

Endoscopic Visualization of the Submarginal Gingiva Dental Sulcus and Tooth Root Surfaces

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Background: Direct, real-time visualization of the hard and soft tissues within the gingival sulcus may aid the clinician in diagnosis and therapy of periodontal disease. This report describes an endoscope specifically designed for this purpose and the interpretation of dental endoscopic images.

Methods: Medical endoscope technology was modified for application in the dental environment. A fixed, fused fiber optic bundle, less than 1 millimeter in diameter, was coupled to an active matrix LCD-TFT flat panel video monitor for viewing by the clinician. A bilumen sheath was designed to provide irrigation of the sulcus and a sterile barrier between the patient and the fiber bundle. Standard dental curets and ultrasonic scalers were adapted for instrumentation aided by the endoscope.

Results: Endoscope technology has been successfully adapted for use in periodontal diagnosis and therapy. Techniques for identification and interpretation of the hard and soft tissue images, as well as the location of root deposits and caries, have been developed.

Conclusions: The dental endoscope gives the clinician direct, real-time visualization and magnification of the subgingival tooth root surface, aiding in the location of deposits on the tooth root. The subgingival soft tissue, including the gingival attachment, sulcus wall, and sulcus contents, can be assessed. Identification and location of subgingival caries, root fractures, tooth root deposits, post perforations, and open restoration margins may aid the clinician in diagnosis and therapy. *J Periodontol* 2002;73:374-382.

KEY WORDS

Dental calculus/diagnosis; dental caries/diagnosis; scaling; periodontal diseases/diagnosis; periodontal diseases/therapy; dental instruments.

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Although scaling and root planing are central to the treatment of most periodontal diseases, the inability of the clinician to completely scale and root plane the majority of the subgingival root surface has been repeatedly demonstrated.¹⁻⁸ This is due in part to the difficulty of detecting some root deposits and to restricted access to root deposits.²⁻⁴ Visualization of the root surface during instrumentation may improve scaling and root planing efficiency.

Evaluation of subgingival root deposits, caries, root fractures, and soft tissues is critical to diagnosis, treatment planning, delivery, and evaluation of therapy. Non-invasive examination of the hard and soft tissues of the subgingival sulcus has been primarily restricted to tactile exploration or radiographs.

Non-invasive imaging of tissues and body structures with the aid of ultrasonics, magnetic resonance imaging (MRI), and computed tomography (CT) is commonplace in medicine and to a lesser extent in dentistry. Virtual-reality technology gives the physician real-time 3-dimensional projection of structures with non-invasive techniques of computed MRI. With the exception of computed tomography, none of these techniques has a current application in dentistry.

Recent advancements in fiber optic technology, coupled with modifications of the standard curet, periodontal probe, and ultrasonic scaler, have led to the development of an instrument which allows the clinician direct vision of the subgingival margin sulcus contents.

This report describes a dental endoscopic instrument and the images it presents to the clinician. Endoscopy is not a technique with which periodontists are familiar; therefore, this report will also discuss basic endoscopy principles and image interpretation in some detail.

PRINCIPLES OF FIBER OPTIC IMAGING

Endoscope is derived from the Greek words “endo” meaning “inside” and “skopein” meaning “to see.” In general, an endoscope has an input image lens located at the distal tip of the device, an image transmission system for relaying the image outside the body, an ocular to magnify and refocus the image for viewing by the eye, and a transmission system to provide illumination from a remotely located lamp. These elements are contained within a rigid or flexible tube. Endoscopes may also have a prism in front of the input lens to alter the direction of view and a video camera attachment to allow the user to view the endoscope image on a video monitor rather than directly viewing the image through an ocular. One or more channels may exist for the introduction of air, water, surgical instruments, probes, etc. A mechanical system may allow the tip of the endoscope to be articulated.

Current technologies available for endoscopes include input lenses, which can be conventional discrete lenses (as in a camera or microscope) or gradient index lenses (glass rod with radially varying index of refraction). The image transmission system can be a stack of discrete lenses (relay lenses), gradient index rod (longer version of gradient index lens), fiber optic bundle (many thousands of individual fiber optic strands), or fused fiber optic bundle (many thousands of individual fiber optic strands fused in a matrix of glass). Each of these technologies has advantages and disadvantages, which must be considered in light of the specific application.

An endoscope with conventional discrete input lenses and a relay lens train usually has the best image quality, but it is also the most expensive to manufacture, cannot be made very small, and the lenses must be kept in accurate alignment. In contrast, an endoscope with a gradient index lens and fused fiber optic bundle can be made relatively inexpensively and very small. These endoscopes are also very flexible.

Fiber optic endoscopes contain bundles of thin glass fibers that use the principle of total internal reflection to transmit light to and from the organ being viewed and to transmit almost 100% of the light entering one end to the other end. Fiber optic endoscopes are delicate and expensive instruments. The fibers are made of special glass, and each fiber is coated with a layer of glass with a different refractive index. In addition, the orientation of the fibers in a bundle used for endoscopy

has to be “coherent.” That is, the spatial orientation of each one of the thousands of fibers has to be constant and not tangled, like the fibers in a rope. Each endoscope has one set of fiber bundles to transmit light inside for illumination and another set to transmit reflected light out to the eye of the viewer. The use of fiber optic technology for both the illumination and image transmission allows the endoscope to be very flexible, owing to the ability of fiber optics to guide light around curves.

Fiber optic bundles used for large scopes (i.e., colonoscopes) may contain 100,000 individual fibers for image transmission, each typically 10 μm (0.010 mm) in diameter. The individual fibers are free to slide relative to the other fibers in the bundle (except at the end of the bundle), allowing the scope to remain flexible. One hundred thousand 10 μm diameter fibers form a 3.3 mm diameter bundle, even if ideally packed. Breakage of individual fibers in these endoscopes is common, and individual black spots accumulate in the image during the lifetime of the endoscope.

Fiber optic bundles used for smaller scopes, such as angioscopes for example, may contain 10 thousand 2 to 3 μm diameter (0.002 to 0.003 mm) fiber cores supported in a glass matrix (typical spacing between individual fiber cores of 3.6 to 4.2 μm). This smaller individual fiber size allows for construction of a small instrument. However, since the individual fibers are not free to move relative to the other fibers, this design is considerably less flexible than the free fiber design. Consequently, this design is reserved for the smallest endoscopes where the fused bundle size still remains flexible enough for the application (typical data for these bundles are: 0.25 to 0.50 mm with 2,000 to 10,000 individual fibers in the bundle). Larger fused fiber optic bundles have also been produced with 30,000, 50,000, 70,000, and even larger fiber count bundles. Although these bundles are quite rigid, they hold promise as a lower cost replacement to relay lenses and rod lenses in larger, rigid endoscopes.

DENTAL ENDOSCOPE

The dental endoscope^{||} was developed with the intention of providing imaging below the marginal gingiva for diagnosis and as an aid in treatment of periodontal disease. The dental endoscope has a subgingival probe adapted to provide fiber optic imaging; a sheath to provide a sterile barrier between the patient and endoscope; a peristaltic pump to provide irrigation to the working field; a lamp to provide illumination to the working field; a CCD (charged couple device) video camera to capture images of the working field for display; and an active matrix LCD-TFT flat panel video display monitor for live viewing of the working field.

|| Dentalview Co., Irvine, CA.

A family of dental instruments including curets, explorers, and an adapter for ultrasonic scalers has been designed to accept the imaging system.

Curets

A stainless steel formed tube was welded to the shank of the curet near the cutting blade (Fig. 1). This tube is designed to accept the endoscope (with window sheath) and to hold the distal end of the endoscope in a precise location. This tube also directs irrigation fluid delivered by the attached endoscope/window sheath onto the blade of the curet.

A gingival retractor (soft tissue shield) was added to the blade of the curet. This retractor holds the gingival tissue away from the tip of the endoscope, providing a clear view of the curet blade and adjacent tooth surface. The curet handle was modified with a longitudinal slot and clip. The body of the endoscope/window sheath can be laid into the slot and the body pressed into the clip. This streamlines the profile and prevents the endoscope from being dislodged from the curet during use.

Explorer/Probe

The explorer/probe is a stainless steel tube welded to a handle (Fig. 2). This tube accepts the endoscope/window sheath. The distal tip was shaped to provide a gingival retractor. This tube also directs irrigation fluid delivered by the attached endoscope/window sheath onto the retractor. As with the curet, the explorer/probe has a slotted handle to accept the endoscope body.

Ultrasonic Adapter

The ultrasonic adapter, constructed of stainless steel collar, strut, and tube, was welded together into a single unit (Fig. 3). The stainless steel collar fits into the end of a standard ultrasonic scaler and is locked in position with a screw. When positioned and locked into place, the tube is positioned along side of the scaler tip. This tube, similar to the explorer, accepts the endoscope/window sheath and locates the tip of the endo-

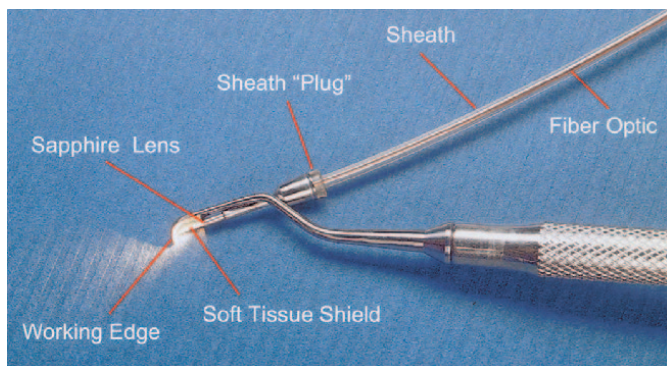


Figure 1.

Curet modified for use with the dental endoscope.

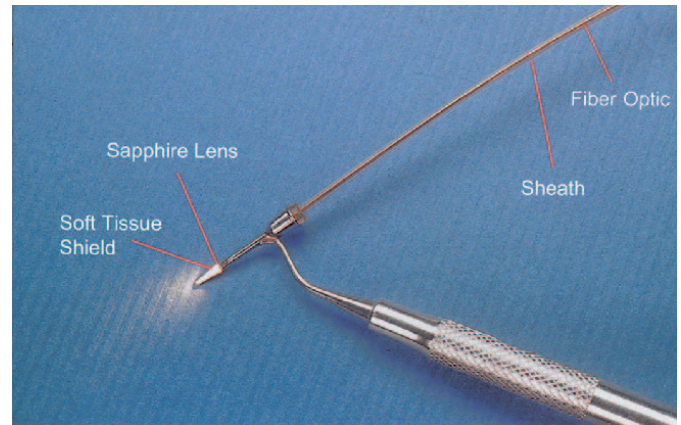


Figure 2.

Explorer/probe modified for use with the dental endoscope.

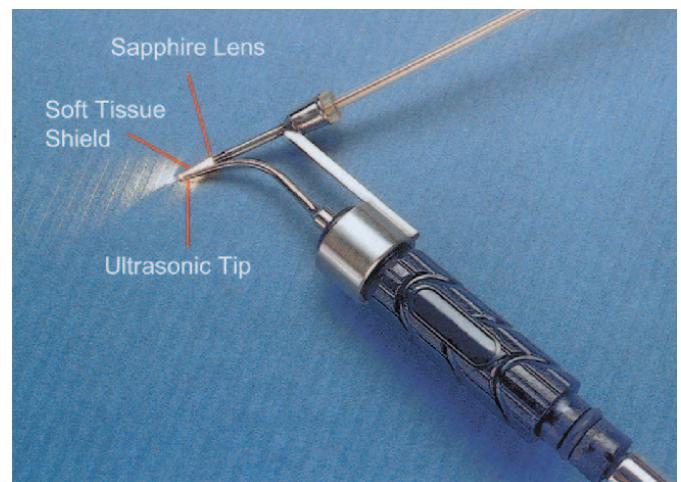


Figure 3.

Ultrasonic scaler adapted for use with the dental endoscope.

scope in position to view the scaler tip and adjacent tooth surface. The distal tip of the tube was shaped to provide retraction of the gingival tissue to ensure an unobstructed view of the scaler tip. This tube also directs irrigation fluid delivered by the attached endoscope/window sheath onto the retractor.

All of the instruments are reusable and compatible with standard autoclave sterilization. The curets, as usual, require periodic sharpening and should be replaced if the blade cross-section becomes too thin. Otherwise, with adequate cleaning and care, all of these instruments have an indefinite lifetime. The instrumentation has been designed so that the endoscope can be rapidly switched from one instrument to another.

Endoscope

A flexible endoscope design was selected for use with the dental instruments. The endoscope has a gradient

index lens located at its distal end. The lens is mounted on the end of a 2 m long fused fiber optic bundle containing 10,000 individual light guiding fibers (pixels). Surrounding the fused bundle and lens are 15 large core plastic fiber optic strands for carrying illumination light from a remote lamp to the operative site. The lens, image transmitting fiber, and illumination fibers are incased in a flexible plastic tube. The entire assembly at the distal end is 0.85 mm in diameter and approximately 2 m long. The endoscope is equipped with a spring-actuated connector located approximately 1 m from the distal end. This connector attaches to the window sheath (see below) with the spring, assuring that the distal lens of the endoscope maintains contact with the distal window of the window sheath. Optical connectors are provided at the end of the endoscope for attachment to a video camera and illumination lamp.

Endoscope Sheath

Because the distal tip of the endoscope comes in direct contact with the patient, sterilization or some form of barrier is required between uses. As sterilization is either time consuming (liquid chemical soak, 10 hours) or reduces the expected instrument lifetime (12 autoclave cycles is the generally accepted maximum), a disposable sheath that can be quickly and easily installed was developed.

For the dental endoscope system, a sterile, disposable sheath that fits over the endoscope providing a barrier to pathogens was developed (Fig. 4). The sheath can be installed on the endoscope in a few seconds and removed and discarded after use. The sheath is fitted with a sapphire window at its extreme distal end, allowing illumination to the working field and a

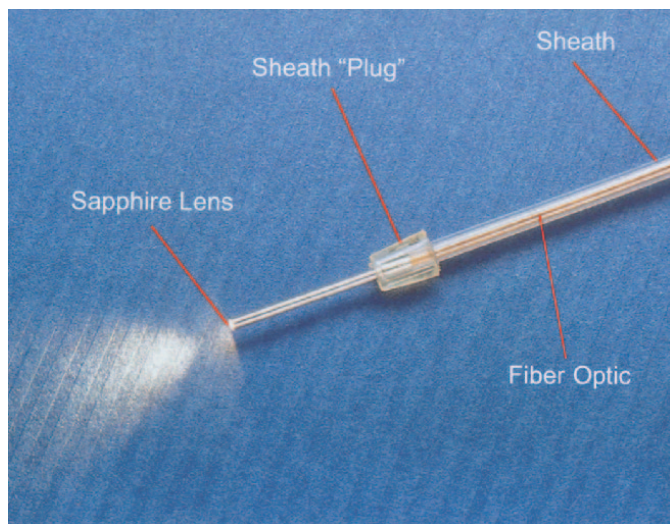


Figure 4.
Dental endoscope sterile sheath.

clear view by the endoscope. The sheath concept provides other benefits. When the instrument is placed subgingivally, a moderate amount of bleeding might occur, which would obscure the field of view and render the endoscope blind. A separate channel in the window allows for the infusion of water from a water source attached to a plastic connector located on the proximal end of the sheath. The water is carried to the distal end where it sprays out and clears the viewing field. The window sheath also is fitted with a small plastic connector plug at its distal end, which fits into a mating stainless steel receptacle built into each instrument (curet, explorer, and ultrasonic adapter). This plug allows for precise positioning of the endoscope tip relative to the working end of the instrument.

The dental endoscope is provided with a standard peristaltic pump for delivery of irrigation fluid, via the window sheath, to the attached instrument and, subsequently, working field. The high-output lamp is equipped with a fiber optic cable that carries the light to the endoscope. Within the endoscope are 15 light fibers that carry the light to the endoscope's distal end, which exits at the distal end and illuminates the working field.

The endoscope is connected to a medical grade CCD video camera via a camera coupler. The camera coupler magnifies and focuses the image transmitted by the endoscope onto the CCD image sensor of the camera. As with all CCD cameras, the light is converted to electrical signals by the CCD sensor. The electrical signals are transmitted to the camera control unit, which digitizes the signal and applies various processing signals (gain controls, white balances, etc.). The resulting digitally processed signal is converted to standard S-video signal (Y/C) for output to an attached monitor.

The endoscope used was provided with a 12.1 inch diagonal, active matrix, thin film transistor, back lit, LCD display. The display provides 800 pixel horizontal \times 600 pixel vertical resolution. Although the input signal is 30 frames/second and (60 fields per second, 2 interlaced fields per frame) (standard NTSC video), flicker on LCD-TFT displays is markedly absent when compared to cathode ray tubes (CRT), since each pixel is on during the entire time between refreshes. Also, the small size and light weight of these displays allow them to be mounted on an arm and positioned close to the patient. This enables the user to easily glance up to the display without turning his/her head and minimizes refocusing the eyes, which could lead to eye strain.

Magnification

The objective lens of the endoscope has a nominal 70° field of view in air. Under water, the field of view is decreased due to the index of refraction of water:

$70^\circ/1.33 = 53$ degrees. The distance between the endoscope lens and the cutting edge of the curet is 4.5 mm. Thus, in the plane of the cutting edge, the field of view is a circle with diameter $2 * (4.5 * \tan [53/2]) = 4.5$ mm. This varies, of course, with different distances from the endoscope lens.

The endoscope is adjusted so that a field between 1.8 mm and about 5 mm is in focus in air. Under water, this changes to $1.8 * 1.33$ to $5 * 1.33 = 2.4$ mm to 6.6 mm. The midpoint in the depth-of-focus range is 4.5 mm ($= 2.4 + [6.6-2.4]/2$), with about 2 mm closer or further away also in sharp focus. The distance from the endoscope lens to the extreme tip of the explorer and the ultrasonic tip is 4.5 mm. For the instruments, the main point of interest (curet edge, explorer tip, scaler tip) is centered in the depth of focus in a 4.5 mm diameter field of view. Objects 2 mm closer or 2 mm further away will also be in sharp focus.

The best gauge of magnification is the ratio of the image diameter on the screen to the object diameter in the endoscope best focus plane (the 4.5 mm diameter field mentioned above). The screen image diameter is set to 110 mm so the magnification is $110/4.5 = 24\times$ (object in water). Other magnifications can also be obtained. For example, if viewing an object 2.4 mm away (also in water), then the field of view is only 2.4 mm in diameter and the magnification is $110/2.4 = 46\times$. On the other hand, at 6.6 mm distance (still in focus), the field of view is 6.6 mm, for a $15\times$ magnification. So, the magnification realized on the monitor ranges from $46\times$ to $15\times$, depending on the distance of the object from the tip of the endoscope. The magnification at the plane of the cutting edge of the curet is $24\times$.

Interpretation of Images

As discussed above, an endoscope with conventional discrete input lenses and a relay lens train will have the best image quality, but is also the most expensive to manufacture, cannot be made small, and the lenses must be kept in accurate alignment. In contrast, an endoscope with a gradient lens and a fused fiber optic bundle can be made less expensively, in a smaller size, and be flexible. The dental endoscope is the latter type, meaning the image is less than perfect. A pictorial and diagrammatic presentation of the most basic image is presented below. It is not exhaustive, because as the instrument is used, additional observations will be made and reported. It is important to understand several instrument parameters before attempting to interpret the images.

Magnification

The image that is projected onto the monitor is always a round image with the field of view varying between 2.4 to 6.6 mm in diameter. The magnification on the monitor can be from $46\times$ to $15\times$ depending on the distance of the object from the tip of the endoscope. The

magnification, for example, at the cutting edge of the curet is $24\times$. The clinician must keep in mind that the images are highly magnified.

Relative Motion

It is important to note that the endoscope is mounted on the end of the instrument and, as a result, the image on the monitor appears as if the tooth, rather than the instrument, is moving.

Orientation

The instrument has a retractor to displace the soft tissue away from the field of view. With the probe/explorer, half of the screen will be the retractor with a bright reflection on both outer edges of the shield. The curet retractor will look like a curet tip extending about a third into the field of view. By training the eye to locate the retractor first, the clinician can make the mental adjustments for magnification, relative motion, and orientation.

Sulcus Environment

The gingival sulcus is not a dry, empty void. The image on the screen can appear disquieting to the clinician who has not thought about the milieu of the gingival sulcus, which is filled with fluids (sulcular fluid, blood, and water from the instrument), debris, plaque, and granulation tissue. As the instrument is used, there will be a constantly changing field of sulcus contents. It is helpful to “look beyond” or “through” the debris and concentrate on the root surface. Structures do not appear as the dental clinician would expect. For example, black calculus appears white, almost crystalline, under the magnified intense light of the endoscope. Depressions, stains, and shadows on the root surface may appear as caries or deposits. As the clinician moves the instrument around a calculus deposit, it may appear to change color, consistency, and form. One must keep in mind the magnification and the intense

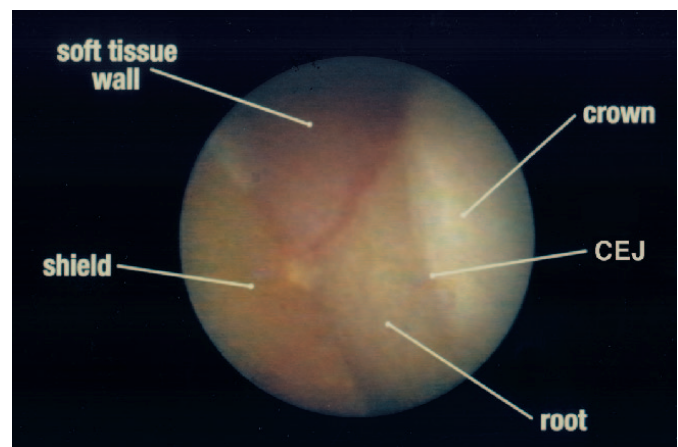


Figure 5.

Subgingival view of a 6 mm periodontal pocket.

illumination of all defects, structures, and deposits and that one is most often looking down or across the root surface. This has been described by some clinicians as “looking down a well.”

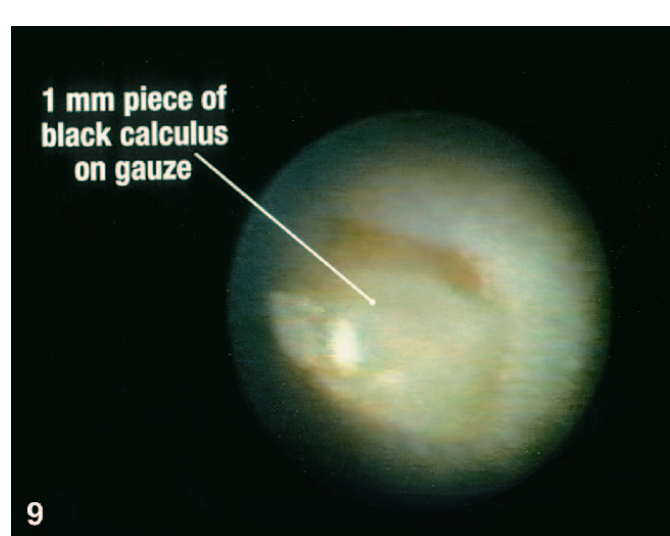
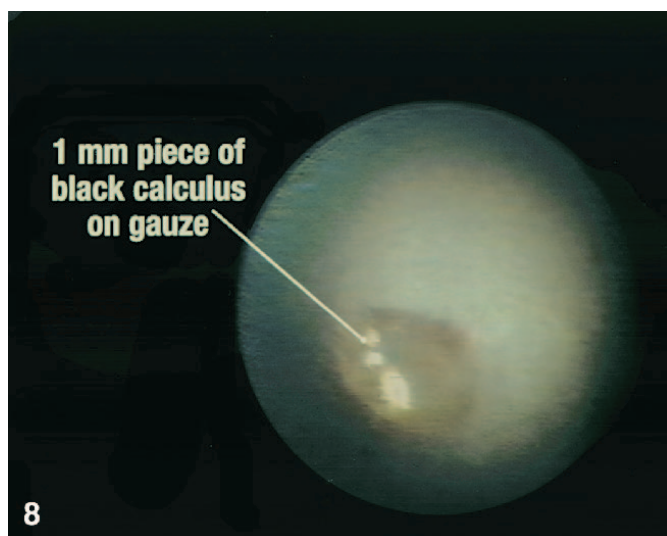
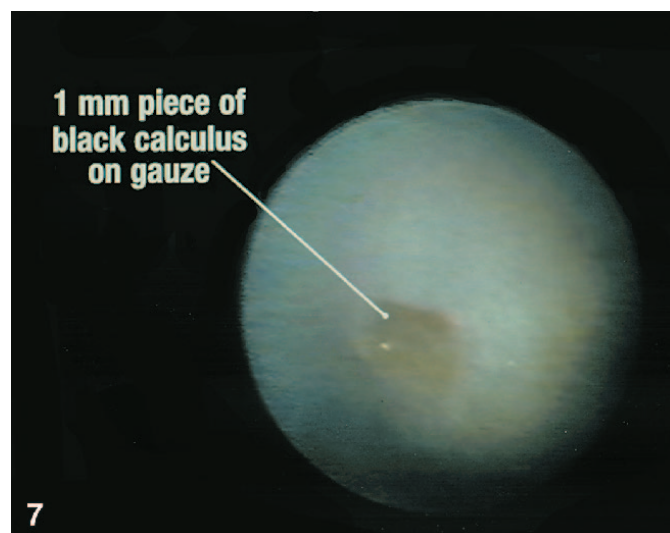
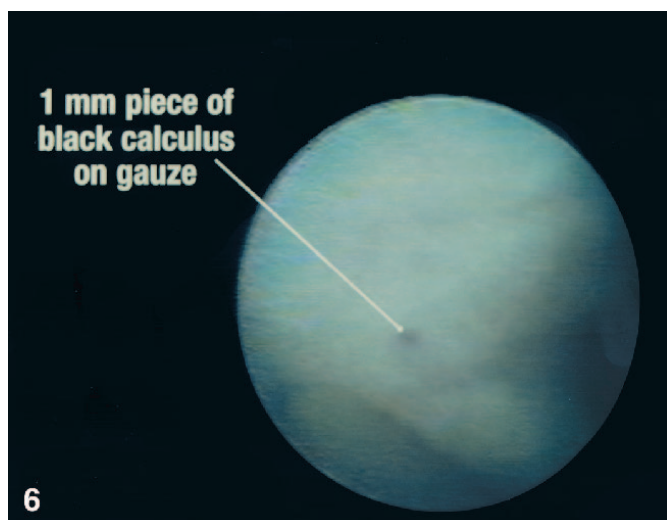
Endoscope Images

These images are reproduced from a digital video recorder attached to the video monitor for the endoscope. They are unaltered photographs made from digital tape, downloaded to a computer hard drive, and labeled. Prints are produced from the computer image.

The clinician should first locate one or more of the following anatomical landmarks: crown of the tooth, cemento-enamel junction (CEJ), soft tissue of the gingival sulcus, or the instrument shield. Figure 5 is a view of the gingival sulcus and the root surface. The

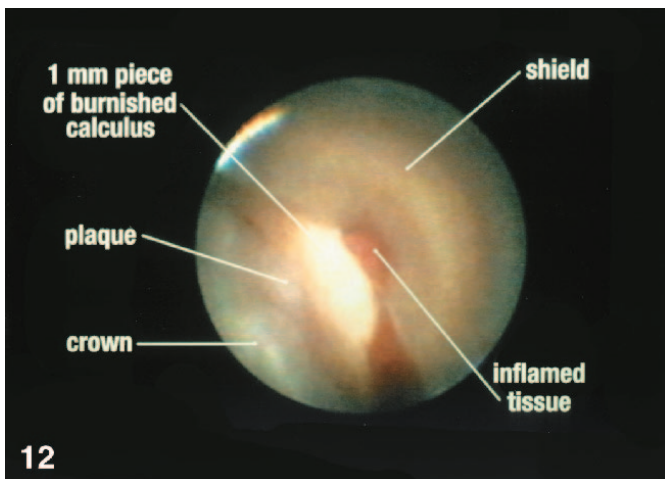
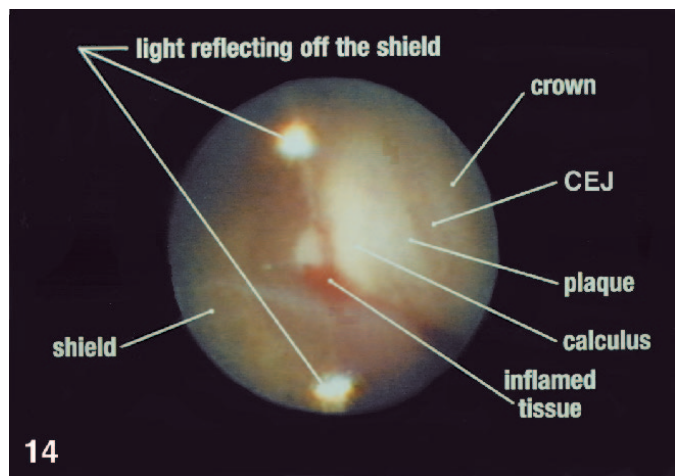
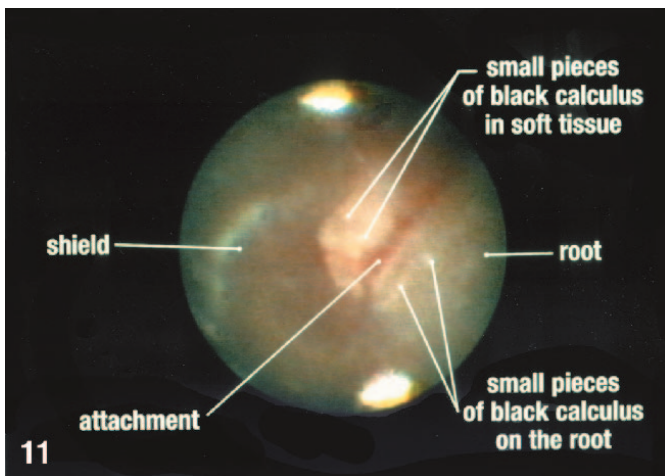
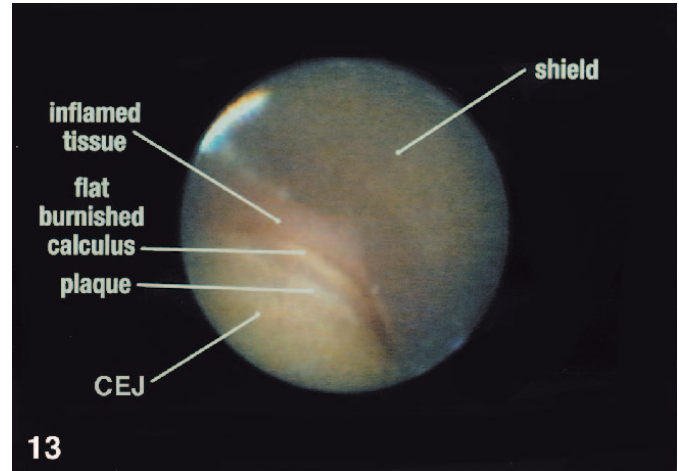
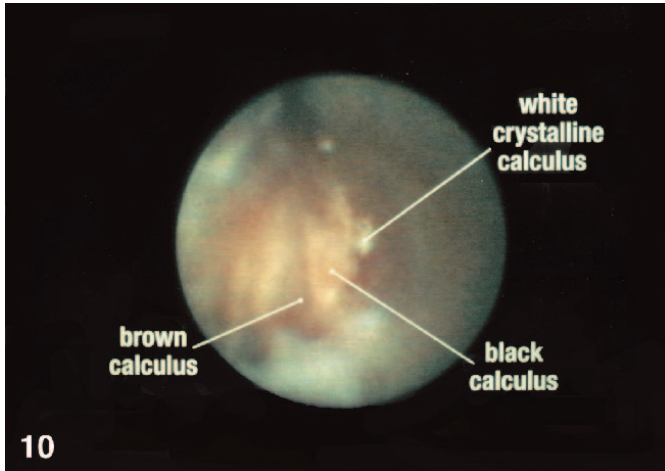
sulcus depth is 6 mm and the perspective is one of looking down the root surface at approximately 45°. A small band of inflamed tissue adjacent to a moderate amount of plaque on the root surface can be observed. Once these are identified, the endoscopic instrument should be moved slightly to establish perspective, focus, orientation, and a sense of motion of the instrument relative to the landmarks identified. The relative motion is such that the root surface and the other structures appear to move and the instrument (shield) appears to remain stationary. As one moves the instrument, the tissue structures move as a panorama past the shield.

A black piece of calculus changes its apparent color when observed through the endoscope at a closer perspective (Figs. 6 through 9). The color becomes lighter



Figures 6 through 9.

Black subgingival calculus as depicted by the dental endoscope at distances ranging from 6 cm to 2 mm. The calculus appears white in the closer views.



Figures 10 through 12.

Subgingival calculus. Note the variation in apparent color.

Figures 13 and 14.

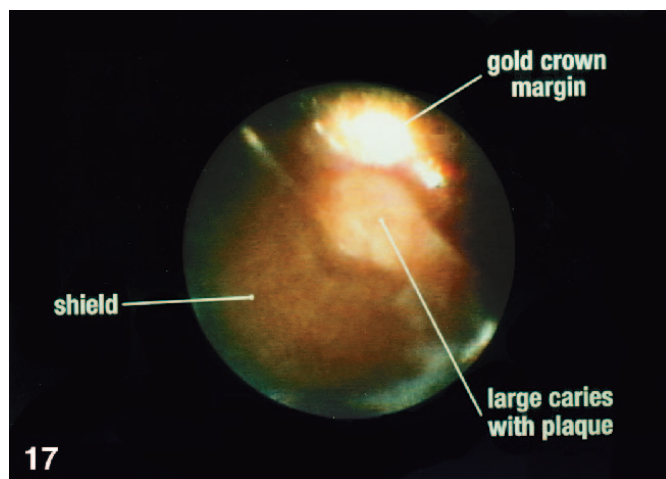
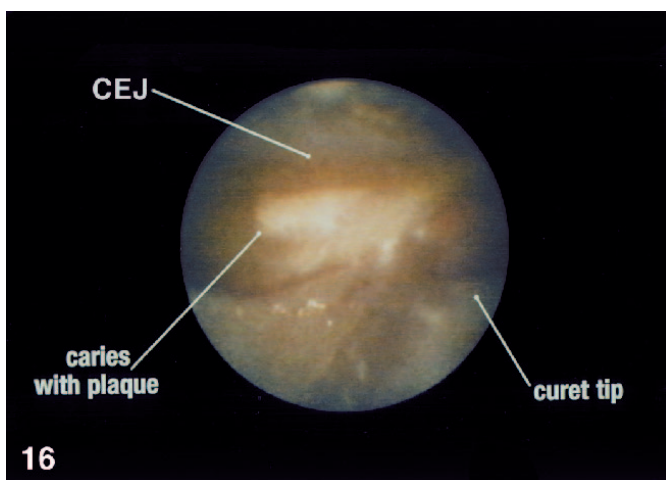
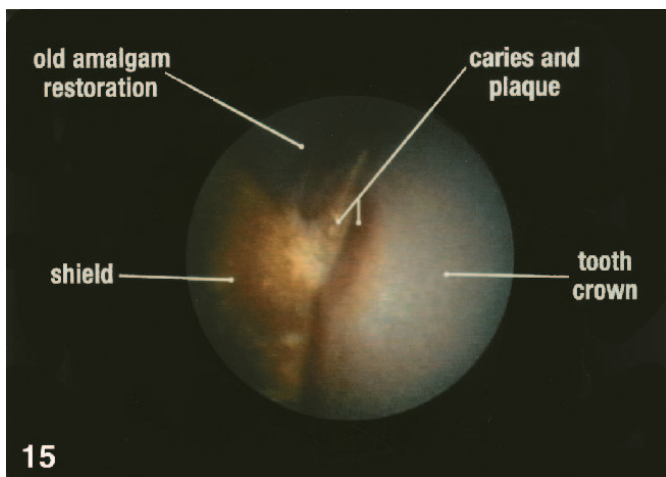
Illustrations of flat, burnished calculus, not detectable by tactile exploration.

chalky white to shades of opaque brown (Figs. 10 through 12).

It is quite common to observe deposits of flat, burnished calculus (Figs. 13 and 14) on the root surface after scaling and root planing. One can observe these deposits with the endoscope, but they cannot be detected with an explorer, periodontal probe, or curet. This is true even when directly visualizing the deposits with the endoscope.

Caries

A frequent finding with the dental endoscope is caries, which cannot be detected by radiograph or clinical examination (Figs. 15 through 17). The magnification of caries is, on average, between 15× to 46×. These can be very small lesions usually at the margin of a restoration, which appear large and extensive due to magnification. The caries in Figures 15 and 17 were not detected on initial examination, nor were they detected with an explorer after discovery with the endoscope.



Figures 15 through 17.
Subgingival caries.

Radiographic and clinical examination may not disclose the occasional large carious lesion. The caries seen in Figure 17 were missed radiographically (Fig. 18) and clinically by 3 dentists who had recently examined the patient.

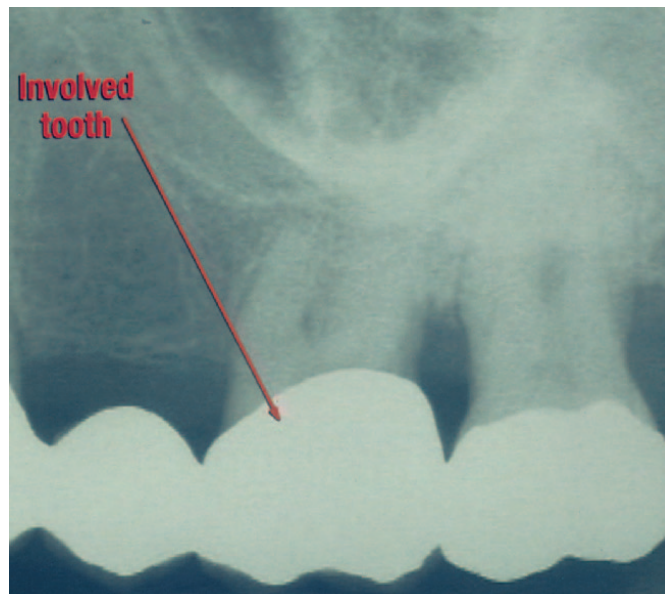


Figure 18.
Radiograph of caries in Figure 17. The caries are located on the mesial lingual aspect of tooth #14.

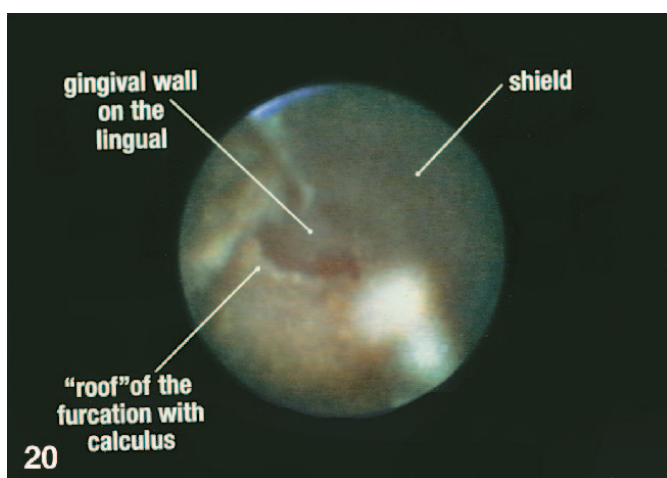
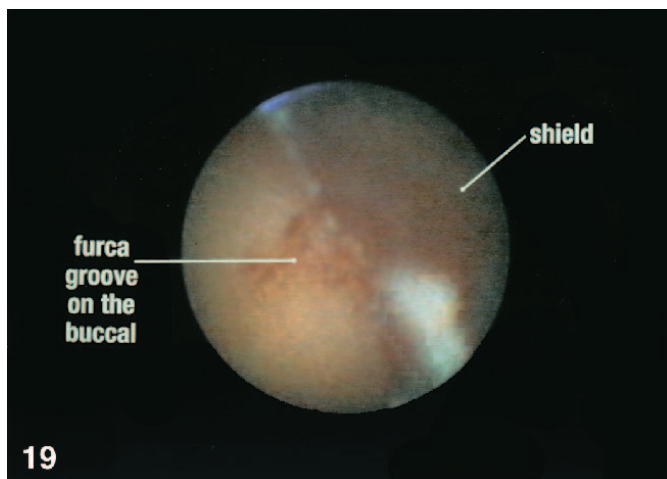
Furcations

Furcations with significant horizontal and vertical probable depth lend themselves to exploration with the dental endoscope. Figures 19 and 20 are views of a buccal furcation of a mandibular first molar. In Figure 20, the furcation is seen about 5 mm subgingivally. As the endoscope is placed further toward the lingual aspect, calculus and plaque on the “roof” of the furcation and soft tissue on the lingual aspect of the tooth can be observed (Fig. 20). Calculus on the mesial aspect of the distal root can be seen in Figure 21. This calculus is 6 mm apical to the gingival margin and is not detectable by exploration with a periodontal probe or a dental explorer.

DISCUSSION

The inability of the clinician to completely scale and plane the majority of the root surface apical to the gingival margin has been repeatedly demonstrated.¹⁻⁸ This is thought to be due, in part, to failure of the clinician to detect some root deposits and to restricted access to root deposits. The dental endoscope provides direct vision of the subgingival margin root surface and may provide the clinician with the ability to locate and evaluate the extent and nature of subgingival root deposits.

Not all sites are accessible for viewing and instrumentation with a dental endoscope. However, preliminary studies indicate that up to 95% of all root surfaces may be accessed for visualization with the instrument.⁹ In addition, root deposits that are not accessible to non-surgical root instrumentation are occasionally viewed, and these sites may require surgical intervention.



Figures 19 and 20.

The buccal furcation of a mandibular first molar, subgingival view.

The basic clinical skills required to gain access to subgingival structures and interpret the images can be acquired with 8 hours of training. Mastery of these techniques can take 2 to 4 weeks of clinical experience. Rapid location and accurate assessment of subgingival deposits can become a relative routine clinical procedure.

We suggest that the time-consuming aspect of endoscope-aided subgingival, non-surgical scaling and root planing will be the actual mechanical debridement, not the location of root deposits. Currently available instrumentation will be ineffective for complete debridement in areas such as furcations, the mesial aspects of maxillary bicuspid, and tooth root flutes and grooves in deep periodontal pockets.

CONCLUSIONS

The dental endoscope gives the clinician direct, real-time visualization and magnification of the subgingival margin root surface, deposits on the root, soft tissue, including the gingival attachment, and sulcus contents. Identification and location of subgingival root deposits,

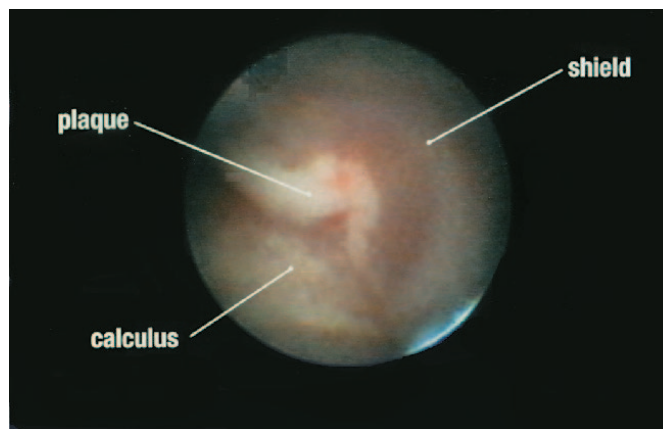


Figure 21.

Calculus on the mesial aspect of the distal root of the mandibular first molar (6 mm subgingivally).

caries, and root fractures may aid the clinician in diagnosis and therapy.

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