roots

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A description, diagnosis and
discussion of optional management

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in root-canal disinfection

oemus

Interdisciplinary dentistry:
An absolute essential

Dr Gary Glassman

_**We are fortunate to live** in a society in which we have access to comprehensive health care and in which the level of dental care is considered among the best in the world. Unfortunately, this is not the case for countless other regions in the world.

In an attempt to pay it forward, I have for many years now been doing charitable work for the people of Jamaica, in addition to teaching the local dentists there how to provide proper endodontic care to their patients. Recently, a new dental school was constructed at the University of Technology in Kingston, Jamaica, and I was appointed Adjunct Professor of Dentistry and was asked to construct an endodontic programme, which will produce its first graduates in 2015. Following the graduation of these well-trained individuals, for the very first time, the 2.6 million residents of Jamaica will finally have accessible to them the number of dentists per capita that is required.

This past weekend I had the good fortune to return to Kingston and speak at the Rosalie Warpeha Caribbean Institute for Strategic Planning and Research in Oral Health.
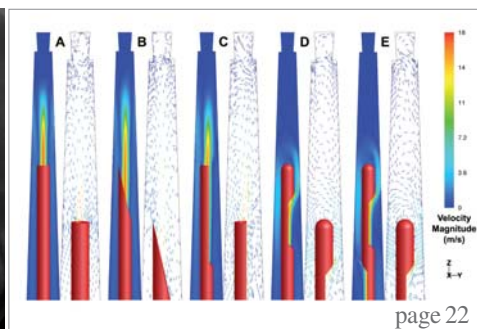
I spent the weekend with a restorative dentist, an oral radiologist, a cosmetic dentist, an orthodontist, an oral pathologist and a paediatric dentist. What started out as social events quickly became brainstorming sessions, during which we all soon realised how integrated *all* disciplines of dentistry need to be but are unfortunately lacking in many respects.

As specialists, we tend to pigeonhole ourselves into our specific areas of expertise and often lose perspective, unable to see the forest for the trees. Discussions of horizontal and vertical integration in dental school curricula soon became a topic of total agreement among our esteemed colleagues. A continuum of integration through case learning is both beneficial and essential. This allows students to be capable of using their acquired foundational knowledge to approach subject matter with critical thinking skills.

Case-based teaching has a long tradition in medicine, nursing, law and many dental programmes. It is an important method of distilling the basic knowledge learnt in texts and lectures and applying it to a patient in a practical manner. As practising dentists, many of us were not exposed to this type of learning, and were left alone with the skills that we acquired in dental school to figure it out on our own.

Through properly structured continuing education programmes, we can return to the roots of education and combine our knowledge in an interdisciplinary manner by conferring intimately with members of other specialties, through panel discussions and case presentations. By approaching learning in this capacity, all of our patients in all of our respective countries will benefit from continued oral health, with successes that will be enjoyed at levels never seen before.

Dr Gary Glassman
Doctor of Dental Surgery
Fellow of Royal College of Dentists of Canada

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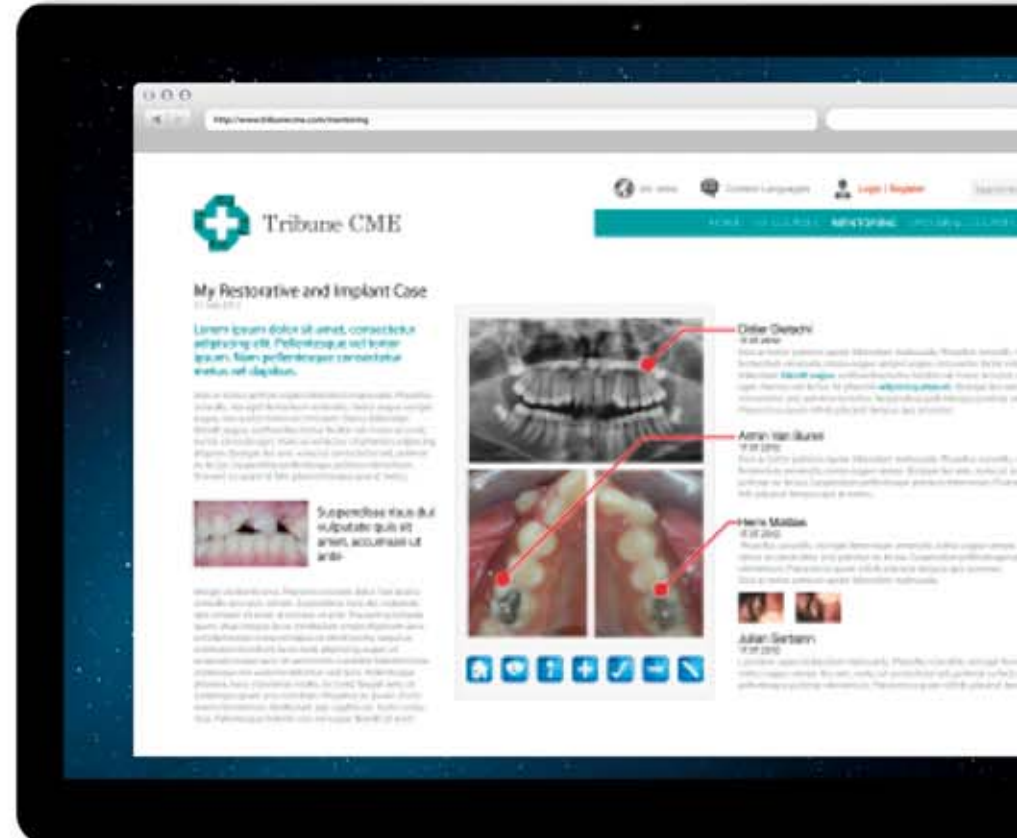## Session II: 24 - 27 April 2013 (4 days)

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Invasive cervical resorption (ICR): A description, diagnosis and discussion of optional management —A review of four long-term cases

Author_ John J. Stropko, USA

_Abstract

The external resorptive process of the permanent dentition referred to in this article has been given several different terms over the years, so therefore some confusion exists. Just a few popular labels are extra-canal invasive resorption (ECIR), invasive cervical resorption (ICR), external cervical resorption (ECR),

subepithelial external root resorption, and idiopathic external resorption. They all refer to a relatively uncommon form of dental resorption. If left undiagnosed, misdiagnosed, mistreated or untreated, it will usually be quite devastating for a tooth. An Australian dentist, Dr Geoffrey Heithersay, has contributed much to the literature regarding all facets of this type of dental resorption. His work has become the basis of research and treatment. With few changes over the past several years, the aetiology, predisposing factors, classification, clinical and radiological features, histopathology and the treatment of this resorptive process he described are still used in our practice today.[1–4, 6] For this reason, this article will adopt the same nomenclature used in his numerous publications: invasive cervical resorption (ICR).

I will present treatment of four cases—two Class 2 cases, one Class 3 and a Class 4—in an attempt to share some experiences, both good and bad, over the years when dealing with ICR. Hopefully, the following article will be successful in removing some barriers that may currently prevent the doctor from accepting the challenge presented by the next case of ICR.

_Aetiology of invasive cervical resorption

ICR is not a common occurrence, is insidious and often an aggressive form of external tooth resorption, and can occur in any tooth in the permanent dentition.[4] External resorption can be divided into three broad groups: (*a*) trauma-induced tooth resorption; (*b*) infection-induced tooth resorption; and (*c*) hyperplastic invasive tooth resorption.[5] ICR is one form of hyperplastic invasive tooth resorption.[6] It results in the loss of cementum and dentine by an odontoclastic type of action.[7] The ICR lesion begins just apical of the epithelial attachment of the gingiva at the cervical area of the tooth, but can be found anywhere
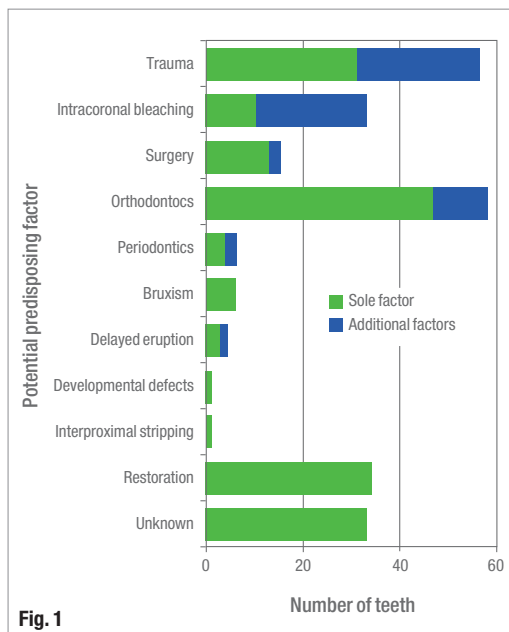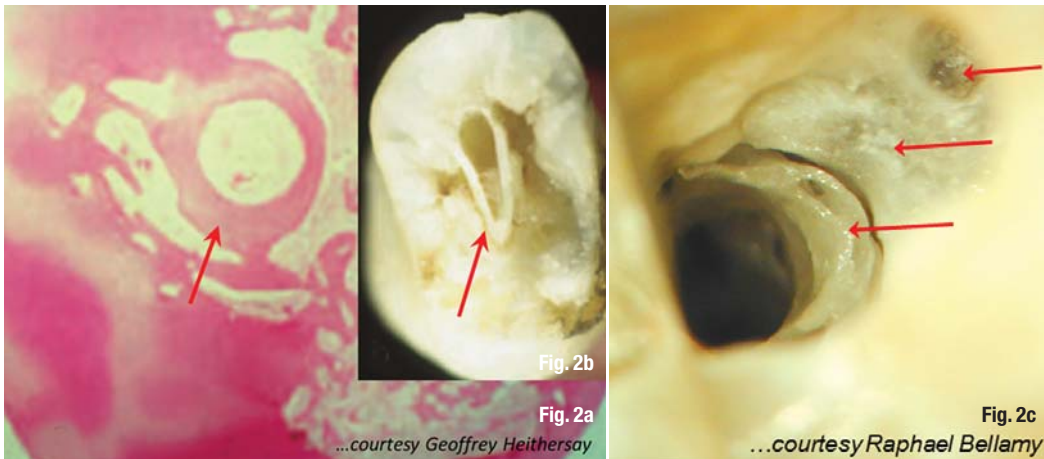

Fig. 1_ Invasive cervical resorption: Distribution of potential predisposing factors for patients. (Reproduced with permission from Quintessence Publishing).[2]

Figs. 2a & b_The pulp remains intact, encircled by a narrow band of dentine (red arrows). Histologically, the pulp remains intact and is protected from the extensive resorptive lesion by a narrow wall of dentine **(a)**. A low powered photograph shows the walling off of the pulp by dentine, protecting it from the surrounding extensive resorptive process **(b)**. (Slide adaptation reproduced with permission from Dr Geoffrey Heithersay.)

Fig. 2c_High magnification of the distal orifice of a mandibular second molar being treated for ICR. The pulp remains intact encircled by a narrow band of dentine (bottom arrow). The affected dentine can be observed (middle arrow) and a possible distal penetration area (top arrow). (Slide adaptation reproduced with permission from Dr Raphael Bellamy.)

Figs. 3a & b_Both the clinical view **(a)** and histological view **(b)** show how the dentine has been extensively replaced by a bone-like tissue. A mass of fibro-vascular tissue infiltrated with inflammatory cells is evident, located within a large resorptive cavity that has a wide connection with the periodontal tissue (large arrow). A small section of intact pulp can be seen on the superior aspect of the section (small arrow). Haematoxylin-eosin stain; original magnification X 30. (Reproduced with permission from Quintessence Publishing and Dr Henry Rankow.)[1]

on the root.[8] Owing to its location, the beginning lesion is difficult or almost impossible to recognise. The exact mechanism of ICR is still not clearly understood. Microscopic analysis of the cervical region of teeth has shown that there appear to be frequent gaps in the cementum in this area, leaving the underlying mineralised dentine exposed and vulnerable to osteoclastic root resorption.[9] It is broadly accepted that either damage to or deficiency of the protective layer of cementum apical to the gingival epithelial attachment exposes the root surface to osteoclasts, which then resorbs the dentine.[7] In general, an area of radicular dentine around the cervical area of the tooth may be devoid of the protective covering of cementum, exposing the root surface to colonisation by osteoclast-like cells, allowing the resorptive process to begin. Osteoclastic action in that area of the radicular dentine eventually results in a hyperplastic resorptive lesion containing fibro-osseous tissue. In order for dental resorption to occur, three conditions are necessary: a blood supply, breakdown or absence of the protective layer, and a stimulus. In the case of ICR, the external protective layer is the cementum, and the internal layer is the predentine of the pulp.

Several potential predisposing factors have been identified: trauma, intracoronal bleaching, surgery, orthodontics, periodontics, bruxism, delayed eruption, developmental defects, interproximal stripping and restoration. Heithersay studied a group of 222 patients with a total of 257 teeth with various degrees of invasive cervical resorption. From the subjects' dental histories, it was determined whether there was a sole predisposing factor, or a combination of factors. The results are shown diagrammatically in Figure 1.[2] The results indicated that a history of orthodontic treatment was the most common sole factor (found in 47 patients), while other factors, mainly trauma and/or bleaching, were present in an additional 11 subjects. Trauma was the second-most common sole factor, with 31 teeth. Intra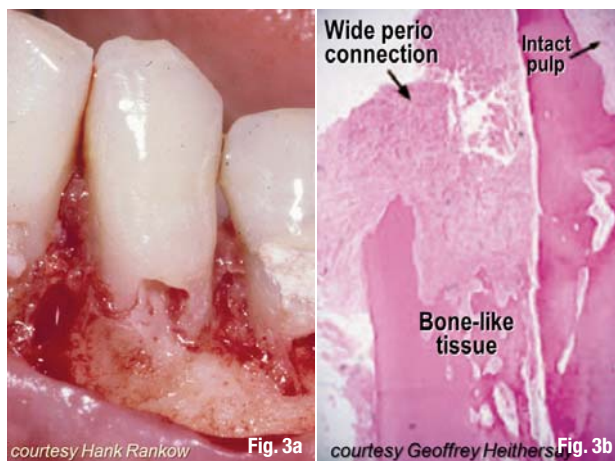coronal bleaching, combined with other factors, had the third-most affected teeth.[2] The pulp plays no role in the aetiology of ICR and remains normal until the ICR becomes very advanced.[1, 7, 10]
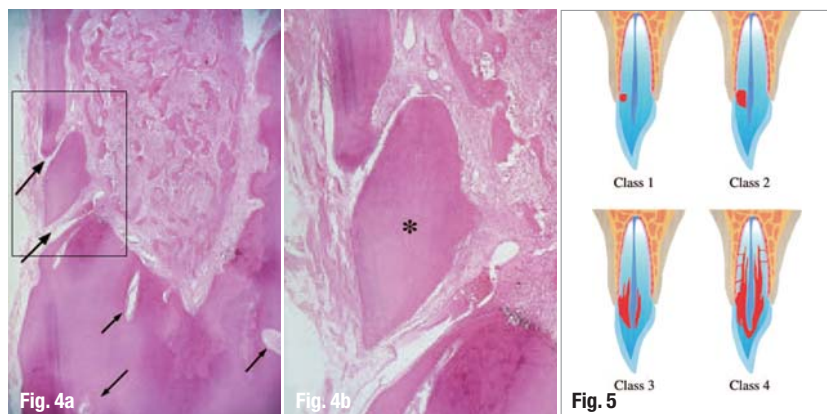
A recently published study has indicated there might be a connection between human and feline ICR. Four cases of multiple invasive cervical resorption (mICR) were presented. There was direct contact with cats in two cases, and indirect contact in the other two cases. Neutralised testing was done for feline herpes virus Type 1 (FeHV-1). Two of the cases were neutralised, and two were partly inhibited. The study indicates a possible transmission of FeHV-1 to humans and the possibility of its role as an aetiological (co)factor in ICR.[11]

_Histology

An interesting observation is that even in extensive lesions, the pulp is protected from the surrounding resorptive process by a narrow band of dentine (Figs. 2a–c). In some cases of ICR, the clinical and histological views of the lesion substantiate that bone-like tissue has replaced the fibro-vascular tissue located within the resorptive cavity (Figs. 3a & b). In the larger Class 3 and Class 4 lesions, communication channels

Fig. 4a

Fig. 4b

Fig. 5

Class 1   Class 2

Class 3   Class 4

Figs. 4a & b_Histological appearance of an extensive ICR with radicular extensions. Masses of ectopic calcific tissue are evident both within the fibro-vascular tissue occupying the resorption cavity and on resorbed dentine surfaces. In addition, communication channels can be seen connecting with the periodontal ligament (large arrows). Other channels can be seen within the inferior aspect of the radicular dentine (small arrows). Haematoxylin-eosin stain; original magnification X 30. Higher magnification **(b)** shows communication channels from the periodontal ligament to the resorbing tissue. An island of hard tissue remains (∗), consisting of an external surface of cementum and cementoid with some residual dentine, but the bulk has been replaced with a bone-like material with a canalicular structure. Although some red blood cells are evident near the deeper channel, no inflammatory cells can be seen. Haematoxylin-eosin stain; original magnification X 50. (Reproduced with permission from Quintessence Publishing.)[1]

Fig. 5_Clinical classification of invasive cervical resorption. (Reproduced with permission from Quintessence Publishing.)[2]

can be seen connecting with the periodontal ligament. Other channels can also occur within the internal aspect of the radicular dentine (Figs. 4a & b). The larger, more advanced lesions can be described as consisting of granulomatous bone-like fibro-osseous material with a canalicular structure that has extensions into the radicular dentine and periodontal tissue. Osteoclasts might be observed on the resorbing surface within the lacunae.[2] Over varying amounts of time, the lesion expands apically and coronally, encircling the pulpal tissue that is protected by a thin wall of predentine and dentine.

_Clinical classification

Heithersay's clinical classification was developed as a guideline for treatment planning and comparative clinical research.[2] The classification is shown diagrammatically in Figure 5. The classification allows the operator to determine the probable extent of treatment more precisely. The more extensive the lesion, the more complex the treatment options become.

_Class 1: Small invasive resorptive lesion with shallow penetration into dentine.
_Class 2: Well-defined invasive resorptive lesion close to the coronal pulp chamber.
_Class 3: Deeper invasion extending into the coronal third of radicular dentine.
_Class 4: A large invasive lesion extending beyond the coronal third of the root.

Normally, a Class 1 lesion can be successfully treated without much difficulty. Class 2 lesions often require minor gingival flap surgery for retraction to achieve adequate access and removal of the affected dentine, and to restore the defect. Class 3 lesions usually involve a surgical approach and/or or orthodontic extrusion. Class 1 and 2 lesions can be treated predictably, but the success rate in treating Class 3 and 4 lesions drops dramatically. Thus, in general, as the classification increases, the prognosis decreases.
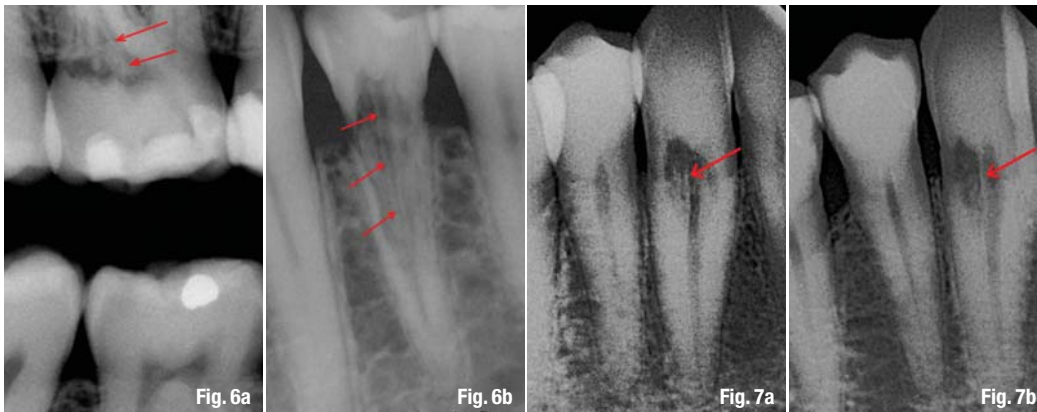
_Diagnosis

The earlier the diagnosis, the more predictable the outcome of treatment will be. Owing to the nature of the lesion, treatment based on an incorrect diagnosis will usually result in continued progression of the resorptive process and eventual loss of the tooth.

Unfortunately, the smaller Class 1 lesion is often not discovered owing to its location beneath the gingival attachment, but will usually show a small radiolucency on a radiograph. The dental examination may reveal a slight irregularity in the gingival contour, which will bleed upon probing.[4] It is my experience that Class 1 lesions are seldom found during routine dental examinations at this early stage.

One of the problems with early diagnosis is that the lesion is asymptomatic and can remain so even in the more advanced stages. Pulp testing will be of no value because the pulp remains unaffected until late in the process. However, the larger Class 2 lesion can present with more obvious clinical signs. For example, a patient notices a pinkish area on an anterior tooth. The discoloration is the result of osteoclastic activity replacing the radicular structure of the tooth with reddish granulation tissue that shows through the more translucent enamel.

Radiographically, the smaller Class 1 lesion can be confused with a carious lesion, internal resorption or adumbration (cervical burn-out) of the radiograph. If the lesion is a Class 2, Class 3 or Class 4, bitewing radiographs will often present an atypical radiolucency and the examining dentist will be more inclined to believe that it is not just a carious lesion. If the lesion is on the proximal surface of the tooth, the outline of the pulp can usually be observed. The larger lesions can also be misdiagnosed as caries or internal resorption. The usual indication that the lesion is not carious is the irregularity of the radiolucency and/or the radiopaque outline of the protective predentine layer of the pulp (Figs. 6a & b). By utilising varying angulation of the radiographs, internal resorption can be ruled out. If the lesion is due to internal resorption, it will remain centered what the direction, or "off-angle" the radiograph is taken. However, if the lesion is one of ICR, Clark's Rule, or SLOB Rule, can be used to determine the location of the lesion (the most lingual object moves with the direction of the X-ray head). (Figs. 7a & b).

With the advent of Cone Beam Computed Tomography (CBCT), the clinician is given the opportunity to view teeth and anatomical entities in three dimensions. Compare with the typical periapical radi-

Fig. 6a | Fig. 6b | Fig. 7a | Fig. 7b

ographs (Fig. 8a). Even if numerous angles, a complete view of the extent of the lesion cannot be established with any definitive accuracy. The extracted tooth #16 was a hopeless Class 4 lesion involving most of the cervical half of the lingual surface and extending into the area (Fig. 8b). Three planes of sections can be evaluated with CBCT: the frontal/coronal (X), sagittal (Y) and axial (Z; Fig. 8c). The X plane moves anterior ⇔ posterior (B ⇔ L in the anterior teeth and M ⇔ D in the posterior). The Y plane moves left ⇔ right (M ⇔ D in the anterior and B ⇔ L in the posterior). The Z plane moves coronal ⇔ apical for all teeth in the dental arch. Depending on the machine, up to 512 slices of the field of view can be visualised. The slice thickness is variable, again depending on the machine, from nearly 0.1 to several mm. However, generally speaking, the thinner the slice, the higher the spatial resolution.[12] When evaluating resorptive defects, higher resolution and 3-D images allow the experienced clinician to make a more definitive diagnosis and establish a confident and realistic plan for treatment, with a higher predictability of success.

In summary, the characteristic diagnostic signs that indicate that the lesion is a result of ICR are as follows:

_The tooth is asymptomatic.
_The pulp tests are within normal limits.
_The ICR defect moves with varying X-ray angulations.
_The protective pulpal wall is often intact and can be seen on the radiographs.
_The portals of entry are near the osseous crest.
_The portals of entry are difficult to locate clinically.[13]

I suggest that during the initial dental examination the patient be asked whether any of the three major predisposing factors have occurred in their dental history (bleaching, trauma or orthodontics). ICR can occur in any permanent tooth and once found in a patient, it is important to initiate regular follow-up visits to ensure no further lesions occur.

_Treatment

After the diagnosis of ICR has been confirmed, the treatment should be scheduled as soon as possible. If, for some reason this is not practical, the tooth should be monitored closely. The lesion can be very aggressive, so best not to wait for too long (Figs. 9a–c).

The Heithersay classification is of great help for advising the patient of the extent of treatment and gaining a better idea of the possible prognosis. The patient and doctor can decide on treatment together: (a) no treatment and extraction if the tooth becomes symptomatic; (b) extraction and possible replacement with an implant; or (c) to begin endodontic treatment in an attempt to eliminate the lesion and restore the tooth for as long as possible. In Class 1 and Class 2 cases, the patient must be advised that the treatment will probably be non-surgical but that the surgical approach may be necessary. In the more advanced Class 3 and Class 4 cases, the patient must be advised that both the non-surgical and surgical approaches will be necessary. Dental implants have become popular and, unfortunately, have led to a greater percentage of patients choosing the first two options.[8] However, there are still enough pa-

Fig. 8a | Fig. 8b

Fig. 9b 10/12/00

Fig. 8c

Fig. 9a 5/18/00

Fig. 9c 2/14/01

Fig. 8c_CBCT is essential to demonstrate the extent of the lesion and the amount of destruction that has occurred.

Figs. 9a–c_In a matter of just a few months, the lesion had advanced **(a)**. The diagnosis was made **(b)**. The patient was seen again in five months and was scheduled for treatment **(c)**.

tients who want to save their natural teeth, no matter what.

Heithersay developed what has become the standard guide for the treatment of ICR. Depending on the extent of the lesion, it is accessed either non-surgically or surgically. The granulation tissue is removed with either curettes or a round bur of varying sizes. During the removal of the bone-like tissue, 90% trichloroacetic acid (TCA) is applied with a small cotton pellet numerous times, with increasing pressure, to achieve coagulation necrosis. Using magnification, the fibro-osseous granulation tissue is removed until no communication channels are observed and the defect is lined with unaffected dentine, then restored with an appropriate restorative material. Endodontic treatment is performed when indicated. The aim of treatment is to eliminate all active resorbing tissue and restoration of the defect so the tooth can be maintained for as long as possible.[4] It has been my experience that all Class 2 to 4 cases required endodontic treatment.

I wish to make something very clear. In the following cases, 90% TCA was not used. There was
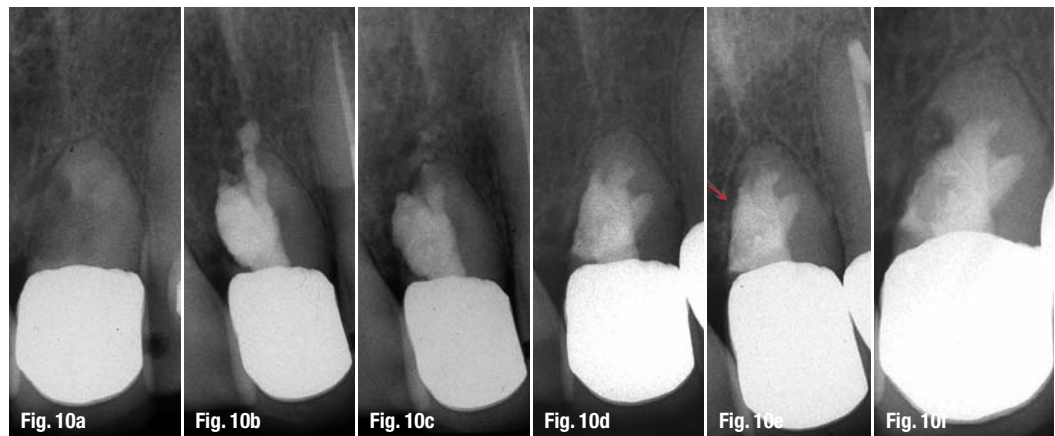
absolutely no disagreement about the use of TCA, but when the cases were treated, it was not available. The cases were treated with what was on hand. As a matter of convenience and necessity, Monsel's solution (MS), a 72% solution of ferric sulphate with sulphuric acid, was used. It had been used for many years as a coagulant when performing apical microsurgery. The use of MS to achieve coagulation necrosis when treating ICR over the years appeared to work well. As a result, the use of MS was continued.

_First patient

In 1993, a 62-year-old male patient presented for an evaluation of tooth #21 (Fig. 10a). His general dentist had recommended that the tooth to be extracted. At that time, a definitive protocol for the diagnosis and treatment of ICR had not been established. But the patient wanted us to do something to save the tooth. Sensing the sincerity of the patient, we agreed to attempt the salvation of the tooth, but informed him that we could not guarantee the outcome. At that time, there were some practising endodontists participating in clinical research for Dr Torabinijad using mineral trioxide aggregate (MTA)

Figs. 10a–c_Pre-operative X-ray **(a)**. Immediate post-op MTA fill **(b)**. Seven-month FUV **(c)**.
Figs. 10d–f_Immediate post-op radiograph following microsurgical recontouring and enhancement of previous MTA fill **(d)**. The 44-month FUV indicated an intact periodontal ligament (**e**; red arrow). Pre-op radiograph for extraction of tooth at 81 months **(f)**. When comparing **(f)** with **(e)**, there appears the probability of a continuation of the resorptive process (arrow).

Fig. 10a Fig. 10b Fig. 10c Fig. 10d Fig. 10e Fig. 10f

Fig. 11a

Fig. 11b

Fig. 11c

Fig. 11d

Fig. 11e

Fig. 11f

Fig. 11g

Fig. 11h

Fig. 11i

Figs. 11a & b_ The updated pre-op radiograph indicated an advanced Class 2 ICR **(a)**. After gross removal of granulation tissue, the affected dentine could be seen **(b)**.

Figs. 11c–f_A micro-brush was used to apply Monsel's Solution and brushed onto the floor of the defect **(c)**. After application of the MS, the area was irrigated with NaCl, rinsed and dried for inspection of remaining affected dentine **(d)**. Note the perforation in the distal surface of the tooth (large arrow), and remaining affected dentine (small arrows; **f**). A variety of Munce burs are available for removal of the affected dentine.

Figs. 11f & g_ Most of the lesion has been removed, resulting in a perforation of the distal wall of the chamber into the gingival sulcus (**f**; large arrow). A smaller Munce bur will be necessary to remove slightly more of the affected dentine (small arrows). The epinephrine-soaked pellet was placed for an adequate time for haemostasis before bonding a glass ionomer repair **(g)**.

Figs. 11h & i_ The immediate post-op radiograph **(h)**. The four-year FUV radiograph indicates a healed tooth **(i)**.

in pulp capping, perforations and root-end filling.[14] I had used MTA on just a few patients previously and had some confidence that it might serve as a last hope in this case. The MTA was an easy material to work with and required moisture to set completely. After the access was created, the obvious haemorrhaging was difficult to control whenever more granulation tissue was removed using curettes and a #6 round bur. Ferric subsulphate (MS) was repeatedly used for haemostasis, then irrigated with a 50% sodium hypochlorite solution (NaCl) and rinsed with sterile water, then gently air dried using the Stropko Irrigator (DCI). Haemostasis was achieved and vision was maintained while using an Aus-Jena surgical operating microscope (SOM) fitted with a co-observer tube for the assistant. After shaping to a #80 Kerr file at the terminus, and removing as much granulation tissue as possible, the canal system and defect were again copiously irrigated and dried as well as possible. Owing to the size of the apical opening, extra-large absorbent paper points (Kerr) were used to remove any remaining moisture and the entire case was obturated using MTA. The post-operative radiograph indicated that a significant amount of excess MTA was extruded (Fig. 10b). The patient was dismissed and reported no post-operative problems.

At the seven-month follow-up visit (FUV), the tooth #21 was totally asymptomatic, but I was concerned with the appearance of the very obvious overfill on the radiograph and wanted to eliminate

the excess MTA with a surgical approach. If the patient was seen by another dental office in the future, one could imagine someone saying, "Who in the heck did this to your tooth?" (Fig. 10c). On the appointed day, a full gingival flap was created and access to the area was achieved. In order to minimise the vibration that would be created when trimming the excess MTA from the root surface, a high-speed surgical handpiece with fibre optics (Impact Air 45 Star Dental), fitted with a surgical length, taper fissure #1171 bur (SS White), was used. After a satisfactory root profile had been established, a very small, inverted-cone, surgical length #330 bur (SS White) was used to prepare any of the lesion's periphery that was missed during the original non-surgical treatment. Once the necessary "troughing" had been completed, new MTA was added to the originally placed MTA for a more complete seal (Fig. 10d). Sutures were removed in a few days, and healing was uneventful. Regular FUVs were scheduled. A radiograph taken at the 44-month FUV was diagnosed as healing complete with an intact periodontal ligament (Fig. 10e).

About four years later, the patient returned with a three-unit fixed bridge replacement of tooth #21. The patient stated that tooth had become very loose and it was removed. The preoperative extraction radiograph was located (Fig. 10f). However, later comparison of the 44-month FUV to the pre-extraction radiograph indicated a possible continuation of the resorptive process—isn't it amazing what you can see when the light is just right?

_Second patient

A 64-year-old male patient presented for evaluation of tooth #17 because of the unusual appearance of the distal surface of the tooth. The previous clinical examinations and radiographs over the past ten months had diagnosed ICR (Figs. 11a–c). An updated radiograph was taken, all options were explained to the patient, and endodontic treatment was initiated (Fig. 11a).

The tooth was accessed and a gross removal of fibrous granulation tissue was achieved using curettage. The chamber was copiously irrigated with NaCl, rinsed and dried gently. The ICR dentinal defect and granulation tissue were evaluated to obtain a better understanding of its position in relation to the distal wall of the access and to the pulp tissue (Fig. 11b). A micro-brush dipped in MS was applied to the involved area (Fig. 11c). The MS is used for coagulation necrosis and to display the affected dentine that needs removal. It is not necessary to use copious amounts when applying the MS. Instead it is best to rely more on a sequence of repeated brushing with MS, irrigation with NaCl, rinsing and gentle drying. Study under the SOM at varying magnifications for affected dentine (Fig. 11d). Then, if necessary, remove more of the affected dentine using varying sizes of Munce burs (CJM Engineering; Fig. 11e). This process is repeated as necessary to achieve adequate vision. The floor of the access should be observed under the microscope at varying magnifications to determine whether any affected dentine remains. A celluloid strip was placed in the distal sulcus to act as a barrier to the flowable glass ionomer restoration (Fig. 11f). An epinephrine-soaked cotton pellet (EpiDry, Pascal) was also used to maintain haemostasis and enable the attempt at a non-surgical repair of the defect (Fig. 11g). The defect was etched and restored with a bonded glass ionomer, allowing the maintenance of sterility in the remaining chamber until the endodontic treatment had been completed. The pulp tissue was extirpated and canal system partially shaped. Enough calcium hydroxide (CaOH) was injected into the canals to cover the floor of the chamber, capped with a cotton pellet, and sealed with a bonded composite as a temporary restoration.

Two weeks later, the patient was scheduled to complete the endodontic treatment. During the process, a #6 file separated in the apical third of the distobuccal canal and had to be retrieved. At the final visit, the canal system was obturated using a Calamus (DENTSPLY Tulsa) for the injection of pre-warmed gutta-percha to the terminus. A bonded composite core was placed to seal the rest of the canal system and facilitate future restoration with a crown (Fig. 11h). The restorative dentist extended the distal margin of the full crown well apical to the distal defect for a good seal. The four-year FUV radiograph demonstrated complete healing (Fig. 11i).

_Third patient

A 47-year-old male patient presented for evaluation of "a small area of tingling, or numbness to the right of the nose". The initial radiograph was classic for ICR (Fig. 12a). All options were explained, and endodontic treatment was initiated.

The tooth was accessed, and as much fibrous granulation tissue was removed as possible. Monsel's solution was applied using a micro-brush to achieve coagulation necrosis. Then the chamber was irrigated with NaCl, rinsed with sterile saline, and gently dried using the Stropko Irrigator. The floor of the access was observed under the microscope at varying magnifications to determine whether any affected dentine was present. Any remaining affected dentine was efficiently removed with various Munce burs. Then CaOH was sealed in with a bonded composite as a temporary restoration.

Fig. 12a | Fig. 12b | Fig. 12c
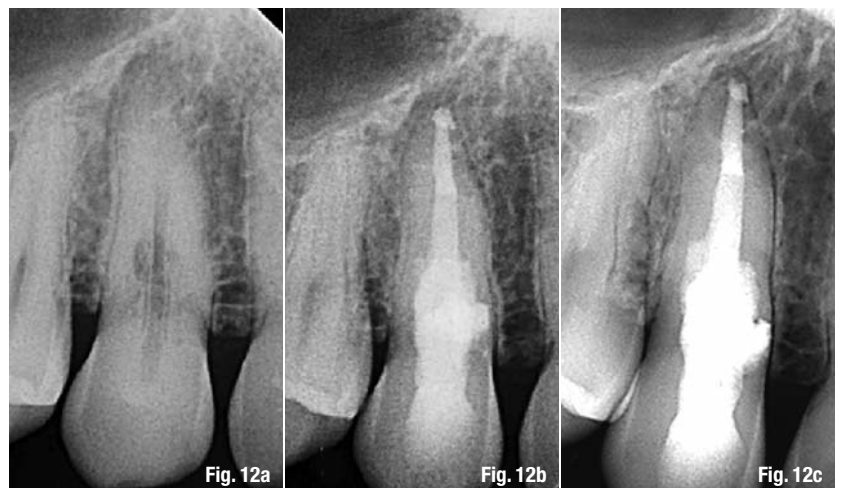
Two weeks later, the patient was seen in order to complete the non-surgical part of the treatment. The final shaping and cleaning was done, and the canal was filled to the terminus by injection of pre-warmed gutta-percha using a Calamus. A bonded FibreKor post (Pentron) with a bonded composite core (Core Paste, DenMat), was placed to seal the rest of the canal system and DenMat Marathon to repair the access opening. Then a simple flap was reflected to expose the lingual defect so it could be prepared and restored with bonded Geristore (DenMat; Fig. 12b). Healing was uneventful, and the numbing sensation beside the patient's nose was resolved. The radiograph at the four-year FUV showed uneventful healing (Fig. 12c).

Figs. 12a–c_The pre-op radiograph clearly demonstrates the appearance of the protective layer and the typical mottled radiolucent appearance of the resorptive lesion **(a)**. The radiograph immediately after non-surgical obturation and surgical repair of the lesion **(b)**. Normal healing is apparent in the four-year FUV radiograph **(c)**.

_Fourth patient

This 64-year-old male patient was referred by his general dentist because of the unusual radiographic appearance of tooth #43 (Fig. 13a). Even though there were no symptoms present, the referring doctor was

Figs. 13a & b_At the initial visit, the radiograph for tooth #43 in a 64-year-old male patient was taken at a normal angle **(a)**. Taking a radiograph from a more distal angle demonstrated that the lesion was located to the lingual of the tooth. Both radiographs clearly show the protective dentinal wall surrounding the pulp **(b)**.

Fig. 13a

Fig. 13b

Fig. 13c

Fig. 13d

Fig. 13e

Fig. 13f

Figs. 13c & d_The initial access demonstrated the unusual texture of the fibrous bone-like granulation tissue in the coronal area **(c**; arrow). After removal of most of the granulation tissue, white MTA was placed into the chamber and a temporary placed **(d)**.
Figs. 13e & f_At the second visit, in an attempt to maintain the vitality of the pulp, MTA was placed into the canal **(e**; arrow). CaOH was placed as an inter-appointment medication and to allow the MTA to achieve a complete set **(f)**.
Figs. 13g & h_After a few days, the chamber was irrigated and a bonded core was placed and was finished with a bonded composite (DenMat; **g)**. The two-month FUV radiograph demonstrated that the attempt to maintain the vitality of the tooth had not been successful **(h)**.

concerned about the integrity of the tooth. Routine off-angled periapical radiographs were taken. The distal off-angled radiograph clearly indicated that the lesion was on the lingual surface of the tooth (Fig. 13b). Both radiographs clearly showed the thin predentine/dentinal wall protecting the pulp. His dental history revealed that he had had complete orthodontics during his early teens. In addition, the patient stated that tooth #43 had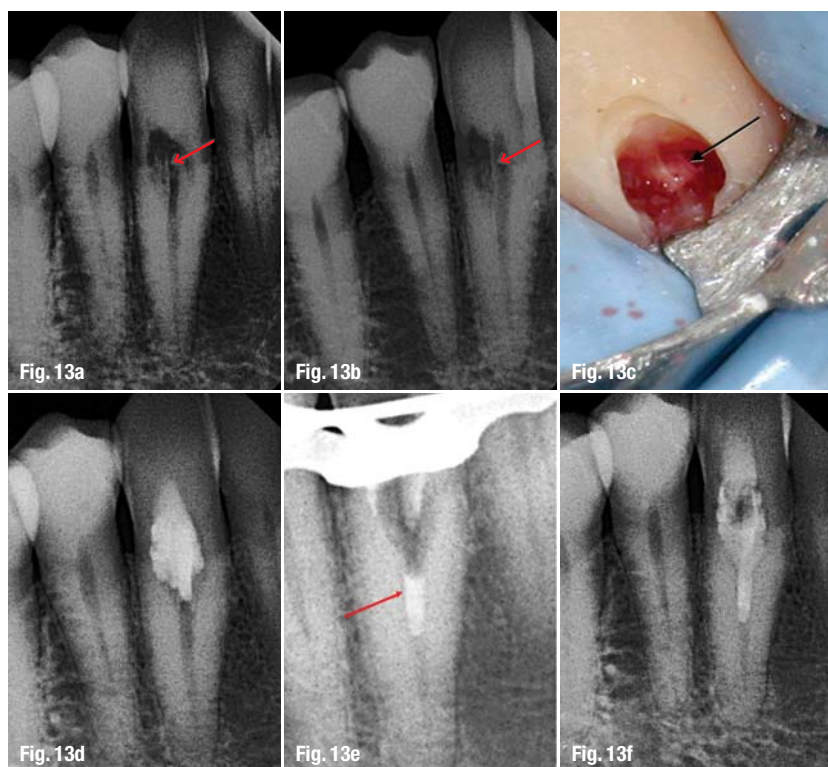 become misaligned about 20 years ago. In order to correct the misalignment of the tooth, the doctor reduced the tooth on each side and repositioned it with a removable appliance. Clinical examination was essentially within normal limits, except that a 4-6-4 mm periodontal probing of the lingual tissue resulted in moderate bleeding. All teeth in the posterior quadrants had been restored with full porcelain coverage, and the occlusion was a normal Class 1 molar relationship. All pulp tests were within normal limits. The diagnosis was clearly a Class 3 ICR. All things were explained to the patient, and we agreed to be as conservative as possible during treatment. At the time, I had no idea what a learning experience this case would be.

At the first visit, the initial access confirmed the diagnosis. The granulation tissue consisted of granules of bone-like haemorrhagic tissue (Fig. 13c). The pulpal wall was very thin, and pieces would come out with the granulation tissue. During the curettage, the fibrous tissue resembled a "crumbling sponge made of bone that was soaked with blood". Pieces of tissue were sent to an oral pathology laboratory for the following definitive diagnosis:

Microscopic description: Histological examination reveals multiple pieces of soft and hard tissue composed chiefly of inflamed granulation and fibrous connective tissues with bone and tooth structure. The granulation and fibrous tissues consist of interlacing bundles of dense to more delicate collagen fibres supporting varying numbers of fibroblasts, fibrocytes and small blood vessels. A mild infiltrate of chronic inflammatory cells, chiefly lymphocytes and plasma cells, is present within this tissue. Also prominent within our specimen are scattered trabeculae of bone containing osteocytes within lacunae, as well as fragments of dentinal tooth structure and calcified debris.

Diagnosis: Right posterior mandible, lingual aspect of tooth #43. Histological findings consistent with idiopathic external resorption.

Gradually, as more of the tissue was removed, the bleeding noticeably decreased, but haemostasis was not achieved. As an interim medication, a thick mixture of white MTA was firmly placed into the chamber, covered with a sterile cotton pellet and temporarily restored with a bonded composite (Fig. 13d). During the initial examination, pulp testing indicated a normal pulp, and I was wondering whether the vitality of the tooth could possibly be maintained at that point. All options, including the possible need for conventional root-canal treatment, were explained. Both the doctor and patient agreed to attempt to maintain the vitality of the tooth. The patient was rescheduled for a second visit in about two weeks.

During the second visit, the chamber was reopened, the MTA was eliminated and more granulation tissue was removed with small curettes. Under varying high magnifications of the microscope (Global Surgical Corporation), as much of the remaining affected dentine was removed with Munce burs, and the remaining pulp tissue was identified. After irrigation with NaCl, an additional few millimetres of the pulp was removed and a pellet of grey MTA was placed into the canal using a medium Dovgan MTA Carrier (Quality Aspirators; Fig. 13e). CaOH was then placed, covered with a cotton pellet, and sealed in with a bonded composite temporary (Fig. 13f). To allow for a complete set of the MTA, the patient was scheduled two days later for a third appointment.

On this third visit, the CaOH was removed, and the floor of the defect was lightly brushed with Munce burs of various sizes and studied under varying magnifications until no affected dentine was observed. The chamber was irrigated with NaCl, rinsed, gently dried and etched with 35% phosphoric acid gel (Ultra-etch, Ultradent). A bonded core was placed

Fig. 13g   Fig. 13h   Fig. 13i   Fig. 13j

and access restored with a bonded composite (Fig. 13g). An FUV was scheduled for two months later.

At the two-month FUV, the periapical radiograph revealed that the response to treatment was not as expected. The ICR lesion had significantly progressed in that short time (Fig. 13h). All options were discussed with the patient, but there was no doubt that conventional endodontic treatment, followed by surgical repair of the lesion would be necessary.

During this visit, adequate access was created to remove the previously placed MTA. Using Gates Glidden burs and a #4 round bur, more affected dentine was removed in the coronal aspect of the canal. The canal system was then shaped and cleaned to the terminus, and CaOH was sealed in with a bonded composite temporary (Fig. 13i). After about ten days, the canal system was obturated by the injection of pre-warmed gutta-percha to the terminus with a Calamus. Then, most of the core was removed and a post space created. A fibre post with a composite core was bonded in, and the access opening filled with Geristore to prepare the tooth for the surgical repair of the ICR lesion (Fig. 13j).

A sulcular flap was reflected enough to adequately access the ICR lesion. The lesion was at the lingual crestal bone and had been slightly stained from the previous use of Monsel's Solution (Fig. 14a). After gross removal of the remaining granulation tissue and affected dentine, more solution was applied with a micro-brush to achieve coagulation necrosis and the stained affected dentine was removed using smaller Munce burs (Fig. 14b). The process was repeated until all affected dentine had been removed. After the preparation had been completed, a bonded Geristore was placed (Fig. 14c). A radiograph from a normal view indicated that the restoration was appropriate (Fig. 14d). A radiograph was taken from a distal off-angle view to ensure that post-operative integrity had been achieved (Fig. 14e).

The patient was followed at regular intervals. The most recent FUV occurred after over eight years

post-operatively. The patient remained asymptomatic from the beginning to the end of the entire treatment process. The recent buccal view does show a slight grey shadow in the cervical half of the tooth as a result of the earlier use of the MTA when trying to maintain the vitality of the pulp (Fig. 14f). Apart from normal staining, the lingual view was within normal limits and the periodontal probing was still 5 mm (Fig. 14g). The post-operative radiographs indicate complete healing with good integrity of the fill (Figs. 14h & i). Note that the excess filling material from the original obturation (Fig. 13i) was resolved.

_Discussion

Unfortunately, ICR is normally not detected in its early stages and/or is often misdiagnosed. By the time it is discovered, the resorptive process is advanced enough to be at least a Class 2 or worse. Fortunately, ICR is not a very common occurrence in an endodontic practice, though it can be quite demanding of our time. Some Class 2 ICR cases and all Class 3 and Class 4 cases, with rare exception, will involve conventional endodontic treatment.
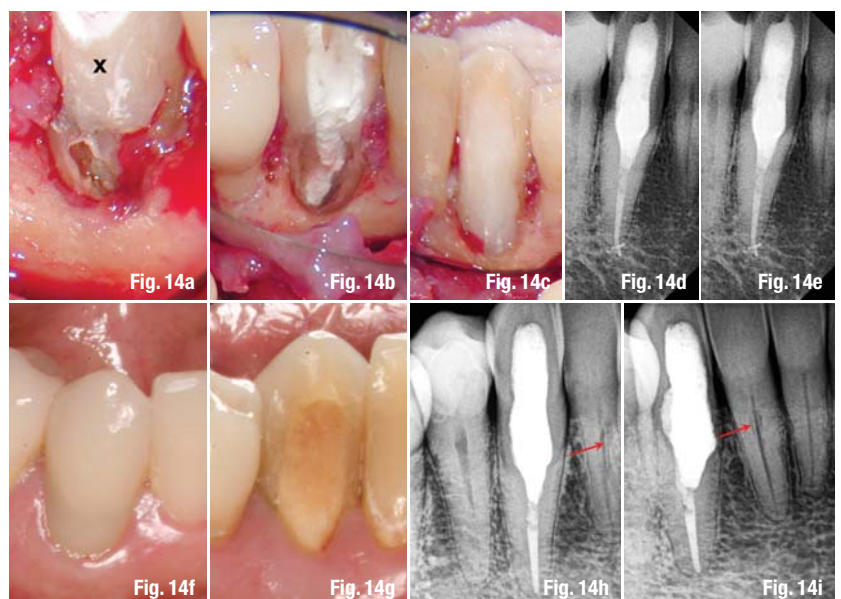
Fig. 14a   Fig. 14b   Fig. 14c   Fig. 14d   Fig. 14e
Fig. 14f   Fig. 14g   Fig. 14h   Fig. 14i

The diagnosis of ICR is made more precise with currently available radiographic technology. Digital radiographs and CBCT have set a new standard of clinical management, allowing more predictable results with less stress. The 3-D view presented by CBCT removes many of the unknowns from the diagnosis.

In today's world, the use of a surgical operating microscope (SOM) is essential to enable the operator to overcome the difficulty of treating ICR cases. The variable magnification and superior lighting of the SOM give the operator the enhanced vision necessary to treat ICR cases with less stress and a higher probability of success. Having a dental assistant involved, using a co-observer tube during any dental procedure, is an incredible help because now he or she is able to see what you see at the time you see it and better anticipate what is needed next.

In all cases presented, Monsels solution (MS) was used successfully for coagulation necrosis. Based on an early report, I used it routinely during microsurgery for crypt management.[15] As a result, when the first case of ICR presented for treatment, 90 % TCA acid was not a familiar alternative protocol. Having never used TCA, I can offer no comparison or comment. The original protocol for the clinical management of ICR using 90 % TCA, suggested by Heithersay in 1999, is still the most popular and well documented. There are various techniques for restoring a tooth with ICR, as previously described in the literature, that are different from what is presented in this publication. However, the real purpose in the treatment of ICR was, and still is, to eliminate as much of the affected dentine as possible. If this is not achieved, the process will progress and be a disaster for the tooth.

While MTA was extensively used in the first case presented (Figs. 13a–g), I do not intend to suggest the use of it as a material for the repair of ICR defects. I did that case almost 20 years ago. Today the materials of choice would be bonded glass ionomers or composites for their strength and adhesiveness. MTA is currently used as a pulp capping material, for perforation repairs or as a restorative material for the repair of a radicular defect that is apical to the osseous crest.

It is important to remember that unless the challenge to treat a seemingly hopeless or extremely difficult case is accepted, the opportunity to learn what can be accomplished is lost. Experience has shown that in such cases there have been more pleasant and favourable surprises than unpleasant results. As William F. O'Brien said, "It is better to try and fail, than to not try at all." Hindsight is always 20-20, and it is one of the best teaching tools we always have at our disposal. The important thing is to learn from our mistakes and those of others.

If a tooth can be saved for only a few years, the rapid advancement of technology will permit a significantly better treatment in the future. So, if an opportunity is presented to save the tooth, then why not? If the question remains, the words of Dr Herbert Schilder are pertinent, "Make yourself the patient, and you have the answer!" The important consideration is what is in the best interest of the patient. Remember, an implant can always be done, and should be the last resort.

In conclusion, the quote from Dr Henry Rankow gives the best explanation of the predicament presented for the clinical management of this lesion, "ICR is an 'outside-in' problem that is very difficult to treat 'inside-out'!"

Editorial note: A complete list of references is available from the publisher.

_about the author   roots

John J. Stropko received his DDS from Indiana University in 1964. For 24 years, he practised restorative dentistry. In 1989, he received a certificate for endodontics from Boston University and has recently retired from the private practice of endodontics in Scottsdale, Arizona. Stropko is an internationally recognised authority on micro-endodontics and has performed numerous live micro-endodontic and microsurgical demonstrations. He has been a visiting clinical instructor at the Pacific Endodontic Research Foundation, an adjunct assistant professor at Boston University, an assistant professor of graduate clinical endodontics at Loma Linda University, and a member of the endodontic faculty at the Scottsdale Center for Dentistry in Scottsdale, as an instructor of microsurgery; and is a co-founder of Clinical Endodontic Seminars. His research on in vivo root-canal morphology has been published in the *Journal of Endodontics*. He is the inventor of the Stropko Irrigator, has published in several journals and books, and is an internationally known speaker. Stropko and his wife currently reside in Prescott, Arizona. He may be contacted at docstropko@gmail.com

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Iatrogenic errors before and after non-surgical root-canal treatment

Author_ Dr Rafaël Michiels, Belgium

Fig. 1_Diagnostic radiograph, showing the separated instrument in the mesiobuccal canal.
Fig. 2_Size 15 Flexile file passing through the perforation.

Fig. 1

Fig. 2

_**Several reports in the literature** describe iatrogenic errors during root-canal treatment. The most common errors include perforations, ledging, transportation, zipping, overextension, file separation and underfilling. Little emphasis is placed on the preparation of a tooth before starting root-canal treatment, or on the finishing of the tooth after obturation of the root-canal system. On various online forums and in several clinical articles, beautifully executed root-canal treatments are shown with coronal restorations that are less than ideal. This is a serious problem, since it has been demonstrated that a successful outcome depends not only on adequate root-canal treatment, but also on adequate coronal restoration. In this article, I will elaborate on these aspects and present a case as an example.

_Before starting root-canal treatment

As endodontists, we are specialised in the treatment of root-canal systems. However sometimes we focus on this only, forgetting that there is more to a tooth than a root. When a patient comes into our office, often he will have (a) symptomatic apical periodontitis. Whether the tooth has been treated before is somewhat irrelevant in the scope of this article. The first thing that we, as practitioners, should try to determine is the cause of the problem. The most cited causes are previous inadequate root-canal treatment, primary decay, recurring decay, worn restorations and poor restorations overall. If the tooth has not undergone root-canal treatment previously, then the cause of the problem is most likely one of the

coronal factors. It is important to address this. After all, what is the point of performing a beautiful root-canal treatment if the primary cause of the problem is not treated?

The best way to do this is by removing the old restoration completely, followed by full caries removal. This may sound logical, but it is not. There are certain disadvantages with this approach, and it is these disadvantages that guide many practitioners in their decision-making. Removing an existing restoration might result in the sacrifice of healthy tissue and it might make it more difficult to obtain proper isolation with a rubber dam. Another factor is time; removing an old restoration is time-consuming and even more so if a build-up is required before endodontic treatment. These are some reasons that many practitioners choose to leave the old restoration in place. This can compromise the treatment outcome and is a risk that can be avoided.

Fortunately, there are advantages too. By removing the old restoration and subsequently all the caries, the practitioner eliminates one of the major causes of failure and can assess immediately whether the tooth is restorable and thus avoid unnecessary treatment. Another advantage is that it is necessary to fabricate a completely new restoration afterwards, which avoids patching up of old restorations. Overall, the advantages are greater than the disadvantages and the only thing it requires from the practitioner is a change in behaviour and some perseverance.

_After root-canal treatment

Once root-canal treatment has been completed, often we need to send the patient back to the referring dentist. In this case, an adequate temporary restoration must be placed. Typically, a temporary filling material like Cavit (3M ESPE) or a glass ionomer cement is used. A cotton pellet or some other form of space maintainer is generally placed underneath this temporary filling. This is done because the referring dentist then has easier access to the pulp chamber so that he can gain better retention when placing the permanent restoration. There are several disadvantages to this approach. Leaving space between the temporary restoration and the canal orifices puts the patient at risk of contamination. As practitioners we cannot guarantee that the patient will show up for the permanent restoration, sometimes the appointment is cancelled for a variety of reasons. Another risk is fracture of the restoration and/or tooth. If that happens the gutta-percha can be exposed to saliva, which too might lead to contamination. Ideally, however, the tooth should be restored immediately after the root-canal treatment has been carried out. This means that the endodontist places the permanent restoration.

Fig. 3

Fig. 4

Fig. 5

Advantages with this approach are:

_It saves the patient a visit to his regular dentist.
_The tooth is already isolated, creating the ideal environment for a restoration.
_It saves the referring dentist time, which he can spend on other treatments.
_It offers the endodontist some variety in the treatments he performs, enabling him to broaden his skill set.

Again, this only requires a change in behaviour of the practitioner and some perseverance. It will also require that the referring dentist allow the endodontist to place the restoration. The endodontist will have to upgrade his skills, so that he can also create beautiful coronal restorations.

Following, is a case that illustrates the advantages and disadvantages of the above-mentioned approaches.

Fig. 3_Perforation repair with grey MTA-Angelus.
Fig. 4_Post-op radiograph.
Fig. 5_Follow-up radiograph after nine months, showing coronal restoration that was less than ideal.

Fig. 6

Fig. 7

Fig. 8

Fig. 6_Diagnostic radiograph of another referred tooth (tooth #16).
Fig. 7_Working length, together with complete removal of the old restoration.
Fig. 8_Post-op radiograph, with temporary glass ionomer restoration.

_Case report

When I had just graduated as an endodontist, a 36-year-old male patient was referred because he was experiencing some mild pain in his left mandibular second molar. I was acting as a third-line practitioner in this case. Another endodontist did not wish to begin treatment and finally referred the patient to me.

The tooth was diagnosed as having symptomatic apical periodontitis and was previously treated inadequately, including a separated instrument in one of the mesial canals (Fig. 1).

In the first visit, I removed the gutta-percha from the mesiolingual canal, and cleaned and shaped it completely. The separated instrument was located in the mesiobuccal canal, but I could not remove it completely. I left the distal canal untouched. Calcium hydroxide was used as an inter-appointment dressing, and the tooth was restored with a cotton pellet and glass ionomer cement. An initial error was made by not removing the old restoration and caries completely.

One month later the patient returned in agony. When I re-opened the tooth, a great deal of pus and blood came out of the tooth. I then tried to bypass the remainder of the fragment in the mesiobuccal canal, but perforated the root with a 15.04 ProFile (DENTSPLY Maillefer; Fig. 2). I also retreated the distal canal in this session and fractured a small piece of a 25.06 ProFile in the apical part, but could bypass it. I then filled the canals again with calcium hydroxide and sealed the tooth with a glass ionomer filling.

One month later, I saw the patient again for the completion of the treatment. He no longer had any symptoms. I restored the perforation with grey MTA-Angelus (Fig. 3). I obturated the canals with gutta-percha and Topseal (DENTSPLY Maillefer) using warm vertical condensation. I sealed the cavity with Fuji IX A1 (GC) immediately on top of the gutta-percha (Fig. 4). I then referred the patient back to the dentist for a permanent restoration, with the explicit advice to have the distal restoration replaced too.

Nine months later the patient returned to my office for another tooth. I decided to take a follow-up radiograph of the left mandibular second molar to see if healing was favourable. The patient had not experienced any complaints since I completed the treatment and the radiograph showed a favourable apical outcome. However, the permanent restoration was less than ideal (Fig. 5). I had to refer the patient back to the dentist for a new restoration.

_Conclusion

Looking back upon this case, I can conclude that I should have removed the old restoration and the caries at the start of the treatment. Positively, it was good that the glass ionomer filling was placed immediately above the canal orifices, preventing contamination via a leaky restoration. Ideally, I should have finished the restoration myself.

It required a change in my behaviour and some perseverance to begin to perform cases in accordance with the afore-mentioned approaches, as can be seen in Figures 6, 7 and 8._

_about the author   roots

Dr Rafaël Michiels graduated from the Department of Dentistry at Ghent University, Belgium, in 2006. In 2009, he completed the three-year postgraduate programme in endodontics at Ghent University. He works in two private practices specialised in endodontics in Belgium. He can be contacted at rafael.michiels@ontzenuwen.be and via his website www.ontzenuwen.be

Fluid dynamics of syringe-based irrigation to optimise anti-biofilm efficacy in root-canal disinfection

Authors_ Dr Christos Boutsioukis, Netherlands, & Dr Anil Kishen, Canada

_Bacterial biofilm as a therapeutic target

A mature bacterial biofilm is composed of multiple layers of bacteria embedded in a self-made matrix formed of extracellular polymeric substance. This substance has the potential to modify the response of the resident bacteria to antimicrobials by acting as a shield against the chemical effects of antimicrobials. There is also a localised high density of bacterial cells in a biofilm structure. This spatial arrangement will expose the cells in the deeper layers of the biofilm to less nutrients and redox potential than the cells on the biofilm surface. Since the degree of nutrient and gas gradients increases with the thickness and maturity of a biofilm, the influence of growth rate and oxygen on the antimicrobial resistance is particularly marked in aged biofilm. The resistance associated with biofilm bacteria is further associated with the slow growth rate (starvation) and/or due to the adoption of resistant phenotypes in bacteria residing in a biofilm. It is recognised that no single mechanism may account for the general resistance to antimicrobials in a biofilm. It is apparent that different mechanisms may act in concert within the biofilm, and amplify the effect of small variations in the susceptible phenotypes (Dunne et al. 1993; Costerton et al. 1994). Thus from a clinical perspective, bacteria are observed to demonstrate considerably high resistance to antimicrobials when they are in a biofilm (Kishen 2012).

The current concepts in endodontic microbiology emphasise endodontic disease as a biofilm-mediated infection. Ricucci and Siqueira (2010) found a very high prevalence of bacterial biofilms in the apical root canals of both untreated and treated teeth with apical periodontitis. The pattern of arrangement of bacterial communities in the root canal is noted to be consistent with the acceptable criteria for including apical periodontitis in the set of biofilm-mediated diseases. They also suggest that the biofilm morphology/structure varied from case to case, and no unique pattern for endodontic infections was determined. Elimination or significant reduction of endodontic bacterial biofilms is essential for successful outcomes of endodontic treatment (Fig. 1). However, clinical studies have demonstrated that even after meticulous chemomechanical disinfection and obturation of the root canals bacteria may persist in the un-instrumented portions and anatomical complexities of the root canal (Nair et al. 2005). It is vital to comprehend that the limitations in endodontic disinfection are not just due to the biofilm mode of bacterial growth in the root canals. The complexities of the root-canal system, in addition to the structure and composition of the root dentine, play a decisive role in limiting the efficacy of endodontic disinfection. Nair et al. (2005) demonstrated that following one-visit conventional endodontic treatment the teeth revealed microbial biofilm in the inaccessible recesses and diverticula of instrumented main canals, the intercanal isthmus and accessory canals. The main limiting factors in conventional irrigation are the complexity of the root-canal anatomy, the ultrastructure of the dentine and the characteristics of the bacterial biofilms (Kishen 2010). Attempts to surmount these limitations have recently led to renewed interest in understanding the fluid dynamics associated with different root-canal irrigation techniques through numerical and experimental investigations.

_General considerations of fluid dynamics in irrigation

Endodontic irrigants are primarily liquid anti-microbials used to combat microbial biofilms within the root-canal system. The process of delivery of irrigants within the root canal is called irrigation, and irrigation dynamics deals with how irrigants flow, penetrate and exchange within the root-canal space, and the forces produced by them. Hence, in endodontic disinfection, the process of delivery is as important as the antibacterial characteristics of the irrigants. The overall objectives of root-canal irrigation are (a) to inactivate bacterial biofilms, in-activate endotoxins, and dissolve tissue remnants/smear layer (chemical effects) from the infected root canals; and (b) to allow the flow of irrigant throughout the root-canal system in order to de-tach the biofilm structures and loosen/flush out the debris from the root canals (mechanical effects).

The chemical effectiveness will depend upon the concentration of the antimicrobial irrigant, the area of contact and the duration of interaction between irrigant and infected material. The mechanical ef-fectiveness will depend upon the ability of irrigation to generate optimum streaming forces within the entire root-canal system. Mechanical effects can be produced even by inert irrigants (e.g. water, saline), but chemical effects are only exerted by chemically active solutions (e.g. sodium hypochlorite). The final efficiency of endodontic disinfection will depend upon its chemical and mechanical effectiveness (Gulabivala et al. 2005; Haapasalo et al. 2005). Cur-rently, there is no consensus on the relative impor-tance of these effects for the overall success of root-canal treatment; therefore, efforts to maximise both effects seem justified. Even the most powerful irri-gant will be of no use if it cannot penetrate the api-cal portion of the root canal, interact with the root-canal wall and exchange frequently within the root-canal system (Druttman & Stock 1989; Mott 1999; Tilton 1999; White 1999; Seal et al. 2002). However, over-enthusiastic efforts to deliver the irrigant may result in its inadvertent extrusion towards the periapical tissue (Hülsmann et al. 2009). Depending on the irrigant, severe tissue damage, pronounced symptomatology and possibly delayed healing may develop, as documented in a number of case re-ports (e.g. Hülsmann & Hahn 2000; Gernhardt et al. 2004; Bowden et al. 2006; Pelka & Petschelt 2008; Behrents et al. 2012). Therefore, irrigant penetra-tion should be kept within the confines of the root-canal system and a critical balance should always be maintained between efficient cleaning and pre-vention of irrigant extrusion (Haapasalo et al. 2010), especially when chemically active irrigants are used.
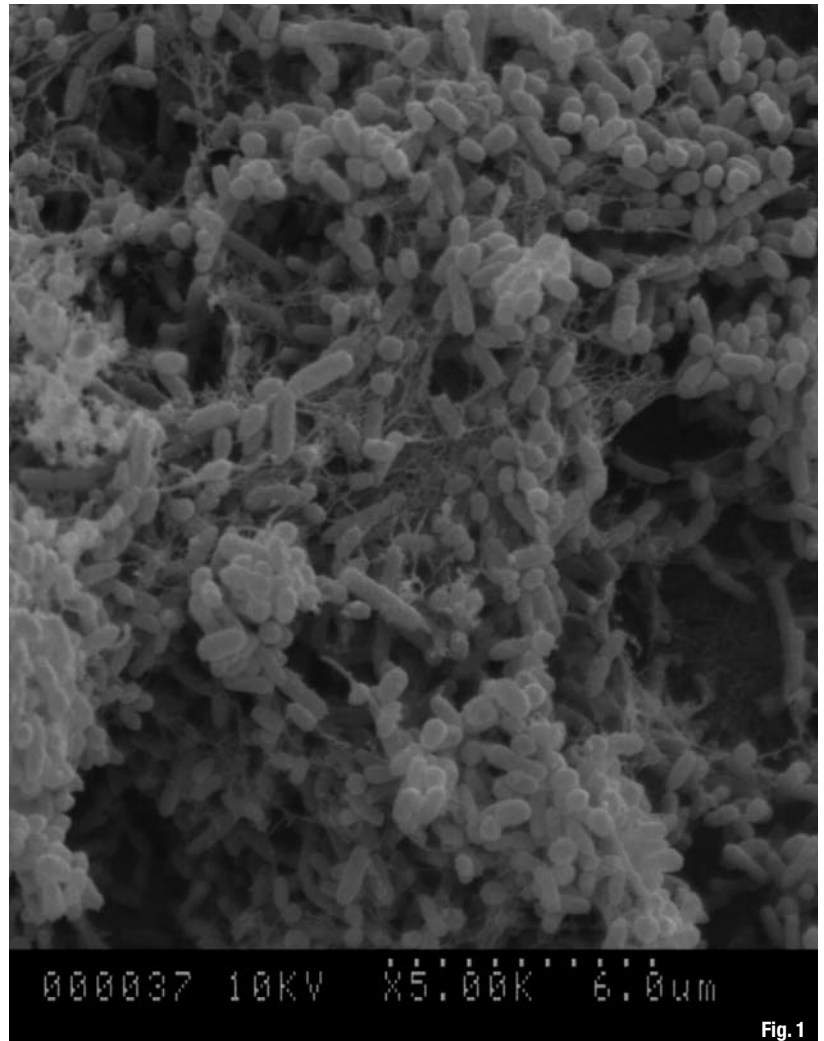

Fig. 1

In general, root-canal irrigation can be regarded as the flow of a liquid (irrigant) within an irregularly shaped domain (root-canal system). Consequently, a fluid dynamics approach would be appropriate for elucidating the procedures of root-canal cleaning and disinfection. The above-mentioned objectives of root-canal irrigation can be restated briefly in terms of fluid dynamics as:

_flow of the irrigant to the full extent of the root-canal system and subsequently to the canal orifice in order to come in close contact with microbes, debris and tissue remnants, and carry them away;
_frequent refreshment and mixing of the irrigant in order to retain a high concentration of its ac-tive component(s) and compensate for its rapid consumption (for chemically active irrigants);
_application of force to the canal wall (wall shear stress) in order to detach/disrupt microbes/biofilm, debris and tissue remnants;
_restriction of the flow within the confines of the root canal and prevention of irrigant extrusion towards the periapical tissue (Boutsioukis 2010).
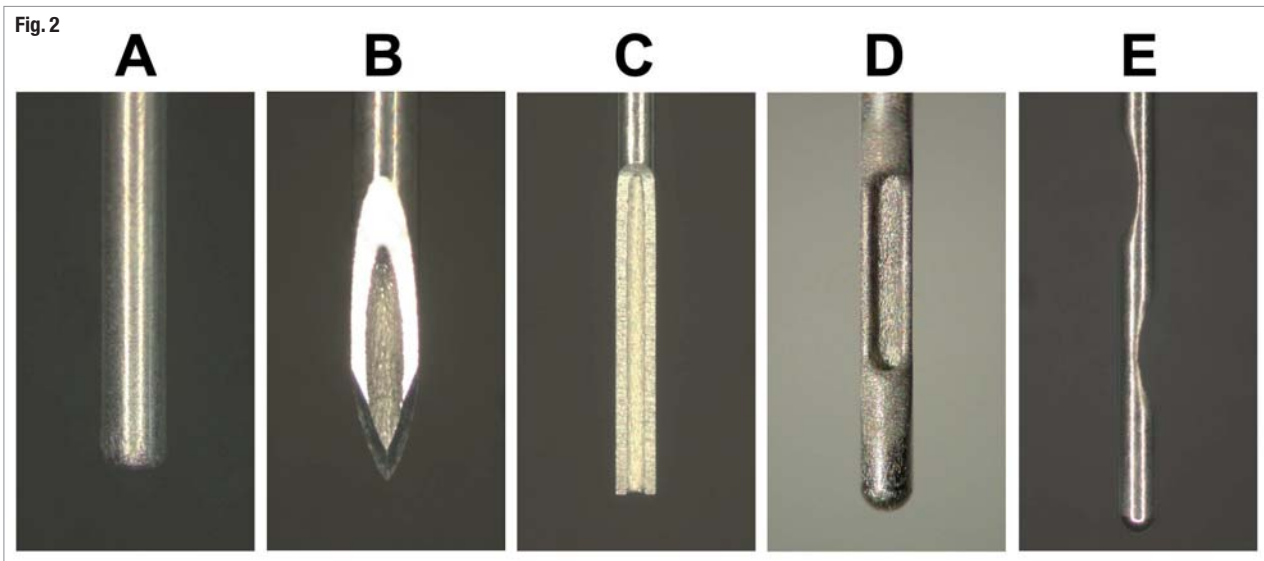
Fig. 1_Multispecies bacterial biofilm grown on root-canal dentine *in vitro*.

Fig. 2

_Syringe irrigation

Irrigant delivery techniques are frequently categorised as positive-pressure or negative-pressure, according to the mode of delivery employed (Brunson et al. 2010). In positive-pressure techniques, the pressure difference that is necessary for irrigant flow is created between a pressurised container (e.g. a syringe) and the root canal, where the pressure remains much lower (nearly atmospheric). Irrigant is delivered deep inside the root canal, usually by a needle, and then flows towards the canal orifice, where it is evacuated by a suction system. In negative-pressure techniques, the irrigant is delivered passively near the canal orifice at nearly atmospheric pressure and a suction tip placed deep inside the root canal creates a pressure difference. The irrigant then flows from the orifice towards the apex, where it is evacuated.

Perhaps the most traditional method of positive-pressure irrigant delivery is by a syringe and a needle. Despite the development of various irrigation systems, conventional syringe irrigation remains widely accepted (Ingle et al. 2002; Peters 2004; Dutner et al. 2012). However, over the years it has been argued that the performance of root-canal irrigation is limited mostly because syringes and needles fail to deliver the irrigant to all the parts of the complex root-canal system (Ram 1977; Rosenfeld et al. 1978; Druttman & Stock 1989; Haapasalo et al. 2005). A detailed evaluation of the irrigant flow developed during syringe irrigation could provide some insight into this problem.
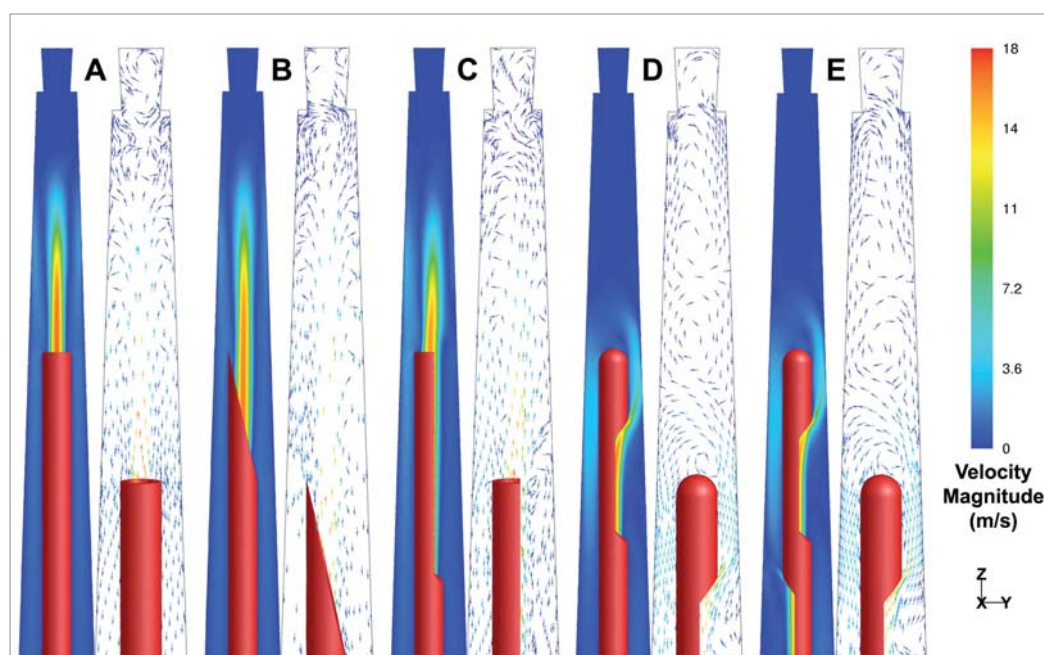
Fig. 3

_Irrigant flow during syringe irrigation

Most studies on root-canal irrigation have focused on the direct outcomes of irrigation, that is debridement, tissue dissolution, antimicrobial action or removal of the smear layer, employing a trial-and-error approach and speculating on the aetiology. Few studies have actually attempted to evaluate directly the flow developed within the root canal (e.g. Teplitsky et al. 1987; Druttman & Stock 1989; Kahn et al. 1995; Bronnec et al. 2010a; Boutsioukis et al. 2009; Shen et al. 2010), which is probably the dominant phenomenon during root-canal irrigation and the primary cause of both the chemical and mechanical effects.

The flow of irrigants is affected by their physical properties, mainly density and viscosity (White 1999). "Density" describes the amount of mass present in a certain volume of the irrigant, and "viscosity" describes the resistance of the irrigant to motion (Mott 1999; Tilton 1999; White 1999). For commonly used endodontic irrigants, these properties are very similar to those of distilled water (Guerisoli et al. 1998; Van der Sluis et al. 2010), which can be explained by the fact that irrigants are mainly sparse aqueous solutions. The surface tension of endodontic irrigants and its decrease by wetting agents (surfactants) has also been studied extensively, under the assumption that it may have a significant effect on irrigant penetration in dentinal tubules and accessory root canals (Abou Rass & Patonai 1982; Taşman et al. 2000) and on dissolution of pulp tissue (Stojicic et al. 2010). However, while density and viscosity affect the flow in all cases, *the effect of surface tension is important only at the interface between two immiscible fluids* (e.g. between irrigant and an air bubble, but not between irrigant and dentinal fluid; White 1999; Kundu & Cohen 2004). Should an air bubble occupy the apical part of the root canal (Tay et al. 2010), surface tension effects could be important, but it is unlikely that bubble entrapment is a common issue during root-canal irrigation. Recent studies have also confirmed that surfactants do not enhance the ability of NaOCl to dissolve pulp tissue (Clarkson et al. 2012; Jungbluth et al. 2012) or the ability of common chelators to remove calcium from dentine (Zehnder et al. 2005) or to remove the smear layer (Lui et al. 2007; De-Deus et al. 2008).

Syringes of variable capacity, ranging from 1 to 10 ml (Abou-Rass & Piciccino 1982; Kahn et al. 1995; Ram 1977; Moser & Heuer 1982; Chow 1983; Sabins et al. 2003; Lee et al. 2004; Sedgley et al. 2005), have been used. Although little attention has been given to the size of the syringe, it can affect the force needed to irrigate at a certain flow rate (Boutsioukis et al. 2007a). The flow rate is defined as the volume of irrigant delivered per unit time. (Mott 1999). A common error among clinicians, which is also reproduced in several irrigation studies, is that delivery of the irrigant at a high flow rate is erroneously termed "forceful delivery" or "delivery under pressure". During syringe irrigation, a clinician applies force to the plunger of the syringe. This force is transmitted to the irrigant in the syringe, where pressure builds up. A clinician will need to apply different amounts of force and will feel different levels of difficulty in pushing the plunger when syringes of different size are used, even if the pressure actually developed is identical (Tilton 1999). Larger syringes are more difficult to depress. Hence, the clinician cannot draw reliable conclusions about the pressure.

Fig. 4_Triads of time-averaged contours (left), vectors (middle) of velocity and streamlines (right) in the apical part of the root canal for a closed-ended (top) and open-ended needle (bottom) positioned at 1 to 5 mm short of WL, respectively. Needles are coloured in red. (Reprinted with permission from Boutsioukis et al. 2010c.)

Fig. 4
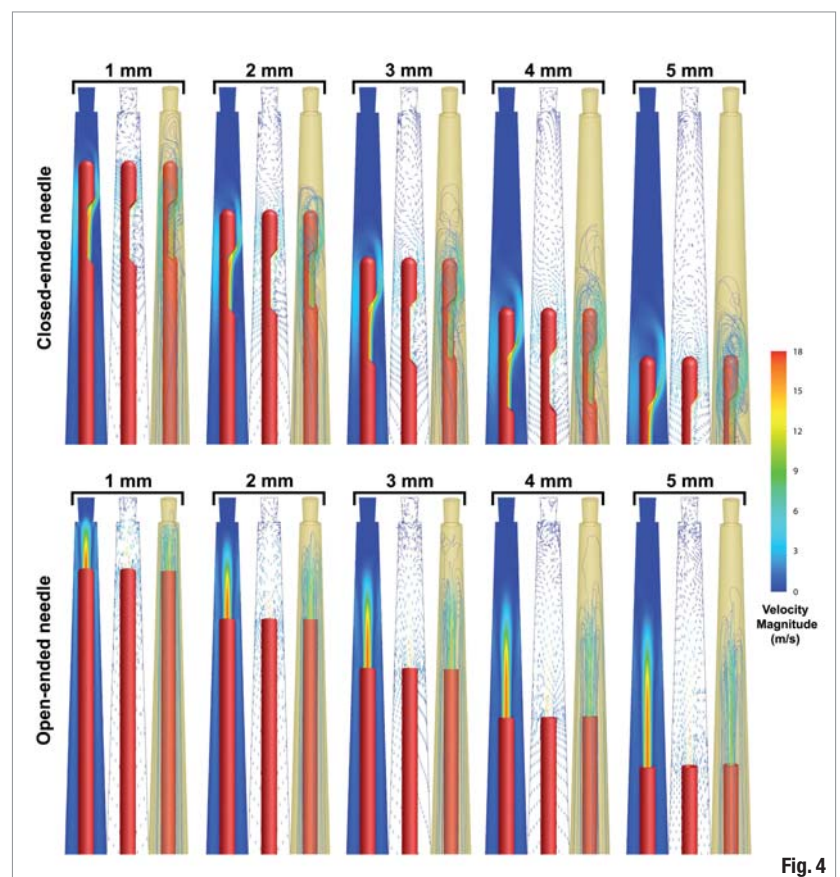
The pressure difference between the syringe and the tip of the needle is the cause of irrigant flow from the syringe through the needle and into the root canal. Irrigant flow rate is proportional to this difference, but is also affected by the size of the needle and several other parameters (Tilton 1999). Therefore, for the same pressure difference, the flow through a smaller needle will be much less than through a larger needle. Therefore, irrigant flow is not described accurately either by the force of the clinician or by the pressure developed in the syringe, but by the flow rate of the irrigant (Boutsioukis et al. 2007a, 2009), which can also be estimated clinically. A 5 ml syringe
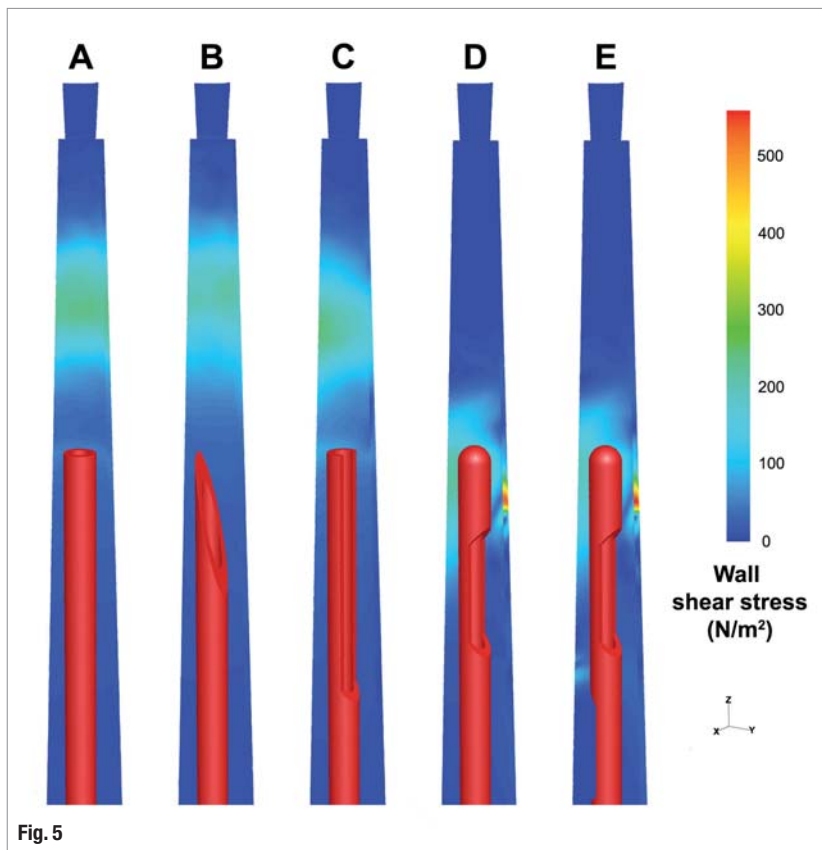
Fig. 5

Fig. 5_Time-averaged distribution of shear stress on the root-canal wall in the apical part of a size 45 root canal with a 0.06 taper during syringe irrigation using various needle types: open-ended (A–C), closed-ended (D & E). Only half of the root-canal wall is presented to allow simultaneous evaluation of the needle position. Needles are coloured in red. (Reprinted with permission from Boutsioukis et al. 2010b.)

In order to increase the efficiency of syringe irrigation, different needle types have been proposed (Moser & Heuer 1982; Kahn et al. 1995; Yamamoto et al. 2006; Vinothkumar et al. 2007; Boutsioukis et al. 2010b; Shen et al. 2010; Fig. 2). The type of the needle has a significant effect on the flow pattern developed (Fig. 3), while other parameters such as needle insertion depth, root-canal size and taper have only a limited influence (Boutsioukis et al. 2010a, 2010b, 2010c, 2010d, 2010e). Based on the resulting flow, the available needle types can be categorised into two main groups, namely closed-ended and open-ended (Boutsioukis et al. 2010b). Both needle groups create a jet at their outlet, but the shape of the outlet determines the orientation and, to some extent, the intensity of the jet.

In the case of open-ended needles (flat, bevelled, notched), the jet is very intense and extends along the root canal to their tip. Within a certain distance, which also depends on the geometry of the root canal and the insertion depth of the needle, the jet appears to break up gradually. Reverse flow towards the canal orifice occurs near the canal wall. The jet formed by the flat and bevelled needle is slightly more intense and extends farther apically than the notched needle. The overall performance of the bevelled and the notched needle is slightly inferior to that of the flat needle. Furthermore, the bevelled needle was originally designed for injections and its sharp tip poses a significant risk of injury to both the patient and the dentist, combined with an increased possibility of wedging inside the root canal, so it should not be used for root-canal irrigation (Boutsioukis et al. 2010b).

In the case of closed-ended needles (side-vented, double side-vented), the jet of irrigant is formed near the apical side of the outlet (the one proximal to the tip for the double side-vented needle) and is directed apically with a small divergence. The irrigant mainly follows a curved path around the tip and then towards the coronal orifice. A series of counter-rotating vortices (rotating flow structures) are formed apical to the tip. Their size, position and number may differ according to needle insertion depth, root-canal size and taper, and flow rate. The velocity of the irrigant inside each vortex decreases significantly towards the apex. The distal outlet of the double side-vented needle has only a minor influence on the overall flow pattern because most of the irrigant flows out through the proximal outlet, so it provides no significant advantage (Boutsioukis et al. 2010b). Contrary to previous reports (Kahn et al. 1995), turbulence is not developed at flow rates up to 0.26 ml/s, but it may develop at higher, clinically unrealistic flow rates (Boutsioukis et al. 2009, 2010a; Verhaagen et al. 2012). It is possible that formation of vortices and unsteady flow were mistaken for turbulence in the past.

combined with a 30G needle may be a reasonable compromise between effectiveness, ease of use and less frequent refilling, and can be used to reach flow rates of up to 0.20 to 0.25 ml/s (Boutsioukis et al. 2007a). High pressures may develop within the syringe during irrigation, so a Luer-lock connector is always necessary to avoid sudden detachment of the needle.

When investigating irrigation, it should be emphasised that the root canal behaves mostly like a closed-end system, thus in most cases the apical foramen should be considered non-patent (Hockett et al. 2008; Boutsioukis et al. 2009; Bronnec et al. 2010a; Parente et al. 2010; Tay et al. 2010). The apex being closed results in a significantly more complicated flow pattern compared with a simple tube open from both sides, even if we consider a simplified root-canal shape (White 1999; Boutsioukis et al. 2010a; Verhaagen et al. 2012). For very low flow rates, in the order of 0.01 ml/s, a steady laminar flow is developed within the root canal (Boutsioukis et al. 2009; Verhaagen et al. 2012). For higher flow rates, the flow becomes unsteady (changing as a function of time) but remains laminar up to a flow rate of approximately 0.26 ml/s (Boutsioukis et al. 2009, 2010a; Verhaagen et al. 2012). For higher flow rates, turbulence may develop in some areas of the root canal, mainly close to the tip of the needle, where irrigant velocity is higher (Boutsioukis et al. 2009).

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		ISO 9626:1991/Amd.1:2001 (Medical needles)			ISO 3630–1:2008 (Endodontic instruments)		
Gauge size	Designated Metric size (mm)	External diameter (mm)		Internal diameter (mm)	Size	Tip diameter (mm)	
		min	max	min		min	max
21	0.80	0.800	0.830	0.490	80	0.760	0.840
23	0.60	0.600	0.673	0.317	60	0.580	0.620
25	0.50	0.500	0.530	0.232	50	0.480	0.520
27	0.40	0.400	0.420	0.184	40	0.380	0.420
28	0.36	0.349	0.370	0.133	40	0.380	0.420
29	0.33	0.324	0.351	0.133	35	0.330	0.370
30	0.30	0.298	0.320	0.133	30	0.280	0.320
31	0.25	0.254	0.267	0.114	25	0.230	0.270

Irrigation needles are available in various sizes, which are most frequently described by the gauge system (Boutsioukis et al. 2007*b*). These units are not directly comparable to clinically related units like the size of endodontic files and obturation materials; thus, an intermediate conversion to millimetres may be useful (Table 1). In the past, large needles (21–25 G) were commonly employed (Brown & Doran 1975; Ram 1977; Salzgeber & Brilliant 1977; Chow 1983; Teplitsky et al. 1987). Such needles could hardly penetrate beyond the coronal third of the root canal, even in wide root canals. More recently, the use of finer-diameter needles (28 or 30 G) has been advocated (Sedgley et al. 2004; Zehnder 2006; Huang et al. 2008; Bronnec et al. 2010*b*), mainly because they can reach farther into the canal, even to working length (WL), and thus may result in better irrigant exchange and cleaning (Ram 1977; Chow 1983; Druttman & Stock 1989), but also because they may be more effective than larger-diameter needles even when positioned at the same depth (Chow 1983; Bronnec et al. 2010*b*).

Assuming other parameters are kept constant, the use of a larger needle would result in a decrease in the space available for irrigant flow between the needle and the root-canal wall. This decrease has been associated with either increased apical pressure for open-ended needles or decreased irrigant refreshment apical to the tip for closed-ended needles, as will be explained below in the relevant sections (Boutsioukis et al. 2010*d*, 2010*e*). Therefore, the use of a larger needle would not provide any advantage, apart from decreasing the clinician's effort in pushing the syringe plunger (Boutsioukis et al. 2007*a*).

The effect of tooth orientation (mandibular, maxillary, horizontal) on irrigant flow has been found to result in only minor differences in the resulting flow (Boutsioukis 2010; Boutsioukis et al. 2010*a*, 2010*b*). In a single-phase system, such as a root canal completely filled with the irrigant, gravity affects the flow through hydrostatic pressure. The latter is very low compared with the dynamic pressure developed owing to the flow of the irrigant. A noteworthy case in which tooth orientation may be important is when an air bubble is trapped in the apical part of the root canal (apical vapour lock), so a two-phase system is created (air and irrigant; De Gregorio et al. 2009; Tay et al. 2010; Vera et al. 2011, 2012). The air bubble could block irrigant penetration and, since air has a lower density than irrigants, it would tend to remain apical in a maxillary oriented root canal, if undisturbed, owing to buoyancy. However, routine trapping of air bubbles in the apical part of the root canal during endodontic treatment has not been shown and remains a speculation.

_Irrigant refreshment

Irrigant exchange in the various parts of the root-canal system is a crucial requirement for ensuring adequate chemical effect, since irrigants are rapidly inactivated when they come into contact with tissue remnants or microbes (Moorer & Wesselink 1982; Druttman & Stock 1989; Haapasalo et al. 2005). Needle type appears to have a significant effect on the extent of apical irrigant exchange. Earlier reports argued that closed-ended needles are more efficient than open-ended ones (Kahn et al. 1995; Vinothkumar et al. 2007). However, recent studies have clarified the limitations in the irrigant refreshment apical to closed-ended needles and clearly proven their inferiority (Zehnder 2006; Boutsioukis et al. 2009, 2010*b*, 2010*c*, 2010*d*, 2010*e*; Verghaagen et al. 2012) No significant difference has been detected between various types of closed-ended needles or between various types of open-ended needles (Vinothkumar et al. 2007; Boutsioukis et al. 2010*b*).

A general trend has been well documented in the literature: needle placement closer to WL results in more efficient irrigant exchange, regardless of needle type (Chow 1983; Sedgley et al. 2005; Hsieh et al. 2007; Boutsioukis et al. 2010c; Bronnec et al. 2010b; Fig. 4). An increase in the preparation size or taper allows penetration of the needle closer to WL (Abou-Rass & Piccinino 1982) and leads directly to more efficient irrigant refreshment (Chow 1983; Falk & Sedgley 2005; Hsieh et al. 2007; Huang et al. 2008; Bronnec et al. 2010a; Boutsioukis et al. 2010d, 2010e). It seems that enlargement to size 25 does not allow effective irrigant flow and apical refreshment even in 0.06 tapered root canals (Hsieh et al. 2007; Boutsioukis et al. 2010d). Enlargement to size 30 allows effective replacement 2 mm apical to an open-ended needle when combined with at least a 0.06 taper (Boutsioukis et al. 2010e), while size 35 combined with a 0.05 to 0.06 taper leads to significant irrigant refreshment almost 3 mm apical to the needle tip (Hsieh et al. 2007; Boutsioukis et al. 2010d). For closed-ended needles, it appears that irrigant replacement extends almost 1 mm apical to their tip in a root canal of size 30 and at least a 0.06 taper, while a further increase in the size or taper has only a minimal additional effect (Hockett et al. 2008;

Boutsioukis et al. 2010d, 2010e). Therefore, these needles should be placed within 1 mm from WL, and a minimum apical size of 35 is required in order for a 30 G needle to reach this depth. Surprisingly, a minimally tapered root-canal preparation (size 60 and 0.02 taper) may present an advantage over tapered ones in terms of irrigant refreshment (Boutsioukis et al. 2010e). However, irrigant exchange should be evaluated together with resistance to root fracture, the possibility of iatrogenic root-canal perforation and obturation technique requirements before deciding the instrumentation strategy.

Apart from the need to enlarge the root canal so that the needle can reach within a few millimetres of WL, it is equally important to ensure adequate space around the needle for reverse flow of the irrigant towards the canal orifice. Assuming that the position and size of the needle remain constant, an increase in the apical size or taper of the root canal results in an increase in the space available between the needle and the root-canal wall. This increase leads to an increase in the irrigant refreshment in the apical part of the root canal. Effective reverse flow is also necessary for irrigant refreshment coronal to the needle tip (Boutsioukis et al. 2010d,

2010e). It has been speculated that a "dead-water" zone or stagnation zone exists apical to the needle tip (Gao et al. 2009; Shen et al. 2010). However, recent studies have disproved this assumption and have demonstrated that there are no areas in the main root canal where the irrigant is completely stagnant during syringe irrigation, but only areas where the irrigant flow is extremely slow and adequate exchange cannot be ensured within the time limitations of a root-canal treatment (Boutsioukis
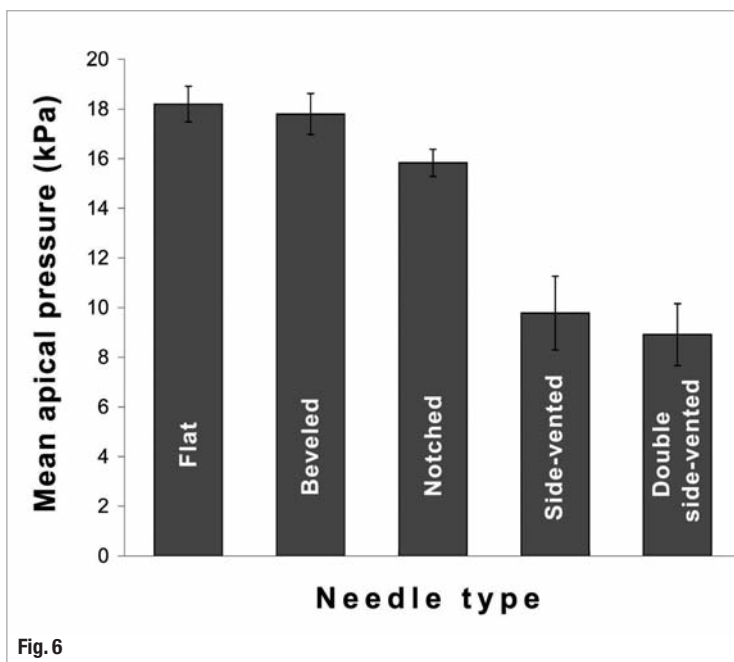

Fig. 6

Fig. 6_Time-averaged irrigant pressure at the apical foramen for various needle types: open-ended (A–C), closed-ended (D & E). Data shown as mean ± standard deviation. (Reprinted with permission from Boutsioukis et al. 2010b.)

et al. 2010a, 2010b, 2010c, 2010d, 2010e; Verhaagen et al. 2012). Increasing the volume of irrigant delivered could help to improve refreshment in such cases (Sedgley et al. 2004, 2005; Bronnec et al. 2010b) because it can be translated into irrigating for a longer time if the flow rate is constant.

Most of the data on irrigant flow and refreshment has been obtained from experiments and simulations in simple, straight root canals; however, many root canals are curved in reality. The effect of curvature on irrigant exchange has been studied indirectly by Nguy and Sedgley (2006), who reported that only a severe curvature in the order of 24 to 28 degrees impeded the flow of irrigants, delivered by a closed-ended needle near WL, even at a low flow rate. It can be assumed that if needles are positioned within 1 to 3 mm short of WL in a curved root canal, in many cases they have already bypassed most of the curvature and the remaining curvature apical to their tip is limited. Small size (30 G) flexible irrigation needles available nowadays in the market facilitate placement near WL, even in severely curved canals provided that the canal is enlarged to at least a size 30 or 35.

_Wall shear stress

During irrigant flow, frictional forces occur between the flowing irrigant and root-canal walls. These forces give rise to wall shear stress (Mott 1999; Tilton 1999; White 1999), which is of particular interest to irrigation because it tends to detach microbes/biofilm, tissue remnants or dentine debris from the root-canal wall; thus, it determines the mechanical effect of irrigation. Currently, there is no quantitative data on the minimum shear stress required for the removal of these targets. However, the overall distribution of wall shear stress provides an indication of the mechanical debridement efficacy.

Similar to the irrigant flow, two basic wall shear stress patterns can be distinguished for the various needle types during syringe irrigation (Fig. 5; Boutsioukis et al. 2010b). Regarding open-ended needles, an area of increased shear stress (which can be linked to optimum debridement) is developed apical to the needle tip, in the region of jet break up. Closed-ended needles lead to almost twice as high maximum shear stress, but limited near their tip, on the wall facing the needle outlet (the proximal outlet for the double side-vented needle). The unidirectional performance of closed-ended needles has also been reported in ex vivo studies that documented the influence of needle orientation on the debridement of the root canal (Yamamoto et al. 2006; Huang et al. 2008). So, in both cases, optimum debridement is expected near the tip of the needle (Huang et al. 2008; Boutsioukis et al. 2010b); therefore, during irrigation it is necessary to move the needle inside the root canal, so that the limited area of high wall shear stress affects as much of the root-canal wall as possible.

Needle insertion depth, canal size and taper do not seem to affect the distribution of wall shear stress significantly (Boutsioukis et al. 2010c, 2010d, 2010e). The maximum shear stress decreases as needles move away from WL, or with increasing size or taper, because more space is available for the back-flow of the irrigant and the irrigant velocity decreases, but the area affected by maximum shear stress becomes larger. It could be hypothesised that over-enthusiastic enlargement of the root canal beyond a certain size or taper may in fact reduce the debridement efficacy of irrigation. Similar to irrigant refreshment, it appears that the overall distribution of wall shear stress may be slightly more favourable in canals with a large apical size and limited taper rather than canals with a small size and increased taper (Boutsioukis et al. 2010d, 2010e). No data is available on the effect of flow rate, but it can be assumed that increasing the flow rate will also increase the wall shear stress. In all cases, high shear stress may lead to the detachment of biofilm or debris from the root-canal wall but is not enough to ensure their removal from the canal space, unless there is a favourable reverse flow to carry them towards the canal orifice.

_Apical pressure—Extrusion

During root-canal irrigation, it is possible that part of the irrigant delivered will be extruded towards the periapical tissue (Vande Visse & Brilliant 1975; Hülsmann et al. 2009). A healthy periodontium seems to provide a reliable barrier against irrigant extrusion (Salzgeber & Brilliant 1977; Chu 2010). However, currently, there is insufficient data to allow a more elaborate understanding of this aspect of root-canal irrigation. In order to conduct some useful comparisons, the irrigant pressure at the apical foramen could be related to the possibility and severity of irrigant extrusion (Boutsioukis et al. 2010b).

In general, the open-ended needles achieve improved irrigant refreshment in the apical part of the root canal but also lead to higher pressure at the apical foramen, indicating an increased risk of irrigant extrusion; closed-ended needles develop much lower pressure (approximately 50% less; Fig. 6; Boutsioukis et al. 2010b). Both needle types present a similar decrease in apical pressure, as the insertion depth decreases or the preparation size or canal taper increases (Boutsioukis et al. 2010c, 2010d, 2010e).

The performance of open-ended and closed-ended needles is expected to be quite different in the hypothetical situation of the needle binding in the root canal. If an open-ended needle is used, the flow would be trapped apical to the needle tip without any route of escape towards the canal orifice, the apical pressure would increase rapidly and forceful irrigant extrusion would probably occur. To the contrary, binding of a closed-ended needle would limit the irrigant flow to the space coronal to its tip. Irrigant exchange apical to the tip would be impossible, but the apical pressure would be almost zero, which is a benefit of the blind tip or safe tip of closed-ended needles, providing safety in such cases (Boutsioukis et al. 2010d, 2010e).

_Concluding remarks

Anatomical complexities of the root-canal system and the existence of microbes as surface-adherent biofilm structures serve as the foremost challenges in root-canal disinfection. One way of circumventing such challenges is by combining ideal irrigants with an optimal irrigation technique to achieve maximum removal of biofilms from the root canals. Accordingly, it becomes imperative to understand the fluid dynamics of irrigation in the root-canal system. The application of Computational Fluid Dynamics (CFD) models provides information on the flow and exchange of irrigant within the root-canal system for a particular mode of irrigation. It appears that the requirements of adequate irrigant penetration and exchange, mechanical debridement and minimum risk of apical ex-

trusion contradict each other and a delicate balance needs to be maintained. Since the prevention of extrusion should precede the other requirements of irrigation, a reasonable compromise for open-ended needles would be 2 or 3 mm short of WL. Based on Computational Fluid Dynamics analyses, this can still ensure adequate irrigant exchange and high wall shear stress, while reducing the risk of extrusion, provided that the canal is enlarged to at least a size 35 with a 0.06 taper or to a larger apical size combined with a minimum taper. The development of lower irrigant pressure by closed-ended needles allows their placement within 1 mm short of WL, so that optimum irrigant exchange can be ensured.

Anatomic irregularities may create additional challenges. Syringe irrigation seems unable to prevent or remove hard-tissue debris from the isthmus between the mesial root canals of mandibular molars (Endal et al. 2011; Paqué et al. 2011) or from artificial grooves and cavities in the apical part of the canal (Rödig et al. 2010). Currently, the irrigant flow in such complicated geometries has not been studied. It can be speculated that flow into narrow spaces connected to the main root canal is dependent on adequate activation, which could force the irrigant laterally into the grooves, cavities and isthmuses (Jiang et al. 2010), while syringe irrigation is possibly unable to achieve this goal predictably under clinical conditions.

In all cases, it must be remembered that regardless of the method and equipment used, irrigation of root canals involves a series of human-controlled actions, inevitably prone to natural human variability and difficult to standardise on a clinical basis. A wide variation in irrigant flow rate, duration, volume of irrigant and force applied to the syringe has been found among endodontists, even when the participants shared a common educational background (Boutsioukis et al. 2007a). Thus, the human factor should also be considered in root-canal irrigation._

Editorial note: A complete list of references is available from the publisher.

_about the authors | roots

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Irrigation for the root canal
and nothing but the root canal

Author_ Dr Philippe Sleiman, Lebanon

Fig. 1

Fig. 2

**Irrigation is a major step** in endodontic treatment. A variety of chemicals are used to achieve what I like to consider the chemical preparation of the root-canal system.

Sodium hypochlorite (NaOCl) is a major component of the chemical preparation, mainly owing to its ability to attack the collagen component of the pulp tissue, and it is very cost-effective. However, one of the problems of using NaOCl is its safety, especially during its delivery inside the root-canal system and the ability to limit its delivery strictly to root-canal space and nothing but the root-canal space.

Going beyond the limit of the root-canal space causes serious problems, the gravity of which depends on the amount of NaOCl passing to the margins of the periodontal ligament or even attacking the periodontal ligament. A small amount can result in pain or discomfort after treatment, whereas a larger amount, especially in cases of large and\or open apices, can accidentally be delivered inside the maxillary bone, travel via veins and arteries to primary anatomical organs and cause extensive, serious and very dangerous reactions. It is possible that the majority of such incidents are treatable with steroids and antibiotics, as they are limited to muscle and bone inflammation and slight reversible necrosis.

Sometimes we are not that lucky. Irrigating the last few millimetres in the root-canal space is an important key to treatment success, and a certain amount of NaOCl may be delivered into the maxillary sinus especially in the area of the maxillary second premolar and first molar. The case discussed below was the result of accidental NaOCl delivery into the maxillary sinus.

Fig. 3

Fig. 4
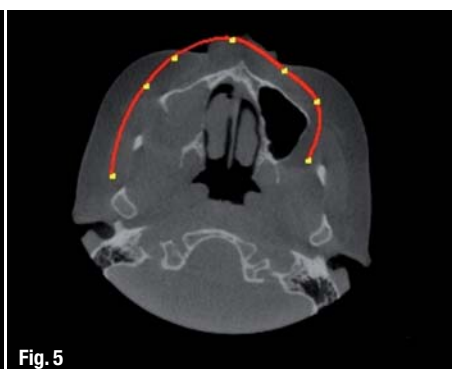
Fig. 5

_Case report

The patient was referred to my office for a complaint regarding the maxillary molar. After examining the patient and looking at her preoperative X-ray, I saw nothing wrong with the existing root-canal treatment, at least concerning the roots, but found a vague image in the sinus that I thought could be related to the maxillary molar and could be the cause of the problem. I asked my assistant to take a panoramic X-ray, which demonstrated a much larger problem inside the sinus but at that point I did not realise the scale of the issue.

Turning back to the patient, I went into some questions related to the issue, such as "Do you have problems breathing through your nose on this side?", "Can you describe to me the pain or discomfort you are having?", "Can you tell me if anything unusual happened during your previous root-canal treatment?" and "What were the indications for this treatment several months before?". The patient, quite unexpectedly, told me that during the procedure she had had a chlorine taste in her throat arising from her nose as if a liquid was dripping internally. Also, after the treatment was over and she was on her way home, a strange liquid with the same chlorine smell began dripping from her nose.

Upon hearing that, I asked the patient to have a CBCT scan of the maxilla because it was necessary to establish the situation in the sinus. The patient was nervous and anxious, so I asked the radiology centre if they could capture the CBCT scan for her on the same day as a favour.

A couple of hours later, the patient returned to my office and I took the time to examine the images. In the panoramic view, it was clear that half of the sinus was filled with inflammatory tissue (Fig. 2); in the sectional views, I noticed that the posterior wall of the sinus was non-existent in some places (Figs. 3–5). Potentially, it could be the position of the patient during the root-canal procedure that made NaOCl stagnate on the posterior wall and aggravate the damage.

The patient was informed of my opinion and recommended to see her otorhinolaryngologist, who took over the case, since it was already beyond the specialty of the dental profession and so she did.

_Conclusion

As we have seen, what seems to be a normal root-canal treatment can hold serious implications for human health. Although it is very true that we need irrigation to clean the root-canal system, those chemicals need to be limited to the root-canal system

Fig. 6
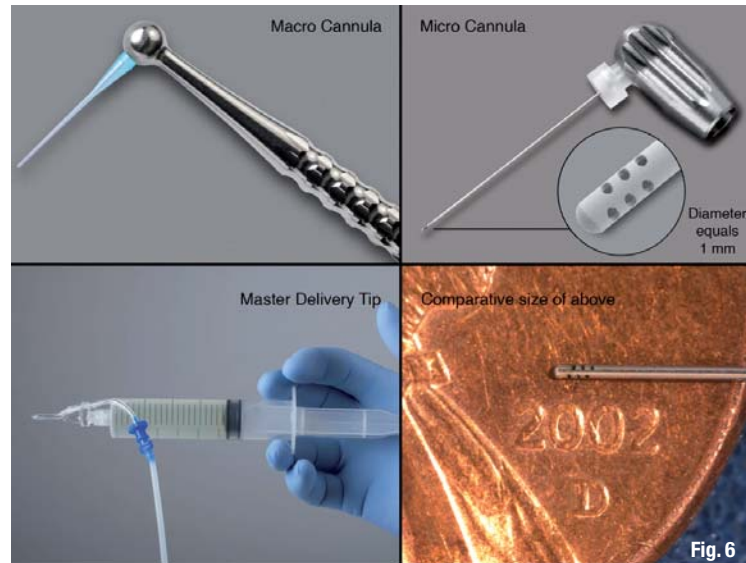
only, as even a few drops of NaOCl approaching the periodontal ligament may create an inflammatory region and area of tissue damage as a result of an aggressive chemical reaction.

Sometimes this process is limited and may only cause minor discomfort for a couple of days, but when the amount of chemical is larger more severe problems may occur, for which the use of steroids and antibiotics is recommended. A major accident can still happen at any time when an amount of chemical travels outside the oral cavity and causes a more serious complication.

One of the safest options that we currently have at our disposal is the EndoVac system (SybronEndo), which is designed specifically to deliver fresh irrigant all along the root-canal system and, most importantly, to clean the last 3 mm of the root-canal system using the MicroCannula. It allows us to be certain that no chemicals can go beyond the limits of the root-canal space, nor cause any serious or even minor damage._

_contact	roots

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Endodontic management of a hypertaurodontic maxillary first molar—

A case report with a two-year follow-up

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_Introduction

Taurodontism is a morphological variation in which the body of the tooth is enlarged and the roots are reduced in size. Taurodontic teeth have large pulp chambers and apically positioned furcation.[1] This variation was first described by Gorjanović-Kramberger;[2] however, the term "taurodontism" was first introduced by Sir Arthur Keith[3] to describe molar teeth resembling those of ungulates, particularly bulls. The term "taurodontism" comes from the Latin term "*tauros*", which means "bull" and the Greek term "*odus*", which means "tooth" or "bull tooth".[4] Such morphological variations are an endodontic challenge and even more difficult to treat when additional roots and/or canals are present. The endodontic management of one such taurodontic molar is reported in this case report.

_Case report

A 44-year-old male patient was referred to our clinic for treatment of the right maxillary first molar (tooth #16). The preoperative periapical radiograph (Fig. 1a) suggested the following possibilities:

_a mesio-occlusal carious lesion with endodontic involvement;
_a highly calcified and elongated pulp chamber extending up to the trifurcation;
_three short roots with the trifurcation in the apical third; or
_a periapical radiolucency in relation to the mesio-buccal and palatal root apex.

Clinically, vitality tests were negative and a diagnosis of hypertaurodontism, according to Shifman and Chanannel,[5] with pulpal necrosis was made for tooth #16 and endodontic treatment was planned.

Local anaesthesia of 2% lidocaine with 1:100,000 epinephrine was administered to the patient. The mesial surface of the tooth was restored with composite resin (Z100, 3M ESPE) after caries excavation to enable optimal isolation. Under rubber dam isola-

Fig. 1a_Diagnostic radiograph of tooth #16 demonstrating hypertaurodontism and coronal pulp chamber obliteration.
Fig. 1b_Initial working length radiograph with three canals located.
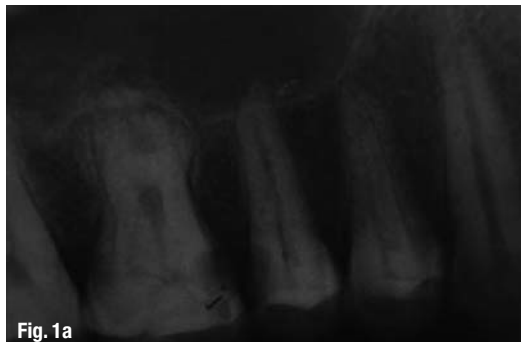
Fig. 1a

Fig. 1b

tion, the access cavity was established with an Endo Access bur and an Endo Z bur (DENTSPLY Tulsa). A dental operating microscope (DOM; Seiler Revelation) was used throughout the procedure to facilitate visualisation. The calcified mass occluding the pulp chamber was removed using ET 18D ultrasonic tips (Satelec/Acteon). Three root-canal orifices were located: two narrow orifices, the mesiobuccal and distobuccal, and a wide palatal orifice. Root-canal orifices were named according to the nomenclature proposed by Kottoor et al.[5] An electronic apex locator (Root ZX, Morita) was used to determine the initial working length, which was confirmed radiographically (Fig. 1b). The root canals were cleaned and shaped with ProTaper (DENTSPLY Maillefer) rotary instruments. The buccal canals were instrumented up to F2 and palatal canal to F4. The canals were irrigated with 2.5 % sodium hypochlorite using ultrasonics, 17 % aqueous solution of EDTA, and 0.2 % w/v chlorhexidine gluconate. The canals were dried using sterile paper points and obturated with gutta-percha cones and AH Plus sealer (DENTSPLY DeTrey) using the cold lateral compaction and vertical compaction techniques. The access cavity was then restored with miracle mix (cermet and Ketac Silver, 3M ESPE; Fig. 1c).

The patient returned to the endodontic clinic after three weeks with sensitivity in the same tooth on consumption of cold foods. The longevity of the complaint prompted a re-entry into the tooth to evaluate the possibility of any additional canal/s. The coronal restoration was removed and the pulpal floor was carefully inspected again under the DOM at a higher magnification. The visual and tactile examination under the DOM revealed a second mesiobuccal canal (P-MB). Under the microscope, it was possible to insert a #15 K-file and the existence of the additional canal was confirmed using an electronic apex locator. A working length radiograph was taken with a #20 K-file in the untreated canal (Fig. 1d). The P-MB canal was instrumented to F2 under irrigation with 3 % sodium hypochlorite and EDTA and obturated by cold lateral compaction of the gutta-percha and AH Plus sealer (Fig. 1e). Follow-up clinical examination after a week revealed that the tooth was asymptomatic and was not sensitive to percussion or palpation. Subsequently, endodontic management of tooth #15 was completed. The 24-month follow-up radiograph showed complete resolution of the periapical radiolucency in relation to the mesiobuccal and palatal root apices (Fig. 1f).

_Discussion

Taurodontism is frequently associated with other anomalies and syndromes. These include Klinefelter syndrome,[6] ectodermal alterations,[7] Down syndrome,[8] Mohr syndrome,[9] Wolf-Hirschhorn syndrome,[10] Lowe syndrome,[11] Tricho-dento-osseous syndrome,[12] Williams syndrome,[13] and Seckel syndrome,[14] but it is not a constant feature of these syndromes.[15] However, identification of patients with multiple taurodontic teeth could lead to early recognition of a systemic disorder and improve quality of life. It has also been found to be associated with dental anomalies such as oligodontia, supernumerary teeth, and amelogenesis imperfecta.[16] In this case, the patient was a healthy male with a negative medical history.

Its aetiology is still unknown, but it has been suggested that it may be caused by a failure of the diaphragm of Hertwig's epithelial root sheath to invaginate at the correct time and horizontal level or changes in the mitotic activity of cells of the developing teeth that can affect root formation or influence by external factors on the development of the teeth.[18] Differences in opinion exist regarding the amount of displacement and/or morphological change required to constitute taurodontism. Based on the relative amount of apical displacement of the pulp chamber floor, Shaw[19] classified taurodontism as hypotaurodontism, mesotaurodontism, and hypertaurodontism. This subjective, arbitrary classification led normal teeth to be misdiagnosed as taurodontism. Feichtinger and Rossiwall[20] state that the distance from the bifurcation or trifurcation of the root to the cemento-enamel junction should be greater than the occluso-cervical distance for a taurodontic tooth. Keene[21] proposed the Taurodont Index, relating the height of the pulp chamber to the length of the longest root. Although there are many classification systems to determine the severity of taurodontism,[22] the classification proposed by Shifman and Chanannel[15] in 1978 is the most widely used system. According to this index, taurodontism is present if the distance from the lowest point at the occlusal end of the pulp chamber to the highest point at the apical end of the chamber, divided by the distance from the occlusal end of the pulp chamber to the apex and multiplied by 100 is 20 or above (hypotaurodontism: TI 20–30; mesotaurodontism: TI 30–40; hypertaurodontism: TI 40–75).

Except for a higher prevalence of taurodontism among females in a Chinese sample,[23] no study has found a gender difference for this abnormality. Although permanent mandibular molars are most commonly affected,[23] taurodontism is occasionally observed in mandibular premolars and even in maxillary premolars, mandibular canines, and incisors.[24–26] Its prevalence has been reported as ranging from 5.67 to 60 % of subjects.[27, 28] In a recent study, it accounted for 18 % of all anomalies.[29]

Endodontic treatment in taurodontic teeth has been described as complex and challenging because the apical position of the pulpal floor can make it difficult to identify and locate root-canal orifices. In the present case, an apical third trifurcation with four root canals was observed. The mesiobuccal and distobuccal canal orifices were very narrow and close to each other, which made identification and negotiation of these orifices very difficult. Additionally, the proximity of the orifices and deeply situated opening of the canals made it difficult to identify the P-MB during the initial visit. However, during the second visit, the use of DOM enhanced the visualisation of the pulpal floor by better illumination of the depths of the cavity. Hence, success was largely dependent on the use of magnification, which allowed for the identification of the P-MB canal with ease. During instrumentation, the shortened length of these canals allowed for instrumentation with only the apical third of the file, also making it time consuming. Thus, endodontic treatment of taurodontic teeth may be complex, particularly regarding the cleaning and shaping of the root canals and root-canal obturation, especially in hypertaurodontic teeth.

_Conclusion

The case report has described the successful endodontic treatment of a hypertaurodontic maxillary first molar that would have seemed impossible to perform with conventional techniques. Success was mostly attributed to the use of magnification, which allowed better visualisation of the four canal orifices. This case report has served to illustrate to clinicians that sound knowledge and modern equipment facilitate enhanced management of endodontically challenging taurodontic teeth._

Editorial note: A complete list of references is available from the publisher.

_about the authors ##   roots

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He is the first author worldwide to have reported seven and eight root canals in a maxillary molar. His work consequently made the cover page of the *Journal of Endodontics*. He has a special interest in root-canal anatomy and is currently a Associate Professor in conservative dentistry and endodontics at Mar Baselios Dental College in Kochi, India.

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VDW Motors produced in Tuscany, Italy

Fig. 1

_**With their product lines** VDW.SILVER and VDW.GOLD, VDW—the specialist in endodontics, has set standards in design, function and user-friendliness of endo motors. In addition to controlling rotary NiTi systems the current device series with the name affix RECIPROC also masters the innovative reciproc technique.

The motors are produced by ATR in Pistoia near Florence, Italy. The company name stands for Advanced Technology Research. From the beginning ATR has specialised in micro-motors for dentistry. In 1999 the then young company has developed the first endo motor with torque control: the ATR TECNIKA. This first motor, and more so the following model ATR VISION were able to offer the user a wide range of applications, including programming individual drive modes via the system menu. Contributions in internet based forums still demonstrate that particularly the ATR motors have allowed to perform trials with the Ghassan Yared technique (known today as the reciproc technique).

A further pillar of the ATR production is the division for powerful precision motors for implantology, which are well established in several markets.

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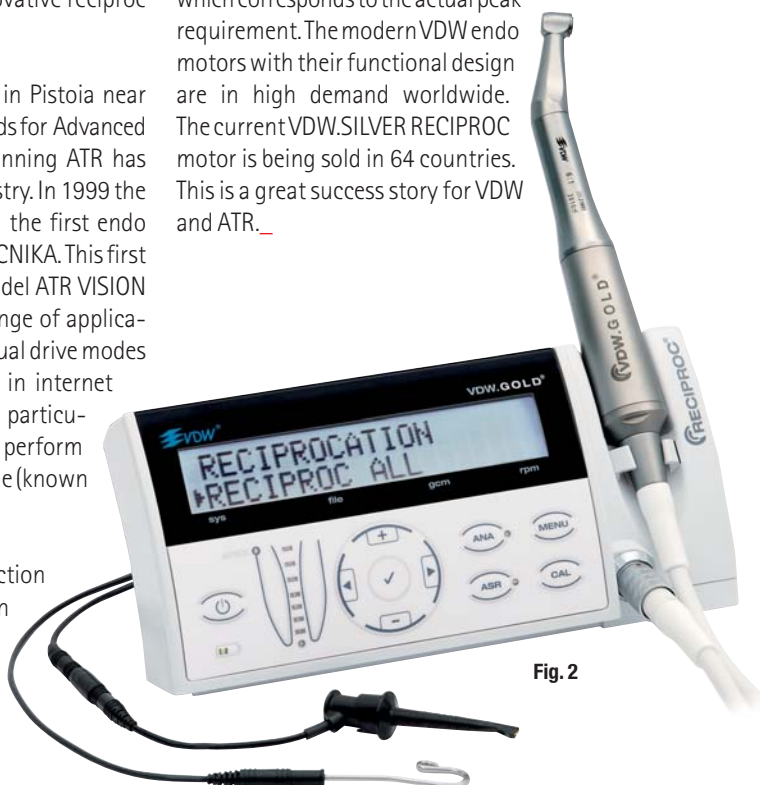
Fig. 2

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