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REVIEW

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Caries removal techniques and instrumentation: a review

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Abstract The invention of rotary instruments not only improved the speed of caries removal but also the destruction of sound tooth substance. Hence, as early as the 1950s, there were attempts to develop a less invasive technique, such as the air-abrasive and ultrasonic techniques, for the purpose of caries removal. The proposed use of air-polishing was published in the early 1980s. Subsequent better understanding of the carious process saw the introduction of the enzyme technique in the late 1980s. Other techniques, such as chemomechanical caries removal and laser systems, have also been attempted and researched during the last four decades to minimise the unnecessary removal of sound tooth substance, although these and other techniques reviewed in this article have not yet superseded the use of rotary instruments. Furthermore, the concept of micro-cavity preparation developed in recent years and the introduction of acid-etch techniques, resin bonding and the use of glass-ionomer cements have also revolutionised the principles of cavity preparation in conservative dentistry. This article reviews the development of these various caries removal techniques and instrumentation and the evolutionary philosophies of cavity preparation promulgated over the last century or so.

Key words Caries removal techniques · Hand instruments · Atraumatic restorative technique · Air-abrasive technique, air-polishing technique · Enzyme, ultrasonic, chemomechanical caries removal systems

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Introduction

The gradual evolution of caries removal techniques has changed the concepts of cavity preparation in numerous ways throughout the last two centuries. Cavity preparation with only hand instruments practised by the forefathers of dentistry entailed only the removal of discoloured carious tissue and undermined enamel. The principles of cavity preparation proposed by G. V. Black in 1893 laid the foundations for the latter technique, which in later years were further modified due to the introduction of man-powered rotary instruments. Essentially, Black's philosophy of "extension for prevention" has perpetuated an interventive procedure that removes a good proportion of the sound tooth substance in addition to carious matter. The subsequent invention of high-speed rotary instruments has not only fulfilled the essential process of caries removal but also the destruction of sound tooth substance.

In the middle ages, carious tissue was scooped out with hand instruments prior to filling the cavity. The nature of the softened decayed portion beneath the lesion was not appreciated. Even in the nineteenth century, the poor choice of filling material available made a lasting result difficult. Various pastes and cements used for filling carious cavities were too soft, and techniques with metallic filling materials did not permit good adaptation of the material to the walls and margins of the cavity. Thus, the restoration of decayed teeth, even in the nineteenth century, was seldom successful [1].

The methods which are currently available to remove caries include mechanical rotary techniques and mechanical non-rotary techniques. Non-rotary techniques includes hand instrument action and air-abrasive, air-polishing, ultrasonic, laser, enzyme and chemomechanical techniques.

Rotary instruments were the first mechanical techniques developed to remove caries, and comprised dental engines, handpieces and dental burs. The following reviews each of these techniques in some detail.

Instrumentation for mechanical non-rotary techniques

In the sixteenth century, Giovanni da Vigo proposed removal of caries with drills, files and scrapers. Pierre Fauchard removed caries with strong probes and plugged the dried cavities with lead or tin pupillary [2]. The demand for systematic conservation of teeth was largely an idea of the nineteenth century, as only the removal of calculus and sharp edges on teeth and the unorthodox techniques of filling cavities with a variety of materials were recognised and practised before then.

In 1815, Derabarre advocated the use of a burin (an instrument used as an excavator) to remove only the caries, thus leaving the enamel intact. Some years later, in 1826, Koecker recognised that complete removal of caries was essential to prevent its recurrence [2]. The procedure of cleaving away over-hanging enamel was undertaken by hand instruments, termed enamel cutters, which enabled the underlying carious dentine to be scooped out with excavators. These instruments were augmented by a wide range of long-handled burs having the same knurled hexagonal handles as the present-day hand instruments. Eventually, different types of hand instruments evolved for caries removal as well as for filling the prepared cavities. During the middle of the nineteenth century, various other instruments were devised such as the Merry's drill, with two handles and a universal joint which permitted rotation of the bur by holding the lower handle still and twisting the upper handle. However, manual dexterity was essential to handle this rather cumbersome instrument.

A number of factors may contribute to the iatrogenic pathological changes induced in dentine and pulp when rotating instruments are used. These include speed, desiccation, heat, pressure, cutting time, depth of the cavity and area of prepared dentine. Although direct experimental evidence is unavailable, Massler [3] has noted that damage to the pulp appeared to be more severe when these early mechanical instruments were used for cavity preparation, compared with electrically operated burs.

Instrumentation for mechanical rotary techniques

Dental engines

The early models of dental engines and cutting instruments used for the removal of carious material were primitive. One of the earliest machines, developed in 1846 by Westcott, was a drill stock consisting of a finger ring and simple drill rotated between the thumb and forefinger [1]. Subsequently, in 1850, Chevalier devised a drill stock, operated by a small crank and bevel gears, which was held at an angle of 45° to the body of the instrument. Although there was a steady rotation in either direction, both hands were required for its operation.

In 1858 a drill was devised by Merry, and this comprised two handpieces, one to hold the instrument in place and the other to drive the instrument. The latter was connected via a universal joint to a spirally wound wire. This was the beginning of the separation of functions between the handpiece components.

A further evolution of functional components of the dental handpiece was the foot treadle, devised by Morrison [2]. The mechanical foot pedal was eventually replaced by a new source of power, the electric motor, which was introduced in 1864. However, the wide use of electrically driven motors was not popular until the end of the 1950s. The direct predecessor of today's air-driven dental turbine was, however, introduced in 1868 by Green, who devised an engine in which a foot-driven bellow transferred air through a rubber tube to a handpiece [1]. The handpiece contained draught screens which rotated a canula within which various drills could be mounted. Subsequently, air-driven dental turbines were produced by the manufacturer Norlen in 1955, termed Dentalair, and in 1957 as the Borden Airotor.

Dental handpieces

Prior to 1870, dentists had no mechanically driven rotary tools for the removal of caries and cavity preparation. Straight handpieces with a variety of intricate chuck-closing mechanisms were developed during the 1880s, and these were permanently linked to the flexible cable of a foot engine. A subsequent modification of this device was the angled handpiece, which held the burs in place by so-called lock-bit attachments to their front end. These lock-bits were available in right angle, acute angle, and obtuse angle patterns. Other early twentieth century developments included right-angled handpieces fitted with a latch-lock mechanism, balanced contra-angled handpieces and multi-jointed engine arms.

Although throughout the 1940s little change worthy of note occurred in dental handpiece design and in their driving mechanisms, the subsequent decades saw radical improvements to these features. Handpieces with water jets or water spray nozzles were introduced (by the Amalgamated Dental Company) in 1955, and these permitted dentine to be cut in a wet state. Further, due to the spray cooling effect of water there was a dramatic increase in the maximum speed at which burs could be used. Studies have shown that an efficient water spray keeps the cavity preparation under constant water cover, a factor crucial for minimising pulpal damage [4, 5].

Handpieces were subsequently improved to drive steel and diamond burs at a much faster rate than the 9000 rpm which was the maximum permissible speed prior to the introduction of water coolants. The handpiece bearings were also improved to withstand the high speeds, which reached 20 000 rpm or more.

Significant advances in handpiece development have occurred during the 1980s, these include the push-button chuck, the multiple coupling, and fibre-optic lighting [6]. The obvious advantage of the multiple coupling is that it enables different types of handpieces to be inserted and removed with a single quick movement. Air and water lines are automatically connected through the coupling device and, in addition, the tip of the coupling may house a small bulb for fibre-optic light transmission through the connected handpiece. This mode of lighting dramatically improved the illumination of the bur tip in the operational vicinity [6].

The improvements in modern mechanical cutting devices, the increased speed and cutting power of the burs, may also create a few disadvantages. As tactile sensation decreases with increasing speed, overcutting of tooth structure during cavity preparation is a major disadvantage. This is particularly the case with inexperienced operators, leading to iatrogenic morbidity such as pulpal exposure. Also, injuries to soft tissues of the patient may occur if the high-speed handpieces are improperly utilised.

For a comprehensive review of rotary cutting instruments, readers are referred to reviews by Dyson and Darvell [7–9].

Dental burs

Early models of the dental engine as well as the burs used were inefficient in cutting enamel. It was not until the end of nineteenth century that an improved range and quality of cutting and polishing burs and discs became available.

A very high demand was created for an efficient bur after the invention of the foot treadle-operated dental engine by Morrison in 1871 and the development of the first electric dental drill shortly afterwards. It is unknown who invented the modern bur, but it is likely that the entire manufacturing process was performed manually in a laborious manner. Filing a small piece of steel and grinding it into a specific shape with each tiny blade exquisitely hand sharpened to a razor-like edge requires experience and talent.

In 1891, S. S. White revolutionised and set the standard for the dental industry when the first machine-made bur was introduced. This revolutionary bur had a continuous blade or drill edge across its centre which enabled cutting in the direction of its axis. Further, no single blade followed the path of another, instead, each blade cut across the path of its leader. These early burs were made of steel alloys and were very similar to the modern steel burs [10]. Since then, gradual improvements in the properties of alloys have resulted in burs with superior thermal and cutting properties.

A milestone of the story on bur development occurred when Furke discovered the process of hardening steel with tungsten carbide, and applied this technique to the dental bur in 1917 [11]. However, he had to wait for more than 40 years before a method was developed to process a tungsten carbide bur which cuts dental tissues efficiently. The early tungsten carbide burs had only four basic shapes; round, inverted cone, straight fissure and tapered fissure.

The introduction of the air turbine in 1957 dramatically changed the practice of dentistry as this Airotor was capable of 300 000 rpm. This created an urgent requirement for a carbide bur which could withstand previously unrealised speeds. Furthermore, in the latter half of this century, when plastic and composite materials were introduced, a wide range of burs was developed to cope with these new demands [11].

Mechanical non-rotary techniques

The air-abrasive technique

A non-rotary technique used for caries removal is termed the air-abrasive method. This is based on the use of powdered aluminium oxide particles which travel at high speed to remove hard tooth structure without perceptible vibration, pressure, heat production or pulpal reaction [12]. This technique, developed in the 1950s, was abandoned as a clinical tool due to an absence of tactile perception and the difficulty in carving precise cavity margins and angles. For the latter purpose, the operator had to resort to conventional hand or rotary instruments. Other disadvantages were that the surface of the mirror was rendered obsolete over a short period by the effect of rebounding abrasive particles, and the pollution of the surgery by dust particles affected both the patient's and the dentist's eyes and respiratory systems [13]. Further, it was ineffective in removing filling material such as amalgam, which required replacement.

This technique was fairly recently reintroduced as the Kinetic Cavity Preparation System (KCPS) [14] and other similar models have also been marketed. KCPS is a much more advanced and improved system, which uses a high-velocity stream of alumina particles (α alumina) to remove caries or preexisting composite or porcelain restorative materials, often without anaesthesia. Rubber dam isolation, eye protection and an additional evacuation system are recommended when the KCPs is used. Further, the use of the mouth mirror is problematic due to the etching effect of the alumina particles.

The system is especially recommended for use in class I cavity preparations and, if accessible, class III and V preparations. It has also been used as a diagnostic tool to detect suspicious pit and fissure caries where tactile, visual and radiographic techniques have failed. The revitalisation of this old concept is largely due to advances in dental technology and the advent of new adhesive restorative materials. Indeed, the conceptual and practical rethinking of the conventional cavity preparation techniques leading to minimal cavity preparation makes it possible for the air-abrasive system to be used in conjunction with adhesive restorative materials. Clinical trials and research findings are beginning to emerge on this technique. For example, in vitro studies have shown that a wide variety of restorative materials, including hybrid composite, high copper amalgam, feldspathic metal–ceramic porcelain, type II gold alloy, high palladium noble metal–ceramic alloy, base metal–ceramic alloy and commercially pure titanium, in association with the air-abrasive technique, achieved strong bonds with dentine bonding agents and composite resin [15]. Fine 50-µm alumina abrasive with a medium velocity at 120 psi was shown to be the optimal conditions for these purposes [15].

The air-polishing technique

As opposed to the air-abrasive technique, the air-polishing technique is a variation of the same theme and involves the use of an air-propelled jet of powder (mainly sodium bicarbonate) shrouded by a concentric water jet. It was developed as a method of removing dental plaque and stains (e.g. coffee and tea stain) [16], although filling materials such as composite could also be removed using the technique. Though effective for the latter purposes, the deleterious effects associated with loss of dentine, cementum and even enamel have raised concern about its use in routine prophylaxis [13, 16, 17].

It has been suggested that air-polishing has the potential for development as a caries removal technique as it differentially removes carious dentine leaving the sound dentine intact when used with care [3]. However, as opposed to the air-abrasive system, this system has not been revitalised.

The ultrasonic technique

High frequency ultrasonic vibrations in conjunction with an abrasive slurry have been used to prepare teeth for restorative treatment. This procedure minimises or eliminates the development of noise, vibration, heat and pressure [17, 18]. The technique appears to produce an effect on pulp tissues comparable to that of rotary instruments, and patient acceptance has been favourable [19]. However, the ultrasonic technique has not gained wide acceptance due to the limited availability of instrument tips, slowness of action, poor visibility due to the abrasive slurry and other maintenance problems. Furthermore, caries and resilient restorative materials such as gold cannot be removed effectively by this technique [10]. More recently, a modified sonic air-scaler handpiece with a diamond-coated working tip has been tested for its cavity preparation efficacy. The authors recommend this technique for minimal cavity preparation of proximal lesions in both anterior and posterior teeth [20]. The use of these and other ultrasonic techniques in restorative treatment warrants extensive clinical trials prior to general adoption.

The laser technique

Two classes of laser (light amplication by stimulated emission of radiation) are available for both medical and dental applications [21]. These can be generalised into “soft” and “hard”lasers [22]. The so-called soft lasers are a source of cold (athermic), low-energy light emitted at wavelengths thought by some to stimulate cellular activity, and hard (thermic) lasers are utilised in surgical procedures as a precise energy source to cut, coagulate and vaporise tissues. The latter group has been mainly used in dentistry for the purposes of caries removal and cavity preparation.

After initial experiments with the ruby laser, most clinicians/surgeons have progressed to using argon, CO_2 and more recently Nd:YAG (neodymium:yttrium–aluminium–garnet), Er:YAG (erbium:YAG) and Excimer (UV) systems. Although the Excimer system possesses the necessary selective ablation in caries removal, it has been questioned whether this is of any importance in clinical settings [23].

The current interest in the fields of restorative dentistry and oral surgery centres on the use of the hard CO_2 and Nd:YAG lasers [24]. Sterilising as it cuts, the latter laser system shows promise not only as a caries removal agent but also in endodontics and gingival curettage.

In addition to caries removal, lasers may have other properties. An in vitro study has demonstrated the significant killing of the cariogenic organism *Streptococcus mutans* by low-power laser light in the presence of a photosensitiser. This was possible even when the bacteria were embedded in a collagen matrix and when the light passed through a zone of demineralised dentine [25]. Lasers can also be used to cut and seal dentinal tubules, reducing the possibility of postoperative sensitivity [26]. Further, the patient acceptance of the muted (popping) sound of lasers is likely to be much better than the infamous sound of the dental drill dreaded by most patients.

The applications currently approved for laser use in dentistry are [27]:

1. Preparation of tooth surfaces for resin bonding, with results similar to enamel etching (CO_2, Nd:YAG, Er:YAG, Ar:F lasers).
2. Fusing hydroxapitate to enamel and dentin, forming a biological seal for pit and fissure (CO_2, Nd:YAG lasers).
3. Creation of an apical seal in endodontic procedures (CO_2, Nd:YAG lasers).
4. Caries removal and cavity preparation (CO_2, Nd:YAG, Er:YAG, Ar:F lasers).

In practical terms, when a carious cavity in an extracted human tooth was exposed to the laser, it was found that the exposed areas of teeth were cleaned of inorganic and organic debris, leading to a clean, hard surface [28]. It has been claimed that the finer control offered by Nd:YAG lasers, as opposed to CO_2 systems, allows the operator to remove carious dentine without damaging sound dentine or enamel. As carious dentine is darker than sound dentine, the energy levels of the laser can be adjusted so that an optimal amount of light is absorbed sufficient to remove only the carious dentine, thus leaving the sound dentine intact. Many operators report that patients can frequently be treated without a local anaesthetic [28]. Moreover, it has been reported that, due to the alteration in the surface structure of the lasered tooth, it will be more resistant to secondary caries ensuing after the treatment procedure [24].

It has, however, been pointed out that the CO_2 laser acts better on dental hard tissue regardless of dentine or enamel colour and its use is preferable to that of Nd:YAG lasers [29]. The Er:YAG laser, on the other hand, was also found to be effective in removal of both enamel and dentine [30] with minimal loss of heat to the surrounding tissues [31].

A 3-year follow-up study of the Nd:YAG laser system has shown that all teeth remained vital and asymptomatic after the removal of caries using the system [32]. The restorations placed after caries removal were intact and clinically serviceable [32].

Undoubtedly, more clinical experience with laser systems will become available during the 1990s and further scientific and technical advances are anticipated. However, the relatively high cost of the currently available laser systems will limit their use in general dental practice.

The enzyme technique

In 1989, Goldberg and Keil reported that a bacterial collagenase from *Achromobacter* species is useful in removing soft carious dentine when the enzyme is applied over a period of 2–5 h [33]. This procedure resulted in a residual sound layer of dentine beneath the lesions. In that study, extracted carious human teeth were immersed in a solution of *Achromobacter* collagenase in borate buffer at 33°C for 2–92 h. The dentinal surfaces were then studied by scanning electron microscopy and no bacteria could be seen in the exposed collagen on the dentinal floor [33]. A recent study has also demonstrated that another enzyme, pronase, is also useful in caries removal [34]. Although the authors have suggested its potential clinical effectiveness, data on the clinical application of pronase is not available as yet.

The chemomechanical technique

Although advocated widely in the late 1970s, chemical means of caries removal have not gained popularity in restorative dentistry. This is partly due to the advantages of mechanical methods of cavity preparation in terms of speed and efficiency and partly because of the difficulties in finding a chemical that would remove caries effectively without causing damage to sound dentine and pulpal tissue. Although a purely chemical caries removal system has yet to be devised, a combination of chemical and mechanical caries removal techniques was first introduced during the 1970s in the USA.

The system, which is known as the Caridex Caries Removal System, consists of a freshly prepared aqueous solution of *N*-monochloro-D,L-2-aminobutyrate (NMAB) which is thought to react with the demineralised, partially degraded collagen of the carious dentine, resulting in a softening of the carious tissue which can then be gently removed [35]. It has been shown that the system can differentially remove the first or outer layer of carious dentine leaving the remineralisable second or inner layer of carious dentine intact [36]. However, an air rotor is still required for access to carious dentine.

As the existing formulation was found to be no more effective than saline, attempts were made to improve the efficacy of caries removal of NMAB with the addition of urea to the formulation [37]. This improvement seemed to be more effective in carious deciduous teeth than in permanent teeth, and more effective in carious lesions with soft to medium consistency.

Scanning electron microscopic findings have shown the dentine remaining after chemomechanical caries removal to be uneven with many undermined areas [36]. Nonetheless, backscattered electron imaging and electron probe X-ray microanalysis showed the dentine was sound and normally calcified [38] and likely to be suitable for the application of restorative materials.

As the chemomechanical removal of dental caries is a conservative procedure, there is minimal cavity preparation required when the technique is used in conjunction with adhesive restorative materials [39]. It is important to realise the limitations of this technique and further studies are required to identify the appropriate areas of application.

An improved product of chemomechanical caries removal product, Carisolv, has recently been introduced [40]. It is made up of two gels, one containing leucine, lysine and glutamic acid, and the other hypochlorite, which are mixed during use. The mechanism is postulated to be similar to that of Caridex (see above). The application of the gel onto the lesion helps to soften the carious tissue and facilitates subsequent mechanical excavation. There are, however, no scientific publications on its clinical suitability despite its approval for use in Sweden.

The atraumatic restorative technique (ART)

Interest in hand excavation of dental caries has been rekindled with the introduction of the ART. This is defined as a procedure based on excavating carious cavities in teeth using hand instruments only and subsequent restoration with adhesive filling material (glass-ionomer) [41].

The ART technique [42] for dental caries is an innovative, largely pain-free, minimal intervention approach of treating decayed teeth, mainly inaugurated for developing countries. This method appears to be an ideal compromise, especially in developing countries where electricity supplies are limited and highly-trained dentists are not readily available or affordable. The technique was developed in Tanzania in the mid-1980s and has been implemented in a school oral health programme in Zimbabwe [43]. It is undergoing field tests in north-eastern Thailand for a period of 3 years. The clinical findings from this longitudinal study [41, 44–46] after 2 years of placement have yielded 86% success rates in the permanent dentition for one-surface restorations, and 69% for multiple-surface restorations [46]. A 3-year study has revealed a survival percentage for one-surface ART restorations of 85.3% [47]. The success rate was defined as the degree of retention using specific evaluation criteria [43]. Failures were far higher and more rapidly progressive in the primary dentition. Failures occurred from marginal and bulk fractures, surface wear and tear and from restoration losses. However, observers have noted that even though the restorations were lost, the exposed and previously actively carious dentine had become hard in many instances [43]. This simple atraumatic process of caries removal, which requires neither a dental drill nor an injection of local anaesthetic, should prove to be an excellent means of introducing young children to dentistry without the fear commonly associated with traditional dentistry. A number of prospective ART trials are currently being carried out in countries such as China, Zimbabwe and Thailand.

Conclusions

In general, the development of caries removal techniques in restorative dentistry is progressing towards a more biological and conservative direction. This has been made possible with better understanding of the aetiology, development and prevention of dental caries, the emergence of new caries removal techniques and advances in dental restorative materials. In particular, the development of reliable adhesive technology in the oral cavity, which led the way to a minimal cavity preparation concept, has given a great impetus to the current thinking in this area. The coming decades will continue to see shifts in the approach to caries removal techniques, cavity preparation and restoration techniques based on rational clinical and scientific principles.

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