Volume 10 • Issue 3 • Fall 2016

ENDO

Endodontic Practice Today

Official Publication of

Belgian Association for Endodontology and Traumatology (BAET)
French Society of Endodontics (SFE)
Norwegian Endodontic Society (NEF)

3 • 2016

ENDO – ENDODONTIC PRACTICE TODAY

VOLUME 10 • ISSUE 3 • 2016

Bugging you to act!

The story of the serendipitous discovery of penicillin by Alexander Fleming may be familiar to many. On 3 September 1928, having returned from holiday, Fleming was going through petri dishes containing colonies of *Staphylococcus* when he observed a zone of inhibition around an area contaminated with mould. The mould, eventually identified as a strain *Penicillium notatum*, appeared to secrete a 'juice' that killed the bacteria.

Although it took another 10 years before the bacteria-killing substance in the 'mould juice' was isolated by Howard Florey, Ernst Chain and colleagues, Fleming's discovery led to the antibiotic age. Since then, other antibiotics, both natural and synthetic, have been discovered, isolated or formulated, helping to treat or prevent many different types of infection, saving countless lives in the process.

Unfortunately, 88 years on, the misuse and overuse of antibiotics has led to the development of bacteria resistant to many antibiotics. Unnecessary and inappropriate prescribing, selection of broad-spectrum or the wrong antibiotics, and incorrect duration or dosage are all contributory factors. In addition, easy access and poorly regulated availability of over-the-counter antibiotics, in some countries, directly purchased for self-medication are also contributory. Furthermore, it is not helped by the agricultural practice of adding low, sub-therapeutic doses of antibiotics to livestock feed and/or water to enhance growth rates, reduce mortality and morbidity, and to compensate for, or cover up, poor husbandry or animal welfare management.

In the UK and the US approximately 10% of antibiotics prescriptions are provided by dentists[1,2]; this equates to approximately 3.6 million[3] and 25.6 million[2] prescriptions, respectively. Increased antibiotic prescription in dentistry has been reported in a number of countries[1,4]. In England alone antibiotic consumption rose by 6% between 2010 and 2013[5].

The antibiotic resistome genes that contribute to antibiotic-resistance is dynamic and ever expanding. Antibiotic resistance is a real and increasingly serious threat to global public health and patient safety. The rise of superbugs and multidrug-resistant bugs is making news headlines worldwide. In the USA, at least 2 million people suffered antibiotic-resistant bacterial infections and approximately 23,000 people die annually as a direct result[2]. In Europe, every year, 25,000 deaths are attributed to antibiotic-resistant bacteria[6].

Serious concerns and recognising the urgent need to address antimicrobial, including antibiotic resistance are shared around the world. In July 2014, the UK Government commissioned the O'Neill Review on Antimicrobial Resistance[7]. The National Institute for Health and Care Excellence (UK) has published good practice guidelines on the effective use of antimicrobials[8]. In addition, led by Public Health England (PHE), in collaboration with other UK authorities and administrations, the 'Antibiotic Guardian' initiative was developed to help increase awareness of the problem[9]. The aim is to encourage the general public, students, educators, farmers, veterinary and healthcare communities, and professional organisations to become 'Antibiotic Guardians'. Other similar campaigns include the 'Antibiotic Stewardship Program' promoted by the Centers for Disease Control and Prevention (CDC) in the US[10]. To mark the European Commission's public health initiative to raise awareness and as a reminder of the problem of antibiotic resistance, 18 November is designated the annual European Antibiotic Awareness Day. As part of the World Health Organization's global action plan to tackle the growing problem of resistance to antibiotics, 14 to 20 November is World

Antibiotic Awareness Week. Even the United Nations has taken action, recently convening a high-level General Assembly meeting, only the fourth time for a health issue, on the 'fundamental threat' of antimicrobial resistance and in order to look into ways of reducing irresponsible antimicrobial usage.

Most root canal infections consist of a mixture of microbes, with bacteria being the main candidate pathogen. In everyday clinical practice, in spite of antibiotics, there is still no better way of relieving the pain of an acutely infected tooth than local measures, such as drainage. Therefore, antibiotics should be strictly reserved for controlling a spreading infection, if there are signs of systemic involvement, or persistent infection despite operative intervention. We must actively participate in every effort to combat the alarming rise of antibiotic resistance. These include following prudent prescribing advice and adhering to good practice guidelines[2,5,11,12]. Antibiotics should not be prescribed for the sake of expediency or doled out without second thought.

This editorial may be preaching to the converted. However, time is running out; nothing is lost by maintaining focus on a problem which could spiral out of control.

BS Chong

References

1. Elouafkaoui P, Young L, Newlands R, et al. An Audit and Feedback Intervention for Reducing Antibiotic Prescribing in General Dental Practice: The RAPiD Cluster Randomised Controlled Trial. PLoS Med 2016;13:e1002115.
2. Fluent MT, Jacobsen PL, Hicks LA; OSAP, the Safest Dental Visit. Considerations for responsible antibiotic use in dentistry. J Am Dent Assoc 2016;147:683–686.
3. Cope AL, Barnes E, Howells EP, et al. Antimicrobial prescribing by dentists in Wales, UK: findings of the first cycle of a clinical audit. Br Dent J 2016;221:25–30.
4. Marra F, George D, Chong M, Sutherland S, Patrick DM. Antibiotic prescribing by dentists has increased: Why? J Am Dent Assoc 2016;147:320–327.
5. Antimicrobial resistance in dentistry. British Dental Association. Available at: https://www.bda.org/amr Accessed: 1 September 2016.
6. Johnson TM, Hawkes J. Awareness of antibiotic prescribing and resistance in primary dental care. Prim Dent J 2014;3:44–47.
7. Review on antimicrobial resistance. HM Government. Available at: https://amr-review.org/home Accessed: 2 September 2016.
8. Antimicrobial stewardship: systems and processes for effective antimicrobial medicine use. NICE guideline. 2015. nice.org.uk/guidance/ng15. National Institute of Health and Care Excellence. Available at: https://www.nice.org.uk/guidance/ng15/resources/antimicrobial-stewardship-systems-and-processes-for-effective-antimicrobial-medicine-use-1837273110469 Accessed: 5 September 2016.
9. Antibiotic Guardian. Public Health England. Available at: http://antibioticguardian.com/ Accessed: 5 September 2016.
10. Centers for Disease Control and Prevention. Core Elements of Hospital Antibiotic Stewardship Programs. Available at: http://www.cdc.gov/getsmart/healthcare/implementation/core-elements.html Accessed: 23 September 2016.
11. Walton RE. Antibiotics: A Risky Prescription. American Association of Endodontics. Available at: http://www.aae.org/publications-and-research/communique/antibiotics--a-risky-prescription.aspx Accessed: 20 September 2016.
12. Managing common infections: guidance for primary care. Public Health England. Available at: https://www.gov.uk/government/publications/managing-common-infections-guidance-for-primary-care Accessed: 2 September 2016.

ENDO – Endodontic Practice Today

Volume 10, Issue 3, Fall 2016

Contents

ENDO
Endodontic Practice Today

ENDO - Endodontic Practice Today is published quarterly by Quintessence Publishing Co. Ltd, Quintessence House, Grafton Road, New Malden, Surrey KT3 3AB, UK. Court domicile and place of performance: London, England.

ENDO is the official journal of the Belgian Association for Endodontology and Traum-atology (BAET), the French Society of Endodontics (SFE)and the Norwegian Endodontic Society (NEF).

Publisher: H.W. Haase
Publishing Director: Johannes Wolters
Editorial Coordinator: Daniel Jenk
Subscription Managers: Angela Köthe: Germany, Austria, Switzerland
Andrew Johnson: All other countries
Advertising: Samira Rummler
Layout/Production: Ina Steinbrück

Printed in Germany

ISSN 1753-2809 (Print)
ISSN 1753-2817 (Online)

Subscription information
Contact your nearest Quintessence office:

Quintessence Publishing Co. Ltd,
Quintessence House, Grafton Road,
New Malden, Surrey KT3 3A B, UK.
Tel: +44 (0)20 8949 6087
Fax: +44 (0)20 8336 1484
Email: info@quintpub.co.uk
www.quintpub.co.uk

Quintessenz Verlags-GmbH
Komturstr. 18, D-12099, Berlin, Germany
Tel: +49-30-761 80-5
Fax: +49-30-761 80-68-0
Email: info@quintessenz.de
www.quintessenz.de

Quintessence Publishing Co. Inc
4350 Chandler Drive,
Hanover Park, Illinois 60133, USA
Tel: (630) 736-3600
Fax: (630) 736-3633
Email: service@quintbook.com
www.quintpub.com

Subscription rates (includes online version, http://endo-eptquintessenz.de)

Europe:

	Surface mail	Air mail
Individual	€118 / £98	£114
Institutional	€210 / £176	£192
Student*	€60 / £50	£66
Single issue	€32 / £26	£30

North America and rest of world:
Individual $170; Institutional $305; Student* $90

*Student verification must accompany order.

Subscriptions may begin at any time. Please allow 6 weeks for any change of address notification to be processed. Claims for missing journals will be serviced only within 6 months of publication date. Otherwise, single copy price will be charged on missing issues.

Postmaster: Send address changes to Quintessence Publishing Co. Ltd, Quintessence House, Grafton Road, New Malden, Surrey KT3 3AB, UK, or Quintessenz Verlags-GmbH, Komturstr. 18, D-12009, Berlin, Germany

Manuscript submission information: Go to www.manuscriptmanager.com/endo-ept to submit online. For more information, see the Guidelines for Authors page in this issue.

Michael Hülsmann

Prevention and management of problems during root canal treatment – A problem-based approach to root canal treatment. Part I

Michael Hülsmann, Prof. Dr.
Department of Preventive Dentistry, Periodontology and Cariology, University of Göttingen, Göttingen, Germany

Correspondence to:
Michael Hülsmann
Prof. Dr.
Dept. of Preventive Dentistry, Periodontology and Cariology, University of Göttingen,
Robert-Koch-Str. 40
D-37075 Göttingen,
Germany.
Tel: +49-551-3922855
Fax: +49-551-3922037
Email: michael.huelsmann@med.uni-goettingen.de

Key words *management, prevention, problems, root canal treatment*

Due to the biologic nature of endodontic diseases; the complex anatomy of the root canal; and the shortcomings and limitations of currently available instruments and materials for root canal treatment; the occurrence of problems is an immanent part of root canal treatment and consequently anticipation, prevention and management of such problems should be part of any treatment concept. The following paper tries to identify several major problems during root canal treatment and suggests a problem-based treatment approach, in order to prevent the occurrence of such issues. Beginning with diagnosis, differential therapy, estimation of degree of case difficulty, preparation of the access cavity, management of intracanal problems, a number of clinically relevant topics will be addressed. The aim of the following review is to convince the reader to accept problems as a part of daily endodontic treatment; to anticipate possible problems as a part of treatment planning; and to include prevention and management of problems into the routine concept for each root canal treatment.

Introduction

Root canal treatment itself aims at solving problems inside and outside the root canal system. Nevertheless, due to the microbial and biofilm nature of endodontic diseases, the complex anatomy of the root canal and the limitations of currently available instruments and materials for root canal treatment it is likely that further problems and complications will occur during root canal treatment. Frequency and severity of those problems additionally will depend on the endodontist's treatment concept and her or his capability to prevent and manage such situations. The endodontic literature presents only a few textbooks or reviews on problems associated with endodontic treatment [1-5].

Unfortunately, legal aspects have to be considered in this context too. Occurrence of complications or even failure of treatment may be attributed by the patient (or his or her lawyer) to failures or mishaps in the responsibility of the clinician or endodontist and could finally end up at a courtyard.

Preoperative considerations

Many problems and complications can be avoided by thorough diagnosis and treatment planning. A detailed diagnosis including evaluation of radiographs of sufficient quality enables the clinician:

- to identify the patient's expectations and cooperation as well as his or her general health and eventual general medical problems (allergies, heart or circulatory problems, diabetes, osteoporosis, bleeding disorders, transplants or implants);
- to identify the correct tooth requiring root canal treatment;

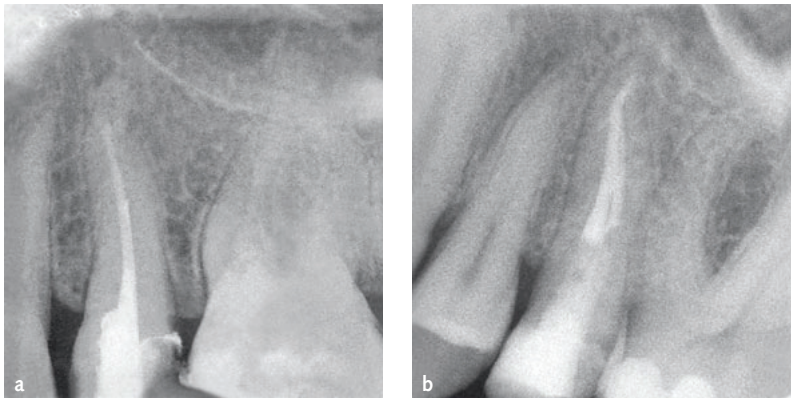


Fig 1a Poor quality radiograph which did not allow the correct diagnosis.

Fig 1b Angled postoperative radiograph demonstrating the presence of two root canals and an s-shaped root canal anatomy.

- to correctly diagnose the disease enabling proper treatment modalities to be selected;
- to estimate the severity of the disease enabling the prognosis of the treatment to be communicated to the patient;
- to anticipate potential problems likely to occur during the different steps of treatment allowing the clinician, if necessary, to modify the treatment plan and to prevent such problems, in order to manage these properly in the case of reoccurence.

Generally, properly angled radiographs (if necessary from different angles) are the most valuable means for anticipating and recognising endodontic problems (Figs 1a to 1b). Due to many patient concerns regarding the estimated risks of radiography, the number of radiographs taken during root canal treatment in many countries seems to be lower than recommended or necessary. It should be noted that in most cases not taking radiographs with sufficient quality results in a consecutive loss of important information. As it takes no more than a few weeks for a periapical lesion to develop to a size visible on the radiograph[6,7], the actual radiograph should not be older than a few weeks. A detailed analysis of preoperative radiographs is mandatory. It should be highlighted that the process of diagnosis is not limited to preoperative examination of the patient, patient's tooth and radiographs, but should be continued throughout the complete treatment. Intracoronal and intracanal/intraradicular examinations are important and the use of different kinds of testing pulp sensitivities is recommended[8,9]. Cone-beam computed tomography (CBCT) can be helpful in cases with difficult diagnosis and complex tooth or root canal anatomy, or most important in cases of dental trauma, but currently should not be regarded as mandatory[10]. In cases with a questionable diagnosis and with diagnostic uncertainty, referral to a specialist or at least referral for a second opinion is recommended.

When considering diagnosis three essentials should always be observed:

- There is rarely any diagnostic test with 100% specificity and sensitivity.
- Any test should give reproducible, logical or explainable, non-contradicting results and data.
- At least two independent findings should be present before a decision for root canal treatment is made.

The location and size of the pulp chamber; the number and length of roots and the root canals; the location, degree and radius of curvature; anatomical irregularities; resorptions and perforations; anatomical relation to the maxillary sinus or the inferior alveolar nerve; identification of previous treatment and many other features are very important for planning of instrumentation of the root canals. If these data cannot be taken from the radiograph, taking additional radiographs from different directions or angles should be considered.

■ Differential therapy

For each case, treatment options have to be considered and weighed against each other with respect to several parameters, which include:

- prognosis;
- risks;
- easibility;

- patient's expectations;
- complete treatment plan;
- costs.

The alternative treatment option of extraction and placing an implant has become quite popular for several reasons. Although properly placed implants have been reported to have an excellent prognosis[11], there are also several drawbacks making tooth retention by root canal treatment a more promising treatment option in many cases. Nevertheless, it must be stressed that there is no clear and evidence-based algorithm to decide among these options[12]. In some cases surgical treatment (apicectomy and hemisection) or extraction with or without prosthetic replacement of the tooth can represent the adequate treatment option. To avoid patient complaints and legal problems in the case of treatment failure or post-treatment complications, the final decision has to be made by the well-informed patient (informed consent). Proper preoperative information of the patient can help to prevent many postoperative problems and complications.

General rules for the management of complications

If a problem occurs during treatment, professional management is mandatory, not at least to maintain the patient's confidence with regard to the skills, capability and professionalism of the clinician.

This includes the following:

- Inform the patient immediately of any problem.
- Keep calm; consider stopping or interrupting treatment at that particular point and continue after re-planning at a new appointment! In most cases there is no reason that treatment has to be continued or finished immediately.
- Consider additional radiographs to obtain more accurate information on the nature, degree and location of the problem. If necessary and indicated take a CBCT.
- Try to identify and analyse the problem and develop a management strategy.
- Do not proceed with the current or even the next step of treatment! Step back to an earlier stage of treatment and repeat previous manipulations (e. g. step back to a smaller size of instrument, remove filling material and start obturation again from the beginning).
- Consider consultation of or referral to a specialist.
- Document any relevant detail accurately in the patient's treatment records.

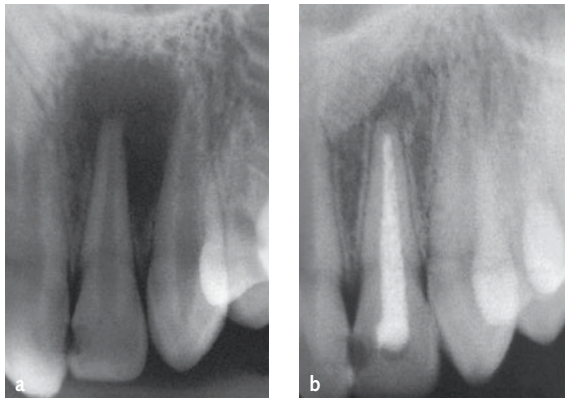


Fig 2a-b Low degree of difficulty: maxillary incisor with uncomplicated anatomy. Infection of the root canal system seems to be the main problem. Following proper disinfection, improvement of the apical lesion can be observed after 6 months.

Treatment plan

A proper treatment plan has to be established including anticipation of already identified or potential problems. Sheets for risk analysis or for estimation of the degree of difficulty of a planned root canal treatment can be helpful in guiding the clinician through this part of the treatment. Such documents can be individually designed or are distributed by endodontic societies[13].

Several features are assigned to different difficulty degrees from low to moderate or severe. The features include aspects of the patient's general health as well as criteria concerning the tooth (diagnosis, difficulty of rubber dam placement, tooth type [incisors and premolars: low difficulty, first molars: moderate difficulty, second and third molars: severe difficulty], type of restoration, root canal anatomy, resorption, trauma, previous root canal treatment etc). A numerical scale can facilitate classification of potential problems. The estimated degree of difficulty can be subdivided into three categories as suggested by the American Association of Endodontists[13]:

- Low degree of difficulty: The preoperative conditions indicate an uncomplicated routine treatment. Examination reveals only findings with a low level of difficulty. The most critical factor radiographically seems to be the apical inflammation. A good treatment outcome can be predictably achieved even by a clinician with limited endodontic experience[13] (Figs 2a to 2b).

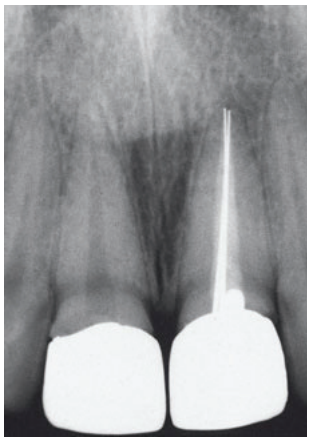


Fig 3 Retreatment case with a moderate degree of difficulty: due to a post-crown the coronal restoration had to be removed without damaging the silver cones. If not severely corroded (which cannot be evaluated from the radiograph), bypassing and removal should be relatively easy as there seems to be a large sealer-filled space. The type (and hardness) of the sealer or paste is unknown and therefore the ease of removal remains unclear. The internal anatomy of the root looks unchanged, therefore regaining access to the apical foramen seems feasible, all in all offering a fair prognosis for retreatment.

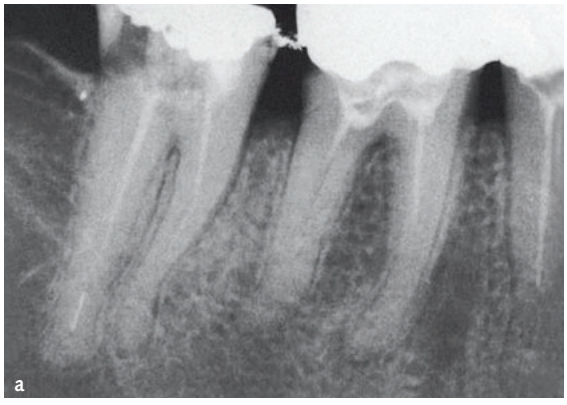


Fig 4a Mandibular molars presenting with a high degree of difficulty: previous root canal treatment with a fractured instrument, incomplete negotiation and treatment of root canals, ledging and severe coronal breakdown.

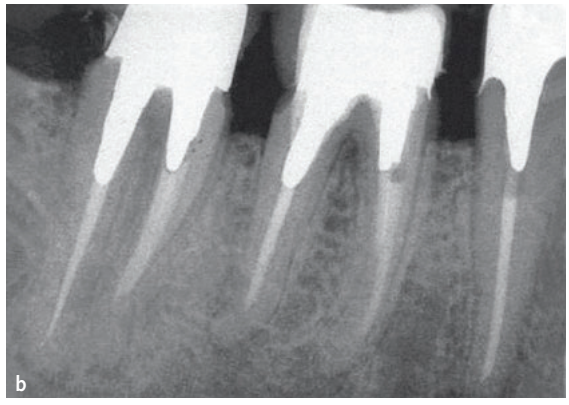


Fig 4b Even the endodontic specialist was unable to solve all the problems present. The apical constriction could not be accessed in all root canals.

- Moderate degree of difficulty: The preoperative conditions suggest a case presenting complications. At least some findings indicate problems (moderate degree of difficulty). A predictable positive outcome may be a challenge even for an experienced clinician[13] (Fig 3).
- High degree of difficulty: The preoperative conditions suggest a highly difficult case, presenting several features with a moderate or at least one or two features with a high degree of difficulty. To achieve a predictable outcome may be a challenge even to a specialist. At least for all teeth of this group, referral to a specialist should be considered seriously[13] (Figs 4a to 4b).

The diagnosis, treatment options and final treatment plan should be communicated to the patient as well as any obvious or potential problems and complications of the planned treatment and this should be documented thoroughly in the treatment records.

■ "Let's do a root canal!"

One of the major mistakes and conceptual misunderstandings in endodontics is addressing root canal treatment as a single and uniform entity.

Regarding anatomy and pathology of the tooth, the root and the endodontic space, there are several slightly or completely different situations and/or pathologies and difficulties as outlined above which consequently should be addressed as slightly or completely different (Table 1).

Several additional features could be added. It should be kept in mind that widely differing figures for prognosis indicating different types (and grades) of inflammation and/or infection or the technical difficulty of treatment have been published in the endodontic literature. Specifically addressing the disease as well as the tooth anatomy will avoid mistreatment, overtreatment or undertreatment and increase the success rates.

Problems in diagnosis

Nature of the problem

From a preventive point of view it is evident that the quality of treatment depends on the quality of diagnosis. Unfortunately, endodontic diagnosis is based on a number of investigations and tests with only limited sensitivity and specifity, making it difficult and sometimes impossible to evaluate the type and severity of a pulpal disease correctly and completely. Additionally, pain of a non-endodontic origin in many cases is difficult to differentiate from symptomatic apical periodontitis or symptomatic pulpitis. The frequency of such non-endodontic pain is estimated to be approximately 3% or more of all patients presenting with dental pain[14]. The fact that following root canal treatment more than 5% of patients still experience some degree of pain[15,16] which may not be related to the tooth treated, suggests that the preoperative diagnosis may not have been exact.

Management

Accurately taken radiographs are the main tools for diagnosis and treatment planning allowing the clinician to select the instruments and techniques best addressing the tooth and the disease to be treated. Mainly a number of anatomical problems can be visualised two-dimensionally, such as location and extension of the pulp chamber, the number and location of root canals, the degree and radius of the root canal curvature, the quality of previous root canal treatment etc.

Recently CBCT has gained some attention as a tool for preoperative endodontic diagnosis and as a helpful device in the management of endodontic problems[9,17-23]. It has been demonstrated in several studies that CBCT performs significantly better than periapical radiographs in the:

- detection of apical periodontitis;
- detection of small periapical lesions and earlier detection of developing lesions[18,19];
- identification of additional or previously untreated roots or root canals;
- analysis of root canal anatomy;
- internal resorptions[10,17];
- detection of intracanal problems[20-23].

Table 1 Different clinical situations requiring specific modifications of the treatment plan.

Situation	To be addressed:
Vital pulp	Anaesthesia necessary
	Irrigation to dissolve tissue and remove smear layer
	Medication not necessary
	Treatment should/could be finished in one appointment
	Excellent prognosis
Pulp necrosis and apical periodontitis	Anaesthesia not mandatory
	Infected root canal
	Irrigation for disinfection, dissolution of necrotic tissue and biofilm
	Removal of smear layer
	Medication can be helpful
	Prognosis reasonable
	Higher risk of postoperative pain
Apical abscess	Anaesthesia may be necessary
	Infected root canal
	Infection of the periapical tissues
	Drainage necessary
	Eventually incision necessary
	Eventually antibiotics necessary
	Prognosis unclear (no data available)
Retreatment	Usually no anaesthesia necessary
	Infected root canal
	With apical lesion (biological indication)
	Without apical lesion (technical indication)
	Original anatomy maintained
	Original anatomy changed
	Identification and removal of previous filling materials
	Increased risk of post-treatment pain or flare-ups
	Increased probability of intraoperative complications
Type of tooth	Incisor or bicuspid, molar
Patient	Young tooth, old tooth (sclerosis, calcification), deciduous tooth
Problems - tooth presenting with:	Difficult anatomy
	Developmental irregularities (dens invaginatus or evaginatus, dilacerations, radicular palatal groove and double teeth)
	Extensive restoration
	Perforation
	Straightened root canal
	Calcification and pulp stone
	Fractured instrument
	Apical resorption

Fig 5 Stropko air-blower.

Fig 6 Micro suction constructed by adapting a needle onto the saliva ejector (left): commercially available micro suction device with an adapted irrigation needle (right).

Nevertheless, for some other indications the value of CBCT is considered to be controversial and its benefit in terms of sensitivity and specifity is not clarified. This includes:

- vertical root fractures;
- horizontal root fractures;
- differential diagnosis between apical cysts and granulomas;
- root perforations;
- external resorptions;
- determination of endodontic working length[10,17].

Taking into account the increased radiation dose, the use of CBCT is recommended only in situations when radiographs and clinical investigations do not yield appropriate diagnostic information or when the diagnosis from other available sources is inconclusive[10].

Following proper investigation a clear diagnosis on the state of the pulp and the periapical tissues has to be made, summing up several reproducible symptoms that are logical and explainable in this combination. Diagnostic uncertainty may never be a reason to "do anything" but rather a reason for considering extended examinations (for example CBCT, additional pulp tests, selective anaesthesia, second opinion, referral to a specialist clinician or a physician).

Problems with anaesthesia

Nature of the problem

Without proper anaesthesia root canal treatment cannot be performed in a relaxed environment.

Nevertheless, anatomical and physiological problems can make adequate anaesthesia a major challenge.

Management

Treatment should not be started until sufficient signs of profound anaesthesia can be diagnosed reproducibly. Numbness of the lip and the intraoral soft tissues are less indicative for sufficient anaesthesia than a negative response on the pulp test, failing to reproduce the clinical symptoms. Failure of anaesthesia can be due to anatomical problems (uncommon location of the nerve and secondary innervation by another nerve) but more frequently inflammation of the pulp and/or the periradicular tissues. Mandibular molars presenting with irreversible pulpitis are extremely difficult to anaesthetise. Repeated injection as well as additional anaesthesia using intraligamentary, intrapulpal or intraosseous injection may be necessary until complete onset of anaesthesia can be observed. In some cases pulp inflammation has to be lowered using corticosteroids until sufficient anaesthesia can be achieved.

Anaesthesia can be considered even for treatment of teeth with necrotic pulps in fearful or nervous patients[24].

Visualisation

"You only can treat what you see" has become a popular comment when discussing the need and importance of a dental operating microscope. Of course, it might be considered controversial whether a dental operating microscope really is necessary for each root canal treatment. Its use should be seriously considered in cases with a moderate level of difficulty and will be necessary in the majority of cases with a high level of difficulty. Intraoperatively, the use of illumination and magnification (loupes and a dental operating microscope) as well as proper cleaning and drying of all structures are of utmost importance. It should be kept in mind that observation of moist or wet structures with heavy illumination will easily result in reflection of the light, therefore proper drying is mandatory using micro suction or pres-

surised air. Special devices such as the Stropko airblower have been described and recommended for this purpose. Devices for micro suctioning can easily be constructed in each dental office by adjusting an injection needle to the saliva ejector (Figs 5 to 6).

To avoid misleading the concentration of the operator in terms of the micro-details inside a cavity, which may be misinterpreted, the magnification of the microscope in regular intervals should be reduced in order to regain visual control over the complete cavity.

Preparation of the access cavity

Nature of the problem

Improper access will hinder a direct view of the pulp chamber floor and the detection of root canal orifices, and prevent the straight-line introduction of instruments and controlled preparation and obturation. The primary cause of apical problems is frequently located in the coronal part of the tooth!

Management

Before starting preparation of the access cavity a decision has to be made whether to remove, retain or repair the present coronal restoration.

The advantages of retaining a restoration include:

- no temporary restoration necessary;
- no problems when applying rubber dam;
- it is time-saving and cost-saving meaning the restoration can eventually be retained after root canal treatment.

Advantages of removal of a restoration include:

- better control of access cavity and pulp chamber floor (fractures, cracks, caries and perforations);
- better control of tooth margins (original circumference, control for cracks and fractures and restorability);
- improved conditions when searching for additional root canals[1].

On the other hand application of a rubber dam may be difficult, especially after removal of crowns and a temporary restoration and, if the restoration has to be damaged or destroyed for removal, a new definite restoration will have to be fabricated.

The access cavity has to be prepared to a size allowing removal of all tissue or filling material and complete inspection of the pulp chamber. The pulp chamber has to be carefully inspected for overhangs, tissue remnants, cracks, perforations, pulp stones, colour (secondary and tertiary dentine) and root canal orifices. This is accompanied by irrigation of the pulp chamber with copious amounts of sodium hypochlorite, thereby initiating disinfection of the root canal system. Instrumentation of the root canals should not be undertaken until preparation and cleaning of the pulp chamber are completed.

A strict protocol has to be followed during the search for root canal orifices. The main rule is a rule of exclusion: a tooth has one root canal only if a second one cannot be detected. Further rules have been outlined by Krasner and Rankow[25]. Some rules concerning symmetry, colour change and lines on the floor of the cavity are helpful when missing root canals are searched for[25] (Figs 7 to 8).

There is some controversy on the size of access cavities. The rule should be that the unnecessary sacrifice of dental hard tissues is avoided, but that the size of the cavity allows identification, discovery and straight-line instrumentation, as well as proper preparation, disinfection and obturation of all root canals. No compromise is acceptable.

Instrumentation of the root canals should never be started before preparation of the access cavity has been completed. This includes disinfection of the pulp chamber, thus eliminating a large part of the microorganisms colonising the tooth at an early stage of treatment. Any attempt to reach the working length or the apical part of the root canal in the initial phase of treatment invariably will result in transportation of microorganisms and of debris or tissue remnants into the apical regions or the extraradicular tissues of the root. The technical consequences include apical extrusion, apical blockage with subsequent loss of working length, ledging and even perforation. This is accompanied by biological problems such as flare-ups or failure of apical healing. Again, apical problems will be a consequence of coronal mistakes.

Fig 7 Mandibular molars show symmetry between the buccal and lingual half.

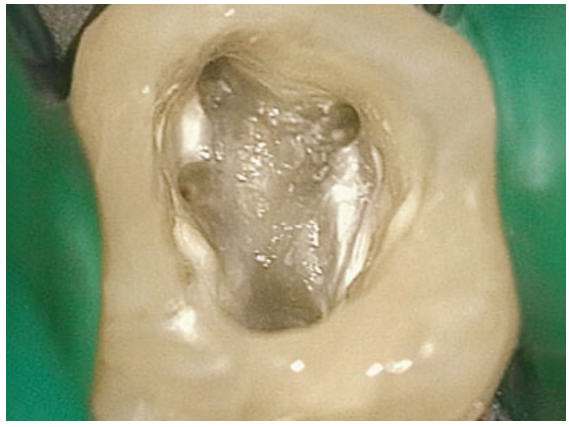


Fig 8 Root canal orifices are located in angles of the cavity where the pulp chamber floor and the root canal walls meet. Additionally, fine developmental lines and colour changes can help to detect root canals.

Determination of working length

Nature of the problem

Incorrect determination of endodontic working length will result in either leaving unnecessarily large amounts of necrotic tissue and microorganisms inside the root canal or in the enlargement of the foramen accompanied by transportation of debris, tissue remnants and bacteria into the periapical bone. Both can jeopardise treatment outcome by initiating or sustaining periradicular inflammation.

Optimal determination of endodontic working length can be achieved today using electronic apex locators. Electric measurements have repeatedly been demonstrated to be exact in more than 90% of the cases within a distance of ± 0.5 mm from the apical constriction[26]. Electric measurements should always be repeated to control reproducibility and reliability of the result and should be verified by a length determination radiograph. If the electric measurement suggests a working length more than 3 mm short of the apex, the electric measurement is probably false, as the apical constriction with a high degree of probability is located within the apical 3 mm of the root. If over-instrumentation is observed in the radiograph, the instrument definitely will have already passed the foramen. It should be noted that the length determination radiograph with a radiopaque contrast inside all root canals presents more information than just the working length, including:

- additional root canals;
- angle of root canal curvature;
- radius of root canal curvature;
- shape of the root canal;
- presence of s-shaped root canals;
- remaining filling material in retreatment cases.

The majority of this information is important for the selection of the size and taper of the subsequent enlargement of the root canal. Some practitioners prefer to control endodontic working length with a cone fit radiograph. Basically, this radiograph will control the achieved length and apical extent of preparation rather than determine the optimal working length. At this advanced stage of treatment it may be difficult if not impossible to correct an inadequate working length, as over-instrumentation and enlargement of the foramen may have occurred, as well as apical blockage by dentine chips or tissue remnants or irreversible procedural errors such as ledging, perforation or straightening.

Root canal preparation

Nature of the problem

Insufficient preparation of the root canal can leave large amounts of the root canal wall and root canal space untreated and covered with a bacterial biofilm, and thus can prevent insufficient preparation, proper disinfection and obturation, and therefore compromises treatment quality and treatment outcome.

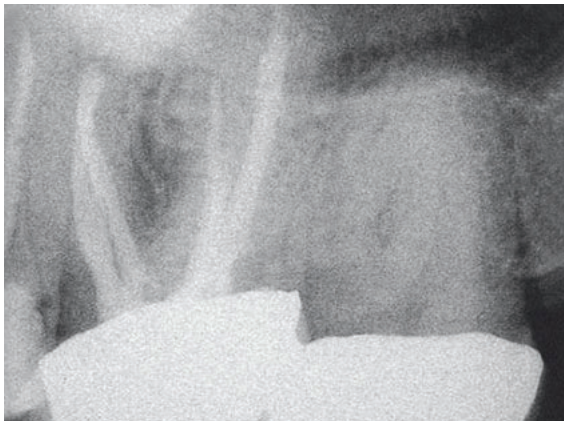


Fig 9 S-shaped palatal root canal in the second maxillary molar. There was a confluence of the first and second mesiobuccal root canals.

Fig 10 Confluence of both mesiobuccal root canals. As both have been prepared to the apical foramen, over-enlargement of the twice prepared apical part of the root has occurred.

Technical problems and shortcomings during preparation are invariably associated with subsequent biological problems (insufficient disinfection).

Besides technical problems anatomical irregularities can make preparation a challenge.

Anatomical problems

S-shaped root canals

The severity of the problem depends on the radius and angle of the curvatures. It should be assumed in many cases that there will be an additional curve in the plane of the radiograph. Depending on the severity of the curve preparation carries a high risk of straightening, ledging and instrument fracture. The use of highly tapered instruments should be avoided. It has been suggested using a crown-down approach for preparation. Preparing the coronal curve first and stepping further apically in a second step of preparation may be another adequate way to treat such root canal configurations[27] (Figs 1 and 9).

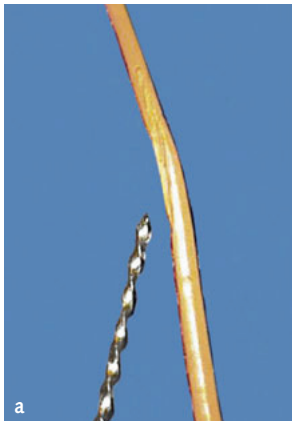
C-shaped root canals

The frequency of root canals with a c-shaped diameter has been reported as 2 to 30%[28] with large ethnic differences. Such cross-sections are mainly seen in mandibular molars with the mesiobuccal and distal root canal joining to one root canal with a c-shape. The root canal presents a rather irregular shape with many small fins, which is difficult to disinfect and sometimes cannot be prepared in its complete entirety. The use of copious irrigation and passive ultrasonic activation of the irrigant is recommended. Obturation preferably is performed using a thermoplastic technique.

Confluence of root canals

If a confluence of two root canals is not detected in time, the apical part of the root canal, which is common to both major canals, will be prepared twice, with a high probability of over-enlargement and/or straightening (Fig 10). If the angle of insertion of the second canal is too large, there is a high risk of ledging or instrument fracture. Additionally, confusion during obturation may occur as the estimated working length cannot be reached in the second canal when the first has already been obturated. Radiographically, a confluence in many cases cannot be clearly diagnosed. Clinically, several tests have been proposed to identify confluencing root canals:

- Endodontic instruments are inserted into both root canals. If only one can be inserted to the working length at any given time, confluence may be present.
- A gutta-percha point is placed into one root canal and endodontic instrument into the other one. If joined, the instrument will leave a mark in the gutta-percha at the point of confluence (Figs 11a to 11b).



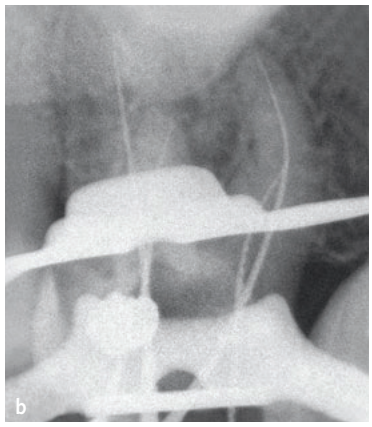


Fig 11a-b Placing a gutta-percha cone in one root canal and inserting an instrument into the second joining root canal will leave a mark on the cone, indicating the position and angle of the confluence.

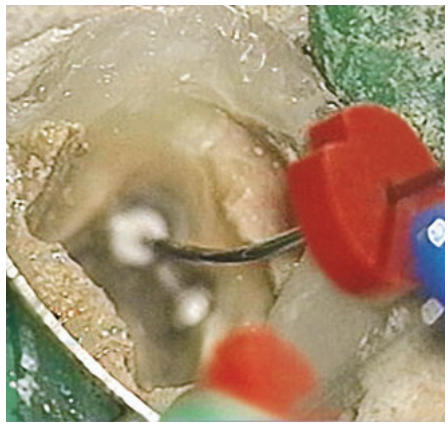


Fig 12 Calcium hydroxide emerging from mb2 during placement in the main mesiobuccal root canal.

- Both root canals are filled with an irrigant: when the level of irrigant is sinking in the second canal during drying the first one, the presence of a confluence is likely.
- The same is true when calcium hydroxide is placed in one root canal and emerges from the second (Fig 12).

Deep splitting of root canals

The main problems with deep splits of a root canal are detection and accessibility of the split. Thorough probing of the root canal with a fine and pre-curved instrument is the best way of diagnosing a split; CBCT may be helpful in difficult cases. For preparation and obturation a good access cavity is mandatory, allowing exact placement of gutta-percha, spreaders or pluggers (Fig 13).

Straightening

Nature of the problem

Straightening of a curved root canal occurs as a result of preparation with insufficiently flexible instruments, removing more dentine apically from the outer side of the curvature than from the inner side thereby altering the original axis of the root canal. In the middle of the root canal more dentine is removed from the inner side of the root canal curvature. The biological impact of straightening results from the insufficient preparation of the inner part of the curvature, leaving behind unnecessarily large amounts of tissue remnants and infected dentine.

Straightening of the most apical part of the root canal is usually associated with transportation and/or enlargement of the apical foramen.

Straightening is irreversible!

As all instruments tend to straighten inside a curved root canal, a typical preparation pattern can be observed: in the coronal part, straightening occurs at the outside of the curve. This is acceptable to a certain degree and in many cases even necessary to decrease the angle of the curve in a relatively "safe" area. In the middle of the root canal, straightening occurs at the inner side of the curve at the furcational, intraradicular area. This results in weakening of the root and even in perforation as a final consequence. This type of perforation is a long, irregular so-called strip-perforation, which is difficult if not impossible to seal, thus significantly reducing the prognosis of the tooth. In the apical region straightening again occurs at the outer side of the curve. The resulting shape of the root canal has been described by Weine et al[29] as elbow, teardrop and zipping (Fig 14). Enlargement and/or transportation of the foramen may be associated with apical straightening as well as loss of working length and ledging (Fig 15), resulting in major difficulties to obtain proper obturation and a sufficient apical seal of the root canal[30]. Gluskin et al[31] described three types of straightening:

- Type I: Slight deviation from the original axis of the root canal and minor displacement of the

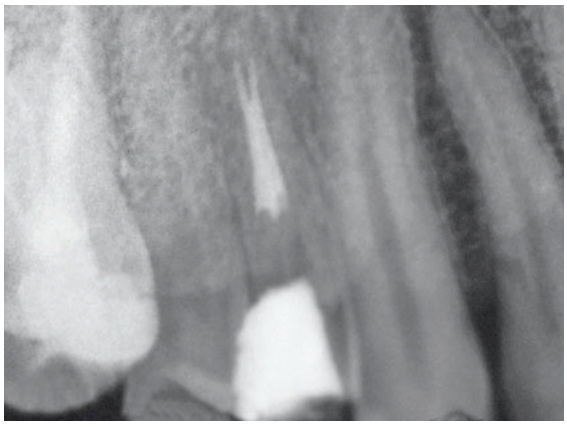


Fig 13 Deep split of the root canal in a maxillary bicuspid. Straight-line access to the "furcation" is necessary for adequate preparation, disinfection and obturation.

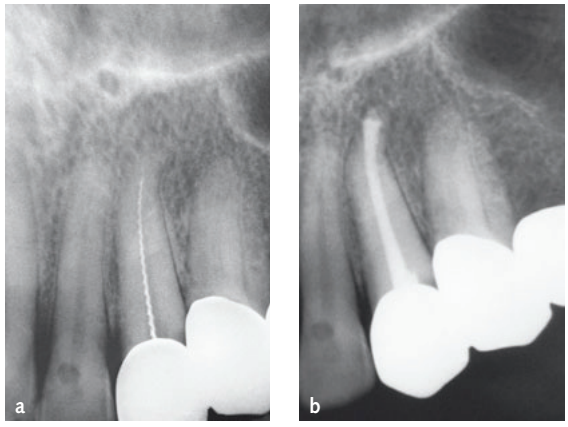


Fig 14 Severe straightening in the apical part of the root canal in combination with zip and elbow and a nearby perforation. The reasons for this problem are possibly due to underestimation of the radius and degree of the curvature and use of inflexible stainless steel hand instruments.

apical foramen; minor modification of the internal anatomy of the root canal. The problem can be managed by careful secondary preparation.

- Type II: Moderate displacement of the apical foramen and severe modification of the internal root canal anatomy. The problem can be managed by placement of an apical barrier (e. g. Mineral Trioxide Aggregate or bioceramic materials) in order to limit obturation to the confines of the root canal.
- Type III: Severe displacement of the foramen; surgical treatment necessary.

In any case straightening results in over-preparation of one side of the root canal wall with simultaneous under-preparation at the opposite side, leaving behind tissue remnants, debris, a smear layer and microorganisms or biofilm. The mechanical shortcomings of preparation mistakes will inevitably cause a biological problem in terms of insufficient cleaning and disinfection of the root canal.

Straightening can best be prevented by proper planning of the preparation including thorough probing/scouting of the root canal with a fine and pre-curved hand instrument and careful radiographic evaluation to determine location and degree of the curvature(s). Taking into account the angle and radius of the curvature, as well as the three-dimensional nature of the (multiplanar) curvature, preparation has to be adjusted to these parameters, mainly with respect to flexibility, size and taper of the instruments. Preparation of a glide-path and use of flexible instruments with non-cutting safety tips are strongly recommended[30]. Crown-down techniques have been shown to produce less straightening than immediate instrumentation to full working length, at least for stainless-steel instruments. Flexible NiTi instruments have been shown in a plethora of studies to produce significantly less straightening than stainless steel instruments[32,33]. For selection of an adequate NiTi file, the radius of the curvature is essential: the smaller the radius or the greater the angle of the curve, the smaller the taper and size and the higher the flexibility the instruments should have. This is even more important for s-shaped root canals with a double (or triple or more) curvature.

Management

If straightening is apparent during an early state of preparation, great care has to be taken to prevent subsequent perforation. Following proper irrigation, the root canal has to be obturated as well as possible. If straightening has already resulted in apical perforation this can be controlled by electric measurement (indicating over-instrumentation before reaching the calculated working length), using a paper point and controlling the site and extent of bleeding. Repair with materials such as MTA, Biodentine (Septodont, St. Maur-des-Fossés, France), bioceramics or even apicectomy also have to be considered. In case of a mid-root perforation, which is a long strip perforation, sealing may be impossible and amputation of the root or extraction of the tooth will be indicated.

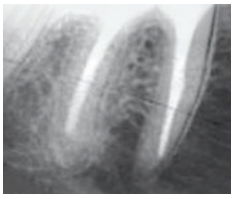


Fig 15 Straightening occurred in the distal and mesial root canals. In the mesial canal, straightening is associated with loss of working length and ledging.

Fig 16a Ledge at the outer side of the curvature.

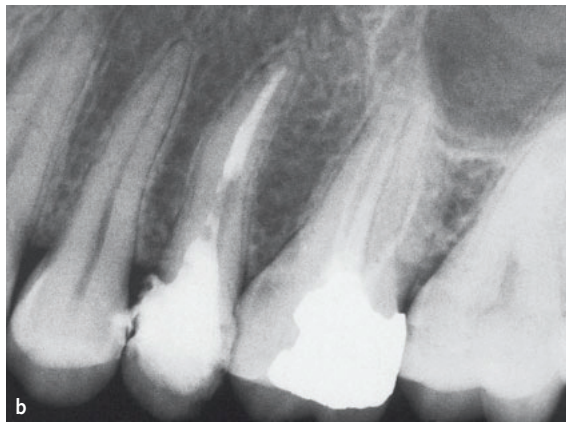


Fig 16b The ledge could be bypassed with pre-curved instruments.

Ledges and blockages

Nature of the problem

Ledges and blockages frequently occur simultaneously, with the blockage being the cause of subsequent ledging. Both prevent complete apical preparation, disinfection and obturation of the root canal system. Ledging can also be associated with straightening of the root canal (Fig 15).

Blockages are a consequence of deposition of tissue remnants (collagen) or dentine shavings in the apical part of a root canal and hinder access to the apical foramen for the root canal instrument, but not for the remaining microorganisms. Blockages are frequently misinterpreted as complete calcification of a root canal. When an attempt is made to overcome the blockage by use of larger and stiffer instruments or by forceful and rotational use of instruments, deviation of the instrument tip from the original axis of the root canal occurs and a ledge is created at the outer side of the curvature. This ledge will increase in size with each instrument. Blockage should be carefully distinguished from calcification, which sometimes also prevents complete instrumentation of a root canal.

The frequency of ledges has been calculated to be 6% to 60%, depending on the severity of the root canal curvature[34]. Ledges are mainly caused by inflexible instruments or instruments with actively cutting tips deviating from the axis of the root canal. Ledges can frequently be detected in retreatment cases or in teeth treated previously for endodontic emergencies.

Management

Copious irrigation with sodium hypochlorite and a chelating agent can assist in dissolving tissue remnants and dentinal shavings blocking the root canal. Fine instruments (ISO sizes 06 to 10) can be used to stir up the debris and to relocate the root canal up to its entire length. The use of ultrasonics cannot be recommended, as this will result in an increase in the ledge and will have no clinical effect on a blockage. Rotary instruments will further condense the debris rather than remove it[35].

The only route to overcome or bypass a ledge, respectively, is along the inner side of the curvature, which has not been altered by previous instrumentation. To detect the original course of the root canal, the location and degree of the curvature needs to be investigated carefully with pre-curved instruments. The three-dimensional nature of the curvature has to be considered when attempting to bypass the ledge. For example, the mesiobuccal root canal of a mandibular molar should not be probed only in the mesiodistal direction, as additional curvature in the buccolingual direction will be present in many cases (Figs 16a to 16b) requiring respective pre-curving of the instrument. Bypassing in molars should be carefully undertaken at the furcal side of the root canal, which will present an unchanged anatomy. Only the tip of the instrument is pre-curved over a small distance and

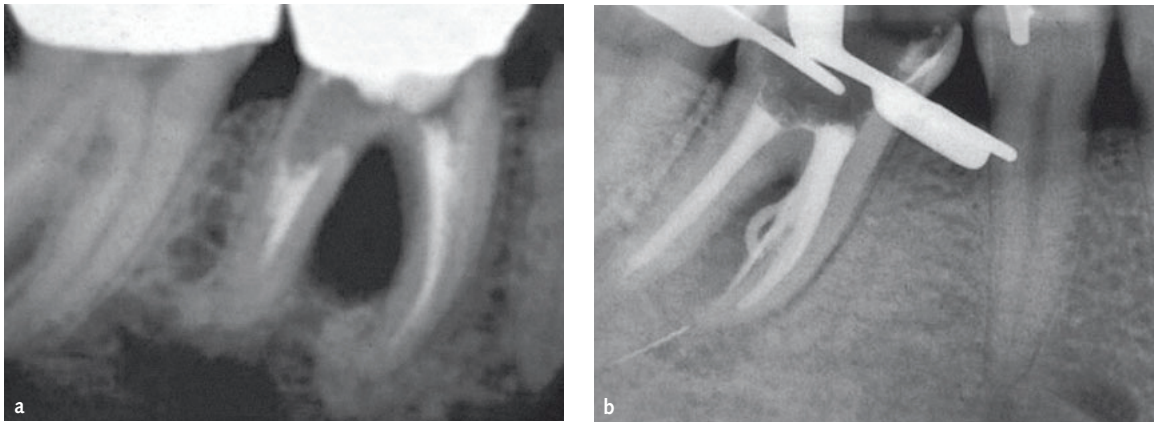


Fig 17 a) Perforation of the distal root resulting in irreparable interradicular bone loss. b) Strip perforation at the inner side of the curved root canal resulting in extrusion of root canal filling material.

the degree of the instrument curvature should slightly exceed the curvature of the root canal, thus forcing the instrument tip to the inner side of the curvature. Once bypassing of the ledge has been successfully managed, only small filing movements in an up-and-down motion are recommended, thus rounding up the ledge and enabling further preparation. Rotary preparation with flexible Ni-Ti-instruments in most cases does not present an option, as the instruments will always stop at the ledge due to its memory shape.

Perforations

Nature of the problem

A perforation of the root canal system creates artificial communication between the root canal system and the periradicular tissues allowing inflammation to spread into the circumference of the root.

The incidence of perforations has been calculated to be 3% to 10%[36]. Perforations mainly occur at the pulp chamber floor during preparation of the access cavity, during the search for missing root canal orifices or inside the root as a consequence of apical straightening (apical perforation at the outer side of the curvature), mid-root straightening (stripping perforation at the inner, furcal side of the curvature) or due to preparation of intracanal posts. Frequently improper preparation of the access cavity fails to remove coronal dentine overhangs and results in severe angles of root canal curvature.

Management

Using a dental operating microscope allows successful treatment of perforations of the pulp chamber floor in many cases with MTA or comparable bioceramic materials as repair material. Great care has to be taken in order to avoid blocking or even closing the root canals with the repair material. The prognosis seems to be good to excellent, except for old perforations or perforations with communication to the oral cavity (Fig 17). The success rates presented in the endodontic literature range from 40% to 60%[37-40].

References

1. Hülsmann M, Schäfer E (eds). Problems in Endodontics. Prevention, Identification and Management. Berlin: Quintessence, 2009.
2. Gutmann JL, Lovdal PE. Problem solving in endodontics. Prevention, Identification and management, ed 5. Elsevier: Michigan, 2011.
3. Lambrianidis T. Risk management in root canal treatment. University Studio Press: Thessaloniki, 2001.
4. Pitt Ford TR, Rhodes JS, Pitt Ford HE. Endodontics. Problem solving in Clinical Practice. M. Duniz: London, 2002.
5. Patel S, Duncan HF. Pitt Ford's Problem-based learning in endodontology. Wiley-Blackwell: Oxford, 2011.
6. Tanomaru-Filho M, Jorge EG, Duarte MA, Gonçalves M, Guerreiro-Tanomaru JM. Comparative radiographic and histological analyses of periapical lesion development. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;107:442–447.
7. Yu SM, Stashenko P. Identification of inflammatory cells in developing rat periapical lesions. J Endod 1987;13:535–540.
8. Mejare IA, Axelsson S, Davidson T, et al. Diagnosis of the condition of the dental pulp: a systematic review. Int Endod J 2012;45:597–613.
9. Abbott PV, Yu C. A clinical classification of the status of the pulp and the root canal system. Aust Dent J 2007;52 (1 Suppl):S17–S31.

10. Patel S, Durack C, Abella F, Shemesh H, Roig M, Lemberg K. Cone beam computed tomography in Endodontics – a review. Int Endod J 2015;48:3–15.
11. Moraschini V, Poubel LA, Ferreira VF, Barboza ES. Evaluation of survival and success rates of dental implants reported in longitudinal studies with a follow-up period of at least 10 years: a systematic review. Int J Oral Maxillofac Surg 2015;44:377–388.
12. Zitzmann NU, Krastl G, Hecker H, Walter C, Weiger R. Endodontics or implants? A review of decisive criteria and guidelines for single tooth restorations and full arch reconstructions. Int Endod J 2009;42:757–774.
13. AAE Available at: https://www.aae.org/uploadedfiles/dental_professionals/endodontic_case_assessment/2006casedifficultyassessmentformb_edited2010.pdf. Accessed: 7 October 2016.
14. Yatani H, Komiyama O, Matsuka Y, et al. Systematic review and recommendations for nonodontogenic toothache. J Oral Rehabil 2014;41:843–852.
15. Nixdorf DR, Moana-Filho EJ, Law AS, McGuire LA, Hodges JS, John MT. Frequency of persistent tooth pain after root canal therapy: a systematic review and meta-analysis. J Endod 2010;36:224–230.
16. Pak JG, White SN. Pain prevalence and severity before, during and after root canal treatment: a systematic review. J Endod 2011;37:429–438.
17. Venskutonis T, Plotino G, Juodzbalys G, Mickeviciene L. The importance of cone-beam computed tomography in the management of endodontic problems: a review of the literature. J Endod 2014;40:1895–1901.
18. Wu MK, Shemesh H, Wesselink PR. Limitations of previously published systematic reviews evaluating the outcome of endodontic treatment. Int Endod J 2009;42:656–666.
19. Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J Endod 2008;34:273–279.
20. Eskandarloo A, Mirshekari A, Poorolajal J, Mohammadi Z, Shokri A. Comparison of cone-beam computed tomography with intraoral photostimulable phosphor imaging plate for diagnosis of endodontic complications: a simulation study. Oral Surg Oral Med Oral Pathol Oral Radiol 2012;114:e54–e61.
21. D'Addazio PS, Campos CN, Özcan M. Teixeira HG, Passoni RM, Carvalho AC. A comparative study between cone-beam computed tomography and periapical radiographs in the diagnosis of simulated endodontic complications. Int Endod J 2011;44:218–224.
22. Patel S, Dawood A, Ford TP, Whaltes E. The potential applications of cone beam computed tomography in the management of endodontic problems. Int Endod J 2007;40:818–830.
23. de Alencar AH, Dummer PM, Oliveira HC, Pecora JD, Estrela C. Procedural errors during root canal preparation using rotary NiTi instruments detected by periapical radiography and cone beam computed tomography. Braz Dent J 2010;21:543–549.
24. Reader A, Nusstein J, Drum M. Successful local anaesthesia. Quintessence: Chicago, 2011.
25. Krasner P, Rankow HJ. Anatomy of the pulp-chamber floor. J Endod 2004;30:5–16.
26. Kim E, Lee SJ. Electronic apex locator. Dent Clin North Am 2004;48:35–54.
27. Lopez-Ampudia N, Gutmann JL. Management of 'S-shaped' root canals – technique and case report. ENDO (Lond Engl) 2011;5:7–15.
28. Seo MS, Park DS. C-shaped root canals of mandibular second molars in a Korean population: clinical observation and in vitro analysis. Int Endod J 2004;37:139–144.
29. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. J Endod 1975;1:255–262.
30. Schäfer E, Dammaschke T. Development and sequelae of canal transportation. Endodontic Topics 2009;15:75–90.
31. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559–567.
32. Hülsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. Endodontic Topics 2005;10:30–76.
33. Gluskin A, Peters CI, Ming Wong RD, Ruddle CJ. Retreatment of non-healing endodontic therapy and management of mishaps. In: Ingle JI, Bakland LK, Baumgartner C (eds). Textbook of Endodontics, ed 6. Hamilton: Ontario, 2008:1088–1161.
34. Lambrianidis T. Ledging and blockage of root canals during canal preparation: causes, recognition, prevention, management and outcomes. Endodontic Topics 2009;15:56–74.
35. Jafarzadeh H, Abbott PV. Ledge formation: review of a great challenge in endodontics. J Endod 2007;33:1155–1162.
36. Fuss Z, Trope M. Root perforations: classification, and treatment choices based on prognostic factors. Endod Dent Traumatol 1996;12:255–264.
37. Farzaneh M, Abitbol S, Friedman S. Treatment outcome in endodontics: the Toronto Study. Phases I and II: Orthograde retreatment. J Endod 2004:30;627–633.
38. Kvinnsland I, Oswald RJ, Halse A, Gronningsaeter AG. A clinical and roentgenological study of 55 cases of root perforation. Int Endod J 1989;22:75–84.
39. Krupp C, Bargholz C, Brüsehaber M, Hülsmann M. Treatment outcome after repair of root perforations with mineral trioxide aggregate: a retrospective evaluation of 90 teeth. J Endod 2013;39:1364–1368.
40. Mente J, Leo M, Panagidis D, Saure D, Pfefferle T. Treatment outcome of mineral trioxide aggregate: repair of root perforations-long-term results. J Endod 2014;40:790–796.

Michael Hülsmann

Prevention and management of problems during root canal treatment – A problem-based approach to root canal treatment. Part II

Michael Hülsmann, Prof. Dr.
Department of Preventive Dentistry, Periodontology and Cariology, University of Göttingen, Göttingen, Germany

Correspondence to:
Michael Hülsmann
Prof. Dr.
Dept. of Preventive Dentistry, Periodontology and Cariology, University of Göttingen,
Robert-Koch-Str. 40
D-37075 Göttingen,
Germany.
Tel: +49-551-3922855
Fax: +49-551-3922037
Email: michael.huelsmann@med.uni-goettingen.de

Key words *management, prevention, problems, root canal treatment*

Due to the biologic nature of endodontic diseases, the complex anatomy of the root canal, and the shortcomings and limitations of currently available instruments and materials for root canal treatment, the occurrence of problems is an immanent part of root canal treatment and consequently anticipation, prevention and management of such problems should be part of any treatment concept. The following paper tries to identify several major problems during root canal treatment and suggests a problem-based treatment approach in order to prevent the occurrence of such problems. Beginning with diagnosis, differential therapy, estimation of degree of case difficulty, preparation of the access cavity and management of intracanal problems, a number of clinically relevant topics will be addressed. The aim of the following review is to convince the reader to accept such problems as a part of daily endodontic treatment; to anticipate possible problems as a part of the treatment planning; and to include prevention and management of problems in the routine concept for each root canal treatment.

Introduction

Root canal treatment itself aims to solve problems inside and outside the root canal system. Nevertheless, due to the microbial and biofilm nature of endodontic diseases, the complex anatomy of the root canal, and the shortcomings and limitations of currently available instruments and materials for root canal treatment, it is likely that further problems and complications will occur during root canal treatment. The frequency and severity of these problems will depend on the endodontist's treatment concept and her or his capability to prevent and manage such situations. In Part I of this review, problems in diagnostics, differential therapy, anaesthesia, preparation of the access cavities, determination of working length and perforations have been discussed. Part II deals with instrument fractures, loss of working length, problems during root canal preparation, disinfection and obturation, retreatment, post-treatment pain and determination of success and failure.

Instrument fracture

Nature of the problem

The fracture of an endodontic instrument prevents complete preparation, disinfection and obturation of the root canal if the fragment cannot be removed completely. When a file fracture happens during treatment of a non-infected root canal, prognosis remains good; in cases of fracture in an infected root canal the results are contradictory. It has to be considered that removal attempts may weaken the root excessively and worsen the prognosis of the tooth even more than a retained fragment.

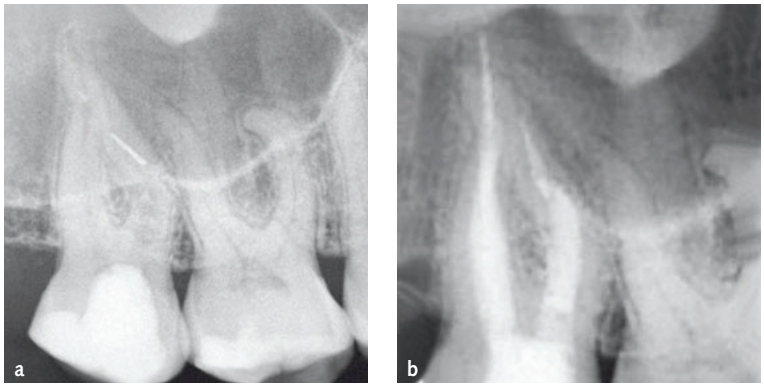


Fig 1a-b Fracture of a size 25/08 reciprocating instrument in a root canal with a relatively large angle and a low radius of curvature. The fragment was removed completely.

Treatment of teeth with fractured instruments should be classified as having a high degree of difficulty, therefore requiring treatment by a specialist, special equipment and a sufficient routine (and time)[1-2].

The incidence of instrument fractures seems to be as low as 1% to 2% of treated root canals[1-2], with no significant difference between stainless steel and nickel-titanium instruments[3]. Fracture of root canal instruments happens as a result of excessive use (cyclic fracture) or excessive forces (torsional fracture) or a combination of both. Prevention basically includes limited and passive use of instruments. The number of prepared root canals, as suggested by the manufacturers, is a poor parameter. However, the number of rotations describes the risk of fracture more precisely. Depending on the type, size, diameter, taper and material of the file, the number of cycles until fracture varies between 300 and 1,000 rotations, which for the majority of NiTi instruments represents a working time of 1 to 4 mins until fracture is likely to occur.

The degree and more importantly the radius of the curvature of the root canal should be explored before rotary preparation. The basic rule is the smaller the radius the smaller the conicity the instrument should have (Fig 1). The use of an adequate motor with constant speed and torque control and preparation in a wet root canal with minimal digital force is recommended.

It should be noted that removal of fractured instruments is not absolutely necessary in each case for long-term success of treatment, therefore removal attempts should be performed carefully and with minimal loss of tooth substance[4]. If successful removal seems to be unlikely or associated with a high risk of additional complications, the fragment should be left in the root canal and differential therapies, such as apicoectomy or a wait-and-see-approach should be considered.

It also has to be noted that the primary goal of further treatment is not to remove the fragment but rather to regain access to the apical foramen allowing complete disinfection and obturation. Therefore complete bypassing without removal also has to be rated as a success (Figs 2a to 2b). A risk-benefit analysis is mandatory when dealing with the problem of instrument fracture (Table 1).

If there is a high risk of removal failure or perforation or severe weakening of the root and the root is not associated with apical periodontitis, only observation of the tooth without intervention or surgical treatment should be considered as the best treatment option.

Management

Removal attempts preferably should not be undertaken immediately following the fracture in an excited or frustrated mental state. The first steps should be interruption of treatment, informing the patient on the incidence and taking a radiograph, which is important for medicolegal reasons (documentation of the incident) as well as for planning further treatment. The access cavity is temporised and closed. Treatment is continued in a new appointment.

If removal of the broken instrument is necessary, all of the other root canals should be blocked (cotton or gutta-percha) to prevent the loosened fragment from falling into another root canal. Subsequently the access cavity has to be controlled or modified,

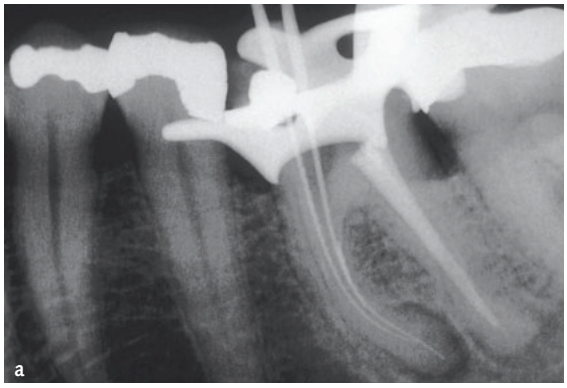


Fig 2a-b The fragment can be bypassed so the major issue - incomplete disinfection and obturation - can be solved even without complete removal.

in order to gain straight-line access to the top of the fragment.

When the top of the fragment cannot be visualised, removal attempts should be stopped because of the enormous risk of root perforation. If visualisation is possible, some space should be prepared around the top of the fragment, so that the ultrasonic tips can be placed alongside the fragment[5]. Loosening and removal using fine ultrasonic tips, loop or braiding techniques or special devices (e.g. IRS [Dentsply, Konstanz, Germany] and EndoRescue [Komet, Lemgo, Germany]) constitutes the final step[1,2]. A final radiograph is taken to document complete removal, however, even intermediate radiographs may become necessary to control the progress of removal attempts and to ensure that all instruments are still in the long axis of the root.

The success rates for removal of fractured instruments using modern techniques have been reported to range between 70% and 90%[6-10]. It is important to define an individual timeframe for such attempts: some publications report on approximately 45 min as an optimum interval, but this depends on several factors and has to be determined on an individual basis for each operator. Increased working time results in only slightly higher success rates but significantly higher risks of further mishaps (perforation, weakening of the root, ledging and additional file fracture).

It has to be recognised that removal attempts are associated with a high risk of further problems:

- loss of dental hard tissue;
- weakening of the root;
- perforation;
- fracture of a second instrument;
- ledging.

Table 1 Factors influencing the prognosis of removal attempts.

Favourable	Difficult
Coronal or middle part of the root canal	Apical part of the root canal
Long fragment	Short fragment
Straight root canal	Curved root canal
Top of fragment coronal to the curvature	Top of fragment apical to the curvature
Lentulo or reamer	Hedström file, NiTi instrument
Irregular canal diameter (Canines, distal root canal of mandibular molars, lower incisors)	Round diameter
Bypassing possible	Bypassing impossible
Apicoectomy possible	Apicoectomy difficult or impossible

Loss of working length

Nature of the problem

Loss of working length results in incomplete preparation, disinfection and obturation of the root canal system. The cause of this problem can be apical blockage by tissue remnants and dentinal shavings or use of improper instruments with respect to size, taper and flexibility. Microorganisms in the apical part of the root canal still have access to the periapical tissues, which means access to nutrients, therefore they can survive and multiply in a biofilm environment and start or sustain periapical inflammation. An approach to regain correct working length frequently results in additional ledging of the root canal.

Table 2 The chain of asepsis and antisepsis.

Tight coronal restoration	Prevention of ingress of new microorganisms
Placement of rubber dam	
Disinfection of the working field	
Use of sterile instruments	
Preparation of the root canal	Reduction in the number of microorganisms inside the root canal Destruction of the intraradicular biofilm
Irrigation	
Medication	
Root canal obturation	Prevention of ingress of new microorganisms and of multiplication of surviving bacteria
Temporary restoration	
Definite restoration	

Management

If loss of working length is registered, treatment should be interrupted and an attempt made to identify the cause of the problem, most likely a ledge and/or apical accumulation of debris and/or tissue remnants. A radiograph can help to ascertain whether or not preparation still follows the original axis of the root canal. Copious irrigation with sodium hypochlorite and/or EDTA is necessary to dissolve tissue remnants or inorganic debris. Fine and flexible pre-curved instruments are used to bypass a ledge and in order to stir up any accumulation of tissue or dentinal debris. Ultrasonics should be used extremely carefully in order to avoid ledging.

Problems with rotary root canal preparation

It should be recognised that a number of problems with rotary or reciprocal preparation have recently begun to attract some more interest, such as dentinal cracks or apical extrusion of debris[11-13]. There have been reports that 20% to 50% of roots show dentinal defects or cracks following rotary preparation, in a continuous rotary or reciprocating motion. At what frequency these cracks develop into vertical root fractures is still unknown. There are also alarming reports on excessive amounts of apically extruded debris, which may cause postoperative pain or even treatment failure due to periapical inflammation or even infection[14]. Unfortunately, the clinical impact of these problems has still not been completely and accurately clarified. The same holds true for achieving the optimal balance between the removal of infected root dentine and avoiding root weakening by removal of dentine.

Problems during root canal disinfection

Nature of the problem

Insufficient disinfection results in unnecessarily large numbers of microorganisms and bacterial biofilm retained in the root canal and persistent intracanal infection with a consequently high risk of treatment failure[15]. Problems or mistakes in the mechanical act of disinfection (irrigation) may result in severe tissue damage and harm to the patient.

One of the major problems of endodontics is a misconception of root canal disinfection, which is frequently reduced to the mechanical act of root canal irrigation. Root canal disinfection should be regarded as the main principle of root canal treatment, composed equally of aseptic and antiseptic components[16].

The chain of disinfection is presented in Table 2.

The quality of this chain of asepsis and antisepsis depends on the strength of its weakest link.

Potential problems in root canal disinfection amongst others include:

- selection of proper irrigants which are able to eradicate the microorganisms inside the root canal system up to a degree promoting success of treatment and healing of the disease, but at the same time not irritating the periradicular tissues;
- application of the irrigants to sufficient depths;
- at the same time avoiding apical extrusion of the irrigants;
- in the case of apical extrusion, management of the incident.

An exhaustive review on complications during root canal irrigation has been published by Hülsmann et al[17]. One of the major problems of all currently accepted irrigants is the critical balance between antimicrobial efficacy and biocompatibility. Also, the

effect of the irrigants on the radicular dentine (dissolution of collagen, erosion of dentine and reduction of adhesion of sealer or posts) and the periradicular tissues should be taken into account[18].

Apical extrusion of sodium hypochlorite

The sequelae of apical extrusion of sodium hypochlorite depends on the concentration and amount of extruded solution and may range from minor discomfort, short episodes of pain and severe long-standing pain, to extensive tissue necrosis, swelling and ecchymosis[17].

If extrusion of sodium hypochlorite occurs, tissue in the periradicular space is dissolved, including the rupture of blood vessels. Also, infection may spread into the periapical bone. The clinical symptoms include immediate severe pain, immediate swelling and discolouration of the skin (ecchymosis) (Fig 3).

For the management of such incidences, immediate pain control is mandatory (analgesics and anaesthesia; the latter should not be applied directly into the swollen tissue) including root canal irrigation with saline or distilled water and temporisation of the tooth. The patient is advised to use cold water, rinsing the mouth for that day. The following day rinsing should be changed to warm water in order to stimulate blood circulation in the damaged region. Antibiotics can be considered but are not mandatory. Analgesics are helpful for controlling discomfort and pain.

Apical extrusion of chlorhexidine or EDTA

A swelling can develop with a differing degree and duration of pain. Usually no intervention is necessary. Analgesics can be prescribed.

Apical extrusion of hydrogen peroxide

If hydrogen peroxide is used for irrigation (although no longer recommended for root canal irrigation) and is extruded beyond the apical foramen, the patient will experience immediate severe pain and swelling, frequently accompanied by heavy bleeding from the root canal. Palpation of the swollen tissue may reveal a typical 'pergament sound'. Following proper anaesthesia and analgesia, the root canal is carefully irrigated with saline, dried, medicated and sealed. Usually, swelling and slight pain will persist for several days with no further problems remaining.

Fig 3 Ecchymosis of the skin following extrusion of sodium hypochlorite via a perforation in the maxillary left canine.

Injury of the eye

If an irrigant is splashed into the eyes of the patient or members of the dental team, immediate eye wash using large amounts of tap or distilled water or saline are recommended. An ophthalmologist should be contacted in due course.

Root canal obturation

Nature of the problem

Incomplete obturation, including both incorrect extension of the obturation and missing tightness to the root canal wall will enable surviving microorganisms to multiply inside the root canal and regain access to the periapical tissues, thus initiating or sustaining periradicular inflammation.

Overextension of obturation material can result in an inflammatory response of the host tissue against the extruded filling materials. Many sealers exert some cytotoxicity during the setting period. Underfilling as well as overfilling both directly and indirectly can induce or sustain apical periodontitis, negatively influencing treatment outcome.

Incomplete obturation

Nature of the problem

Incomplete obturation leaves empty spaces inside the root canal system providing residual microorganisms with space to survive and multiply again. When gaining access to the periradicular tissues, these microorganisms can initiate or sustain a periradicular inflammatory process. If the foramen is not sealed properly, tissue fluids may provide the remaining intracanal bacteria with nutrients.

Post-obturation radiographs should be evaluated and interpreted with great care. Due to the two-dimensional nature of the images and the limited resolution, no final decision can be made on the quality of the seal.

Management

In a Brazilian study using CBCT, underfilling was detected in 33.5% and overfilling in 8.0% of 200 root canal-treated teeth. Similar data were presented by Moura et al[19] with 10% of overfillings in anterior teeth. Underfilling, i.e. more than 2 mm distance from the radiographic apex, in several studies have been demonstrated to reduce the success rate to 60%[20]. After extirpation of a vital, non-infected pulp and subsequent root canal treatment under aseptic conditions, larger distances from the apex are acceptable, as the remaining pulp remains vital and uninflamed in many cases[21,22].

In the case of incomplete obturation, i.e. termination of the obturation material more than 2 mm from the radiographic apex (or radiographically, there are visible voids inside or empty spaces lateral to the filling material) first the reasons for this treatment result should be considered. In case there is a difference between determined working length, actual preparation length and obturation length, immediate removal of the filling material would be the optimal treatment, as the setting of the sealer will still not be completed. Taking a new radiograph for length determination can clarify or reassure the correct endodontic working length and can help to prevent repeated obturation failure. Depending on the time available, immediate reobturation is possible, otherwise medication is recommended. The same is recommended when the radiograph shows voids inside or empty spaces alongside the obturation material. When preparation length and obturation length are identical and no deeper penetration of the root canal can be achieved retreatment does not present a promising option.

Apical extrusion of obturation material

Nature of the problem

Extrusion of filling material may occur as a result of incorrect determination of endodontic working length, insufficient control of working length during preparation, with resulting overpreparation and enlargement of the apical foramen or failures during obturation (excessive amounts of sealer, apical pressure during obturation, inadequate cone fit and excessive heating of gutta-percha). Depending on its composition and its chemical/pharmacological properties, post-obturation pain, allergic reactions and treatment failure are possible sequelae.

Management

If overextension of obturation material occurs, orthograde removal should be attempted for overextended gutta-percha, which frequently can be removed with Hedström files carefully screwed into the gutta-percha. The apical part of the gutta-percha can be removed using a file similar to a corkscrewer. If only sealer has been extruded, a conservative approach is recommended with radiographic controls in short intervals as long as no clinical or radiographical symptoms indicating periradicular inflammation are present. Depending on the type of extruded sealer, resorption can be observed over time. In case of new or persisting apical inflammation, surgical removal will be indicated.

For a detailed description of procedural incidents such as perforation, fracture of instruments or mishaps related to irrigation, medication and obturation the reader is referred to the Online Study Guide on procedural accidents published by the editorial board of the Journal of Endodontics[23].

Flare-ups

Nature of the problem

A flare-up is defined as acute exacerbation of a previously asymptomatic tooth following root canal treatment or as an occurrence of pain or swelling during or after root canal treatment. Stricter definitions limit flare-ups to cases requiring an unscheduled emergency appointment or at least the need for analgesics. The incidence of flare-ups has been calculated to be 1.5% to 20.0%; the large differences are due to a lack of exact evaluation criteria. In a meta-analysis of six studies including 982 cases, an incidence of 8.4% was calculated[24].

The reason for flare-ups seems to be polyaetiologic with systemic factors (allergenic predisposition and compromised immune system), mechanical factors (over-instrumentation, apical extrusion of debris, tissue remnants, irrigants, medicaments and obturation materials), chemical factors (biocompatibility and cytotoxicity of extruded materials) and microbiological factors (extruded microorganisms and changes in intracanal environment) contributing to acute exacerbations[24]. Periradicular inflammation is regarded as the most important factor of flare-ups. Although a controversial topic, women seem to be affected more frequently and more seriously.

Management

The management of flare-ups depends on the severity and the time of occurrence. Removal of the obturation material or exchange of medication may be required. Copious irrigation is recommended. Sometimes flare-ups are short in duration and can be managed by the prescribing of analgesics.

Post-endodontic pain

It has been shown that approximately 5% of patients report on persistent pain following root canal treatment[25,26], with half of these cases not being of dental origin. Thorough clinical and radiographic investigations are necessary for a correct diagnosis and development of a treatment plan, avoiding unnecessary retreatment, which is not indicated, or even extraction of the tooth.

Nonsurgical retreatment

Nature of the problem

Persistence or establishment of a bacterial biofilm has been identified as a main cause of failure of root canal treatment[15,27-29]. Compared to primary root canal treatment, several additional aspects have to be considered and different problems have to be solved in the case of retreatment. The main problems include analysis of the reasons for treatment failure, decision making on the optimal treatment option, extraction, non-surgical retreatment and apicoectomy, removal of the filling material, management of alterations of root canal anatomy (straightening, ledging, blockage, perforation etc), detection and disinfection of previously uncleaned spaces inside the roots, detection and treatment of additional root canals and eradication of microorganisms resistant to commonly used disinfectants.

As a variety of different reasons for endodontic failure exist, the first and main problem will be diagnosis of reasons for failure. Although in many clinical cases, shortcomings of primary treatment can be diagnosed radiographically such as incorrect working length or suboptimal radiographic appearance of the obturation, it should be kept in mind that the primary reasons for failure are always persistence of primary root canal infection or secondary (re) infection following root canal treatment. Technical problems during primary treatment, which are visible radiographically such as deficiencies in length, taper, shape and density of preparation and/or obturation will hardly result in treatment failure. These problems will definitely impair success in cases of persistent infection of intraradicular spaces with the bacteria regaining access to the periradicular tissues. Untreated spaces inside the root, incomplete removal of biofilm, necrotic tissue or debris and smear layer can contribute, as well as coronal leakage. In a considerable number of cases, more than one problem or reason for failure can be present. Even when the reason for failure can be identified as a technical problem, for example an untreated additional root canal, all retreatment cases should be regarded as infected and the main focus of retreatment should be on improved disinfection of the root canal system.

Table 3 Classification of teeth with persisting periradicular lesions as suggested by Wesselink et al[30].

Orthograde retreatment
Inadequate root canal-treated teeth without iatrogenic alterations of root canal morphology such as ledges, straightening or loss of working length.
Orthograde retreatment or apical surgery
Inadequate root canal-treated teeth with iatrogenic alterations of root canal morphology
Presence of inaccessible spaces inside the apical part of the root harbouring microorganisms
Orthograde retreatment not indicated
Vertical root fractures
Extraradicular infections
Foreign body reactions
True cysts

Management

The first and in many cases the main problem in cases of unsuccessful primary treatment concerns diagnosis and decision making. Wesselink et al[30] suggested three categories of root canal-filled teeth with persisting apical lesions (Table 3).

The final decision for or against retreatment should be based on proper diagnosis including clinical symptoms as well as on evaluation of actual radiographs; if necessary taken from various angles. Additionally taking a CBCT can assist in the detection of problems not visible in the radiograph[31]. Although not feasible in all cases it can be helpful to monitor the development of treatment failure by comparative evaluation of several radiographs from primary treatment until there is evidence of an unsuccessful outcome.

The timeframe for a definite judgement on success or failure and consequently on the need for endodontic retreatment or surgical intervention (extraction and apical surgery) has been suggested to be up to 4 years (Guidelines of the European Society of Endodontology). A study by Ørstavik[32] demonstrated that if healing occurs this can be seen on the radiograph in 85% of the cases within 2 years. If a lesion developed this was observed in 90% of the cases after 2 years. Wu and Wesselink[33] therefore questioned the clinical suitability of long recall intervals of 4 years or more and suggested a stricter regime:

- No lesion and no symptoms 1 year after treatment: success and no treatment necessary.
- Decrease in size of the lesion and no symptoms 1 year after treatment: there is hope for the tooth, further control 1 year later. If no healing occurs 1 year later: further treatment (retreatment or apical surgery).
- Lesion is unchanged in size, 1 year after root canal treatment: further treatment is indicated (retreatment and apical surgery).

Retreatment cases are most challenging as the number of problems are frequently significantly higher and the problems significantly more severe than in primary treatment.

Major problems in retreatment comprise[34,35]:

- relocation of pulp chamber and root canal orifices;
- identification and negotiation of previously untreated root canals (Figs 4a to 4b);
- identification, localisation and disinfection of previously untreated spaces inside the root;
- removal of root canal filling materials;
- management of ledges and blockages;
- detection and management of perforations;
- removal of fractured instruments;
- disinfection of the (re-)infected root canal system or eradication of microorganisms which were not eliminated during primary treatment.

Again, proper treatment planning is crucial. Figure 5 gives an example of a retreatment case which at first glance looks considerably easy to handle, but after more detailed and systematic analysis presents several serious problems and complications.

Problems in determination of success or failure of root canal treatment

Nature of the problem

The definition of success may vary depending on the diagnosis and the expected or desired clinical outcome. In some cases, retention of a tooth can be considered a success. Furthermore in some cases a decrease in the size of a lesion can be an acceptable

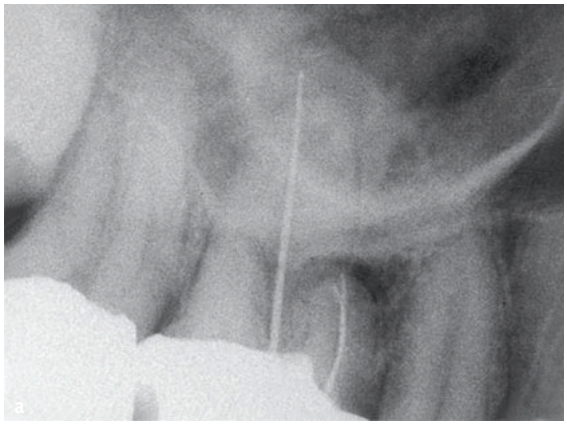


Fig 4a The radiographic lesion around the mesiobuccal root tip only is an excellent hint at the presence of a second mesiobuccal root canal.

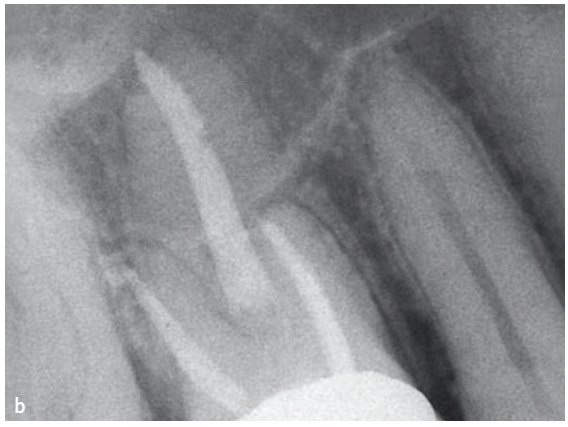


Fig 4b Complete healing after retreatment and detection and treatment of the mb2.

outcome, but usually strict criteria should be applied, i.e. complete radiographic healing, absence of clinical signs and symptoms and full functionality of the tooth. A controversial topic is whether 1, 2, or even 4 years is an adequate timeframe for the evaluation of success and failure[32,33].

Immediately after root canal obturation a control radiograph is mandatory, which is frequently taken as a basis for judging the quality of the root canal treatment performed. Of course, evaluation of a two-dimensional radiograph is a poor parameter for the quality of treatment, as it can demonstrate some geometrical (and aesthetical) aspects of preparation and length and homogeneity of obturation. It cannot provide any information on the quality of disinfection and the tightness of obturation; even complete treatment of the complex root canal system cannot be evaluated to a sufficient degree (Fig 6). This cannot even be evaluated absolutely using micro computed tomography, but can be judged with a higher degree of certainty.

Additionally, it should be noted that the post-obturation radiograph marks the beginning of healing so that any prognosis on treatment outcome can only be speculative in nature at that time.

The endodontic literature presents a wide range of success rates for retreatment, which only represent mean values. This should be regarded a consequence of the different clinical situations present before treatment, with each single factor influencing the final outcome to some degree.

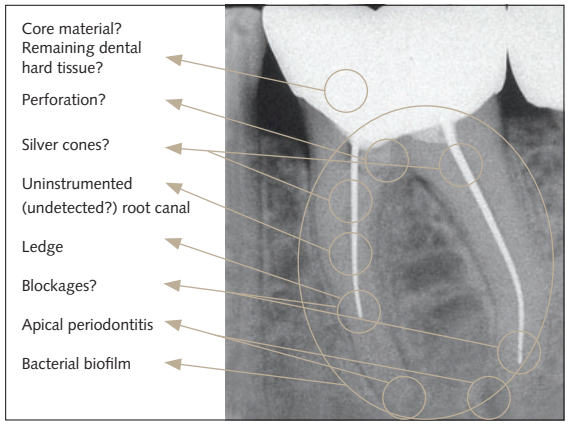


Fig 5 Potential problems that might occur during retreatment of this mandibular molar.

Influence of procedural errors on prognosis

It has been demonstrated that the majority of problems, incidents and errors during root canal treatment are associated with insufficient preparation, disinfection and obturation of the root canal system. Persistent microbial infection at the time of definite root canal obturation and the preoperative presence of an apical inflammatory lesion have been shown to be two main factors determining the prognosis of root-filled teeth[36,37]. If no infection is present at the time of primary treatment, treatment complications may facilitate infection and establishment of an intraradicular biofilm[15,27-29].

In some studies such as the Toronto study, root perforations have been discussed as a major factor

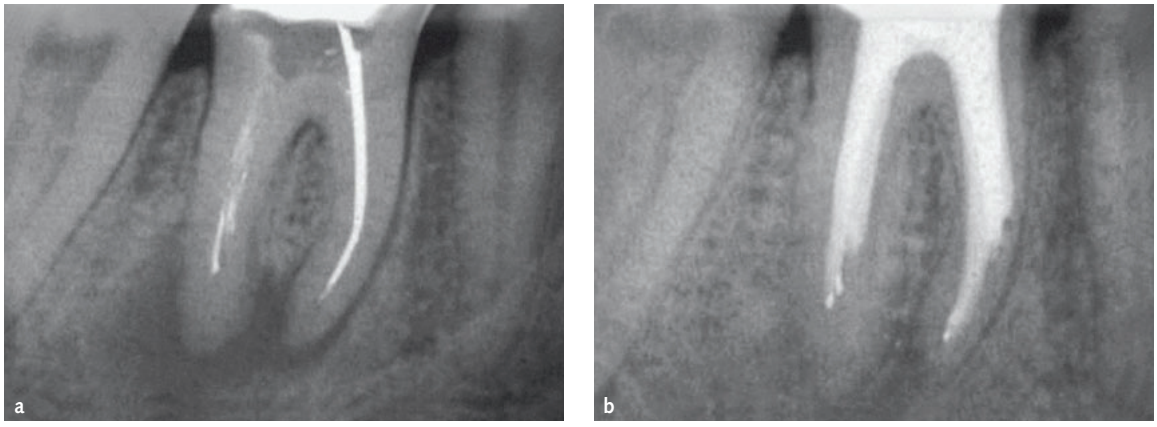


Fig 6 Silver cone retreatment case. Due to problems removing the corroded silver cones (at that time without a microscope), the post-obturation shape looks rather poor, nevertheless the lesion presented with a significantly reduced size 6 months later, indicating proper disinfection (and a healthy immune system).

for treatment failure. In others the radiographic quality of the coronal restoration has been identified as an important factor[38].

Procedural errors per se do not result in treatment failure or reduced success rates as long as these are not associated with or followed by persisting or secondary infection of the root canal system and subsequent periradicular inflammation. Technical problems in many cases are connected to biological sequelae.

Conclusions

- For each single root canal treatment, the occurrence of intraoperative problems should be expected.
- Proper treatment planning including a serious risk analysis allows the anticipation of many problems and in many cases adequate prevention.
- Problems which occur should be carefully analysed and managed properly according to the best clinical evidence.
- There is only limited clinical evidence available concerning the management of endodontic problems.

References

1. Hülsmann M. Methods for removing metal obstructions from the root canal. Endod Dent Traumatol 1993;9:223–237.
2. Madarati AA, Hunter MJ, Dummer PM. Management of intracanal separated instruments. J Endod 2013;39:569–581.
3. Parashos P, Messer HH. Questionnaire survey on the use of rotary nickel-titanium endodontic instruments by Australian dentists. Int Endod J 2004;37:249–259.
4. Ruddle CJ. Nonsurgical retreatment. J Endod 2004;30:827–845.
5. Cheung GSP. Instrument fracture: mechanisms, removal of fragments, and clinical outcomes. Endodontic Topics 2007;16:1–26.
6. Cujé J, Bargholz C, Hülsmann M. The outcome of retained instrument removal in a specialist practice. Int Endod J 2010;43:545–554.
7. Shen Y, Peng B, Cheung GS. Factors associated with the removal of fractured NiTi instruments from root canal systems. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;98:605–610.
8. Suter B, Lussi A, Sequeira P. Probability of removing fractured instruments from root canals. Int Endod J 2005;38:112–123.
9. Hülsmann M, Schinkel I. Influence of several factors on the success or failure of removal of fractured instruments from the root canal. Endod Dent Traumatol 1999;15:252–258.
10. Spili P, Parashos P, Messer HH. The impact of instrument fracture on outcome of endodontic treatment. J Endod 2005;31:845–850.
11. Bürklein S, Tsotsis P, Schäfer E. Incidence of dentinal defects after root canal preparation: reciprocating versus rotary instrumentation. J Endod 2013;39:501–504.
12. Capar ID, Arslan H, Akcay M, Uysal B. Effects of ProTaper Universal, ProTaper Next, and HyFlex instruments on crack formation in dentin. J Endod 2014;40:1482–1484.
13. Shemesh H, Roeleveld AC, Wesselink PR, Wu MK. Damage to root dentin during retreatment procedures. J Endod 2011;37:63–66.
14. Tanalp J, Güngör T. Apical extrusion of debris: a literature review of an inherent occurrence during root canal treatment. Int Endod J 2014;47:211–221.
15. Di Filippo G, Sidhu SK, Chong BS. The role of biofilms in endodontic treatment failure. ENDO (Lond Engl) 2014;8:87–103.

16. Zehnder M. Root canal irrigants. J Endod 2006;32:389–398.
17. Hülsmann M, Rödig T, Nordmeyer S. Complications during root canal irrigation. Endodontic Topics 2007;16:27–63.
18. Hülsmann M. Effects of mechanical instrumentation and chemical irrigation on root canal dentin and surrounding tissues. Endodontic Topics 2013;29:55–86.
19. Moura MS, Guedes OA, De Alencar AH, Azevedo BC, Estrela C. Influence of length of root canal obturation on apical periodontitis detected by periapical radiography and cone beam computed tomography. J Endod 2009;35:805–809.
20. Kojima K, Inamoto K, Nagamatsu K, et al. Success rate of endodontic treatment of teeth with vital and nonvital pulps: A meta-analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;97:95–99.
21. Wu MK, Wesselink PR, Walton RE. Apical terminus location of root canal treatment procedures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:99–103.
22. Ricucci D, Siqueira JF Jr. Fate of the tissue in lateral canals and apical ramifications in response to pathologic conditions and treatment procedures. J Endod 2010;36:1–15.
23. JOE Editorial Board. Procedural accidents: an online study guide. J Endod 2008;34 (5 Suppl):e65–e70.
24. Tsesis I, Faivishevsky V, Fuss Z, Zukerman O. Flare-ups after endodontic treatment: a meta-analysis of literature. J Endod 2008;34:1177–1181.
25. Nixdorf DR, Moana-Filho EJ, Law AS, McGuire LA, Hodges JS, John MT. Frequency of persistent tooth pain after root canal therapy: a systematic review and meta-analysis. J Endod 2010;36:224–230.
26. Nixdorf DR, Moana-Filho EJ, Law AS, McGuire LA, Hodges JS, John MT. Frequency of nonodontogenic pain after endodontic therapy: A systematic review and meta-analysis. J Endod 2010;36:1494–1498.
27. Nair PN. On the causes of persistent apical periodontitis: a review. Int Endod J 2006;39:249–281.
28. Siqueira JF Jr. Aetiology of root canal treatment failure: why well-treated teeth can fail. Int Endod J 2001;34:1–10.
29. Chavez de Paz LE. Redefining the persistent infection in root canals: possible role of biofilm communities. J Endod 2007;33:652–662.
30. Wu MK, Dummer PM, Wesselink PR. Consequences of and strategies to deal with residual post-treatment root canal infection. Int Endod J 2006;39:343–356.
31. Huumonen S, Kvist T, Grondahl K, Molander A. Diagnostic value of computed tomography in re-treatment of root fillings in maxillary molars. Int Endod J 2006;39:827–833.
32. Ørstavik D. Time-course and risk analyses of the development and healing of chronic apical periodontitis in man. Int Endod J 1996;29:150–155.
33. Wu MK, Wesselink PR. Timeliness and effectiveness in the surgical management of persistent post-treatment periapical pathosis. Endodontic Topics 2005;11:25–31.
34. Cantatore G, Berutti E, Castellucci A. Missed anatomy: frequency and clinical impact. Endodontic Topics 2006;15: 3–31.
35. Hülsmann M, Drebenstedt S, Holscher C. Shaping and filling root canals during re-treatment. Endodontic Topics 2008;19: 74–124.
36. Sjögren U, Figdor D, Persson S, Sundqvist G. Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis. Int Endod J 1997;30:297–306.
37. Lin LM, Rosenberg PA, Lin J. Do procedural errors cause endodontic treatment failure? J Am Dent Assoc 2005;136:187–193, quiz 231.
38. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature -- Part 2. Influence of clinical factors. Int Endod J 2008;41:6–31.

Niharika Jain, Ajinkya M. Pawar, Meena Naganath, Abhishek Gupta, Hemasha Daryani

Incidence and severity of postoperative pain after canal instrumentation with reciprocating system, continuous rotary single file system, versus SAF system

Niharika Jain, B.D.S., M.D.S.
Assistant Professor, Department of Conservative Dentistry and Endodontics, Hitkarini Dental College and Hospital,Jabalpur, Madhya Pradesh, India

Ajinkya M. Pawar, B.D.S., M.D.S.
Assistant Professor, Department of Conservative Dentistry and Endodontics, Nair Hospital Dental College, Mumbai, Maharashtra, India

Meena Naganath, B.D.S., M.D.S.
Professor and Head, Department of Conservative Dentistry and Endodontics, V.S. Dental College and Hospital, Bangalore, Karnataka, India

Abhishek Gupta, B.D.S., M.D.S.
Assistant Professor, Department of Orthodontics and Dentofacial Orthopaedics, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India

Hemasha Daryani, B.D.S., M.D.S.
Senior Lecturer, Department of Public Health Dentistry, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India

Correspondence to:
Dr Niharika Jain
Reader, Department of Conservative Dentistry and Endodontics, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India.
Tel: +91-9424392599
Email: niharika.dr@gmail.com

Key words *Nickel-Titanium instruments, One Shape, Self Adjusting File, WaveOne*

Objective: To evaluate the incidence and severity of postoperative pain and analgesics intake after root canal treatment of molars using single file systems: WaveOne (WO; Dentsply Maillefer, Ballaigues, Switzerland) and One Shape (OS; Micro Méga, Besançon, France) versus the Self Adjusting File (SAF; ReDentNova, Ra'anana, Israel).

Methods: One hundred and forty-one patients with vital molars indicating for conventional single-visit root canal treatment were randomly assigned to one of three groups (n = 47) according to the instrumentation system used: WaveOne, One Shape and SAF. Participants were asked to rate the intensity of postoperative pain on a Functional Pain Scale and to record the quantity of prescribed analgesic medication taken after 24 h, 48 h, 72 h and 7 days.

Data were statistically analysed using SPSS software (version 20; Chicago, Illinois, USA). Intergroup analysis was performed using the Kruskal-Wallis, followed by Mann-Whitney U tests for intragroup comparison. The Friedman test was applied for comparison between different time intervals. The level of significance was set at $P < 0.05$.

Results: Patients treated with the SAF system were associated with significantly less postoperative pain and lower analgesic intake compared to the other two groups at the four timepoints assessed.

Conclusion: The SAF system caused less postoperative pain and lower intake of analgesic medication at the timepoints assessed.

Introduction

A major complication of root canal treatment is the frequent pain[1]. Postoperative pain, defined as a sensation of discomfort after endodontic intervention, is reported in 25% to 40% of patients, irrespective of pulp or periradicular status[2,3]. According to Pak and White, the prevalence of pain in the first 24 h is 40%, falling to 11% after 7 days[4]. Although root canal treatment reduces the prevalence and severity of pain, the immediate post-treatment pain severity levels may sometimes slightly exceed the pre-treatment severity levels. The cause of this maybe the extrusion of dentinal debris, pulp tissue, microorganisms and irrigants into the periradicular tissues during root canal preparation, leading to inflammation of the tissues, which is especially exacerbated by pre-existing periradicular inflammation[4]. The extruded debris can lead to postoperative complications, such as flare-ups[5]. Therefore adequate control of working length may reduce the extrusion of material through the apical foramen but cannot prevent this completely[6]. All root canal preparation techniques and instruments available to date are still associated with some degree of apical extrusion of debris[7-9].

Recently, the concept of single file root canal preparation was introduced, which requires a shorter period of time to prepare curved canals[10]. The WaveOne (WO) Nickel-Titanium (Ni-Ti) file system (Dentsply Maillefer, Ballaigues, Switzerland) is a single file system working in a reciprocating motion that involves initial rotation of the instrument in a counterclockwise direction, in which the instrument penetrates and cuts the dentin; followed by rotation in the opposite direction, during which the instrument is released. The One Shape (OS) Rotary Ni-Ti files (Micro Méga, Besançon, France) work in a continuous clockwise rotation. These files are designed with a variable cross-section along the blade of the instrument in order to increase their flexibility and reduce the instrument screwing effects.

The Self-Adjusting File (SAF; ReDentNova, Ra'anana, Israel) is also a single file system with a hollow compressible design. The SAF, accompanied by continuous irrigation with any desired solution, is used in a vibrating movement.

The purpose of the present study was to clinically compare the incidence of postoperative pain after root canal instrumentation of posterior teeth using single file systems: the Reciprocating System (WaveOne), Continuous Rotary System (One Shape) and Self Adjusting Files. Analgesic medication intake by patients was also studied.

Materials and methods

Patient selection and study protocol

The clinical study protocol was reviewed and approved by the University Research Ethical Committee. The subjects were treated in accordance with the Declaration of Helsinki and received thorough explanations concerning the experimental rationale, clinical procedures and possible complications of the procedures. Every selected patient signed an informed consent form. On receiving their informed consent, a total of 141 patients (aged 30 to 55 years) were included in the study. The sample size calculation was done using Cochran's method (1986). Based on a type I error of 5%, a confidence interval of 95% and 80% power, the sample size was calculated as 47 subjects per group. Two experienced operators, who were specialists in endodontics with over 4 years of practice, performed the clinical portion of this study.

All 141 patients were consecutively and independently selected between January and December 2015 from the specialists' private practice, which characterises the multicenter profile of the current setup. All participants had maxillary and mandibular molar teeth exhibiting normal root canal anatomy (maxillary: one of each root canal - mesiobuccal, distobuccal and palatal; mandibular: one of each root canal - mesiobuccal, mesiolingual and distal), diagnosed with symptomatic irreversible pulpitis (teeth containing vital pulps, that were exposed due to trauma, caries or mechanical reasons) or teeth indicating for intentional pulpectomy due to prosthetic reasons. The diagnosis of the tooth being treated was established by an experienced endodontist (more than 20 years into specialty practice), and confirmed by a radiologist. Patients were excluded from the study if they had non-vital teeth or third molars, apical periodontitis, endodontic retreatment, root resorption, immature/open root apex or a root canal in which patency of the apical foramen could not be established.

Patients refusing to participate in the study included those whose teeth had issues precluding single-visit treatment; those who had used any type of medication preoperatively, such as nonsteroidal or steroidal anti-inflammatory drugs or analgesics; and patients with any uncontrolled systemic disease.

Appropriate history (medical and dental), examination, investigation (intraoral periapical digital radiograph and cold test using 1,1,1,2-tetrafluoroethane), diagnosis and treatment planning preceded treatment in all patients. Occlusal adjustment was carried out and carious teeth were appropriately restored. Diagnostic findings were checked by comparing the tooth's response with that of an adjacent tooth with a vital pulp.

Treatment Protocol

In the current study, three clinicians, who were well trained in using the three different file systems (WO, OS and SAF), who had been using these instruments for a minimum of 3 years, performed the root canal treatment. After administering local anaesthesia

using 2% Lidocaine and 1:100,000 Epinephrine (Xylocaine; Dentsply Pharmaceutical, Pennsylvania), a rubber dam was applied and an access cavity was established, utilising a dental operating microscope (Opmi Pico, Carl Zeiss, Oberkochen, Germany). Disinfection of the tooth and the rubber dam was carried out by scrubbing a cotton roll, moistened with 5.25% of NaOCl, in a circular movement, starting from the tooth and going outwards to the rubber dam. The pulp chamber was rinsed with 3% sodium hypochlorite irrigant solution and using a watch-winding motion, the canals were explored with sizes 06, 08, 10 and 15 K-type hand files (Dentsply Maillefer) according to the initial diameter of the foramen and the canal curvature. The working length (WL) was established by introducing a size 10 K-file to the apical foramen as determined by an apex locator (i-Root, Micro Méga), and radiographically confirmed. All instruments were driven by a torque controlled endodontic motor (WaveOne Endomotor, Dentsply Maillefer). WO instruments were applied in a reciprocating mode, OS was used in a continuous rotary motion and SAF was operated in transline in-and-out vibration. Torque limits and rotation speeds were pre-set individually for each file system used. On reaching the WL after each file insertion, irrigation with 2 ml of 2.5% sodium hypochlorite was performed with a 24 G needle (Max-I-Probe; Dentsply Tulsa Dental, Pennsylvania, USA) during access and canal exploration and with a 31 G Navi Tip needle (Ultradent Products, Utah, USA). The teeth were randomly allocated to the three different instrumentation systems:

Group One (Wave-One; WO): Using Glyde (Dentsply Maillefer) as the lubricating agent, the glide path was created with PathFiles sizes 1, 2 and 3 (Dentsply Maillefer) until the full WL. The WO primary file (25.08) was used to prepare narrow and curved canals, and the WO large file (40.08) was used for large canals. Three in-and-out motions were applied in the cervical, middle and apical thirds, with an amplitude not exceeding 3 mm, until the established WL was attained.

Group Two (One Shape; OS): The glide path was created with G-Files (Micro Méga) until the full WL. Shaping was finished with OS files (size 25 and 6% taper) in a continuous mode of rotation. In-out strokes, dependent upon the complexity of the root canal anatomy were given in three steps without applying any pressure: up to one third of the WL; up to 3 mm short of the WL; and up to the WL.

Group Three (Self Adjusting File; SAF): The glide path was established up to a size 20 K-file in order to facilitate effective placement of the SAF until the apex, as described by Solomonov[11]. The root canal orifices were then enlarged using the Gates Glidden drill (Mani, Tochigi, Japan) size 2, followed by placement of the SAF up to the WL, which was confirmed radiographically. SAF 1.5 mm was used to prepare narrow and curved canals, and SAF 2.0 mm was used for large canals. The files were operated using a RDT3 handpiece head (ReDentNova) with a torque-control motor (WaveOne Endomotor, Dentsply Maillefer) at a frequency of 83.3 Hz (5000 movements per min) with an amplitude of 0.4 mm. In accordance with the manufacturers' instructions, it was used in a pecking motion for 4 min. The SAF was connected to a Vatea system irrigator (ReDent Nova) that pumped 2.5% sodium hypochlorite at a rate of 5 ml/min in a continuous flow.

Glyde File Prep (Dentsply Maillefer) was used as a canal lubricant before utilising each instrument. All instruments were used in only one tooth (single use) and then discarded. During all root canal preparations, apical patency was maintained by introducing a size 10 or size 15 K-file (Dentsply Maillefer) about 1 mm beyond the WL at each instrument change. In concluding the instrumentation, a size 25 hand K-file (with the SAF group: usually a size 30 K-type file) was checked for the previously agreed length and for apical gauging. The access cavity was flushed using 1 ml of 2.5% NaOCl and the solution was ultrasonically agitated for 1 min per root canal with a size 20/25 Irrisafe tip (Satelec Acteon Group, Merignac, France) placed inside the root canal up to 2 mm short of the WL. To remove the smear layer, 5 ml of a 17% EDTA solution was used and ultrasonic agitation was performed for 1 min. Irrigation was repeated with 5 ml of 2.5% NaOCl, and finally with 5 ml of 0.9% saline solution. The final aspiration was performed, using a capillary tip (Ultradent). An average of 40 ml of irrigant was used for root canal preparation of each tooth. All root canals were then dried, using absorbent paper points. Using the continuous wave of condensation technique, the canals were subsequently obturated with the gutta-percha cones of the

Table 1 Baseline demographic and clinical features of patients in the study groups.

Baseline demographic data and clinical features	WO Group N (%) (n = 47)	OS Group N (%) (n = 47)	SAF Group N (%) (n = 47)	Total (n = 141)
Male	28 (36.4)	27 (35.0)	22 (28.6)	77
Female	19 (29.7)	20 (31.2)	25 (39.1)	64
Maxillary teeth	26 (35.6)	23 (31.5)	24 (32.9)	73
Mandibular teeth	21 (30.9)	24 (35.3)	23 (33.9)	68

respective systems (for WO:25/0.08, OS:25/0.06 and SAF: usually 30.04 master cones were used. For SAF, as there is no taper or no definite size of apical preparation, the master cones were selected following apical gauging [which master cone felt a tug-back] and AH-Plus sealer [Dentsply Maillefer]).

The treatment phase was concluded by sealing the coronal access cavity with a dentine adhesive and composite resin (Filtek Bulk Fill, Posterior Restorative 3M Dental Products, Minnesota, USA).

A post-obturation radiograph was taken to confirm the quality of obturation. On completion of the root canal treatment procedure, each patient was instructed in the event of pain, to take analgesics (400 mg Ibuprofen) at a dosage of 1 tablet every 6 h.

Postoperative pain assessment

On completion of treatment, each patient was given a questionnaire based on the Functional Pain Scale to record the assessment of pain and analgesic intake (frequency and quantity) after 24 h, 48 h, 72 h and 7 days. After the defined time intervals the patients were asked by the clinical assistant to provide the following information over the telephone. This included their perceived pain rating, whether they had taken the analgesic medication prescribed and, if so, the quantity of tablets and the number of days that were required to control the pain. Each patient was instructed, in the event of severe pain or any other type of emergency, to contact the clinician in charge of the treatment.

Statistical analysis

The recorded data was compiled, entered in a spreadsheet computer program (Microsoft Excel 2007), and then exported to SPSS version 20.0 (SPSS, Illinois, USA). Nonparametric tests were applied since the data was non-normal and categorical. For intergroup comparison (between groups) the Kruskal-Wallis test was applied, followed by the Mann-Whitney U test for intragroup comparison (within the group) based on gender and dosage. The Friedman test was applied for comparison between different time intervals.

Results

The baseline demographic data and clinical features of the patients are summarised in Table 1.The mean age of the 141 patients was 36 ± 14 years. The recorded postoperative pain values in the SAF group were significantly lower when compared with the pain values of the WO and OS groups, while no significant differences were observed between the WO and OS groups (Table 2) at any of the four time intervals assessed. The highest postoperative pain scores in all the instrumentation groups were recorded after 24 h, with a decline thereafter (Table 3).

When compared with the other two groups, the analgesic intake was significantly lower in the SAF instrumentation group. However, no significant difference in the analgesics intake was observed between the WO and OS groups (Table 4). None of the 141 patients reported severe pain or any flare-ups during the study.

Discussion

One problem encountered when studying pain is the difficulty in evaluation, both for patients and professionals, because of the threshold range. This issue is

Table 2 Descriptive statistics and Kruskal-Wallis test applied to the postoperative pain results for the groups instrumented with WO, OS and SAF file systems.

	Score	Group 1 (WO)	Group 2 (OS)	Group 3 (SAF)	*P* Value	Intragroup comparison
Time 1 (after 24 h)	0	0	0	14	0.001	Group 3 significant to Group 1 and 2 No significance between Group 1 and 2
	1	1	7	23		
	2	29	24	8		
	3	17	16	2		
Time 2 (after 48 h)	0	0	2	29	0.001	Group 3 significant to Group 1 and 2 No significance between Group 1 and 2
	1	15	16	17		
	2	31	25	1		
	3	1	4	0		
Time 3 (after 72 h)	0	2	8	43	0.001	Group 3 significant to Group 1 and 2 No significance between Group 1 and 2
	1	37	31	4		
	2	8	8	0		
	3	0	0	0		
Time 4 (after 1 week)	0	27	35	47	0.001	Group 3 significant to Group 1 and 2 No significance between Group 1 and 2
	1	20	12	0		
	2	0	0	0		
	3	0	0	0		
Test applied: Kruskal-Wallis test (intergroup comparison) followed by Mann-Whitney U test (intragroup comparison) $P \leq 0.001$ (highly significant)						

Table 3 Mean postoperative pain scores after instrumentation with WO, OS and SAF file systems at the four timepoints assessed (24 h, 48 h, 72 h and 7 days).

	Time 1 (after 24 h)	Time 2 (after 48 h)	Time 3 (after 72 h)	Time 4 (after 1 week)	*P* Value
Group 1 (SAF)	3.78	2.93	2.09	1.21	0.001
Group 2 (WO)	3.68	2.98	2.09	1.26	0.001
Group 3 (OS)	3.41	2.62	2.05	1.91	0.001
Test applied: Friedman Test, $P \leq 0.001$ (highly significant)					

Table 4 Descriptive statistics of analgesic dose (frequency x dosage of 1 tablet, 400 mg) to control postoperative pain after instrumentation at different time intervals.

Time interval	Group 1 (Mean ± SD)	Group 2 (Mean ± SD)	Group 3 (Mean ± SD)	*P* Value	Intragroup comparison
Time 1 (after 24 h)	680.85 ± 262.62	672.34 ± 277.96	374.46 ± 357.81	0.001	Significant between 1 and 3 Significant between 2 and 3
Time 2 (after 48 h)	502.13 ± 317.25	570.21 ± 309.21	195.74 ± 342.59	0.001	Significant between 1 and 3 Significant between 2 and 3
Time 3 (after 72 h)	187.23 ± 233.70	297.87 ± 306.09	0	0.001	Significant between 1 and 3 Significant between 2 and 3
Time 4 (after 1 week)	59.57 ± 143.94	51.06 ± 134.92	0	0.027	
Test applied: Kruskal-Wallis test (intergroup comparison) followed by Mann-Whitney U test (intragroup comparison)					

confused by single and variable experience; and pain modulation by various physical and psychological factors. Many techniques have been used to assess pain intensity in human beings as described in the literature such as verbal, functional, numerical, visual analogue, coloured analogue and finger-reach rating scales; calibrated questionnaires; and cortical evoked potentials. The Functional Pain Scale used in the present study is an effective way to assess pain, which has proven to be helpful in identifying changes in pain. A study by Gloth et al compared the Functional Pain Scale, the Present Pain Intensity scale, the Visual Analogue Scale, the McGill Short-form questionnaire and the Numeric Pain Scale. The highest responsiveness was found in the Functional Pain Scale[12].

Preoperative pain is one of the strongest predictors of postoperative pain[13]. In an effort to isolate potential factors of postoperative pain from those strictly related to the instrumentation technique, non-vital teeth, symptomatic/asymptomatic apical periodontitis and endodontic retreatment were all excluded. Studies reported significantly lower postobturation pain in single-visit treatment when compared with a multiple-visit approach[14-16]. This may be attributed to immediate obturation, thereby avoiding complications of intracanal medications, repeated instrumentation and irrigation[17,18]. Nonetheless, a few studies also showed no significant difference in effectiveness (healing rates) and postoperative pain between these two treatment regimens[19,20]. Considering these factors, the single-visit root canal treatment procedure was chosen.

Although interappointment flare-up is uncommon, postoperative pain is relatively frequent; it is related to several factors, including infection, retreatment, preoperative pain, intracanal medication and physical and chemical damage to periapical tissues[5,21]. Possible causes of sustained postobturation pain include inadvertently missed strands of pulp tissue; possible extrusion of irrigant beyond the apex; failure to adequately seal the access cavity; and even non-cooperation of the patient with respect to postoperative instructions[22,23].The extrusion of infected debris into the periradicular tissues during chemomechanical preparation is considered to be one of the principal causes of postoperative pain[5]. Any injury to the periapical tissue during root canal treatment promotes more intensive secretion of inflammatory mediators, such as prostaglandins, serotonin, leukotrienes, histamine and bradykinin (all of which are also pain mediators)[24]. Root canal preparation techniques significantly diverge in terms of the amount of extruded debris, with some techniques extruding less than others. In the present study, the low pain rates observed in the SAF group could be related to a lower apical extrusion of bacteria, irrigants, dentin chips and inflamed pulp tissue, which could elicit postoperative pain. SAF is a single-file system which is devoid of a central metal core or any cutting edge or flutes; instead, it has an abrasive surface and is associated with continuous simultaneous irrigation. This continuous flow of the irrigant does not build up any pressure in the root canal, as the metal meshwork allows free escape of the irrigant. The SAF is effective in the narrowest apical part of a canal prepared up to a size 20 K-file, leaving more than 38% of the canal cross-section free for the backflow of fluid and dentinal debris[25]. De Melo Ribeiro et al stated that, in the apical third, the SAF system created cleaner inner canal walls when compared to a rotary system[26]. The results of this study demonstrated similar pain values in both the reciprocating and rotary instrumentation groups. This is supported by studies carried out regarding debris extrusion by De-Deus et al[27] and Kocaket al[28], who reported no differences between rotary and reciprocating movements. In contrast, previous studies have concluded that reciprocating systems can lead to a greater amount of extruded debris or debris remnants in the root canal than in rotary systems[8,29]. The WO files exhibit a larger taper of 0.08 at the apical 3 mm, which can be attributed to excessive debris formation apically and extrusion periapically.

Nonsteroidal anti-inflammatory drugs have been recommended as the medication of choice for postoperative pain management after root canal treatment and Ibuprofen has been included in several studies on pain relief that investigated the effects of different techniques and medications after root canal treatment procedures[30]. It is possible due to less periapical inflammation caused by reduced debris extrusion using the SAF system, the results of the present study demonstrated a lower intake of Ibuprofen by patients who underwent instrumentation by the SAF system when compared to the other two file systems.

The results obtained from the current study may be explained by differences in the instrument design and movement kinematics between the WO, SAF and OS file systems. In the present study, variations in the manipulation method were minimised by using protocols based on the manufacturers' recommendations. Instrumentation on root thirds, using three in-and-out motions with an amplitude not exceeding 3 mm was carried out with the reciprocating system, and for cases where the rotary system was used, a brushing action was employed. The Self-Adjusting File was operated with a trans-line in-and-out vibration accompanied by continuous irrigation with sodium hypochlorite solution.

In analysing the time course of reported pain, the overall intensity of postoperative pain was found to be greater after 24 h of root canal treatment but declined thereafter. These findings are in agreement with those of several authors[31-33].

The psychosocial factors of the participants in this study were not comprehensively assessed. Their absence could be a limiting factor in the study findings since, in other types of procedures, research exploring postoperative pain repeatedly demonstrates their significance as predictors[34].

Conclusion

In comparison with the other two types of Ni-Ti instruments assessed in the study, the Self Adjusting File system produced minimal postoperative pain after single-visit root canal treatment.

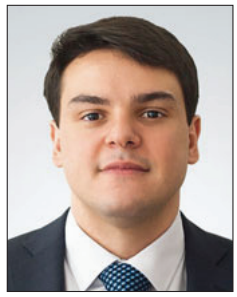
References

1. Oguntebi BR, DeSchepper EJ, Taylor TS, White CL, Pink FE. Postoperative pain incidence related to the type of emergency treatment of symptomatic pulpitis. Oral Surg Oral Med Oral Pathol 1992;73:479–483.
2. Nekoofar MH, Sadeghipanah M, Dehpour AR. Evaluation of meloxicam (A cox-2 inhibitor) for management of postoperative endodontic pain: a double blind placebo controlled study. J Endod 2003;29:634–637.
3. Pochapski MT, Santos FA, de Andrade ED, Sydney GB. Effect of pretreatment dexamethasone on postendodontic pain. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:790–795.
4. Pak JG, White SN. Pain prevalence and severity before, during, and after root canal treatment: a systematic review. J Endod 2011;37:429–438.
5. Siqueira JF Jr. Microbial causes of endodontic flare-ups. Int Endod J 2003;36:453–463.
6. Seltzer S, Naidorf IJ. Flare-ups in endodontics: I. Etiological factors. J Endod 1985;11:472–478.
7. Ferraz CC, Gomes NV, Gomes BP, Zaia AA, Teixeira FB, Souza-Filho FJ. Apical extrusion of debris and irrigants using two hand and three engine-driven instrumentation techniques. Int Endod J 2001;34:354–358.
8. Bürklein S, Schäfer E. Apically extruded debris with reciprocating single-file and full-sequence rotary instrumentation systems. J Endod 2012;38:850–852.
9. Kirchhoff AL, Fariniuk LF, Mello I. Apical extrusion of debris in flat-oval root canals after using different instrumentation systems. J Endod 2015;41:237–241.
10. Alves FR, Rocas IN, Almeida BM, Neves MA, Zoffoli J, Siqueira JF Jr. Quantitative molecular and culture analyses of bacterial elimination in oval-shaped root canals by a single-file instrumentation technique. Int Endod J 2012;45:871–877.
11. Solomonov M. Eight months of clinical experience with the Self-Adjusting File system. J Endod 2011;37:881–887.
12. Gloth FM 3rd, Scheve AA, Stober CV, Chow S, Prosser J. The Functional Pain Scale: reliability, validity, and responsiveness in an elderly population. J Am Med Dir Assoc 2001;2:110–114.
13. Glennon JP, Ng YL, Setchell DJ, Gulabivala K. Prevalence of and factors affecting postpreparation pain in patients undergoing two-visit root canal treatment. Int Endod J 2004;37:29–37.
14. Albashaireh ZS, Alnegrish AS. Postobturation pain after single- and multiple-visit endodontic therapy. A prospective study. J Dent 1998;26:227–232.
15. Sathorn C, Parashos P, Messer HH. Effectiveness of single-versus multiple-visit endodontic treatment of teeth with apical periodontitis: a systematic review and meta-analysis. Int Endod J 2005;38:347–355.
16. Su Y, Wang C, Ye L. Healing rate and post-obturation pain of single- versus multiple-visit endodontic treatment for infected root canals: a systematic review. J Endod 2011;37:125–132.
17. Eleazer PD, Eleazer KR. Flare-up rate in pulpally necrotic molars in one-visit versus two-visit endodontic treatment. J Endod 1998;24:614–616.
18. Myers JW, Marshall FJ, Rosen S. The incidence and identity of microorganisms present in root canals at filling following culture reversals. Oral Surg Oral Med Oral Pathol 1969;28:889–896.
19. Figini L, Lodi G, Gorni F, Gagliani M. Single versus multiple visits for endodontic treatment of permanent teeth: a Cochrane systematic review. J Endod 2008;34:1041–1047.
20. Sathorn C, Parashos P, Messer H. The prevalence of postoperative pain and flare-up in single- and multiple-visit endodontic treatment: a systematic review. Int Endod J 2008;41:91–99.
21. Abbott PV. Medicaments: aids to success in endodontics: Part 1. A review of the literature. Aust Dent J 1990;35:438–448.
22. Roane JB, Dryden JA, Grimes EW. Incidence of postoperative pain after single- and multiple-visit endodontic procedures. Oral Surg Oral Med Oral Pathol 1983;55:68–72.
23. Marshall JG, Leisinger AW. Factors associated with endodontic posttreatment pain. J Endod 1993;19:573–575.
24. Jain N, Gupta A, Meena N. An insight into neurophysiology of pulpal pain: facts and hypotheses. Korean J Pain 2013;26:347–355.
25. Hof R, Perevalov V, Eltanani M, Zary R, Metzger Z. The self-adjusting file (SAF). Part 2: mechanical analysis. J Endod 2010;36:691–696.
26. De Melo Ribeiro MV, Silva-Sousa YT, Versiani MA, et al. Comparison of the cleaning efficacy of self-adjusting file and rotary systems in the apical third of oval-shaped canals. J Endod 2013;39:398–401.

27. De-Deus G, Brandão MC, Barino B, Di Giorgi K, Fidel RA, Luna AS. Assessment of apically extruded debris produced by the single-file ProTaper F2 technique under reciprocating movement. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110:390–394.
28. Koçak S, Koçak MM, Sağlam BC, Türker SA, Sağsen B, Er Ö. Apical extrusion of debris using self-adjusting file, reciprocating single-file, and 2 rotary instrumentation systems. J Endod 2013;39:1278–1280.
29. Robinson JP, Lumley PJ, Cooper PR, Grover LM, Walmsley AD. Reciprocating root canal technique induces greater debris accumulation than a continuous rotary technique as assessed by 3-dimensional micro-computed tomography. J Endod 2013;39:1067–1070.
30. Al-Negrish AR, Habahbeh R. Flare up rate related to root canal treatment of asymptomatic pulpally necrotic central incisor teeth in patients attending a military hospital. J Dent 2006;34:635–640.
31. Yesilsoy C, Koren LZ, Morse DR, Rankow H, Bolanos OR, Furst ML. Post-endodontic obturation pain: a comparative evaluation. Quintessence Int 1988;19:431–438.
32. Harrison JW, Baumgartner JC, Svec TA. Incidence of pain associated with clinical factors during and after root canal therapy. Part 2. Postobturation pain. J Endod 1983;9: 434–438.
33. Kherlakian D, Cunha RS, Ehrhardt IC, Zuolo ML, Kishen A, da Silveira Bueno CE. Comparison of the incidence of postoperative pain after using 2 reciprocating systems and a continuous rotary system: A prospective randomized clinical trial. J Endod 2016;42:171–176.
34. Ip HY, Abrishami A, Peng PW, Wong J, Chung F. Predictors of postoperative pain and analgesic consumption: a qualitative systematic review. Anesthesiology 2009;111: 657–677.

Emmanuel João Nogueira Leal Silva, Brenda Leite Muniz, Nancy Kudsi Carvalho, Luciana Moura Sassone, Aline de Almeida Neves

Electromagnetic interference of smartphones on apex locators: An in vivo study



Emmanuel João Nogueira Leal Silva
Department of Endodontics, School of Dentistry – Grande Rio University (UNIGRANRIO), Rio de Janeiro, Brazil; Department of Endodontics, Rio de Janeiro State University, Rio de Janeiro, Brazil

Brenda Leite Muniz
Department of Endodontics, School of Dentistry – Grande Rio University (UNIGRANRIO), Rio de Janeiro, Brazil

Nancy Kudsi Carvalho
Department of Endodontics, Rio de Janeiro State University, Rio de Janeiro, Brazil

Luciana Moura Sassone
Department of Endodontics, Rio de Janeiro State University, Rio de Janeiro, Brazil

Aline de Almeida Neves
Department of Paediatric Dentistry, Rio de Janeiro Federal University, Rio de Janeiro, Brazil

Correspondence to:
Emmanuel J. N. L. Silva – Rua Herotides de Oliveira 61/902 – Icaraí, Niterói, Rio de Janeiro, Brazil.
Fax: 55 21 26108439
Email: nogueiraemmanuel@hotmail.com

Key words *cell phones, electronic apex locator, endodontics, Odontometry*

Aim: Electromagnetic interference (EMI) emitted by smartphones can disrupt the functioning of some medical devices. The aim of the present *in vivo* study was to determine the effect of two smartphones (IPhone 5S and Samsung Galaxy S5) on the reliability of two electronic apex locators (EALs) (Novapex and Root ZX II).

Materials and methods: Twelve patients were enrolled in the present study. Thirty-one root canals from sixteen teeth in need of root canal treatment were selected, after clinical and radiographic examination. The effect of smartphones (IPhone 5S and Samsung Galaxy S5) on both tested EALs (Novapex and Root ZX II) was determined under two different conditions: no smartphone in the operatory room (control group); and smartphones with Wi-Fi and Bluetooth setting activated and placed in physical contact with the EAL to maximise the chance of detecting EMI. The EWL was measured three times per tooth under each condition. To evaluate the reliability of EALs when used near smartphones, all measurements were submitted to ANOVA and Tukey's test with a significance level of 5%.

Results: It was possible to determine EWL under all the experimental conditions. No significant differences ($P > 0.05$) were found for EWL measurements in the presence or absence of smartphones for the two tested EALs. A linear correlation between the two different tested EALs in the presence or absence of smartphones was also observed.

Conclusion: It can be concluded that mobile phones used in the present study did not affect accuracy of EWL measurements *in vivo*.

Introduction

The correct determination of working length (WL) is a crucial step in achieving success during root canal treatment[1-3]. Underestimation of the WL may lead to insufficient debridement of the root canal, whereas overestimation may result in damage to the periapical tissues, delaying or preventing healing[4,5]. Electronic Apex Locators (EALs) have been developed with the aim of increasing the success of root canal treatment and reducing the disadvantages associated with conventional radiography in establishing the WL[6,7]. Studies have shown that EALs may provide a more accurate estimation of the WL than radiographs[5,7]. Moreover, the use of EALs reduces treatment time and radiation dose to the patient[8].

One major concern regarding EALs is the possibility of inaccurate or incorrect readings as a consequence of electromagnetic interference (EMI) provided by different electronic devices, including smartphones. In fact, the effect of EMI is an inherent property of radio waves, occurring when electromagnetic waves radiate from a smartphone near a medical device. In this situation, there is a

possibility that the electric field produced in space may exceed the immunity of the medical device[9]. It is widely known that several medical devices are prone to have EMI radiated by equipment such as cell phones, iPods and dental devices[10-15]. Some precautions are taken to avoid interference, such as cell phone usage restricted in all hospital areas, with a distance greater than 1 m from all sensitive medical equipment. Dental offices however rarely apply these practical procedures as smartphones are used without limitation by dentists, dental assistants and patients close to dental devices[16]. The possibility of EMI might explain some clinical difficulties during electronic working length (EWL) determination due to the reported lack of stability of EALs. Although it has been recently demonstrated *in vitro* that reliability and stability of EALs were not influenced when placed in direct contact with smartphones[16,17], no *in vivo* study has yet to be performed regarding the accuracy of EALs in WL determination when these devices are used near smartphones.

Therefore, the aim of the present study was to determine the reliability of two commonly used EALs (Novapex [Forum Technologies, Rishon LeZion, Israel] and Root ZX II [Morita, Tokyo, Japan]), when used near two smartphones (IPhone 5S and Samsung Galaxy S5). The null hypothesis tested was that there are no differences in electronic working length determination when performing this measurement *in vivo*, with or without close contact with smartphones.

Materials and methods

Thirty-one root canals from sixteen teeth in need of root canal treatment were selected from 12 patients after clinical and radiographic examination. Patient age ranged from 18 to 78 years, with a mean age of 50 years. Teeth presenting metallic restorations, fractures, signs of root resorption or open apices were not included in the study. Informed written consent was obtained from all patients, and the study was conducted in compliance with the ethical principles of the Helsinki Declaration and Good Clinical Practice. Approval for conducting the study was granted by the Institutional Review Board (25592914.3.0000.5283).

Local anaesthesia was administrated in all cases. Access cavities were prepared with round diamond burs (Dentsply Maillefer, Ballaigues, Switzerland) and refined with an Endo-Z bur (Dentsply Maillefer). When appropriate, the occlusal cusps were flattened using diamond burs at high speed to obtain a stable reference for WL measurements. After that, rubber dam isolation of the tooth was performed, and root canal patency was obtained with size 15 K-files (Dentsply Maillefer) using 5.25% sodium hypochlorite as an irrigant.

EALs

EWL was performed using two different EALs:

1. Novapex, which uses voltage difference, operates on the principle that the impedance measurement not only differs between two electrodes, depending on the frequencies used, but also differs greatly in apical constriction regions.
2. Root ZX II, a dual frequency device, operates based on the quotient method principle, which calculates the canal impedance by the ratio of the two frequencies (0.4 and 8.0 kHz)

Smartphones

Two smartphones were used in this study:

1. An Apple iPhone 5S, used with the network provider Oi (Rio de Janeiro, Brazil) at a frequency of 2100 MHz (with a 4G/Universal Mobile Telecommunications System connection);
2. A Samsung Galaxy S5, used with the network provider Vivo (Rio de Janeiro, Brazil) at a frequency of 900 to 1800 MHz (dual-band GSM).

Clinical determination of EWL

For each canal, EWL was performed under two different conditions:

1. No smartphone in the operatory room (control group).
2. Smartphone with Wi-Fi and the Bluetooth setting activated and placed in physical contact with the EAL to maximise the chance of detecting EMI.

EWL measurements were obtained until the device reached the '0.0' level, according to the manufacturer's recommendations. Measurements were considered valid if the obtained reading remained stable for at least 5 s. Unstable measurements were recognised when the scale bars on the display of the EALs jumped from one point to the other. The silicon stop was adjusted, and the distance between the silicon stop and the file tip was measured with a 0.1 mm precision digital caliper (Mitutoyo Digimatic Caliper, Mitutoyo, Kawasaki, Japan).

During all the experiments, no other smartphone was present in the room. All EWL determinations were performed in the same place to ensure that the signal intensity of the smartphone reception was stable. A dental office with a weak incoming signal was selected for conducting the experiments.

Three EWL measurements were recorded per canal, per smartphone and for each EAL, which led to 372 electronic measurements becoming available for further statistical analysis.

Statistical analysis

Statistical analysis was performed with the aid of SPSS software (LEAD Technologies, Illinois, USA). All data was analysed by using ANOVA and Tukey's test with a significance level of 5%.

Table 1 Mean values of working length for each condition.

Electronic apex locator	Cell phone model	Working length (mm)
Novapex	No phone	17.90 ± 2.98
	Iphone 5S	17.98 ± 3.04
	Samsung Galaxy S5	17.99 ± 3.09
Root ZX module	No phone	17.93 ± 2.97
	Iphone 5S	18.01 ± 3.11
	Samsung Galaxy S5	17.96 ± 3.09

*No statistically significant difference was recorded amongst the different groups

Results

It was possible to determine EWL under all the experimental conditions. No significant differences ($P > 0.05$) were found for EWL measurements in the presence or absence of smartphones for the two tested EALs (Table 1). Figure 1 presents a scatter plot showing the linear correlation between the two different tested EALs in the presence or absence of smartphones.

Discussion

Smartphone usage by the general population has grown continuously in recent years, in addition to the introduction of new phone systems and models. According to a worldwide survey, in 2015, 4.9 billion

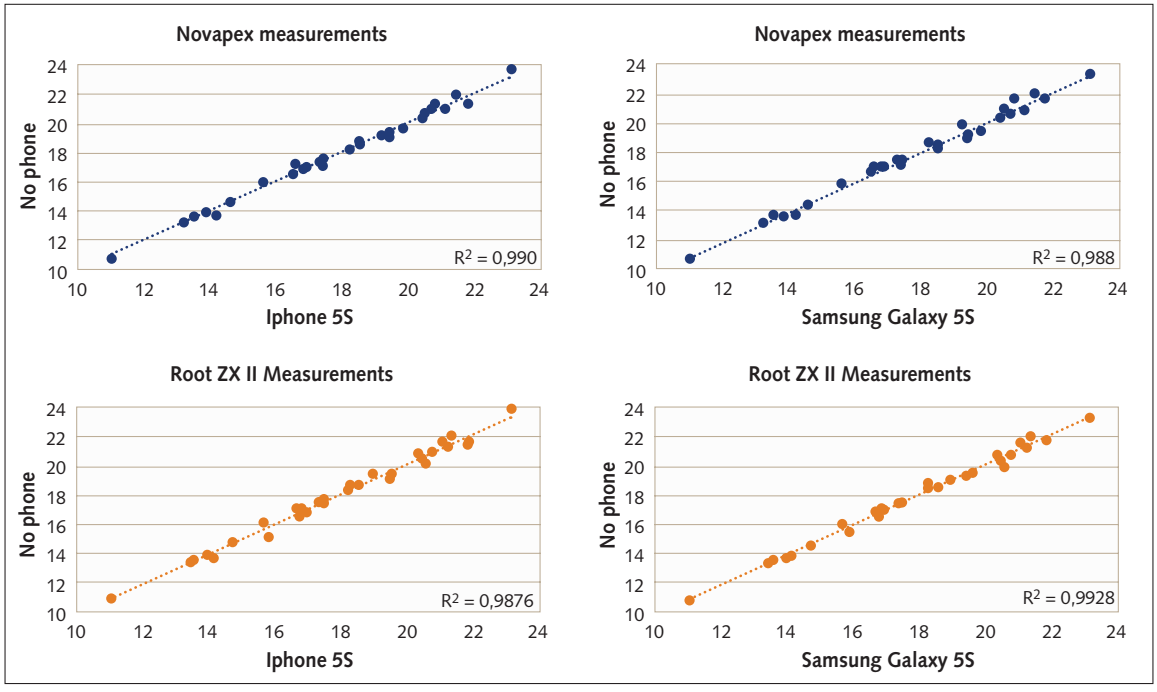


Fig 1 Statistical correlation of the working length determination with and without the presence of smartphones.

people own a mobile phone, representing more than half of the world's population today[18]. The technical support documents of several EALs state that EMI from portable and mobile radiofrequency communication equipment such as smartphones can cause interference with an accurate reading of the EAL and should not be used in close proximity to any part of the EAL. The results of the present study showed that EWL measurements were not influenced by direct contact with two different models of smartphones. Both EALs worked correctly, with good stability and reliability even in close contact with smartphones. Therefore, the null hypothesis was plainly accepted.

The present results are in accordance with two recent *in vitro* studies demonstrating that the reliability and stability of different EALs were not influenced when placed in direct contact with different mobile phones[16,17]. Sidhu et al[16] evaluated the effect of a Samsung Galaxy Note Edge smart phone on WL determination of Propex II and Rootor EALs under two experimental settings: (1) in a closed room with poor signal strength; and (2) in a polyclinic set-up with good signal strength and five conditions: (a) electronically, without a mobile phone in the room; (b) electronically, with a mobile phone in physical contact with EAL; (c) electronically, with a mobile phone in physical contact with EAL and in calling mode for a period of 25 s; (d) electronically, with a mobile phone placed at a distance of 40 cm from the EAL; and (e) electronically, with a mobile phone placed at a distance of 40 cm and in calling mode for a period of 25 s. The authors concluded that EWL measurements were not influenced by the presence of a mobile phone and could be determined under all experimental conditions[16]. Moreover, Hurstel et al[17] evaluated the effect of an Apple iPhone 5 or LG KP100 mobile phone placed in direct contact with a Dentaport Root ZX (J Morita, Osaka, Japan) module or Propex II (Dentsply-Maillefer, Ballaigues, Switzerland) on WL determination under four different conditions: (1) visually, under the microscope until the file tip reached the canal terminus; (2) electronically, without the mobile phone in close proximity; (3) electronically, with the mobile phone in standby mode, placed in physical contact with the EAL; and (4) electronically, with the mobile phone activated by a call in the same position. The authors concluded that neither the mobile phone type nor the EAL affected the measurements[17]. However, to the best of the authors' knowledge, this is the first time that EMI of mobile phones on EALs is tested *in vivo*.

Smartphones tested in the present study operated on the Global System for Mobile Communications system (GSM). This system was developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second-generation (2G) digital cellular networks used by smartphones. Third generation mobile telecommunications technology (3G) have followed, replacing 2G standards. In Europe, this is known as the Universal Mobile Telecommunication System. The frequency bands identified for this system are 1885 to 2010 and 2110 to 2200 MHz, and this is currently the standard for the majority of mobile phones. The safety profile of these smartphones is still unknown for many medical devices[10] and moreover, digital mobile phones may emit higher strength electromagnetic fields than analogue mobile phones[19].

Results from a simulation study have shown that field strengths emitted from mobile phones may meet the recommended EMI immunity level of 3 V/m set by the International Electrotechnical Commission (IEC) for medical equipment, keeping a separation distance of more than 1 m from mobile phones[19]. Although most modern medical devices with better shielding and filtering may be immune to mobile phone emissions[20], the potential for EMI still does exist. EMI may occur when mobile phones operate at high power and in close proximity to very sensitive medical devices with digital circuits for extended periods of time[19]. The direct contact between EALs and smartphones was established to maximise the possibility of interference.

In the present study, EWL measurements were performed with the smartphones in the stand-by mode to prevent any electronic interference. The clinical experiments were carried out in the same room in order to obtain a stable intensity of the signal, ensuring the reliability of the measurement comparison. Future studies should be conducted with EWL measurements obtained while the phones are in the call-mode or using Wi-Fi, as this may result in different results.

In summary, the smartphones used in the present study did not affect accuracy of EWL measurements *in vivo*. Further evaluations of electro-

magnetic interference caused by different kinds of electronic devices on dental equipment should be considered.

Acknowledgements

The authors deny any conflicts of interest related to this study.

The authors affirm that they have no financial affiliation (e.g., employment, direct payment, stock holdings, retainers, consultantships, patent licensing arrangements or honoraria), or involvement with any commercial organisation with direct financial interest in the subject or materials discussed in this manuscript, nor have any such arrangements existed in the past 3 years. This work was supported by FAPERJ E-26/201.491/2014. Dr EJNL Silva, LM Sassone and AA Neves were supported by a FAPERJ/JCNE grant.

References

1. Huang L. An experimental study of the principle of electronic root canal measurement. J Endod 1987;13:60–64.
2. Bernardes RA, Duarte MA, Vasconcelos BC, et al. Evaluation of precision of length determination with 3 electronic apex locators: Root ZX, Elements Diagnostic Unit and Apex Locator, and RomiAPEX D-30. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:e91–e94.
3. Angwaravong O, Panitvisai P. Accuracy of an electronic apex locator in primary teeth with root resorption. Int Endod J 2009;42:115–121.
4. Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part 2. A histological study. Int Endod J 1998;31:394–409.
5. Beltrame AP, Triches TC, Sartori N, Bolan M. Electronic determination of root canal working length in primary molar teeth: An in vivo and ex vivo study. Int Endod J 2011;44:402–406.
6. Dunlap CA, Remeikis NA, BeGole EA, Rauschenberger CR. An in vivo evaluation of an electronic apex locator that uses the ratio method in vital and necrotic canals. J Endod 1998;24:48–50.
7. Chen E, Kaing S, Mohan H, Ting SY, Wu J, Parashos P. An ex vivo comparison of electronic apex locator teaching models. J Endod 2011;37:1147–1151.
8. Kim E, Lee SJ. Electronic apex locator. Dent Clin North Am 2004;48:35–54.
9. Nojima T, Tarusawa Y. A new EMI test method for electronic medical devices exposed to mobile radio wave. Electron Comm Jpn 1 2002;85:11–18.
10. Klein AA, Djaiani GN. Mobile phones in the hospital – past, present and future. Anaesthesia 2003;58:353–357.
11. Hayes DL, Wang PJ, Reynolds DW, et al. Interference with cardiac pacemakers by cellular telephones. N Engl J Med 1997;336:1473–1479.
12. Patel MB, Thaker JP, Punnam S, Jongnarangsin K. Pacemaker interference with an iPod. Heart Rhythm 2007;4:781–784.
13. Miller CS, Leonelli FM, Latham E. Selective interference with pacemaker activity by electrical dental devices. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1998;85:33–36.
14. Lawrentschuk N, Bolton DM. Mobile phone interference with medical equipment and its clinical relevance: a systematic review. Med J Aust 2004;181:145–149.
15. Hietanen M, Sibakov V. Electromagnetic interference from GSM and TETRA phones with life-support medical devices. Ann Ist Super Sanita 2007;43:204–207.
16. Sidhu P, Shankargouda S, Dicksit DD, Mahdey HM, Muzaffar D, Arora S. Evaluation of interference of cellular phones on electronic apex locators: An in vitro study. J Endod 2016;42:622–625.
17. Hurstel J, Guivarc'h M, Pommel L, et al. Do cell phones affect establishing electronic working length? J Endod 2015;41:943–946.
18. Statista – The statistics portal. Number of mobile phone users worldwide from 2012 to 2018 (in billions). Available at: http://www.statista.com/statistics/274774/forecast-of-mobile-phone-users-worldwide/. Accessed: 12 August 2015.
19. Chen HY, Chou CY. Evaluation of EMI risk due to the interaction between cellular phones and medical devices. Microw Opt Technol Lett 2010;52:1449–1454.
20. Rosenthal K. Is electromagnetic interference still a risk? Nurs Manage 2005;36:68, 71.

Patrícia Reis Rezende de Brito, Patrícia Mayer Lima, Emmanuel João Nogueira Leal Silva, Sandra Rivera Fidel, Rivail Antonio Sérgio Fidel, Luciana Moura Sassone

Effectiveness of ProTaper Next, ProTaper Universal and WaveOne systems in reducing intracanal bacterial load

Patrícia Reis Rezende de Brito

Patrícia Mayer Lima
Both:
Rio de Janeiro State University (UERJ), School of Dentistry, Department of Endodontics, Rio de Janeiro, Brazil

Emmanuel João Nogueira Leal Silva
Rio de Janeiro State University (UERJ), School of Dentistry, Department of Endodontics, Rio de Janeiro, Brazil; Grande Rio University (UNIGRANRIO), Health Sciences Center, Department of Endodontics, Rio de Janeiro, Brazil

Sandra Rivera Fidel
Rio de Janeiro State University (UERJ), School of Dentistry, Department of Endodontics, Rio de Janeiro, Brazil

Rivail Antonio Sérgio Fidel
Rio de Janeiro State University (UERJ), School of Dentistry, Department of Endodontics, Rio de Janeiro, Brazil

Luciana Moura Sassone
Rio de Janeiro State University (UERJ), School of Dentistry, Department of Endodontics, Rio de Janeiro, Brazil

Correspondence to:
Patricia Reis Rezende Brito
Boulevard vinte e oito de setembro, 157; Vila Isabel, Rio de Janeiro, Brazil 20551-030.
Tel: 55 21 2868-8355
Email: patyrezendebrito@gmail.com

Key words *Enterococcus faecalis, ProTaper Next, Root canal instrumentation, sodium hypochlorite*

Aim: The aim was to evaluate the bacterial reduction achieved by ProTaper Next (PTN) system in root canals contaminated with *Enterococcus faecalis*. ProTaper Universal (PTU) and WaveOne (WO) systems were used as references for comparison.

Materials and methods: A hundred human mandibular premolars were selected and ninety-five were contaminated with *E. faecalis* for 4 weeks. Then the teeth were randomly divided into six groups (n = 15): PTN + 2.5% NaOCl; PTU + 2.5% NaOCl; WO + 2.5% NaOCl; PTN + saline solution; PTU + saline solution; and WO + saline solution. Positive and negative control groups were created with five specimens each. The irrigation volume was standardised for all experimental groups. Samples taken before (S1) and after (S2) chemomechanical procedures were cultured and the colony-forming units (CFUs) were counted. The paired t-test was used for intragroup analysis, and one-way ANOVA for intergroup analysis. When significant differences were found amongst the groups, the Tukey test was used. The significance levels were set at 5% ($P < 0.05$).

Results: After root canal instrumentation (S2), there was a significant reduction in bacterial load in all groups ($P < 0.01$). The WO/saline solution group showed a lower level of bacterial reduction when compared with the other tested groups ($P < 0.01$). Groups irrigated with NaOCl showed a higher level of bacterial reduction when compared with saline solution irrigation ($P < 0.01$), with no statistical differences amongst the systems used ($P > 0.05$).

Conclusion: The PTN system was as effective as PTU and WO in the removal of bacteria during root canal treatment.

Introduction

Bacteria and their by-products play an essential role in the development of pulp and periapical diseases and are factors which affect the results of root canal therapy[1,2]. Eradication of these microorganisms is accomplished by a combination of mechanical instrumentation, irrigation solutions and intracanal medicaments[3]. Up to now, there is no cleaning and shaping protocol capable of eliminating the entire bacterial load from the root canal system[2,4]. The limitations of technology used presently have led to the exploration of more efficient preparation techniques, which may improve the disinfection of the root canal system.

Recently, ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland) was developed as the successor of the ProTaper Universal system (Dentsply Maillefer). The PTN system is made of a unique Nickel-Titanium (Ni-Ti) alloy and M-wire, manufactured by means of a thermal treatment process. This system incorporates a progressive and regressive

taper design and an off-centred rectangular design, which is claimed to improve the strength and flexibility along the active part of the instrument[5]. According to the manufacturer, the design of PTN results in an asymmetric rotary motion intended to decrease the screw-in effect by minimising the engagement between the instrument and the dentinal wall (manufacturer's information). Overall, research findings on the PTN system have reported increased cyclic fatigue life[5,6], a low amount of debris extrusion[7] and good shaping ability[8,9].

The present study was designed to evaluate the bacterial reduction achieved by the PTN system in root canals contaminated with *Enterococcus faecalis*. ProTaper Universal (PTU) and WaveOne (WO; Dentsply Maillefer) systems were used as a reference for comparison. The null hypothesis tested was that there are no differences among the tested systems.

Materials and methods

Specimen preparation

The study was approved by the local ethics committee (Protocol 870.714). One hundred mandibular premolars were selected for this study. The teeth were stored in 0.9% saline solution until use. Sample selection was based on relative dimensions and similarity of root canal morphology. Teeth with mature root apexes, no evidence of resorptions and a single, narrow, straight root canal were included. Preoperative radiographs were taken to ensure that the teeth had no root caries, calcifications, curvatures or fractures.

Conventional access cavities were performed using round and Endo-Z burs (Dentsply Maillefer). Apical patency was determined by inserting a size 10 K-file (Dentsply Maillefer) into the root canal until the tip was visible at the apical foramen. Working length was established 1 mm short of the major apical foramen. After this, occlusal reduction was performed to standardise root length to 21 mm. Apical constriction was standardised up to a size 20 K-file (Dentsply Maillefer). Afterwards, the apical foramen was sealed with fast setting epoxy resin, (Scotch mix: 3M, Sumaré, São Paulo, Brazil) the teeth were mounted vertically in plaster blocks up to their cementoenamel junction, and autoclaved at 121°C and 1 atm for 20 min. To check the efficacy of the sterilisation, each specimen on the negative control group (n = 5) was irrigated with 1 ml of sterile saline solution and a sample was taken sequentially introducing 3 size 20 paper points in the root canals, plated in Mitis salivarius agar plates (Difco, Maryland, USA) and incubated at 37°C for 48 h. No microbial growth was observed.

Specimen contamination

A pure culture of *E. faecalis* (ATCC 29212) was cultivated overnight in brain-heart infusion broth (BHI-BD, Biosciences, Maryland, USA) and used to prepare an inoculum suspension. The cell suspension was adjusted spectrophotometrically to match the turbidity of 1.5 x 10^8 colony-forming units (CFU ml), equivalent to ± 0.5 McFarland standard. Sterile pipettes were used, under laminar flow, to inoculate each specimen with 2 µl of the bacterial suspension. A sterile size 15 K-file (Dentsply Maillefer) was used to spread the bacterial suspension along the entire root canal length. Samples were kept at 37°C for 28 days and every 2 days; freshly prepared BHI was added to the samples.

After the contamination period, the canal of each specimen was irrigated with 1 ml of sterile saline solution and the first bacterial sample (S1) was taken by sequentially introducing three sterile paper points (Dentsply Maillefer), size 20, into the canal and keeping them there for 1 min. The bacterial samples were individually placed in 1.5 ml Eppendorf tubes containing 1 ml of sterile saline solution. The CFU counts were performed as described in the quantification of the bacterial load.

Root canal preparation

For each specimen, all preparation and sampling procedures were performed by an experienced operator, in a class I laminar airflow cabinet, to prevent airborne contamination. The specimens were randomly assigned to six groups (n = 15) according to the instrumentation system and the irrigation solution used for root canal preparation: sodium hypochlorite (NaOCl) or saline solution (Fig 1).

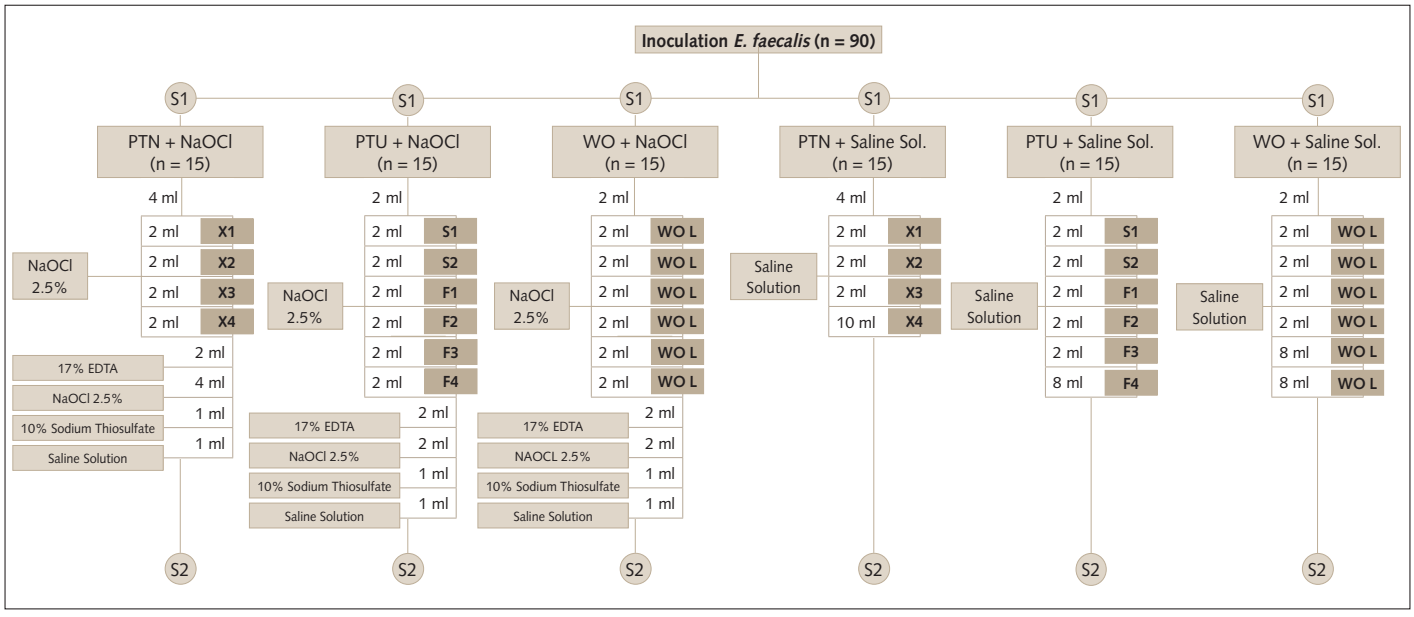


Fig 1 A flowchart of experimental procedures.

PTN + 2.5% NaOCl (n = 15) – ProTaper Next instruments were used according to the manufacturer's instructions, in gentle in-and-out movements. The instrumentation sequence was X1, X2, X3 and X4 instruments at the working length. Two and a half percent NaOCl (Fómula & Ação, São Paulo, Brazil) was used during instrumentation.

PTU + 2.5% NaOCl (n = 15) – ProTaper Universal instruments were used according to the manufacturer's instructions, with gentle in-and-out movements. The instrumentation sequence was S1, S2, F1, F2, F3 and F4 instruments at the working length. Two and a half percent NaOCl (Fómula & Ação) was used during instrumentation.

WO + 2.5% NaOCl (n = 15) – The WaveOne Large instrument was gently inserted into the cervical third with an in-and-out pecking motion at low amplitude. After this, the instrument was reused in the same manner along the middle third, with subsequent irrigation. Lastly, the instrument was inserted at the working length with a brushing motion against the lateral walls of the root canal. Two and a half percent NaOCl (Fómula & Ação) was used during instrumentation.

In the NaOCl groups, during the conclusion of the root canal preparation, teeth were irrigated with 17% EDTA (Asfer, São Caetano do Sul, Brazil), then with 2.5% NaOCl and, afterwards, 1 ml of 10% sodium thiosulfate (Fómula & Ação) was used to neutralise the NaOCl. Next, the canal was rinsed with 1 ml of sterile saline solution (Fig 1).

PTN + saline solution (n = 15) - The same instrumentation procedure as PTN + 2.5% NaOCl was performed. Saline solution was used as irrigation solution.

PTU + saline solution (n = 15) - The same instrumentation procedure as PTU + 2.5% NaOCl was performed. Saline solution was used as irrigation solution.

WO + saline solution (n = 15) – The same instrumentation procedure as WO + 2.5% NaOCl was performed. Saline solution was used as irrigation solution.

Positive control group (n = 5) – In this group, root canals were contaminated, however, no instrumentation was performed.

Negative control group (n = 5) - In this group, neither contamination nor instrumentation were performed.

All instruments were used with a 6:1 contra-angle handpiece (Sirona, Bensheim, Germany) powered by a torque-limited electric motor (VDW Silver Reciproc; VDW, Munich, Germany). For the ProTaper Next and ProTaper Universal instruments, the individual torque limits and rotational speeds programmed in the instrument library of the motor were used, whilst the WaveOne instruments were used in a reciprocating working motion generated by the motor.

Table 1 Individual mean values (Log 10) of bacterial content found before (S1) and after chemomechanical preparation (S2).

Groups	Before instrumentation (S1)	After instrumentation (S2)	Percent reduction
Positive control group	4.09 ± 0.14	X	X
Negative control group	0 ± 0	X	X
WO + NaOCl	4.00 ± 0.36	0.06 ± 0.22*	99.99%^{A}
PTU + NaOCl	4.10 ± 0.49	0.24 ± 0.47*	99.94%^{A}
PTN + NaOCl	4.61 ± 0.64	0.23 ± 0.38*	99.99%^{A}
WO + Saline solution	4.46 ± 0.78	2.33 ± 1.51*	95.05%^{C}
PTU + Saline solution	4.07 ± 0.24	1.65 ± 1.21*	97.83%^{B}
PTN + Saline solution	5.08 ± 0.55	1.40 ± 1.48*	98.59%^{B}

*Statistically significant differences between initial and final sampling (Paired t-test, $P < 0.01$). Different letters indicate statistically significant differences between groups, with regard to bacterial reduction (ANOVA test, $P < 0.05$).

Due to the different number of instruments in the groups, a total volume of 20 ml of irrigant per canal was then standardised (Fig 1). All irrigation procedures were performed with a 5 ml syringe and a 30 gauge Navitip needle (Ultradent Products, Utah, USA), which was inserted into the root canal without binding, in an in-and-out motion for better flow, up to 3 mm from the apical foramen.

In order to collect dentin shavings for the S2 samples, a size 40 Hedströem file was used to file the dentin walls[10]. After this, a 1 ml disposable plastic syringe was used to aspirate canal contents and place them into tubes containing 1 ml of sterile saline. Two paper points size 40 were placed at the canal to absorb the canal contents and these were transferred to the same tubes containing 1 ml of saline and agitated in a vortex for 1 min[10]. S2 samples were treated in the same way as S1 samples.

Quantification of bacterial load

The Eppendorf tubes containing the collected samples (S1 and S2) were agitated in a vortex for 1 min and a 10-fold serial dilution with sterile saline up to 10^{-3} was prepared. A volume of 100 µl of each dilution was inoculated in Mitis salivarius agar plates (Difco, Maryland, USA), incubated at 37°C for 48 h, and then subjected to bacterial counting.

Statistical analysis

The data collected (CFU counts) was statistically analysed by using the SPSS for Windows (SPSS, Illinois, USA). The Shapiro-Wilk's test showed that the distributions of the studied variables deviated from normality. Therefore, data were transformed by Log10 as suggested by the software. The paired t-test was used for intragroup analysis and one-way analysis of variance, for intergroup analysis. When significant differences were found between the groups, the Tukey test was used. The levels of significance were set at 5% ($P < 0.05$).

Results

Sterility of the specimens was confirmed by the negative control group showing no microbial growth. The culture technique indicated that there were bacteria present in 100% of the root canals investigated (S1) (95 out of 95 samples). No differences were observed amongst all groups in S1 ($P > 005$). After root canal instrumentation (S2), there was a highly significant reduction in bacterial load in all the groups ($P < 0.01$ by t-test). The WaveOne/saline solution group showed a lower level of bacterial reduction when compared with the other groups tested ($P < 0.01$). Groups in which irrigation was performed with NaOCl showed a higher level of bacterial reduction when compared with saline solution irrigation ($P < 0.01$), with no statistical differences amongst the systems used ($P > 0.05$). Table 1 provides an overview of the mean values of bacterial load and the percentage of bacterial reductions in all groups tested in the different sampling times.

Discussion

The present study was designed to compare the antibacterial efficacy of ProTaper Next in reducing *E. faecalis* presence during chemomechanical preparation. ProTaper Universal and WaveOne systems were used as references for comparison. According to the results of this study, all systems showed a significant reduction in the bacterial populations during intragroup analysis. When NaOCl was used, no differences were observed amongst the groups. These results are in agreement with those of previous studies that also showed similar effectiveness of single-file reciprocating systems and full-sequence rotary systems in reducing the presence of cultivable bacteria, using irrigants with antimicrobial properties[4,11,12]. Moreover, the present results are consistent with recent studies that demonstrated that ProTaper Next was found to be effective in reducing the number of intracanal bacteria[13,14]. In contrast, when saline solution was used, the single-file reciprocating system WaveOne presented a lower level of *E. faecalis* reduction when compared with the full-sequence rotary systems. Therefore, the null hypothesis was partially rejected. Saline solution was used as an irrigant solution because it has no antibacterial effect on *E. faecalis*. Therefore, elimination of the bacteria could only be attributed to the mechanical action of the instrumentation[15]. The interplay amongst several factors, such as pitch length, cutting ability, kinematics and number of instruments, may all contribute to the lower bacterial reduction in this group.

It is important to standardise the experimental design when evaluating bacterial reduction of different types of Ni-Ti systems. Several factors such as instrument design, preparation technique, operator and root canal anatomy are known to significantly impact the overall antimicrobial efficacy. For this reason, efforts were made to standardise not only the tip size but also the taper of the last instrument used during root canal preparation. In this study, WaveOne Large instruments were used and for the full-sequence rotary systems, ProTaper Next and ProTaper Universal instruments up to X4 and F4 were used, respectively. Therefore, in all of the three systems tested, root canal preparations were concluded with an instrument tip size of 40 and a 0.06 taper, except for WaveOne large, which had a 0.08 taper along the first 3 mm. Moreover, attempts were made to ensure anatomical comparability of the experimental groups, selecting specimens with similar anatomy and standardising the apical constriction as well as the root canal length.

It is important to point out that the irrigation was adjusted to ensure use of the same volume of irrigants for all groups and the time of operation between the groups PTN and PTU were basically the same, whereas the WO group had a reduced preparation time due to the simplicity of the technique. Even with this reduced preparation time, no differences were observed when NaOCl was used as irrigant, demonstrating the ability of all tested systems to reduce *E. faecalis* counts.

It has been well established in the literature that the mechanical action of instruments is capable of reducing the bacterial load[11,12]; however, this reduction is limited and the use of an active irrigant solution is mandatory for achieving efficient disinfection of the root canal system[16]. NaOCl seems to present most of the required prerequisites of an endodontic irrigant[17]. It has the ability to dissolve necrotic tissue[18] and the organic compounds of the smear layer[19]. NaOCl inactivates endotoxins[20] and disintegrates endodontic biofilms[21].

Enteroccocus faecalis has been widely used as a valuable microbiological marker for *in vitro* studies, because it has shown to be capable of successfully colonising the root canal, invading dentinal tubules and resisting some root canal treatment procedures[22]. It is often involved in persistent endodontic infections and periradicular inflammation, and has the ability to survive even under unusual environmental stresses, such as low nutrient availability[2]. Moreover, it is relatively easy to culture and manipulate[2]. The root canals were infected with *E. faecalis* for 4 weeks, taking into account that the biofilms were considered to be mature, with regard to their structural development, from 3 weeks onwards[23]. It is important to emphasise that the status of *E. faecalis* as the most important pathogen associated with endodontic failure has been questioned by recent studies[24,25]. Although recent molecular studies demonstrated that persistent infections may present a diverse bacterial community[25-27], *E. faecalis* biofilm has been largely used in *ex vivo* studies[28-31].

The sampling method using paper points could be regarded as a limitation of the present study, as it can reveal the bacteriological conditions only in the main root canal and the tissues in its immediate surrounding area. As bacterial infection can occur in the lateral canal, isthmuses, dentinal tubules and apical ramifications [32], bacteria can pass unnoticed by the paper point sampling approach. In the present study, S2 samples were collected using Hedstroem files in an attempt to collect bacteria from the dentine biofilm and dentinal tubules, as previously recommended[33]. This strategy was not used in S1 sampling to avoid disruption of *E. faecalis* biofilm by the root canal preparation procedure.

The plate culture method is frequently used in bacterial reduction studies[2,12]. Although molecular methods have been suggested as the most sensitive bacterial detection tests, Alves et al[34] found no significant differences in post-treatment samples comparing the quantitative real-time polymerase chain reaction and culturing methods. These results indicated that both methods can be adopted reliably for ex vivo studies. However, owing to the different nature of the two methodologies, results obtained by either method require careful interpretation. Since the clonal origin of a single CPU is not necessarily one single cell, the CPU based analysis can lead to an underestimation of the actual cell number. Conversely, the real-time polymerase chain reaction method can exceed the actual cell number since it detects DNA from nonviable cells[35,36].

Rarely is root canal anatomy restricted to a single straight canal. Clinical outcome studies suggest that this anatomy is typically associated with successful outcomes[37]. Future studies should be performed with more complex root canal anatomy, shortening the distance from the laboratory setting to a challenging real-life clinical situation.

Conclusions

Within the limitations of this *in vitro* study, it may be concluded that the ProTaper Next system provided a similar percentage of reduction in *E. faecalis* counts compared with the ProTaper Universal and WaveOne systems, with the use of 2.5% NaOCl.

Acknowledgements

This work was supported by grants from FAPERJ (Fundação Carlos Chagas Filho de amparo à pesquisa do Estado do Rio de Janeiro, Grant numbers: E-26/202.839/2015).

References

1. Kakehashi S, Stanley HR, Fitzgerald RJ. The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg Oral Med Oral Pathol 1965;20:340–349.
2. Siqueira JF Jr, Roças IN, Santos SR, Lima KC, Magalhães FA, de Uzeda M. Efficacy of instrumentation techniques and irrigation regimes in reducing the bacterial population within root canals. J Endod 2002;28:181–184.
3. Siqueira JF Jr, Roças IN. Optimising single-visit disinfection with supplementary approaches: a quest for predictability. Aust Endod J 2011;37:92–98.
4. Martinho FC, Gomes AP, Fernandes AM, et al. Clinical comparison of the effectiveness of single-file reciprocating systems and rotary systems for removal of endotoxins and cultivable bacteria from primarily infected root canals. J Endod 2014;40:625–629.
5. Elnaghy AM. Cyclic fatigue resistance of ProTaper Next nickel-titanium rotary files. Int Endod J 2014;47:1034–1039.
6. Nguyen HH, Fong H, Paranjpe A, Flake NM, Johnson JD, Peters OA. Evaluation of the resistance to cyclic fatigue among ProTaper Next, ProTaper Universal, and Vortex Blue rotary instruments. J Endod 2014;40:1190–1193.
7. Koçak MM, Çiçek E, Koçak S, Saglam BC, Yilmaz N. Apical extrusion of debris using ProTaper Universal and ProTaper Next rotary systems. Int Endod J 2015;48:283–286.
8. Zhao D, Shen Y, Peng B, Haapasalo M. Root canal preparation of mandibular molars with 3 nickel-titanium rotary instruments: a micro-computed tomographic study. J Endod 2014;40:1860–1864.
9. Saber SE, Nagy MM, Schäfer E. Comparative evaluation of the shaping ability of ProTaper Next, iRaCe and Hyflex CM rotary Ni-Ti files in severely curved root canals. Int Endod J 2015;48:131–136.
10. Brito PR, Souza LC, Machado de Oliveira JCM, et al. Comparison of the effectiveness of three irrigation techniques in reducing intracanal Enterococcus faecalis populations: an in vitro study. J Endod 2009;35:1422–1427.
11. Siqueira Jr JF, Alves FR, Versiani MA, et al. Correlative bacteriologic and micro-computed tomographic analysis of mandibular molar mesial canals prepared by self-adjusting file, Reciproc, and Twisted File systems. J Endod 2013;39:1044–1050.
12. Nakamura VC, Candeiro GT, Cai S, Gavini G. Ex vivo evaluation of three instrumentation techniques on E. faecalis biofilm within oval shaped root canals. Braz Oral Res 2015;29:1–7.
13. Karatas E, Gültekin E, Arslan H, Kirici DÖ, Alsancak M, Topçu MÇ. Evaluation of instrumentation systems in reducing E. faecalis from root canals: TF adaptive and ProTaper next versus single file systems. Int J Artif Organs 2015;38:161–164.
14. Tewari RK, Ali S, Mishra SK, et al. Mechanical reduction of the intracanal Enterococcus faecalis population by Hyflex CM, K3XF, ProTaper Next, and two manual instrument systems: an in vitro comparative study. J Investig Clin Dent 2016;7:168–173.

15. Machado ME, Nabeshima CK, Leonardo MF, Reis FA, Britto ML, Cai S. Influence of reciprocating single-file and rotary instrumentation on bacterial reduction on infected root canals. Int Endod J 2013;46:1083–1087.
16. Hülsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: Shaping goals, techniques and means. Endodontic Topics 2005;10:30–76.
17. Zehnder M. Root canal irrigants. J Endod 2006;32: 389–398.
18. Naenni N, Thoma K, Zehnder M. Soft tissue dissolution capacity of currently used and potential endodontic irrigants. J Endod 2004;30:785–787.
19. Haikel Y, Gorce F, Allemann C, Voegel JC. In vitro efficiency of endodontic irrigation solutions on protein desorption. Int Endod J 1994;27:16–20.
20. Sarbinoff JA, O'leary TJ, Miller CH. The comparative effectiveness of various agents in detoxifying diseased root surfaces. J Periodontol 1983;54:77–80.
21. Dunavant TR, Regan JD, Glickman GN, Solomon ES, Honeyman AL. Comparative evaluation of endodontic irrigants against Enterococcus faecalis biofilms. J Endod 2006;32:527–531.
22. Love RM. Enterococcus faecalis – a mechanism for its role in endodontic failure. Int Endod J 2001;34:399–405.
23. Shen Y, Stojicic S, Haapasalo M. Antimicrobial efficacy of chlorhexidine against bacteria in biofilms at different stages of development. J Endod 2011;37:657–661.
24. Chugal N, Wang JK, Wang R, et al. Molecular characterization of the microbial flora residing at the apical portion of infected root canals of human teeth. J Endod 2011;37:1359–1364.
25. Antunes HS, Rôças IN, Alves FR, Siqueira JF Jr. Total and specific bacterial levels in the apical root canal system of teeth with post-treatment apical periodontitis. J Endod 2015;41: 1037–1042.
26. Hong BY, Lee TK, Lim SM, et al. Microbial analysis in primary and persistent endodontic infections by using pyrosequencing. J Endod 2013;39:1136–1140.
27. Murad CF, Sassone LM, Faveri M, Hirata R Jr, Figueiredo L, Feres M. Microbial diversity in persistent root canal infections investigated by checkerboard DNA-DNA hybridization. J Endod 2014;40:899–906.
28. Ferrer-Luque CM, Bejarano I, Ruiz-Linares M, Baca P. Reduction in Enterococcus faecalis counts - a comparison between rotary and reciprocating systems. Int Endod J 2014;47:-380–386.
29. Nabeshima CK, Caballero-Flores H, Cai S, Aranguren J, Borges Britto ML, Machado ME. Bacterial removal promoted by 2 single-file systems: Wave One and One Shape. J Endod 2014;40:1995–1998.
30. Tinoco JM, De-Deus G, Tinoco EM, Saavedra F, Fidel RA, Sassone LM. Apical extrusion of bacteria when using reciprocating single-file and rotary multifile instrumentation systems. Int Endod J 2014;47:560–566.
31. Teixeira JM, Cunha FM, Jesus RO, Silva EJ, Fidel SR, Sassone LM. Influence of working length and apical preparation size on apical bacterial extrusion during reciprocating instrumentation. Int Endod J 2015;48:648–653.
32. Ricucci D, Loghin S, Siqueira JF Jr. Exuberant Biofilm infection in a lateral canal as the cause of short-term endodontic treatment failure: report of a case. J Endod 2013;39: 712–718.
33. Sassone LM, Fidel RA, Faveri M, Figueiredo L, Fidel SR, Feres M. A microbiological profile of unexposed and exposed pulp space of primary endodontic infections by checkerboard DNA-DNA hybridization. J Endod 2012;38:889–893.
34. Alves FR, Rôças IN, Almeida BM, Neves MA, Zoffoli J, Siqueira JF Jr. Quantitative molecular and culture analyses of bacterial elimination in oval-shaped root canals by a single-file instrumentation technique. Int Endod J 2012;45;-871–877.
35. Vianna ME, Horz HP, Gomes BP, Conrads G. In vivo evaluation of microbial reduction after chemo-mechanical preparation of human root canals containing necrotic pulp tissue. Int Endod J 2006;39:484–492.
36. Cohenca N, Silva LA, Silva RA, et al. Microbiological evaluation of different irrigation protocols on root canal disinfection in teeth with apical periodontitis; an in vivo study. Braz Dent J 2013;24:467–473.
37. Gomes AC, Nejaim Y, Silva AI, et al. Influence of endodontic treatment and coronal restoration on status of periapical tissues: A cone-beam computed tomographic study. J Endod 2015;41:1614–1618.

Martin Brüsehaber, Clemens Bargholz, Michael Hülsmann

Mineral trioxide aggregate for root-end closure of non-vital immature permanent teeth: A retrospective study

Martin Brüsehaber, Dr
Private Practice, Hamburg, Germany

Clemens Bargholz, Dr
Private Practice, Hamburg, Germany

Michael Hülsmann, Prof. Dr.
Department of Preventive Dentistry, Periodontology and Cariology, University of Göttingen, Göttingen, Germany

Correspondence to:
Prof. Dr. Michael Hülsmann, Department of Preventive Dentistry, Periodontology and Cariology, University of Göttingen, Robert-Koch-Str. 40, 37075 Göttingen, Germany.
Tel: +44 (0)551-3922855
Fax: +44 (0)551-3922037
Email: michael.huelsmann@med.uni-goettingen.de

Key words *apical barrier, apical closure, clinical outcome, immature apices, MTA, open apex, recall interval*

Aim: This study presents the results of a retrospective evaluation of treatment of immature non-vital teeth using mineral trioxide aggregate (MTA) for root-end closure.
Methods: Forty-six teeth with incomplete root development presenting with apical periodontitis were treated at a dental office limited to endodontics using MTA for apical closure. Success of treatment was defined as absence of clinical symptoms or radiographical signs of pathology and was assessed at least 1 year after treatment. The radiographs were evaluated by two calibrated endodontists.
Results: Follow-up examination was performed on 95.6% (n = 44) of the teeth included in the study. The mean recall interval was 2.6 years. Success rate for the evaluated cases was 72.7%.
Conclusion: This study showed a significant correlation between the success rate and the length of the recall interval (t-test, $P = 0.046$). The success rate significantly increased with increasing recall intervals.

Introduction

When a dental trauma or a carious lesion results in pulp necrosis, regular maturation of the dental root of an immature tooth is unlikely to occur. Depending on the stage of maturation, the affected teeth show roots with thin dentinal walls and wide open apices. Microbial infection of the root canal system results in an early inflammatory reaction of the periapical tissue[1].

Traditionally, root canal medication with calcium hydroxide has been advocated to stimulate formation of an apical hard tissue barrier[2,3]. The excellent anti-bacterial effect and the good tissue-dissolving properties of calcium hydroxide support disinfection and cleaning of the root canal system[4]. Calcium hydroxide induces cement-like deposits in the area of the apex, which often are irregularly structured and interspersed with soft tissue[5]. Depending on the size of the foramen and the periapical lesion, complete formation of the hard-tissue barrier, which is sufficiently stable to resist obturation of the root canal with gutta-percha and sealer, can be anticipated after 6 to 54 months[4,6]. The prognosis for healing of an apical lesion following long-term treatment with calcium hydroxide has been reported to exceed 90%[4]. The main disadvantage of this therapy is the necessity to repeatedly exchange the intracanal medication. Immediate definite treatment of the teeth is impossible and good compliance of the patients or their parents, respectively, is required. The risk of losing a tooth due to fracture has been reported to range as high as 20% and depends highly on the tooth's stage of maturation[4]. Calcium hydroxide, particularly when being used over a longer period, increases the fracture risk of the dentin; similar to sodium hypochlorite, as it destroys the organic dentin structure[7,8] and particularly weakens the thin and immature roots.

Mineral trioxide aggregate (MTA) is recommended for apical closure of immature root canals to overcome the disadvantages of calcium hydroxide[9]. MTA is a modified Portland cement that is mixed with water to create a colloid gel that hardens in the presence of humidity or blood after approximately 3 h[10,11]. It shows good biocompatibility[12] and, similar to calcium hydroxide, induces apical deposition of hard tissue[13]. The material well adheres to dentin and ensures good sealing of root canals[10,11]. Furthermore, MTA - compared to calcium hydroxide - seems to show less negative effects on the composition and physical properties of the dentin[14]. A multitude of cases described the successful use of MTA for apical closure of immature dental roots[15-17]. However, data from systematic evaluations of the treatment of immature teeth using MTA are only available from studies with a low number of cases. The success rates of these studies have been described as ranging between 65% and 85%[18-22].

The objective of the present retrospective evaluation was to determine the probability of successful treatment of apical periodontitis when using MTA for apical closure of immature teeth of juvenile patients. Success or failure of treatment were to be assessed on the basis of radiographic findings, and the dependence of success related to the duration of the recall interval.

Material and methods

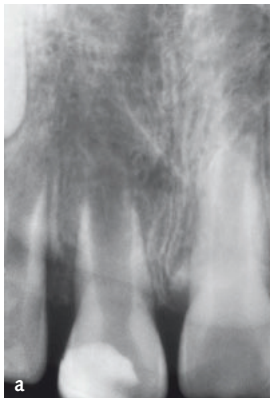
The present evaluation was approved by the responsible Ethics Committee of the Medical Association of Hamburg, Germany (ref. no. WF-006/12).

Forty-six patients treated with MTA in a private dental practice limited to endodontics were included in the study. The inclusion criteria were: (1) the patients to be treated were healthy and did not show any systemic diseases; (2) the pulp of the tooth to be treated was non-vital due to trauma or caries; (3) root length growth had not been completed, and the tooth to be treated showed a foramen with a large diameter that did not allow for conventional obturation with heated gutta-percha; and (4) all treatments were documented with pre-endodontic and post-endodontic radiographs. Patients with (1) systemic diseases and teeth with (2) completed root development, (3) longitudinal or transverse fracture of the root, or (4) an external resorption of the root were excluded from the evaluation. Cases for which preoperative and postoperative radiographs were not assessable were also excluded from the evaluation.

All evaluations, treatments as well as the determination of the variables, were performed by two clinicians with long-term experience in the field of traumatology, in a private dental practice limited to endodontics. There was no systematic allocation of the patients to a certain clinician. Treatment was performed in one or several treatment sessions. Based on the clinical findings, the clinician decided on the number of treatment sessions as well as on the use of a temporary medication.

Before each treatment, a preoperative radiograph was taken in the right-angle technique. Each treatment included isolation of the tooth under rubber dam as well as the use of a dental operating microscope. Primary and secondary access cavities were prepared with rotary diamond burs, rose-head burs, Gates-Glidden burs and ultrasonic instruments. Disinfection of the root canal system was performed using passive ultrasonic activation of sodium hypochlorite in a concentration of 3% to 5%. Working length was determined electronically and confirmed radiographically. Protection of the thin dentinal walls was observed comprehensively, and mechanical preparation of the root canal walls was avoided as much as possible. A temporary medication of calcium hydroxide was placed for only a few days, when required, due to insufficient compliance of the patient, painful teeth or continuing intracanal bleeding.

Apical closure of the root canals was achieved using grey or white mineral trioxide aggregate (Pro Root, Dentsply Maillefer, Ballaigues, Switzerland). The MTA was mixed according to the manufacturer's instructions and applied in several steps to a thickness of approximately 4 millimeters directly onto the periapical tissue, using an application tool (Micro-Apical Placement System, Dentsply Maillefer). In some cases, the material was placed onto a matrix previously created with pieces of collagen (Kollagen-Resorb, Resorba, Nürnberg, Germany)[23]. Placement of the MTA plug was verified radiographically. Hardening of the MTA was facilitated by applying a wet paper point. A few days



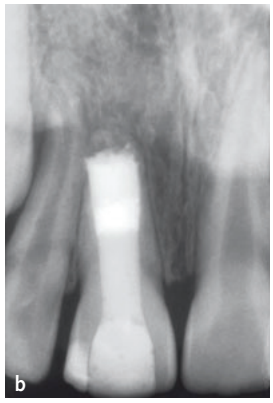


Fig 1 a) Preoperative radiograph of tooth 11 showing an apical translucency. b) Two-year postoperative control radiograph demonstrating a successful outcome.

Fig 2 a) Preoperative radiograph of tooth 21 presenting with pulp necrosis and apical periodontitis after dental trauma. b) Radiographic control 2.5 years after root canal treatment with a persistent apical lesion. Treatment of this tooth was not considered successful.

later, usually within less than 1 week, the MTA was covered with a layer of thermoplasticized gutta-percha and the access cavities were sealed with an adhesive composite restoration.

Follow-up controls were performed at individually defined control dates. A uniform time pattern for follow-up controls could not be established. The clinical findings (fistula, sensitivity on percussion, swelling, pain on palpation and tooth mobility) were determined, and corresponding radiographs were taken.

Analysis of the radiographs

All radiographs were taken in the right-angle technique. Assessment of success or failure of treatment was made on the basis of the preoperative and the recall radiographs. Treatment was only considered successful when the radiographic follow-up with the longest recall interval did not show any evidence of apical periodontitis (periapical translucency). Exemplary cases are presented in Figures 1 and 2.

Assessment of the pseudonymised radiographs was performed by two independent endodontists at the University of Göttingen, Germany. The radiographs were only assessed with regard to the presence or absence of a periapical lesion. In cases where assessment of the radiographs did not result in agreement between both assessors, a consensus was reached after joint discussion. Before the start of the study it had been determined that cases without consensus had to be excluded from the study.

Evaluation of data

The number of healed and non-healed cases was determined. The correlation between length of the recall interval and success of treatment was determined using the t-test (PASW Statistics 18.0 [SPSS]), with the level of significance being $P < 0.05$.

Results

Thirty-nine patients were included in the present study; 24 males (62%) and 15 females (38%). The mean age was 10.9 years (± 2.8 years).

Forty-six teeth were included in the evaluation, and follow-up examinations could be performed on 44 teeth (95.6%). Two patients could not be reached for recall. All 44 recalled teeth preoperatively showed a periapical lesion in the radiograph, although this was not an inclusion criterion. At the time of follow-up examination, all patients were free from clinical findings. The mean recall interval was 2.6 years. The longest period was 7.1 years; the shortest period was 0.4 years.

The evaluators showed an inter-examiner agreement of 89.1% when assessing the preoperative radiographs, and 93.2% when assessing the postoperative radiographs. After joint assessment and discussion of the corresponding radiographs, consensus was reached for all cases where the assessment of the radiographs had not shown agreement between both observers.

Table 1 Summary of results for various recall intervals.

	All recalls (n = 44)		Recall > 1 year (n = 40)		Recall > 2 years (n = 26)		Recall > 4 years (n = 8)	
Postoperative radiographic findings	Diseased	Healed	Diseased	Healed	Diseased	Healed	Diseased	Healed
Number (percentage)	12 27.3%	32 72.7%	9 22.5%	31 77.5%	4 15.8%	22 84.6%	1 12.5%	7 87.5%

For 12 teeth (27.3%), the follow-up examination demonstrated radiological findings of apical periodontitis; 72.7% of the treatments were rated successful during the recall period. The mean recall interval for non-successful treatments was 1.9 years; the recall interval for successful treatments was 2.9 years. There was a significant correlation between the result of treatment and the length of the recall interval (t-test, $P = 0.046$).

With four cases, the recall interval was shorter than 1 year. When excluding these cases from the evaluation, this resulted in a total of 40 cases, of which 31 (77.5%) showed a successful outcome. When only considering the cases with a recall interval of at least 2 years, 22 of the remaining 26 cases (84.6%) showed a successful result. When assessing only recall intervals of at least 4 years, 7 out of 8 remaining teeth (87.5%) showed a positive result (Table 1).

No difference was observed between white and grey MTA.

Discussion

The present study used radiographs of patients from a dental practice limited to endodontics, to evaluate the probability of successful treatment of apical periodontitis when using MTA for apical closure of immature teeth of juvenile patients. The identified success rate was 72.7% with a mean recall period of 2.6 years. A significant correlation between the success rate and the length of the recall interval was proven.

Usually, radiographic assessment of apical findings is made on the basis of the PAI index introduced by Ørstavik et al[24]. However, this index is only of limited suitability for assessment of immature dental roots, as the morphology of these dental roots significantly differs from that of mature teeth. Treatment resulting in a reduction of the size of a lesion, but not in complete healing, was considered to be non-successful in the present study. Apical periodontitis which was currently in the stage of healing was rated as being non-successful, thus probably underestimating the frequency of healing cases.

In 2008, a prospective study including 17 non-vital permanent incisors documented a comparable success rate of 76.5%[18]. Success in that study was defined differently from the present study. Both a radiographically visible periodontal ligament space with physiological width and a periapical lesion, but which was reduced in size, were considered a success. In 2007, a retrospective study evaluated the radiographs of 57 cases[19]. However, this study was not limited to teeth with incomplete root growth; the mean age of the patients was 18 years (± 12). Assessment of success of treatment was made both on the basis of the PAI and the size of the apical lesion. Follow-up examination at an interval of 12 months or more could be made with 43 teeth (75.4%). The absolute rate of success (completely healed apical lesions) reported in that study was 65%. The relative success rate including cases with a reduction in the size of the apical lesion, but no complete healing of the apical lesion during the recall period was 95%. In 2008, a success rate of 85% was reported in a retrospective study, including 20 teeth with a mean recall interval of 24.5 months[20]. Only cases without apical findings in the recall radiograph (PAI = 1 or 2) were considered successful. Five percent (n = 1) of the evaluated cases showed radiographic findings of apical periodontitis in the recall and were considered as failures. That study only included anterior teeth and the mean age of the patients was 20.3 years. A higher maturity level of the teeth can be assumed for that age group.

A study published in 2009 showed a success rate of 84%[21]. The evaluation included 56 teeth of adult patients with large-diameter apical for-

Table 2 Survey on the results from studies on root-end closure using MTA or calcium hydroxide.

Authors	Year	Reference	No. of teeth	Observation time	$Ca(OH)_2$		MTA		Comments
					n	Success	n	Success	
El Meliggy and Avery	2006	28	30	3, 6 and 12 months	15	13 (87%)	15	100%	No. of preoperative lesions not reported
Pradhan et al	2006	29	20		10	Not reported	10	Not reported	Time till resolution of lesion and formation of apical barrier shorter for MTA
Sarris et al	2007	18	17	Mean 12.5 months			Clinical	94.1%	
							Radiogr	76.5%	
Simon et al	2007	19	57 recall rate: 56 (72%)	6 and 12 months			Absolute	67%	
							Relative	72%	Incl improvement of PAI
							Healing	81%	
Mente et al	2009	21	78 recall rate	Median 30.9 months			Healed	84%	Including teeth with apical resorption and apical over-enlargement
							Preop lesion	78%	
							No preop lesion	100%	
Present study			46	Mean 2.6 years			Radiogr	72.7%	
			72	Mean 2.6 years			Clinical	72.7%	

amina due to apical resorption or excessive apical enlargement of the root canals. If the teeth did not show clinical symptoms and had a PAI value ≤ 2, treatment was considered successful. A recent publication[22] investigated 98 teeth with open apices in 79 patients which were treated with MTA. Following a mean observation time of 30 months, 54 teeth in 47 patients (55% recall rate) were re-evaluated. A success rate of 90.2% was reported, but only 50% of these teeth demonstrated apical lesions preoperatively; tooth survival was 96.9% with only three teeth lost during the observation period and five teeth requiring further treatment, such as retreatment or apical surgery. Interestingly, the success rate was significantly higher for teeth with trauma-related treatment than for teeth with non-trauma-related treatment (Table 2).

The success rate verified in the present study is within the range of the documented success rates of 65% to 85% as reported from various studies on comparable treatment approaches[18-22]. The length of the recall interval was identified as a decisive variable for the result. The probability of successful treatment was shown to increase as the length of the interval increased, which has also been clearly shown in a large retrospective evaluation[4] on the long-term success of apexification treatment with calcium hydroxide. With 769 cases, it was proven that temporary medication with calcium hydroxide is capable of promoting healing of a periapical lesion within a period of 3 to 54 months (mean value = 24 months) in 95% of the cases. After another recall of 4 years, 92% of the cases showed a stable result. On first view, this result seems to be significantly above the success rates for treatment with MTA. However, 168 (19%) out of the 885 teeth evaluated originally, showed a fracture during the calcium hydroxide therapy and the 4-year recall period. A significant correlation between the risk of fracture and the maturation stage of the corresponding teeth was statistically verified for this therapy method. Never-

theless, it also has been shown that prolonged contact between dentine and MTA also compromises the collagen matrix and weakens the root[25].

When only comparing the success rates of both treatment approaches, none of the two approaches show obvious advantages. In 2012, Bakland and Andreasen[26] in a review came to the conclusion that unrestricted replacement of calcium hydroxide by MTA at present cannot be recommended due to a lack of long-term clinical studies. Meanwhile a number of studies have proven that an apical plug of MTA achieves comparable results with calcium hydroxide apexification. However, the good antibacterial and tissue-dissolving properties of calcium hydroxide should be considered. Temporary use of calcium hydroxide may be particularly beneficial for disinfection of immature root canal systems. The proven disadvantages of apexification treatment with calcium hydroxide, such as a long duration if undergoing treatment with long-term temporary tooth restoration, the high risks of coronal leakage, regrowth of microorganisms, tooth or root fracture particularly for less mature teeth and the high demands on patient compliance can be reduced considerably when using MTA for apical closure. Grey and white MTA have been shown to achieve comparable sealing of immature roots, whereas previous temporary medication using calcium hydroxide resulted in reduced sealing ability for both MTA formulations[27].

Conclusions

The results of the present evaluation support the assumption that treatment of immature permanent teeth represents a reproducible clinical procedure for the apical closure when using MTA. The success rate increases with increasing observation time.

Acknowledgement

The authors deny any conflict of interest related to this study.

References

1. Sundqvist G. Bacteriological studies of necrotic dental pulps. Umeå: Umeå University Odontological Dissertations, No 7, 1976:1–94.
2. Frank AL. Therapy for the divergent pulpless tooth by continued apical formation. J Am Dent Assoc 1966;72: 87–93.
3. Ghose LJ, Baghdady VS, Hikmat YM. Apexification of immature apices of pulpless permanent anterior teeth with calcium hydroxide. J Endod 1987;13:285–290.
4. Cvek M. Prognosis of luxated non-vital maxillary incisors treated with calcium hydroxide and filled with gutta-percha. A retrospective clinical study. Endod Dent Traumatol 1992;8:45–55.
5. Cvek M, Sundström B. Treatment of non-vital permanent incisors with calcium hydroxide. V. Histologic appearance of roentgenologically demonstrable apical closure of immature roots. Odont Revy 1974;25:379–392.
6. Cvek M. Treatment of non-vital permanent incisors with calcium hydroxide. I. Follow up of periapical repair and closure of immature roots. Odontol Revy 1972;23:27–44.
7. Andreasen JO, Farik B, Munksgaard EC. Long-term calcium hydroxide as a root canal dressing may increase risk of root fracture. Dent Traumatol 2002;18:134–137.
8. Grigoratos D, Knowles J, Ng YL, Gulabivala K. Effect of exposing dentine to sodium hypochlorite and calcium hydroxide on its flexural strength and elastic modulus. Int Endod J 2001;34:113–119.
9. Torabinejad M, Chivian N. Clinical applications of mineral trioxide aggregate. J Endod 1999;25:197–205.
10. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod 1995;21:349–353.
11. Torabinejad M, Higa RK, McKendry DJ, Pitt Ford TR. Dye leakage of four root-end filling materials: effects of blood contamination. J Endod 1994;20:159–163.
12. Torabinejad M, Hong CU, Pitt Ford TR, Kettering JD. Cytotoxicity of four root end filling materials. J Endod 1995; 21:489–492.
13. Faraco IM Jr, Holland R. Response of the pulp of dogs to capping with mineral trioxide aggregate or a calcium hydroxide cement. Dent Traumatol 2001;17:163–166.
14. Ilapogu S. The effect of NaOCl, Ca(OH)2, MTA and MTAD on root dentin fracture resistance [Master's thesis]. Loma Linda: Loma Linda University, 2004.
15. Erdem AP, Sepet E. Mineral trioxide aggregate for obturation of maxillary central incisors with necrotic pulp and open apices. Dent Traumatol 2008;24:e38–e41.
16. Giuliani V, Baccetti T, Pace R, Pagavino G. The use of MTA in teeth with necrotic pulps and open apices. Dent Traumatol 2002;18:217–221.
17. Oliveira T, Sakai VT, Silva TC, Santos CF, Abdo RC, Machado MA. Mineral trioxide aggregate as an alternative treatment for intruded permanent teeth with root resorption and incomplete apex formation. Dent Traumatol 2008;24: 565–568.
18. Sarris S, Tahmassebi JF, Duggal MS, Cross IA. A clinical evaluation of mineral trioxide aggregate for root-end closure of non-vital immature permanent incisors in children – a pilot study. Dent Traumatol 2008;24:79–85.
19. Simon S, Rilliard F, Berdal A, Machtou P. The use of mineral trioxide aggregate in one-visit apexification treatment: a prospective study. Int Endod J 2007;40;186–197.
20. Holden DT, Schwartz SA, Kirkpatrick TC, Schindler WS. Clinical outcomes of artificial root-end barriers with mineral trioxide aggregate in teeth with immature apices. J Endod 2008;34:812–817.

21. Mente J, Hage N, Pfefferle T, et al. Mineral trioxide aggregate apical plugs in teeth with open apical foramina: a retrospective analysis of treatment outcome. J Endod 2009;35: 1354–1358.
22. Bücher K, Meier F, Diegritz C, Kaaden C, Hickel R, Kühnisch J. Long-term outcome of MTA apexification in teeth with open apices. Quintessence Int 2016;47:473–482.
23. Bargholz C. Perforation repair with mineral trioxide aggregate: a modified matrix concept. Int Endod J 2005;38:59–69.
24. Ørstavik D, Kerekes K, Eriksen HM. The periapical index: a scoring system for radiographic assessment of apical periodontitis. Endod Dent Traumatol 1986;2:20–34.
25. Leiendecker AP, Qi YP, Sawyer AN, et al. Effects of calcium silicate-based materials on collagen matrix integrity of mineralized dentin. J Endod 2012;38:829–833.
26. Bakland LK, Andreasen JO. Will mineral trioxide aggregate replace calcium hydroxide in treating pulpal and periodontal healing complications subsequent to dental trauma? A review. Dent Traumatol 2012;28:25–32.
27. Stefopoulos S, Tsatsas DV, Kerezoudis NP, Eliades G. Comparative in vitro study of the sealing efficiency of white vs grey ProRoot mineral trioxide aggregate formulas as apical barriers. Dent Traumatol 2008;24:207–213.
28. El-Meligy OA, Avery DR. Comparison of apexification with mineral trioxide aggregate and calcium hydroxide. Pediatr Dent 2006;28:248–253.
29. Pradhan DP, Chawla HS, Gauba K, Goyal A. Comparative evaluation of endodontic management of teeth with unformed apices with mineral trioxide aggregate and calcium hydroxide. J Dent Child 2006;73:79–85.