle to the tooth surface. At 0 to 2 mm, the cavity has nearly vertical walls; at 2 to 5 mm, the cavity becomes more conical, with cavosurface margin angles approaching 458.

Particle type and size

A variety of particle sizes are available for different applications. Experimentation with particle sizes ranging from 10 to 75 μm has led to the standardization of two sizes: 27-μm (more comfortable, less effective cutting) and 50 μm (more aggressive cutting, but more discomfort). The 50-μm white aluminum oxide particle is suitable for coarse surface finishing and is primarily used in extraoral microetching procedures.

Summary

To help accelerate the dentist's learning of micro air abrasion, the following tips are offered:

1. Cavitation is essential to micro air abrasion.
   - Focus the maximum velocity of the particle stream on the decay.
     Maximum velocity occurs at 1 mm (particle velocity approaches supersonic speeds).
     Cavitation is successfully created.
2. Follow the path of least resistance; decay is softer than sound tooth structure.
3. Practice on extracted teeth a lot to develop the fine differentiation.
4. Use caries-detection dye—overuse it—understand its limits and its strengths in identifying caries at an invisible, microscopic level.

Typical mistakes to avoid include the following:

- Do not touch the surface of the tooth with the air-abrasion tip.
- Do not back up 2.5 mm from the surface.
- Do not blast the whole surface from afar.
- Do not sweep the tip like a brush.

When using air-abrasive technology in tooth preparations, 60 psi with 27-μm particle size is most comfortable and adequate for starting most procedures. Higher pressure and larger particle size will generally cut more aggressively. Pulse modes will cut with more patient comfort.

1. Place the nozzle at a 45° or 90° angle. Use a 0.014-inch tip at a right angle and no farther than 1 mm to the surface to be treated.
2. Visualize: Practice tracing out the path of the grooves, pits, and fissures that will be followed with the kinetic air stream. Do not move back and forth at random. Have planned purpose in movement across the tooth structure. Progress methodically from one end of the tooth to the other. Do not cut across obviously sound tooth structure.
3. Start with a 3-second burst at 80 psi or less, with movement designed to trace out the grooves, pits, and fissures of the occlusal surface of the posterior tooth. The burst should be interrupted over areas of sound enamel, such as the isthmus separating the mesial and distal pits of mandibular molars and the oblique ridges of maxillary molars.
4. Observe and diagnose the cleaned pit and fissures with caries-detecting dye for any remaining decay or missed pits and fissures.
5. Use short, controlled bursts to remove the last signs of any stain in the fissures. Note any exposed dentin.
6. Again, observe and diagnose for decay into the dentin. If no decay is present, the tooth is ready to be restored.
7. If decay is present, continue with a lower (i.e., 60 psi) setting and 27-μm particle size for dentin or decay removal. As tooth penetration becomes deeper, use shorter bursts and less air pressure for patient comfort. Start with the least-affected area first. Use short, controlled bursts to remove any stained dentin or decay.
8. Stop frequently and observe any exposed dentin or decay into the dentin. Appropriately refine the preparation. If discomfort is encountered in deeper preparations, smaller particle size and lower pressure will be more comfortable. Use of increasingly smaller tip sizes will also be more effective for decay removal.
9. Constantly monitor the patient: "Are you doing okay?" "How are you doing?" and so forth.

If a tooth is found to be sensitive approximately 1 week after restoration, it is usually occlusion-oriented; sensitivity immediately after the operative procedure is most likely due to a bonding error, usually underpolymerization.

For class V preparations and desensitization by kinetic burnishing, start with a smaller particle size (27 μm), a lower air pressure (e.g., 40 psi), and a lower powder flow (2 g/min) for more comfort and a more effective dentin seal.

All class II and III preparations must have a matrix band or rubber dam segment and wood wedge in place before starting to protect the gingiva and adjacent tooth. The band also acts as a guide to aid the proximal wall box if there is penetration. For interproximal caries, start with 60 psi aimed at the vertical axis of the tooth, approximately 1.5 mm from the marginal rim contact and never aimed at the interproximal caries. The coronal cemento enamel junction (CEJ) taper of the tooth will allow intersection of the caries. As the deeper recess is entered in the cavity preparation, reduce the pressure and particle size (if necessary) for comfort.

Understanding the dynamics of air abrasion

Many factors are involved in correctly developing the particle air stream, all conforming to the laws of physics. As the airflow progresses toward the handpiece, the decrease of the inside diameter of the delivery tubes generates an increase in the velocity of the particle stream.

The nozzle is the last restriction of the particle stream but the next-to-last increase in velocity. The particle stream does not reach full velocity until it leaves the tip of the nozzle by about 0.75 mm. When exiting any smaller nozzle (e.g., 0.014 inch), the particle stream typically becomes supersonic and can reach twice-supersonic speeds. The stream begins to slow at approximately 1 mm past the nozzle.

The particle stream is a divergent stream, like incandescent light from a tungsten filament. It varies from a collimated stream. Consequently, the stream spreads at approximately 22° as it exits the nozzle. At approximately 4 or 5 mm past the nozzle, the stream becomes too disorganized and carries insufficient energy to act as a cutting mechanism.

A common complaint of newcomers to the practice of air abrasion is that the instrument will not cut. There are three common reasons why there may be a perception that the stream is not cutting:

1. Failure to put the nozzle near the surface to be cut.

Holding the nozzle too far from the surface will only etch and abrade a wide area of surface. Moving too fast will result in skipping areas within the cut. The cut should be controlled in a slow, methodical progression.

2. Failure to hold the nozzle steady. The natural tendency is to wave the handpiece. For the cut to begin, the particle stream must first begin to cavitate the surface to be cut, which takes some time to initiate (3–5 seconds). The time depends on nozzle size, air pressure, quantity of powder, and nozzle distance from the site. As the particle stream begins to cavitate the surface, the cut will become progressively faster as the stream "focuses" into the cut and as particles exiting the preparation

also begin to cut. Waving the handpiece around merely etches a broad expanse of surface.

3. Failure to use magnification. The dentist simply cannot see the micro-preparations initiated by the particle stream.

Decay begins on the microscopic level. To practice micro air abrasion and repair the teeth on the microscopic level requires magnification.

The following are the steps typically followed in restoring a carious first molar:

1. Stain first molar in central-lingual groove.
2. Initiate procedure by cleaning out superficial stain on the surface with air abrasion.
3. Start with 0.011-inch tip to abrade superficial stain. Slowly open up pits, fissures, and grooves of the five grooves that stained. Remove any decay.
4. If one of the distal fissures has deeper decay, switch to a 0.014-inch regular or 0.011-inch turbo tip. Remove a sufficient amount of enamel to inspect the condition of the walls of the lesion.
5. Soft caries absorbs some of the energy of the particle stream, reducing cutting and causing stream scattering into sound dentin and enamel. Large amounts of soft decay may be removed by a spoon or small round bur in slow speed. Alternatively, the caries can be desiccated by laser and then air abraded.
6. Use the presence of decay at the bottom of the fissure to facilitate the removal of decay and hypocalcified enamel on the walls of the fissure.
7. Restoration: If a deep area, use a priming agent on entire tooth, a compomer as first layer (which has fluoride-releasing properties), followed with some sort of posterior composite; if superficial and in the enamel only, then a small amount of flowable composite (compomer will wear out).
8. Check occlusion (the areas being restored are functionally part of the occlusion).
9. Do not smooth with a composite sealer. Smoothing does not allow wear of high spots (if any) and may lead to occlusal trauma.

There are two types of decay: nonvital caries and vital caries [43]: It is important to minimize invasion into the vital caries areas of carious lesions. The vital carious portion of a lesion, although demineralized, retains the ability to remineralize. Caries-detection dyes allow the practitioner to differentiate between the non-vital and vital structures.

These are typical steps in treating carious lesions with air-abrasion:

1. Stain with caries-detection dye. Often in class V preparations the superficial layer contains oil, which may not stain properly. It is often valuable to abrade a suspicious area lightly and restain.
2. Select a medium tip diameter (e.g., 0.014 inch) and select the correct angulation. Start with a fairly low air pressure(less than 60 psi) and low flow rate (less than 2 g/sec).

3. If the suspicious area is carious, the moisture in the decayed area will pick up the aluminum oxide particles, and subsequent particles will bounce off, reducing cutting effectiveness.
4. Attempt to point stream within confines of decay to avoid cutting sound areas. The carious area will begin to desiccate, making it easier to cut.
5. Remove decay.
6. Restoration: If one is having trouble maintaining moisture control and aesthetics are not important, base the tooth with autocure glass ionomer. In deep cavities that can be bonded, a compomer base is a good compromise because it is harder, adheres better, still imparts caries resistance to the tooth, and has a fluoride-reuptake capability.

Noncarious

1. Determine major cause of lesion: abrasion or abfraction.
2. When abfraction is the major cause, the restoration should have a higher degree of flexibility than that for abrasion-microfill anterior composite. If abrasion is the major cause, the best thing is a posterior composite, because it has the greater resistance to abrasion.
3. If posterior composite with abfraction is used, it will likely pop out; if anterior composite with toothbrush abrasion is used, the patient will wear it out.
4. In noncarious class V preparations, the tubules of the superficial dentin are often sclerotic, particularly in abfraction-type lesions, making adhesion difficult.
5. The first goal is to remove any superficial contaminants.
6. Any such lesion found to be hypersensitive is treated with a dentin-bonding priming agent. If the tooth becomes less sensitive, it can probably be controlled just by bonding. If it continues to be sensitive, the problem may be some form of irreversible pulpal hyperemia, and the patient needs to be warned of a possible root canal.
7. If hyperemia resolves within 2 weeks, dyclone is applied to the tissue for a full 2 minutes. Use the smallest tip possible with low air pressure (40 psi) to abrade biofilm and any bonding priming agent that was applied previously as a desensitizing agent.
8. Acid etch the tooth first, and then place priming agent.
9. Restoration: With abfraction, use flowable, flowable/stackable, or anterior microfill (caries resistance less necessary, longevity more important). With abrasion, use a thick, heavy posterior composite.
10. Trim and polish with a high-speed drill.
11. Polish.
12. Place sealer over the composite.

Air abrasion, in conjunction with microdentistry, has opened up a whole new method of treatment for patients that preserves far more tooth structure than was ever previously possible, with greater patient comfort and superior aesthetics. The resulting preparations and surfaces are also far better prepared to receive and retain bonded restorations compared with traditional methods of preparation. Air abrasion eliminates the needless destruction of sound tooth structure associated with traditional restorative techniques, while leaving the tooth ideally conditioned [44] for the beneficial caries-inhibiting and strengthening properties of bonded restorations.

References

[1] Walls AWG, Murray JJ, McCabe JF. The management of occlusal caries in permanent molars: a clinical trial comparing a minimal composite restoration with an occlusal amalgam restoration. Br Dent J 1988;164(9):288–92.
[2] Black RB. Technic for nonmechanical preparation of cavities and prophylaxis. J Am Dent Assoc 1945;32:955–65.
[3] Hamilton J. CDS Review 1999;92(4):12–8.
[4] Black RB. Application of reevaluation of the air abrasive technic. J Am Dent Assoc 1955; 46:298–303.
[5] Black RB. Airbrasive: some fundamentals. J Am Dent Assoc 1950;41:701–10.
[6] Black GV. The management of enamel margins. Dental Cosmos 1891;33:85–100.
[7] Black GV. Lectures on operative dentistry and bacteriology. Chicago: Blakeloe Printing Co.; 1899.
[8] Christensen GJ. Dental radiographs and dental caries: a challenge. J Am Dent Assoc 1996; 127(6):792–3.
[9] Sigurjons H. Extension-for-prevention has fallen into disfavor. Oper Dent 1983;8(2): 57–63.
[10] Xu HH, Kelly JR, Jahanmir S, Thompson VP, Rekow ED. Enamel subsurface damage due to tooth preparation with diamonds. J Dent Res 1997;76(10):1698–706.
[11] Ross G. Advantages and procedures using air abrasion. Ont Dent 1998;75(2):36–42.
[12] Ferdianakis K, White GE. Newer class I cavity preparation for permanent teeth using air abrasion and composite restoration. J Clin Pediatr Dent 1999;23(3):210–6.
[13] Goldstein RE, Parkins FM. Using air-abrasive technology to diagnose and restore pit and fissure caries. J Am Dent Assoc 1995;126(6):761–6.
[14] Fusayama T. Two layers of carious dentin: diagnosis and treatment. Oper Dent 1979; 46:63–70.
[15] Pitel M. The resurgence of air abrasion into restorative dentistry, part 1. Dent Today 1998;106:62–9.
[16] Lubin B, Raskin IM. A new paradigm for a new age. Ontario Dent 1998;75(2):47–9.
[17] Nash RW. Air abrasion: the future of restoration microdentistry. Compendium 1997; 18(6):534–40.
[18] Morse R, Cohen B. Desensitization using meditation-hypnosis to control needle phobia in two dental patients. Anesth Prog 1983;30:83–5.
[19] What do dental patients fear most? Pediatric Dent 1987;9(3):207.
[20] Rosenberg S. Air-abrasive microdentistry: a new perspective on restorative dentistry. Dental Econ 1995;Sept:96–7.
[21] Xu HH, Kelly JR, Jahanmir S, Thompson VP, Rekow ED. Enamel subsurface damage due to tooth preparation with diamonds. J Dent Res 1997;76(10):1698–706.
[22] Stanley. Traumatic capacity of high-speed and ultrasonic dental instrumentation. J Am Dent Assoc 1961;12(63):749–66.
[23] Rainey JT. A sub-occlusal oblique transverse ridge: identification of a previously unreported tooth structure—the Rainey Ridge. J Clin Pediatr Dent 1996;21(1):9–13.
[24] Rainey JT. The maxillary molar mesial sub-occlusal enamel web: identification of a previously unreported tooth structure—the maxillary Rainey web. Pediatr Dent 1998;22(3): 195–8.

[25] Fares Al-Sehaibany F, White G, Rainey JT. The use of Caries Detector Dye in diagnosis of occlusal carious lesions. Pediatr Dent 1996;20(4):293–8.
[26] Milicich GW, Rainey JT. Clinical presentations of stress distribution in teeth and the significance in operative dentistry. Pract Periodontics Aesthet Dent 2000;12(7):695–700.
[27] Gelb MN, Barouch E, Simonsen RJ. Resistance to cusp fracture in Class II prepared and restored premolars. J Pros Dent 1986;2(55):184–5.
[28] White SN, Yu Z, Zhao XY. High-energy abrasion: an innovative esthetic modality to enhance adhesion. J Esthet Dent 1994;6(6):267–73.
[29] Brantley CF, Bader JD, Shugard DA, Nesbit SP. Does the cycle of restoration lead to larger restorations? J Am Dent Assoc 1995;126(10):1407–13.
[30] Penning C, van Amerogen JP, Seef RE, ten Cate JM. Validity of probing for fissure caries diagnosis. Caries Res 1993;26(6):445–9.
[31] Bader JD. Dilemmas in caries diagnosis. J Am Dent Assoc 1993;124(6):48–50.
[32] Speechley M, Johnson DW. Some evidence from Ontario, Canada, of a reversal in the dental caries decline. Caries Res 1996;30:423–7.
[33] Chan DCN. Current methods and criteria for caries diagnosis in North America. J Dent Educ 1993;57(6):422–5.
[34] Rock WP, Kidd EAM. The electronic detection of demineralization in occlusal fissures. Br Dent J 1988;164(8):243–7.
[35] Black GV. Operative dentistry. vol. I. 7th ed. London: Henry Kimpton; 1924. p 32.
[36] Al-Sehaibany F, White G, Rainey JT. The use of caries detector dye in diagnosis of occlusal carious lesions. J Clin Pediatr Dent 1996;20(1):293–8.
[37] Ross G. DIAGNOdent in pit and fissure caries diagnosis: clinical guidelines. Oral Health 2000;2:29–30.
[38] Ross G. Caries diagnosis with the DIAGNOdent laser: a user's product evaluation. Ont Dent 1999;3:21–4.
[39] Sigurjons H. Extension for prevention: historical development and current status of G. V. Black's concept. Oper Dent 1983;8(2):57–63.
[40] Brantley CF, Bader JD, Shugard DA, Nesbit SP. Does the cycle of restoration lead to larger restorations? J Am Dent Assoc 1995;126:1407–13.
[41] Robbins JW, Summitt JB. Longevity of complex amalgam restorations. Oper Dent 1988; 13(2):54–7.
[42] Fares Al-Sehaibany F, White G, Rainey JT. The use of caries detector dye in diagnosis of occlusal carious lesions. Pediatr Dent 1996;20(4):293–8.
[43] Fusayama T. Two layers of carious dentin: diagnosis and treatment. Oper Dent 1979; 46:63–70.
[44] White SN, Yu Z, Zhao XY. High-energy abrasion: an innovative esthetic modality to enhance adhesion. J Esthet Dent 1994;6(6):267–73.