

Caries Excavation: Current Concepts and Techniques

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Abstract

The advent of newer caries excavation technique has simplified the guidelines for cavity preparation enormously. The extent and shape of the caries lesion basically defines the design and extent of the present preparations, potentially slightly extended by bevelling the cavity margins in order to satisfy the fashionable concept of minimally invasive dentistry. New caries excavation techniques described by Ahmed AA *et al.*, are introduced, like the utilization of plastic and ceramic burs, improved caries-disclosing dyes, enzymatic caries dissolving agents, caries-selective sono/air abrasion and laser ablation.¹ They all aim to get rid of or help remove caries-infected tissue as selectively as possible, while being minimally invasive through maximum preservation of caries affected tissue. Each technique entails a selected caries-removal endpoint and produces residual dentin substrates of various natures and thus different receptiveness for adhesive procedures. New caries excavation techniques favor current situation of COVID-19 era since they are free of aerosol and infection control can be achieved.⁴

Keywords: Minimal Invasive Dentistry; Caries excavation technique; Ceramic burs; Cariesdisclosing dyes; Enzymatic caries-dissolving agents; caries-selective sono/air abrasion; Laser ablation.

Key Messages: This article tends to increase insight on various caries excavation methods with recent advances further reducing chair time and increasing efficiency.

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INTRODUCTION

"As the Greeks see it, elegance arises from excavation, from the cavity."

- Roberto Calasso

The general principles of cavity preparation have been altered due to the potential to bond restorative materials to tooth. With new steps added to cavity preparation, especially for bonding, others like cutting retentive cavity were omitted.

As described by Sturdevant, caries is a multifactorial microbial infectious disease characterized by destruction of the organic substance



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and demineralization of the inorganic of the tooth. It is still a matter of debate whether to remove dentin till the extent of caries to achieve mechanically and biologically successful restoration. According to AAPD Guidelines 2016, to manage dental caries it is very important to identify the risk of caries progression and to understand the disease process in all individuals. Decision as of when to restore the tooth should depend on the clinical criteria. In particular, there are no definite diagnostic tools available which can clinically define the caries removal endpoint enabling complete removal of infected tissue without extending beyond the caries progression. Different techniques presently available for caries removal/cavity preparation produce different natures of residual dentin substrates and thus different receptiveness for adhesion.

At the start of the past century, when the primary operative dentistry guidelines were established, the term “caries excavation” was defined as a synonym for “cavity preparation”, which successively consisted of “the injuries to the teeth produced by mechanical treatment of cavity, as would best fit the remaining a part of the tooth to receive a filling”.³ From this, it appears that to prepare a tooth to receive restoration caries excavation were regarded as a mandatory step. Furthermore, it's been described that carious lesion should be excavated “until a hard pulpal floor was reached”. In short, carious dentin should be removed till infected dentin is fully removed and affected dentin was left behind due to lack of infectivity.¹⁰

It is thus clear that when non-adhesive restorations were the only option available, there was no distinct separation between caries removal

and cavity preparation. Perhaps it also explains the general confusion still seen nowadays when dealing with the term “caries excavation” in view of the minimally invasive dentistry concept.²

As caries excavation remains a crucial step towards achieving good quality bonded restorations, subsequent question arises: what's the present definition of endpoint for caries removal? Even now, no better clinical criterion is available to define the caries excavation limit than the “normal” hardness feeling of sound dentin when probed by hand instruments. Although “*cris dentinaire*” is very subjective and it depends on the operator, it is still a gold-standard method to check residual caries. Elimination of infected dentin and preservation of the residual affected dentin were thus defined as prerequisites for effectively arresting the carious process without harming the long-term survival of the pulp and the restoration. This has raised some discussion about moving toward more conservative and more objective approach to selectively remove carious dentin.²

The first detectable change in dentin in response to cariogenic biofilm is an area of sclerotic dentin subjacent to demineralized enamel (Fig. 1A and 1B). The predominant feature of this reactive dentin is its increased translucency, which may be ascribed to intratubular mineral deposition.¹⁶ The translucent dentinal tubules will be localized beneath the demineralized enamel surface appear even before the enamel demineralization has reached dentinenamel junction (DEJ). Only when the caries lesion has progressed to a substantial length along the DEJ, will the subjacent dentin be demineralized and become recognizable as yellow to dark-brown discoloration (Fig. 1C and 1D).

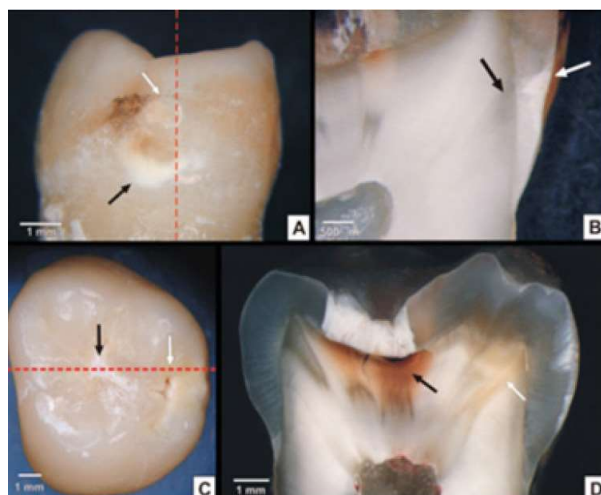


Fig. 1: (A&B) First detectable change in dentin in response to cariogenic biofilm is an area of sclerotic dentin subjacent to demineralized enamel, (C&D) Yellow to dark-brown discoloration of progressed carious lesion along DEJ

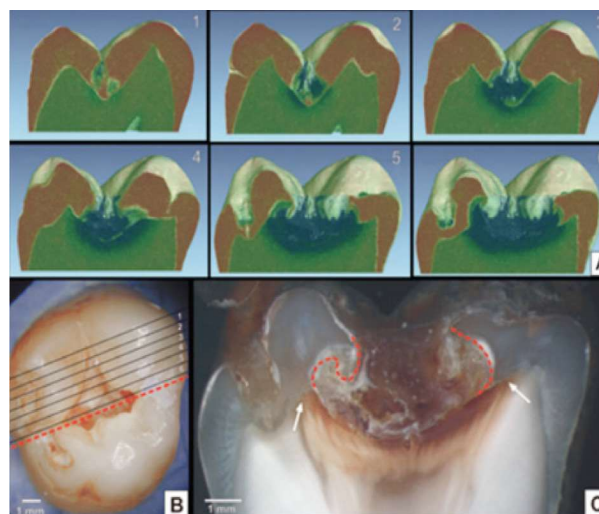


Fig. 2: (A&B) Different phases of caries progression within one lesion, (B&D) “hidden” caries lesion

At this point, keeping in mind that, dentin response to dental plaque is directly related to its metabolic activity and different phases of caries progression will co-exist within one lesion (Fig. 2A and 2B). It is also known that dentinal caries will not spread laterally along the DEJ before dentin is cavitated and colonized by cariogenic bacteria. From this moment, the demineralized and unprotected organic dentin matrix will be directly degraded through bacterial and host-mediated enzymes.¹⁷ Especially at peripheral parts of the cavity where cariogenic biofilm is sheltered by the undermined enamel, the lesion may spread rapidly along the DEJ ("hidden" caries lesion) (Fig. 2B and 2C).

Table 1: Classification of Caries Excavation Methods (According to Banerjee *et al.* 2000).¹²

Category	Method
Mechanical and Rotary	Conventional excavation with Carbon steel or Tungsten-carbide burs
	Polymeric burs
	Ceramic burs
	Caries disclosing dye-aided excavation (caries detector) with Tungsten-carbide burs
	Laser-induced fluorescence-aided excavation (Diagnodent) with Tungsten-carbide burs
	Fluorescence-aided caries excavation (FACE) with Tungsten-carbide burs
	Air-abrasion excavation
Mechanical and Non-Rotary	Air-polishing
	Sono-abrasion excavation
	Chemo-mechanical methods
Chemo-mechanical	Atraumatic restorative treatment
Photo-ablation	Caridex, Carisolv
	Lasers

Current Caries-Excavation Procedures

Conventional Excavation with Burs

Carbon-steel or tungsten-carbide burs

With the introduction of the process of hardening steel with tungsten carbide in the dental bur industry, carbon-steel burs are replaced by tungsten-carbide burs. Tungsten-Carbide burs were introduced in the year 1947 and have VHN in range of 1650-1700. In a matrix of cobalt or nickel at the working end of the bur, microscopic tungsten-carbide particles are held together.¹³ To improve cutting efficiency, the head has typical spiral-like cutting edges with or without

additional cross cuts. Carbon-steel burs are less expensive and possess the same caries-removing properties as tungsten-carbide burs, but are much prone to corrosion and dulling. A round bur is recommended for caries removal, with diameters corresponding to the size of carious lesion. Since low-speed (700 to 800 rpm) counter-angle handpieces are employed, water irrigation is optional. In order to minimize the risk of infection in case of accidental pulp exposure, it is generally advised to start carious dentin excavation from the periphery towards the center of the lesion using larger burs.

The most efficient method to excavate carious lesions in terms of time and still the most widely used caries-excitation method are tungsten-carbide or carbon-steel burs in lowspeed counter-angle handpieces. However, in terms of minimal invasiveness, bur-prepared cavities, combined with using dental explorer to check for caries removal endpoint, tend to over-excavate. This was found, when auto-fluorescence induced by bacterial metabolites was used to detect carious tissue. This method leaves a homogeneous smear layer with more or less uniform roughness dentinal tubules visibly obstructed with smear plugs when studied by scanning electron microscopy (SEM).⁵ It has been shown to potentially reduce the bonding effectiveness of self-etching adhesives but the smear covered surface does not interfere with etch-and-rinse adhesives.

Polymeric burs

A "plastic" bur was made of a polyamide/imide (PAI) polymer, possessing slightly lower mechanical properties than sound dentin in an attempt to develop a selective caries-removal rotating instrument. However, soon it became clear that it quickly becomes dull and produces undesirable vibration, making further cutting impossible if the bur touches sound or cariesaffected dentin.⁶ The blade design was developed to remove dentin by locally depressing the carious tissue and pushing it forward along the surface. When 1% acid-red-propylene glycol solution was used as caries detector, using a prototype, single-use instrument, complete removal of carious tissue was accomplished from extracted teeth.

The commercial version of these burs (SmartPrep, SS White Burs; Lakewood, NJ, USA) consisted of a polymer (PEKK - Polyether-Ketone-Ketone) with a particular hardness of 50 KHN, which was higher than the hardness attributed to carious dentin (0 to 30 KHN), but lower than that of sound dentin (70 to 90 KHN). Their cutting edges were not spiralled but

straight as opposed to conventional carbide burs. By keeping to the recommendation to excavate caries from the center to the periphery in order to avoid contact with sound tooth tissue, the bur would be prematurely and irreversibly damaged was one of the disadvantages.

When excavated tooth sections were stained with Mallory-Azan, the efficacy of the Smart Prep burs for caries removal was questioned in a histological study. In cavities excavated with Smart Prep burs more residual caries was found than in cavities prepared with conventional tungsten-carbide burs. In addition, transmission electron microscopy (TEM) of the bonded interfaces disclosed remnants of carious tissue at the excavated dentin/composite interface when carious dentin was excavated with Smart Prep burs. It was then suggested that if the hardness of the polymeric material could be increased, the efficiency of the polymer burs could be enhanced. An improved version of polymeric burs is available in market (Smart Burs, SS White Burs; Lakewood, NJ, USA). A great amount of residual caries was still found, especially in inactive caries-arrested lesions. This can probably be explained by the still rather low surface hardness of the Smart Burs (26.6 KHN) as compared to the hardness of arrested carious dentin (39.2 KHN).

Ceramic burs

For removal of carious dentin, a new line of slow-speed rotary cutting instruments made of ceramic materials is now commercially available. The CeraBurs (Komet-Brasseler; Lemgo, Germany) are all-ceramic round burs made of alumina-yttria stabilized zirconia and are available in different diameter sizes (Fig. 3).



Fig. 3: CeraBurs with different diameters. From left to right: 10, 14, 18, and 23-mm diameter

The manufacturer claims that besides its high cutting efficiency in infected, soft dentin, the use of this instrument for caries removal replaces both the explorer and the excavation spoon (commonly needed to evaluate the degree of decay removal) by simultaneously providing tactile sensation, self-evidently reducing preparation time.

However, an *in vitro* investigation of the caries-removal efficiency and efficacy did not show any significant difference between the conventional tungsten-carbide burs and ceramic. Nevertheless, its non-specificity is one of the most important aspect to be emphasized. Especially if tactile instrument is not used to check the cavity hardness, areas of underprepared dentin are likely to be left, as can be observed when caries was excavated using ceramic burs in 3D volumetric reconstruction of a carious tooth (Fig. 4).

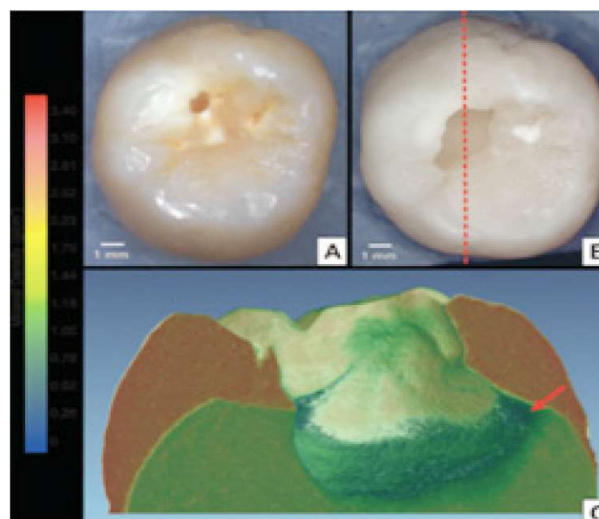


Fig. 4: Caries excavated using ceramic burs in 3D volumetric reconstruction of carious tooth

Further *in vivo* studies are unfortunately still lacking testing the effectiveness of these new burs.

Caries-disclosing Dyes

The most superficial carious layer is necrotic, highly decalcified contains irregularly scattered granular crystals and irreversibly denatured collagen fibrils as revealed by early TEM and biochemical characterization of carious dentin. The deeper “caries-affected” dentin layer exhibits decreased collagen crosslinks underneath this “caries-infected” dentin, but it comprises of needle like apatite crystals, regularly attached to collagen fibrils with no signs of bacterial invasion. Based on this knowledge, the ideal caries disclosing dye should stain solely the caries infected, but not the caries affected dentin.

0.5% Basic fuchsin in a propylene glycol base

0.5% basic fuchsin in propylene glycol is one of the first solution based caries disclosing dye and was claimed to stain exclusively the top, irreversibly destroyed carious layer, enabling differentiation from what could be left in the cavity. The mechanism of this differential staining was initially ascribed to the breakdown of the intermolecular crosslinks through bacterial lactic acid leading to irreversible collagen denaturation of caries-infected dentin. Later, rather than being specific for denatured collagen fibrils, the differential stainability was attributed.⁷ The exact mechanism for the differential staining is however still unknown.

The extent of dentin excavated by the fuchsin-guided method was larger than the extent of demineralized dentin as shown by conventional dental radiographs taken before histological sections were made in the first combined clinical/laboratory study on the reliability of this caries-disclosing dye. Later, others also showed that the cavity walls and floors were still fuchsin-stainable when caries was removed to determine the caries removal endpoint, both in primary and permanent teeth using conventional tactile probing. Some concerns were also raised regarding possible carcinogenic effects of fuchsin for intra-oral. For this reason, alternative

caries-disclosing dyes are sought.

1% Acid-red in propylene glycol base

An alternative to fuchsin for intra-oral use was launched called 1% acid-red solution (Caries Detector, Kuraray; Tokyo, Japan). However, clinical inconsistencies have been reported when assessing the presence of stained tissue at the DEJ by means of the usual tactile probing method. Two studies have shown that teeth could be stained with acid red when more than half of the teeth judged clinically are having no caries at the DEJ. Microbiological assessment failed to disclose differences in level of infection of the caries-stained and stainfree dentin at the DEJ.

Moreover, it has been demonstrated that using 1% acid-red solution can lead to staining of dentin clinically judged as “sound”, with a 30% false positive diagnosis of residual caries. Also, more than half of the teeth diagnosed as having “hard” and “sound” pulpal floors still took up some stain. In fact, it has been reported that because of its lower degree of mineralization, sound circumpulpal dentin takes up stain more easily.^(Fig. 5)⁷ For all these reasons, it is still much criticized to use caries-staining agents.

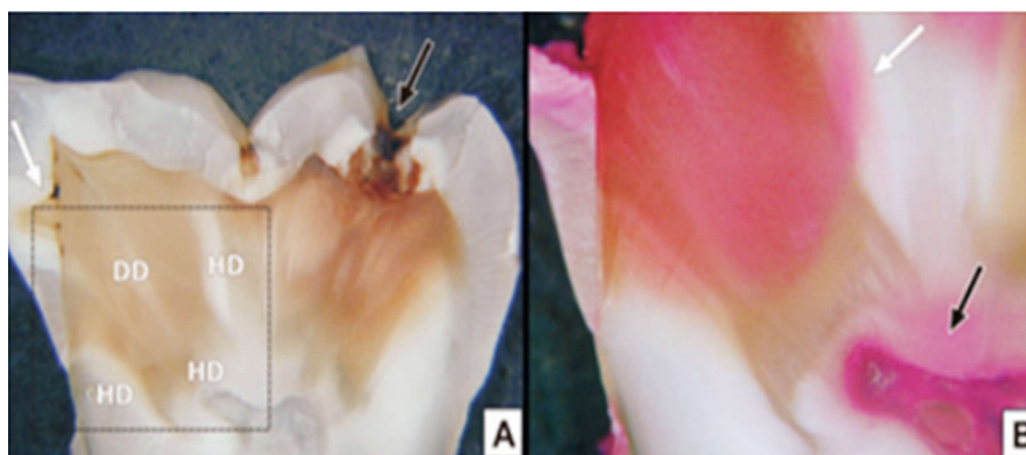


Fig. 5A: Mesiodistal section of a tooth presenting occlusal dentin caries (black arrow) and an approximal lesion (white arrow). DD = demineralized dentin; HD=hypermineralized dentin.

Fig. 5B: Higher magnification of the dotted area in Fig 5A after staining with a 1% acid red-in-propylene-glycol solution. Note staining of circumpulpal dentin (black arrow) and areas of hypermineralized dentin (white arrow).

Comparing acid red to basic fuchsin in propylene glycol base, acid-red produces a less intense and less bound stain with a more intense staining of the outer than the inner layer of carious dentin. Further in vitro studies have shown a low degree or absence of bacterial infection as well as a low level of peritubular dentin dissolution and increased

hardness as light pink staining from acid red, typically seen at the inner layer of carious dentin. For these reasons, the lightly stained tissue should not be removed.

Another concern is that the propylene glycol base due its low molecular weight (76 MW), of

both staining agents can easily penetrate into normal dentin which could thus also explain the overstaining frequently reported for commercial products, such as Caries Detector. This finding recently has led to the introduction of a 1% acid-red dye in a polypropylene glycol base (Caries Check, Nippon Shika Yahuhin; Japan). It makes propylene-glycol-based dye more caries specific because of the higher molecular weight (300 MW). The fluorescence readings of residual dentin after caries removal guided by acid red in polypropylene-glycolbased dye using DIAGNOdent (Kavo Dental; Jena, Germany) were higher than those when caries was removed using a propylene-glycol-based dye, indicating that former caries disclosing dye removed less of dentin.

Chemo-mechanical Excavation

Sodium hypochlorite-based agents

Sodium hypochlorite solution buffered with an amino-acid containing mixture of amino butyric acid, sodium chloride and sodium hydroxide is the first attempted chemical solubilizer that would selectively act on carious dentin.⁹ Caridex and Carisolv introduced in the year 1998 by Mediteam of Sweden are Sodium hypochlorite-based agents. Even though sodium hypochlorite is a nonspecific deproteinizing agent, the buffering effect of the amino acid mixture, originally intended to reduce the aggressiveness of sodium hypochlorite on sound dentin and to enhance the disrupting effect on degenerated collagen within carious dentin makes it more capable to selectively remove carious dentin. The resultant friable collagen fibrils could be more easily removed with a spoon excavator after chlorination and cleavage of the partially degraded collagen fibrils in the carious lesion.

Pepsin-based caries excavation

A new experimental gel considered as an alternative chemo-mechanical caries excavation agent consist of pepsin in a phosphoric acid/sodium biphosphate buffer (SFC-VIII, 3M ESPE; Seefeld, Germany). This includes Caricare and Papacare which was introduced in the year 2003 by in Brazil. The main advantage of this new enzyme based solution is that it is more specific as it digests only denatured collagen (after the triple helix integrity is lost) than the sodium hypochlorite based agents.¹ The phosphoric acid dissolves the inorganic component of carious dentin, while it at the same time gives pepsin access to the organic part of the carious biomass to selectively dissolve the denatured collagen (according to

the manufacturer). To avoid over-excitation, a prototype plastic instrument having hardness between that of sound and infected dentin should be used in combination with SFC-VIII gel. Heavily pigmented, arrested dentin caries is more resistant to pepsin digestion, but this does not present a major drawback to the method.

The new enzymatic caries-removing gel was able to remove equivalent volumes of carious dentin as Carisolv revealed by an x-ray micro-CT evaluation of carious teeth excavated with SFC-V. Figure 6 shows volume-rendering slices based on micro-CT data of a carious tooth before and after caries excavation aided by the prototype plastic instrument with SFC-VIII. Leaving residual dentin with an acceptably high mineral density (1.18 to 1.44g/cm³), SFCVIII selectively removed carious dentin.

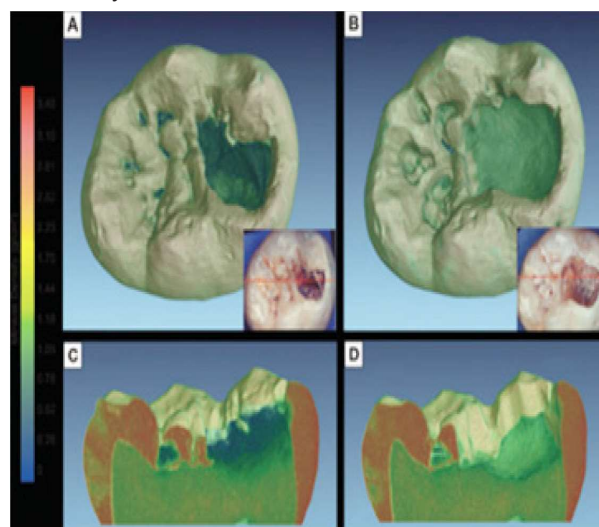


Fig. 6: Volume-rendering slices based on micro-CT evaluation data of carious tooth before and after caries excavation aided by prototype plastic instrument with SFC-VIII

Excavation by sono-abrasion

Caries excavation by “sono-abrasion” is based on the use of high-frequency, sonic, air-scaler handpieces under water cooling coupled with cutting tips. The tips perform an elliptical motion, while the handpiece oscillates in the sonic region (< 6.5 kHz).⁵ The cutting efficiency is reduced due to damping of the oscillations so, a maximum of 2-N torque force should be applied. Sono-abrasion excavation with diamond-coated tips appeared as efficient as conventional hand excavation using dental spoons, but it still takes more time than the carbide-bur excavation method. The Cariex system (Kavo Dental; Biberach, Germany) was launched more recently, including two sets of cutting tips: two diamond-coated tips with different diameters for enamel preparation and two tungsten-carbide

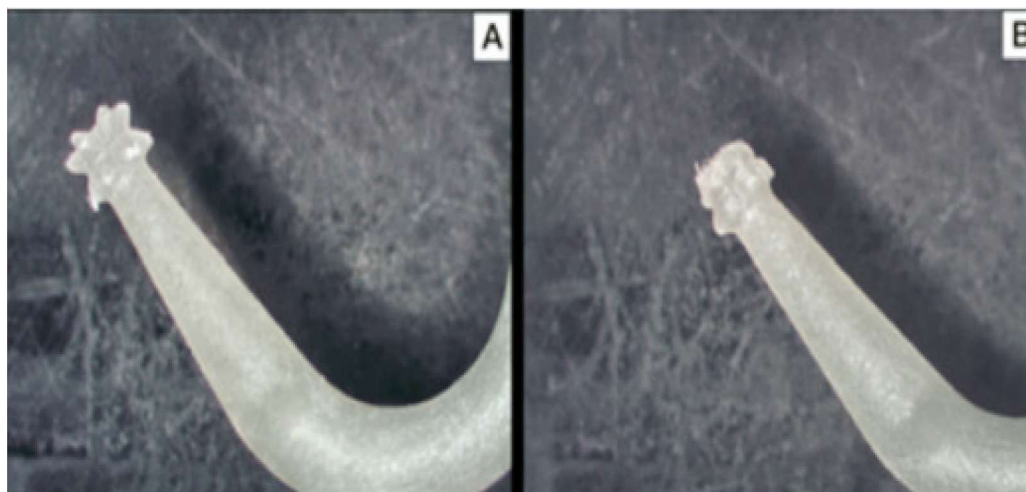


Fig. 7: Prototype plastic instrument (Star v 1.8, 3M ESPE) (A) before and (B) after caries

tips with different diameters for dentin excavation (Fig 8). The effectiveness and efficacy of these new

tungsten carbide tips however, have not yet been explored, in removing carious dentin.⁵

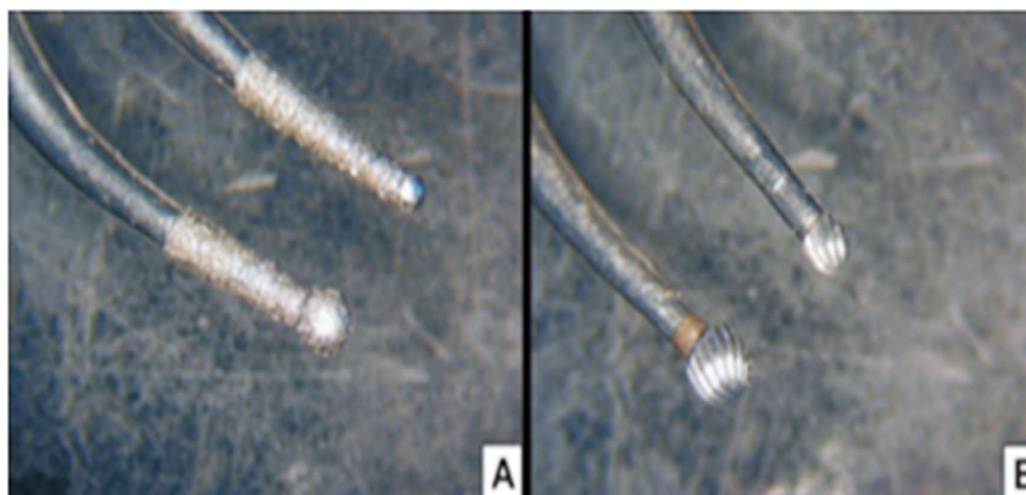


Fig. 8: (A) Diamond-coated tips with different diameters for enamel preparation, (B) Tungstencarbide tips with different diameters for dentin excavation

Air-abrasion Excavation

Air-abrasion systems for cavity preparation uses the kinetic energy of abrasive particles to cut tooth structure in a less invasive way. It also aids in rounding off internal and cavosurface angles which gives direct benefit of the subsequent adhesive restoration. Pure aluminium oxide particles (alumina) as the abrading agent have most frequently been used and they have high cutting effectiveness, chemical stability, low cost, low affinity for water neutral color. Air-abrasion systems using 27- μ m diameter alumina particles as described by Yazici AR *et al.*, are currently available to remove tooth staining or to prepare shallow cavities.⁵

Fluorescence-aided Caries Excavation ("FACE")

As a direct method to clinically differentiate between infected and affected carious dentin, this technique was developed. Based on the fact stated by Alfano RR *et al.*, several oral microorganisms produce orange-red fluorophores as by-products of their metabolism (porphyrins), infected carious tissue will fluoresce especially in the red fraction of the visible spectrum⁴ due to the presence of proto- and meso-porphyrins. In this way, it was thought to be convenient for clinicians for continuous visual detection of orange-red fluorescence during caries excavation.

Areas exhibiting orange-red fluorescence can be selectively identified and removed with the bur by

feeding a slow-speed handpiece with a fibre-optic violet light source (370 to 420 nm) and allowing the operator to use a 530-nm yellow glass filter.^{14,19}

Excavation Aided by Laser-induced Fluorescence

A laser-fluorescence device with wavelength of 655 nm² (Red) has been developed to diagnose hidden occlusal caries (DIAGN)dent, Kavo Dental, Biberach, Germany). A photodiode is attached to the tip of the handpiece and is irradiated. The intensity of fluorescence at occlusal surface is directly proportional to the degree of caries progression into dentin. For Fig. 8 caries to be operatively treated, more than 30 reading of fluorescence with histological presence of caries is considered. However, DIAGNO dent reading increases as caries advances near pulp as well as with stained, sclerotic dentin which can lead to false-positive threshold for caries removal.

Laser Excavation

“Light Amplification by Stimulated Emission of Radiation” is an acronym for the word “laser”, which means coherent and high-intensity light beams are produced from laser devices. Nowadays, there are broad indications for the use of lasers in dentistry, varying from caries diagnosis, caries removal, cavity preparation, disinfection of periodontal pockets or root canals, photodynamic therapy of oral tumours soft-tissue surgeries. Erbium lasers have been pointed out as most promising especially in the field of operative dentistry, due to their specificity in ablating enamel and dentin without side effects to the pulp and surrounding tissues when the appropriate parameters are employed as stated by Walsh LJ *et al.*,^{18,11} Paghdiwala was the person who first time tested the ability of Er:YAG laser.⁸ Stern and Sognates and Goldman *et al* investigated its effect on hard tissue.

The two types of erbium-based devices currently available in the market are the erbiumloaded yttrium-aluminium-garnet (Er:YAG) with wavelength of 2.78 µm and the erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) lasers with wavelength of 2.94 µm. Er,Cr:YSGG laser is more absorbed by hydroxyapatite crystals than Er:YAG but both are very close to absorption peak of water in infrared spectrum due to which their interaction with hard tissues is very similar.

CONCLUSION

To test the performance of dental adhesives by means of standard bond strength protocols, sound

human dentin is most convenient. This “model” dentin which exhibits “mixed” chemical and mechanical characteristics and includes caries-infected, caries-affected, sclerotic, eroded sound dentin is, however, far from the clinically more relevant substrate remaining after caries removal.²⁰ It remains clinically recommended to finish the cavity margins in clean/sound tooth tissue in order to achieve the best performance of adhesives irrespective of the caries excavation method chosen, while being at the same time is least invasive with regard to caries excavation and most conservative with regard to sound-tissue preservation.¹⁵

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Conflict of Interest: NIL

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