

Oliver Pontius (ed)



Comprehensive Endodontic Therapy

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Foreword



It is with great pleasure that I responded to the request by Dr. Pontius to write the foreword to this new and groundbreaking textbook.

I met Dr. Pontius after he completed his specialty program in endodontics with Prof. H. Schilder at Boston University, USA. Since then, we have stayed in touch and I have been able to follow his extraordinary journey in clinical endodontics. I can attest to the fact that not only is Dr. Pontius a great clinician with solid expertise in the different areas of his specialty, but also a professional with sound academic knowledge, as accredited by his Diplomate degree from the American Board of Endodontics. He was therefore the right person to undertake the difficult and demanding task of publishing a new endodontic textbook.

I found this book to be a very useful addition to the existing endodontic literature. More than 30 well-known authors and contributors have been selected and have collaborated in this new work. The book is divided into six sections – the science of endodontics, diagnosis, advances in materials and technology, the practice of endodontics, prognosis, and interdisciplinary endodontics – which set the tone and objective of the work. Indeed, thought needs to be given to each step in the decision-making process, supported by in-depth knowledge of the physiopathology and etiology of the different pulp and periapical states, in order to undertake a treatment with predictable and reproducible results. Accordingly, great importance has been afforded to the chapter on diagnosis and decision-making, which allows the reader to benefit greatly from the guidelines given on the differential diagnoses of orofacial

pain. Factors involved in the outcome of root canal treatment are discussed in depth, and particular attention is given to irrigation and disinfection. All aspects of endodontics are covered, including excellent chapters on dental traumatology and root resorption, and attention has been paid to very useful but not sufficiently well-known procedures such as intentional replantation and autotransplantation of teeth. Additionally, and importantly, the latest scientific and clinical advances on vital pulp therapy, regeneration, NiTi instrumentation, and calcium silicate hydraulic cements have been provided in chapters written by the best-recognized experts in their respective fields.

Since endodontics is the cornerstone of dentistry, its relationship with other dental disciplines is discussed in detail. All the chapters in the interdisciplinary section will be particularly useful to dental professionals.

Dr. Pontius should be congratulated for the enormous amount of time spent in the writing, design, and preparation of this work, and all the contributing authors should equally be congratulated for their excellent work.

Anyone interested in predictable endodontics based on up-to-date research and sound clinical data should consider reading this book.



Prof. Pierre Machtou, DDS, MS,
PhD, FICD
Paris City University, France

Dedication

This book is dedicated with profound gratitude and appreciation to my teacher and mentor, Dr. Herbert Schilder, who raised the specialty of endodontics to the highest level and taught us the major elements for successful endodontic therapy: knowledge, skill, and desire.



Preface

This textbook was written to present the wide spectrum of modern thoughts on endodontics and its interdisciplinary role in dentistry, with the aim of sharing the ultimate goal of preserving the patient's natural dentition in a balanced state of form, function, and health.

Many of the chapters have been written by world-leading international authorities in the different fields of endodontics, thus demonstrating exceptional expertise through years of developed mastery, critical thinking, and thoughtful evaluation of the current literature base. The reader is provided with a deeper understanding of endodontics, including the important clinical considerations and technique nuances required for daily practice.

The book highlights the importance of a thorough examination and diagnostic process, leading to ap-

propriate case selection and treatment planning for a successful result and outcome. It further demonstrates the interrelationships of endodontics with other fields in dentistry and medicine, and creates an understanding that the referral of complex and challenging cases is beneficial for both the patient and the referring doctor.

There should be one standard of care: the specialist standard. Providing the best quality of care should be a leading principle of our treatment.



Oliver Pontius,
Dr med dent, DDS, MSD
Bad Homburg, Germany

Acknowledgments

"I have seen that in any great undertaking it is not enough for a man to depend simply on himself."

*Lone Man, Teton Sioux
Native American Wisdom*

In chronological order, I would like to gratefully thank:

- My wife, Neshat, who gave me so much support living abroad for a three-year postgraduate specialty training in endodontics at Boston University, USA, and throughout my professional career.
- Dr. Joachim Schulz-Bongert, who taught me the restorative treatment concept, precision, and leadership.
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- Prof. Dr. Pierre Machtou, for his friendship and tremendous support throughout all phases of this book project.
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- Mr. Christian Haase and Mrs. Anita Hattenbach from Quintessence Publishing for all her support as well as the entire publishing team for their excellent work.

Last but not least, I thank my co-authors, friends and colleagues for their valuable contributions, for all their time and effort, and for sharing their knowledge and expertise. Without their support, this book would never have been realized. And finally, my staff, in supporting me to practice endodontics in a boutique office striving for excellence in patient care.

Authors and Contributors



Francesc Abella Sans, DDS, PhD
Department of Endodontics
Universitat Internacional de
Catalunya, School of Dentistry
Sant Cugat del Valles, Barcelona,
Spain
franabella@uic.es



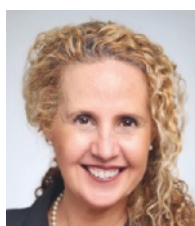
Hacer Aksel, DDS, PhD
Clinical Assistant Professor
Department of Endodontics
University of Illinois Chicago
College of Dentistry
Practice limited to Endodontics,
Chicago, IL, USA
haceraks@uic.edu



Khalid AlHezaimi, BDS, MSc
Former Clinical Professor of
Endodontics, University of
Southern California, Los Angeles,
CA, USA
hezaimik16@gmail.com



Michael Arnold, Dipl-Stom
Office limited to Endodontics and
Operative Dentistry, Dresden,
Germany
info@rootcanal.de



Bettina Basrani, DDS, MSc,
PhD, FRCD(C)
Associate Professor, Director
MSc Endodontic Program
Faculty of Dentistry, University
of Toronto, Toronto, ON, Canada
Bettina.Basrani@dentistry.
utoronto.ca



Elio Berutti, MD, DDS
Professor emeritus
Department of Endodontics
University of Turin, Turin, Italy
elio.berutti@unito.it



João Filipe Brochado Martins,
DMD, MSc
Department of Endodontology
Academic Centre for Dentistry
Amsterdam (ACTA)
University of Amsterdam and
Vrije Universiteit Amsterdam
Amsterdam, The Netherlands
j.f.brochadomartins@acta.nl



Daniel Cabanillas-Balsera,
PhD, DDS
Professor, Conservative
Dentistry and Endodontics
Department of Stomatology
School of Dentistry, University of
Seville, Seville, Spain
dcabanillas@us.es



Josette Camilleri, BChD, FDS
RCPS (Glasg), MPhil, PhD,
FCGDent, FICD, FADM, FIMMM,
FHEA
Clinical Professor of Endodontics
and Applied Materials
University of Birmingham,
Birmingham, UK
J.Camilleri@bham.ac.uk





Arnaldo Castellucci, MD, DDS
Adjunct Assistant Professor of
Endodontics
Henry M Goldman School of
Dental Medicine
Boston University, Boston, MA,
USA
Honorary Diplomate, Indian
Board of Endodontics
Florence, Italy
castellucciarnaldo@gmail.com



Sami Chogle, BDS, DMD, MSD
Herbert Schilder Professor of
Endodontics
Chair, Advanced Specialty
Education Program in
Endodontics
Henry M Goldman School of
Dental Medicine, Boston
University, Boston, MA, USA
schogle@bu.edu



Elisabetta Cotti, DDS, MS
Professor, Conservative
Dentistry and Endodontics
Department of Clinical and
Surgical Endodontics, University
of Cagliari, Cagliari, Italy
Department of Endodontics,
Loma Linda University, Loma
Linda, CA, US
Elisabetta.cotti@unica.it



**Paul MH Dummer, BDS, MScD,
PhD, DDS**
School of Dentistry
College of Biomedical and Life
Sciences
Cardiff University, Cardiff, UK
Dummer@cardiff.ac.uk



**Markus Haapasalo, DDS, PhD,
RCDC(C)**
Fellow of Canadian Academy of
Health Sciences (CAHS)
Professor emeritus, Faculty of
Dentistry
University of British Columbia,
Vancouver, BC, Canada
markush@mail.ubc.ca



**George TJ Huang, DDS, MSD,
DSc**
Professor, Department of
Bioscience Research
Professor and Interim Director of
Graduate Endodontics, College of
Dentistry
Professor (Joint), Department of
Physiology, College of Medicine
The University of Tennessee
Health Science Center
Memphis, TN, USA
ghuang4@uthsc.edu



Kisa Iqbal, DDS
Department of Endodontics
Henry M Goldman School of
Dental Medicine
Boston University, Boston, MA,
USA
iqbalk@bu.edu



Laurence Jordan, PhD, DDS
Professor, Hospital Practitioner
UFR d'Odontologie, Université
Paris Cité
Reference Center for Oral and
Dental Rare Diseases
Hospital Rothschild AHPH
Structural Metallurgy Unit,
IRCP-UMR 8247, Chimie
ParisTech, Paris, France
laurence.jordan@u-paris.fr



Ethan T Kolderman, DDS, MS, MPH
Cariology, Restorative Sciences and Endodontics
University of Michigan School of Dentistry
Ann Arbor, MI, USA
ekolderman@gmail.com



Gabriel Krastl, Dr med dent
Professor, Department of Conservative Dentistry and Periodontology and Center of Dental Traumatology, University Hospital of Würzburg
Würzburg, Germany
gkrastl@gmail.com



Samuel I Kratchman, Dr med dent, DMD
Clinical Associate Professor of Endodontics
University of Pennsylvania, School of Dental Medicine, Philadelphia, PA, USA
sikratch@upenn.edu



Jenifer Martín-González, PhD, DDS
Professor, Conservative Dentistry and Endodontics
Department of Stomatology
School of Dentistry, University of Seville, Seville, Spain
jmartin30@us.es



Maarten Meire, DDS, MSc, PhD
Department of Oral Health Sciences, Section of Endodontology, Ghent University, Ghent, Belgium
EndoPoint – Practice limited to Endodontics, Antwerp, Belgium
Maarten.Meire@Ugent.be



Riccardo Monterubbianesi, DDS, PhD
Department of Clinical Sciences and Stomatology (DISCO)
Università Politecnica delle Marche, Ancona, Italy
r.monterubbianesi@univpm.it



Venkateshbabu Nagendrababu, BDS, MDS, FDS RCPS (Glasg), PhD
Department of Restorative Dentistry
College of Dental Medicine
University of Sharjah, Sharjah, UAE
hivenkateshbabu@yahoo.com



Terrell F Pannkuk, DDS, MSd
Diplomate, American Board of Endodontics, Private Practice, Santa Barbara Endodontics, Santa Barbara, CA, USA
terry@pannkuk.com



Oliver Pontius, Dr med dent, DDS, MSD
Diplomate, American Board of Endodontics
Clinical Assistant Professor of Endodontics
Henry M Goldman School of Dental Medicine
Boston University, Boston, MA, USA
Practice limited to Endodontics, Bad Homburg, Germany
oliver@pontius.de



Angelo Putignano, MD, DDS
Dean of School of Dentistry,
Department of Clinical Sciences
and Stomatology (DISCO)
Università Politecnica delle
Marche, Ancona, Italy
a.putignano@univpm.it



Matthias J Roggendorf, Dr
med dent, DMD, PhD
Associate Professor, Section
Head Endodontics, Policlinic for
Operative Dentistry, Endodontics
and Pediatric Dentistry, Medical
Center for Dentistry, Philipps
University of Marburg and
University Hospital of Giessen
and Marburg, Campus Marburg
Marburg, Germany
matthias.roggendorf@staff.
uni-marburg.de



Ilan Rotstein, BDS, MSc
Clinical Professor of Endodontics
University of Southern California
Los Angeles, CA, USA
ilan@usc.edu



Elia Schirru, DDS, MClintDent,
MEndo RCS
Specialist in Endodontics and
Senior Clinical Teacher
Department of Endodontics,
Centre of Oral Clinical &
Translational Sciences, Faculty of
Dentistry, Oral & Craniofacial
Sciences, Guy's Dental Hospital
King's College London,
London, UK
elia.schirru@kcl.ac.uk



Juan J Segura-Egea, MD, PhD,
DDS
Professor, Conservative
Dentistry and Endodontics
Department of Stomatology
School of Dentistry, University of
Seville, Seville, Spain
segurajj@us.es



Juan J Segura-Sampedro, MBE,
MD, PhD
General and Digestive Surgery
Unit, Hospital Universitario La
Paz
Hospital La Paz Institute for
Health Research (IdiPAZ),
Hospital Universitario La Paz,
Madrid, Spain
segusamjj@hotmail.com



Frank C Setzer, Dr med dent,
DMD, MS
Diplomate, American Board of
Endodontics
Associate Professor
Department of Endodontics
School of Dental Medicine
University of Pennsylvania,
Philadelphia, PA, USA
fsetzer@upenn.edu



Hagay Shemesh, DMD, PhD
Department of Endodontology
Academic Centre for Dentistry
Amsterdam (ACTA)
University of Amsterdam and
Vrije Universiteit Amsterdam,
Amsterdam, The Netherlands
h.shemesh@acta.nl



Ya Shen, DDS, MSc, PhD
Professor, Division of Endodontics,
Department of Oral Biological &
Medical Sciences, Faculty of
Dentistry, University of British
Columbia, Vancouver, BC, Canada
yashen@dentistry.ubc.ca



Jae M Shin, DDS, MS, PhD
Cariology, Restorative Sciences
and Endodontics,
University of Michigan School of
Dentistry, Ann Arbor, MI, USA
jaemshin@umich.edu



Stéphane Simon, DDS, MPhil,
PhD, HDR, MBA
Professor of Endodontics,
Visiting Professor at Genova
University (Italy); Practice limited
to Endodontics, Traumatology
and Surgery, Rouen, France
stephane@endo-academie.fr



Roderick W Tataryn, DDS, MS
Private Practice in Endodontics
Spokane, WA, USA
rod@drtataryn.com



Yoshi Terauchi, DDS, PhD
Private Practice in Tokyo
CT & MicroEndodontic Center
Tokyo, Japan; Tokyo Medical and
Dental University, Department of
Pulp Biology and Endodontics,
Tokyo, Japan; Department of
Endodontics, Faculty of
Dentistry, Bahçeşehir University
İstanbul, Istanbul, Turkey;
Henry M Goldman School of
Dental Medicine, Boston
University, Boston, MA, USA
yoshitsuguterauchi@gmail.com



Vincenzo Tosco, DDS, PhD
Department of Clinical Sciences
and Stomatology (DISCO),
Università Politecnica delle
Marche, Ancona, Italy
v.tosco@univpm.it



Roland Weiger, Dr med dent
Professor, Department of
Periodontology, Endodontology
and Cariology
Center of Dental Traumatology
University Center for Dental
Medicine Basel UZB
University of Basel, Basel,
Switzerland
Roland.weiger@unibas.ch



Garrett W Wingrove, DMD,
FACD, FICD
Department of Endodontics
Henry M Goldman School of
Dental Medicine, Boston
University, Boston, MA, USA
gwingrov@bu.edu



Nicola U Zitzmann, Dr med
dent, PhD
Professor, Chair of Department
of Reconstructive Dentistry
University Center for Dental
Medicine Basel UZB
University of Basel, Basel,
Switzerland
n.zitzmann@unibas.ch

Table of Contents



THE SCIENCE OF ENDODONTICS

- 1** **Keeping the pulp alive with pulp capping and pulp chamber pulpotomy** **3**
Stéphane Simon
- 2** **Endodontic microbiology** **15**
Ethan T Kolderman, Jae M Shin
- 3** **Understanding apical periodontitis** **29**
Juan José Segura-Egea, Daniel Cabanillas-Balsera, Jenifer Martín-González
- 4** **Cell-based and cell-free regenerative endodontics** **41**
George TJ Huang, Hacer Aksel

DIAGNOSIS

- 5** **Endodontic diagnosis** **55**
Oliver Pontius
- 6** **Radiographic detection of apical periodontitis** **89**
Elisabetta Cotti, Elia Schirru
- 7** **Differential diagnosis of orofacial pain** **111**
Garrett W Wingrove, Kisa Iqbal, Sami Chogle, Oliver Pontius

ADVANCES IN MATERIALS AND TECHNOLOGY

- 8** **NiTi instruments in endodontics** **129**
Laurence Jordan
- 9** **Calcium silicate-based hydraulic cements in endodontics** **143**
Josette Camilleri



THE PRACTICE OF ENDODONTICS

- 10 The aseptic field of work 159**
Matthias J Roggendorf
- 11 Endodontic emergencies 173**
Oliver Pontius
- 12 Cleaning and shaping the root canal system 189**
Arnaldo Castellucci
- 13 Irrigation and disinfection of the root canal system 213**
Markus Haapasalo, Bettina Basrani, Ya Shen
- 14 Lasers for cleaning and disinfection of the root canal system 231**
Maarten Meire
- 15 Philosophy of filling roots 247**
Terrell F Pannkuk
- 16 Carrier-based obturation 269**
Elio Berutti
- 17 Endodontic retreatment 285**
Oliver Pontius, Yoshi Terauchi
- 18 Endodontic microsurgery 333**
Frank C Setzer, Samuel I Kratchman
- 19 Intentional replantation 351**
Francesc Abella Sans, Venkateshbabu Nagendrababu, Paul MH Dummer
- 20 Tooth autotransplantation 365**
Francesc Abella Sans, Venkateshbabu Nagendrababu, Paul MH Dummer

21 Traumatic dental injuries of permanent teeth 383

Gabriel Krastl, Roland Weiger

22 Resorption of permanent teeth 399

Gabriel Krastl, Michael Arnold

PROGNOSIS

23 Factors impacting the outcomes of nonsurgical root canal treatments 421

João Filipe Brochado Martins, Hagay Shemesh

INTERDISCIPLINARY ENDODONTICS

24 Maxillary sinus implications in endodontics 433

Roderick W Tataryn

25 Endodontic-periodontal interaction 447

Ilan Rotstein, Khalid AlHezaimi

26 The endo-restorative interphase 465

Angelo Putignano, Riccardo Monterubbianesi, Vincenzo Tosco

27 Endodontics or implants? 483

Nicola U Zitzmann

28 Endodontic medicine 501

Juan J Segura-Egea, Daniel Cabanillas-Balsera, Juan J Segura-Sampedro,
Jenifer Martín-González

THE SCIENCE OF ENDODONTICS





Chapter 1

Keeping the pulp alive with pulp capping and pulp chamber pulpotomy

Stéphane Simon

1.1 Introduction

The dentin–pulp complex is now known to be capable of self-repair, including regenerating mineralized tissue. This regenerative ability is the basis of minimally invasive endodontic treatment approaches aimed at protecting the vital pulp, provoking reactionary dentinogenesis, and stimulating revascularization of a damaged root canal.¹ However, development of these novel treatments still faces significant challenges, chief among them being the highly specialized composition of the dental pulp, its enclosure in a mineralized shell, and its limited blood supply.

The primary aim of pulp capping is to protect the underlying pulp tissue from external stresses, especially bacteria, meaning that the quality of the filling and its seal are critical. This became clear in the 1990s, when, at first, direct pulp caps with adhesive seemed to deliver good results.² However, over longer time frames (as little as a few months), loss of integrity of the seal and subsequent infiltration by bacteria led to acute inflammatory responses or to low-level pulpal necrosis.³ For example, for many years, calcium hydroxide was used as a pulp-capping material, either undiluted or combined with resins.⁴

One of the best-known products of this type is Dycal (Dentsply Sirona, Bensheim, Germany). Though applying calcium hydroxide directly to the

pulp produces a mineral barrier, the barrier is neither uniform nor bonded to the dentin wall, so the seal is not permanent⁵ (Fig 1-1). Moreover, Dycal and similar calcium hydroxide products tend to dissolve over time, so that even after a matter of months, the clinical situation may be no better than if treatment without capping material had been performed.

These disappointing outcomes necessitated a paradigm shift in which complete closure of the wound with a long-term seal was viewed as being essential. To achieve this, biocompatible materials with bioactive properties were developed with the explicit goal of inducing dentin-bridge formation.

An ideal capping material has the following three properties:⁶

1. It creates an impervious seal of the dental cavity that protects the pulp in the first few weeks before the dentin bridge, a mineralized barrier, is formed in situ.
2. It triggers the biologic responses necessary for forming the dentin bridge between the pulp and the capping material itself.
3. It meets all safety and biocompatibility criteria.

Pulp exposure leads to damage of the odontoblast layer. Because these cells are the only dentin-producing cells, it is necessary to induce the growth of neo-odontoblasts to generate a mineralized barrier.

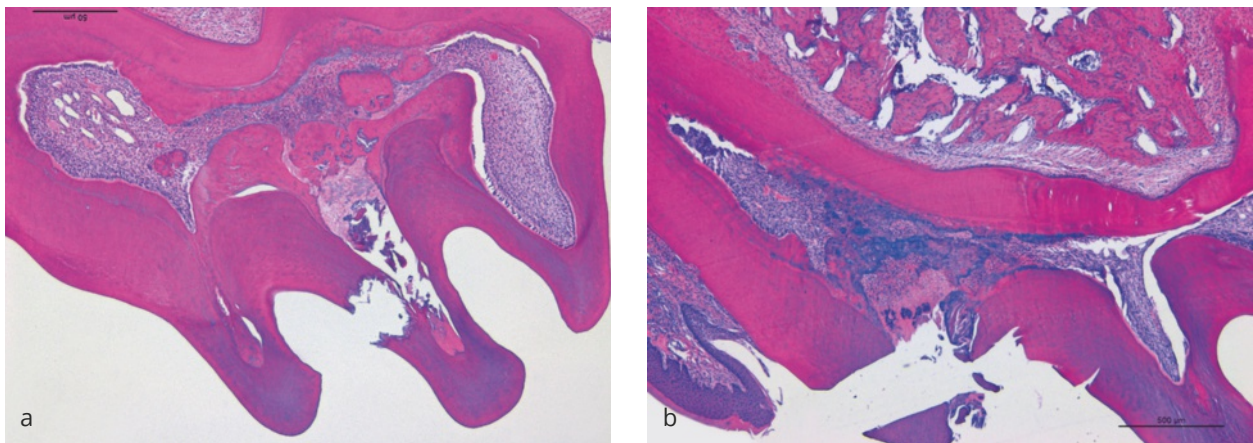


Fig 1-1a and b The pulp healing process and bridge formation depends on the type of material used for direct pulp capping. Maxillary first molars in mice treated by pulp exposure after drilling with a sterile bur. Histologic slice stained with Hematoxylin and eosin – 7 μ m. 7 days posttreatment, capping with Dycal. The mineralized bridge is not regular but made of globular mineralized tissue (a). 7 days posttreatment, capping with pure Hydrogel. The high level of inflammation is the proof of inefficiency of this material for pulp capping (b).

Since these highly differentiated cells are post-mitotic (that is, no longer proliferative), the healing process also involves regenerative processes.⁷

In a reparative process, progenitor cells are recruited to the wound site by chemotaxis.⁸ Upon contact with an appropriate tissue matrix, these cells differentiate into dentin-secreting cells and become activated. Thus, an ideal biomaterial should enable chemotaxis, stimulation of differentiation, and activation of dentin synthesis, as stipulated in the second-listed property above.

Dentin is a partially mineralized tissue whose organic phase consists of a matrix of collagen I enriched with non-collagen matrix proteins.⁹ These proteins are initially secreted by the odontoblasts and then “fossilized” during the mineralization process. The matrix proteins include a large number of growth factors such as transforming growth factor beta (TGF- β), vascular endothelial growth factor (VEGF), and adrenomedullin (ADM). Any biologic (cariou) or therapeutic (etching) process that demineralizes dentin will release these growth factors from the matrix.¹⁰ While most of the released growth factors will likely disappear into the saliva, some will diffuse through the dentinal tubules and reach the dental pulp to exert an effect.

Another way to stimulate the release of growth factors from dentin is to use a biomaterial that triggers partial, but fairly controlled, demineralization when in contact with dentin. Dentin matrix proteins can be released from dentin by exposure of the dentin to calcium hydroxide,¹¹ mineral trioxide aggregate (MTA)¹² or any etching substance used during bonding.¹³ Dentin matrix proteins boost chemotaxis, angiogenesis,¹⁸ and differentiation of progenitor cells into dentinogenic cells.¹⁴ Unfortunately, currently there are no viable therapeutic options that can make use of the properties of these proteins.

Odontoblasts are best known for their role in producing dentin, secreting it, and mineralizing it during primary and secondary dentinogenesis.¹⁵ When a caries lesion occurs, quiescent odontoblasts can be reactivated to synthesize tertiary dentin, known as reactionary dentin (reviewed in Simon et al¹⁰).

While the secretion activity of odontoblasts is their best understood function, these cells have two other special roles:

1. They act as sentinels, mediated by the toll-like receptors (TLRs) on their plasma membranes, which recognize bacteria toxins and signal their presence to the underlying connective tissue.¹⁶
2. They have the capability of mechanosensation owing to the presence of cilia on their cell surface.¹⁷

Thus, odontoblasts act as a protective barrier for the pulp by detecting and fending off aggressors, and producing a signal to call in resident immune cells. In other words, odontoblasts can sense and transmit information about the environment to the underlying tissue. Odontoblasts are also especially sensitive to growth factors and other biostimulators.

1.2 Pulp inflammation and healing

Pulp inflammation, or pulpitis, is associated with pain caused by damaged or necrotic pulp tissue. In dentistry, inflammation has a strong negative connotation. Pain relief requires removal of the inflamed tissue by using a surgical procedure that is often quite invasive. The invasiveness is necessary to determine the extent of the disease, which can be difficult to assess; consequently, most cases end in a complete pulpectomy and root canal treatment. However, acute inflammation is also a normal physiologic process with beneficial effects. Inflammation is a step toward tissue healing, by helping to rid the wound of bacteria and by eliciting the secretion of a variety of substances (cytokines) that aid in healing and regeneration.¹⁸

Endodontists refer to pulpal inflammation as being either “reversible” or “irreversible.” Reversible inflammation refers to an inflammatory process that is controlled well enough so that it can be halted and then redirected to aid in healing. In contrast, irreversible inflammation is too advanced to be controlled. But this term is defined by relatively basic diagnostic elements (for instance, type of pain, persistence), which are poorly related to the actual his-

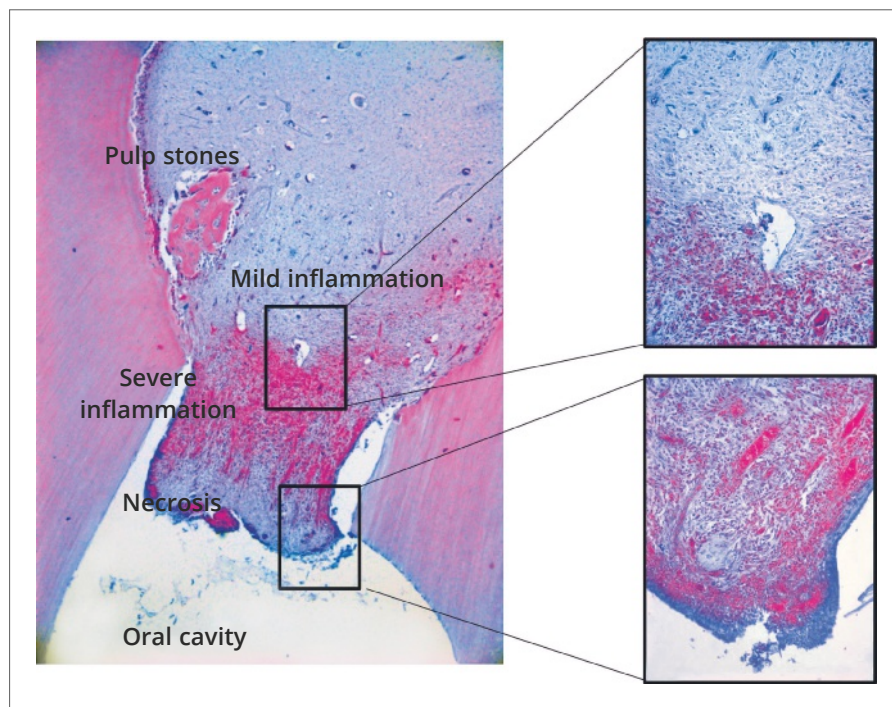


Fig 1-2 Maxillary first molar of a minipig, drilled up to the pulp exposure. The pulp is then left exposed to the oral cavity for 7 days. The histology shows that even if the pulp is exposed to an aggressive environment, the inflammation defense remains a progressive process. The closer the tissue is to the aggression, the more the disease is deleterious. On the same tissue, four levels of pulp defense are present – mineralization like pulp stones (soft aggression), light inflammation, severe inflammation, and a necrosis layer.

to- or physiopathologic status of the tissue. This lack of correlation has been known for years¹⁹ and has been confirmed multiple times.²⁰ Some studies have investigated markers of pulp inflammation and their potential use in diagnosis or treatment (see Zanini et al²¹); however, their clinical application awaits robust investigation.

Without more biologic indicators, practitioners must make a pulpal diagnosis with what is available now: namely, the patient's tooth anamnesis to define the level of pain, and thermal and electrical tests, whose reliability is still suboptimal. Further clues can be obtained by observation such as the amount of hemostasis needed at the time of pulp exposure, and/or partial pulpectomy, which can be used as a crude clinical marker, since inflammation is associated with hypervascularization and, therefore, potential bleeding. However, the same bleeding may arise when vascular tissue is cut. To distinguish the two possibilities, the lesion can be packed with a damp cotton pellet and pressure applied for 1 to 2 min. This is enough time to achieve hemostasis under physiologic conditions. But if bleeding persists, it may be assumed that some of the pulp is still inflamed, and partial removal is necessary until healthy tissue is exposed.

Because of inter-patient and inter-practitioner variability, these markers are not sufficiently reliable to be able to generalize about the status of inflamed pulp tissue. In other words, the methods for identifying the presence of inflamed tissue in exposed pulp are both arbitrary and inadequate. Despite the binary choice of inflammation status (reversible or irreversible), histologic observations reveal a far more complex histopathology, with areas of necrosis, irreversible inflammation, and reversible inflammation present in different layers of the same dentin-pulp complex (Fig 1-2). Therefore, further research is necessary to identify specific biologic or clinical markers as accurate diagnostic tools and to improve long-term outcomes. This is key because controlling inflammation remains critical for the success of pulp-capping therapies.

1.3 Pulp disease classification

The topic of pulp disease classification has always been controversial. The main reason for the ongoing discussion is the lack of relationship between biologic status and clinical signs. Clinically, only the pain reported by the patient and a few rudimentary

Table 1-1 Classifications for pulp inflammation.

Baume classification	AAE classification	Wolters et al ²²
B1	Normal pulp	Normal pulp
B2	Reversible pulpitis	Initial pulpitis
		Mild pulpitis
	Asymptomatic irreversible pulpitis	Moderate pulpitis
B3	Irreversible pulpitis with pain	Severe pulpitis
B4	Pulp necrosis	

tests are available to assess the inflammatory status of the pulp.

It is well known that the clinical symptoms do not allow the clinician to conclude on the pulp inflammation status. Nevertheless, symptoms remain the more accurate and reliable factor informing a clinical decision for treatment.

The most used classification for arriving at a conclusion about pulp health was the Baume one in the 1980s, where Baume classified pulp health into four groups – B1, B2, B3, and B4. This classification was used for many years, mainly in Europe, but has now been abandoned.

The American Association of Endodontists classification remains the easier to use in clinics and is very useful for deciding about treatment. The pulp status is divided into four groups with the recommended treatment:

- Normal and healthy pulp → no treatment needed.
- Reversible pulpitis → pulp vitality preservation.
- Irreversible pulpitis → pulpectomy and root canal treatment (or pulp chamber pulpotomy).
- Pulp necrosis → root canal treatment.

Even if this classification is clear and easy to understand, every clinician knows that the dividing line between reversible and irreversible pulpitis is not so evident. That is why decision making for pulp capping versus root canal treatment is not immediately evident.

Some authors proposed a revised classification of pulp status as follows:²²

- initial pulpitis;
- mild pulpitis;
- moderate pulpitis; and
- severe pulpitis.

This classification is definitely more relevant in terms of inflammatory pulp disease evaluation and could be a true help for making the decision between pulp vitality preservation, pulp chamber pulpotomy or root canal treatment. Unfortunately, it remains clinically unusable as, to date, there is no diagnostic tool specific enough to allow the clinician to categorize the inflammation status into the four groups.

While no new diagnostic tools are available, the AAE classification remains the only one to be used in everyday practice (Table 1-1).



Fig 1-3 The MAP System is a dedicated material carrier for precise placement of capping material (among many other indicated uses such as apexification, retrofilling, perforation filling, etc).

1.4 Pulp capping and biomaterials

MTA, first marketed under the brand name ProRoot MTA (Dentsply Sirona), has become the material of choice for pulp capping.⁵ MTA is a fine powder formulated from medical Portland cement. Its main constituent is tricalcium oxy silicate [$\text{Ca}_3\text{O}(\text{SiO}_4)$] combined with the radiopaque substance bismuth oxide. For application, MTA powder is mixed with water immediately prior to use, placed on a glass tray, and applied directly to the pulp using a dedicated instrument, for instance, MAP System (PDSA, Vevey, Switzerland) (Fig 1-3). The MTA is placed into direct contact with the pulp and lightly tapped into the dentin wall – not packed – using a cotton pellet or piece of thick paper. MTA takes over 4 hours to set; thus, it is necessary to avoid spraying water to rinse the cavity, which would wash away the material that has just been applied. If the restoration protocol requires spraying with water, it is recommended that this step be carried out before applying the MTA.

The advantages of MTA as a biocompatible material have been demonstrated in both *in vitro* and *in*

vivo studies as well as in head-to-head clinical trials versus other materials.²³ For example, the histologic quality of the dentin bridges formed using MTA is superior to that produced with calcium hydroxide.

Disadvantages of MTA are that it is difficult to manipulate, and the presence of bismuth oxide may cause dyschromia of the tooth. Manufacturers of similar dental materials (hydraulic cements) have tried to limit dyschromic effects produced by their products by replacing bismuth oxide with zirconium oxide. Another evolution of this material has been to add calcium chloride (CaCl_2) into the water to decrease the setting time from 4 hours to 10 minutes.

Despite these modifications, MTA remains difficult to manipulate. A new version of MTA ready to be used is now available (NeoPUTTY; NuSmile, Avalon, Houston, TX, USA) (Fig 1-4).

A pure tricalcium silicate-based material (Biodentine; Septodont, Saint-Maur-des-Fossés, France) – initially developed as a dentin substitute for coronal fillings – may also have potential in pulp capping.²⁴ Among Biodentine's noteworthy effects is its ability to stimulate mineralization²⁵ and cellular differentiation. The usefulness of its applicability to pulp capping awaits clinical evaluation. In addition to their sealing ability (to protect the pulp) and their biologic activity (inflammation control), capping materials also elicit the release of matrix proteins – including growth factors and anti-inflammatory molecules – from the dentin upon contact. This effect has been demonstrated for both calcium hydroxide¹¹ and MTA.¹²

Investigating the application of these materials to include the adjacent dentin walls – in cases where preparation of the cavity has made the dentin thinner – may be of value. In principle, the extracted matrix proteins could travel via the dentinal tubules (which are quite large at this depth) and help to heal the pulp.²⁶ This is where Biodentine may have real potential, as it may be used to fill an entire coronal cavity, unlike MTA. However, due to the mechanical behavior of Biodentine, it needs to be coated with a bonded composite to make the restoration more esthetically pleasing and to prevent the substitution material from dissolving.



Fig 1-4a to c Mineral trioxide aggregate (MTA) new generation (Zarc; Avalon). The radio opacifier is zirconium oxide, which avoids any stain of the treated tooth. The powder is mixed with a gel instead of pure water, enriched with calcium chloride. Thanks to the gel, the manipulation of the mixed material makes it easy to use and place very precisely up to the exposed pulp. NeoMTA 2 (Zarc) to be mixed (powder + gel) (**a and b**). NeoPUTTY (Zarc) ready to be used (**c**).

1.5 Step-by-step procedures for pulp capping and pulpotomy

1.5.1 Pulp capping

The objective is to cap the exposed pulp with appropriate biocompatible material. The following steps can be used in most clinical situations (Figs 1-5 and 1-6):

1. Anesthetize the tooth. Use of a vasoconstrictor is possible, but must be considered in light of later treatment steps (particularly bleeding control; see Steps 6 and 7).
2. Place the rubber dam and disinfect the tooth area.
3. Remove the caries lesions and clean the cavity with an excavator and ceramic burs under cooling water. Remove the whole carious tissue before exposing the dental pulp.
4. Create a deep cavity to expose the pulp.
5. Control the bleeding by placing a cotton pellet (moistened with sterile water) into the cavity, and apply gentle pressure.
6. Remove the cotton pellet and check for hemostasis. Do not use any other means to stop the

bleeding (ferric sulphate, laser, and so on). This is important, because control of the hemorrhage is currently the only reliable way to evaluate the inflammation status of the pulp. If the pulp is not inflamed, bleeding caused by the wound can be stopped with gentle compression.

7. If the bleeding cannot be controlled (Step 6), then the exposed pulp must be removed. Use a sterile round bur (tungsten carbide) under copious water to perform a partial pulpotomy. Then, repeat Step 6 to try to control the bleeding. Here, bleeding control is necessary, but bear in mind it is a poor clinical marker. Moreover, the use of a vasoconstrictor for anesthesia may be contraindicated, because a vasoconstrictor may result in good control of bleeding even when the pulp is inflamed.
8. The exposed pulp can be inflamed but not infected. Disinfect with a 2% chlorhexidine solution left in the cavity for 2 to 3 minutes. Disinfection using an Er:YAG laser may also be considered. Sodium hypochlorite is also an option; such a disinfection has been demonstrated to improve the long-term success rate of pulp capping.
9. Place the capping material directly in contact with the pulp by using a dedicated device (for

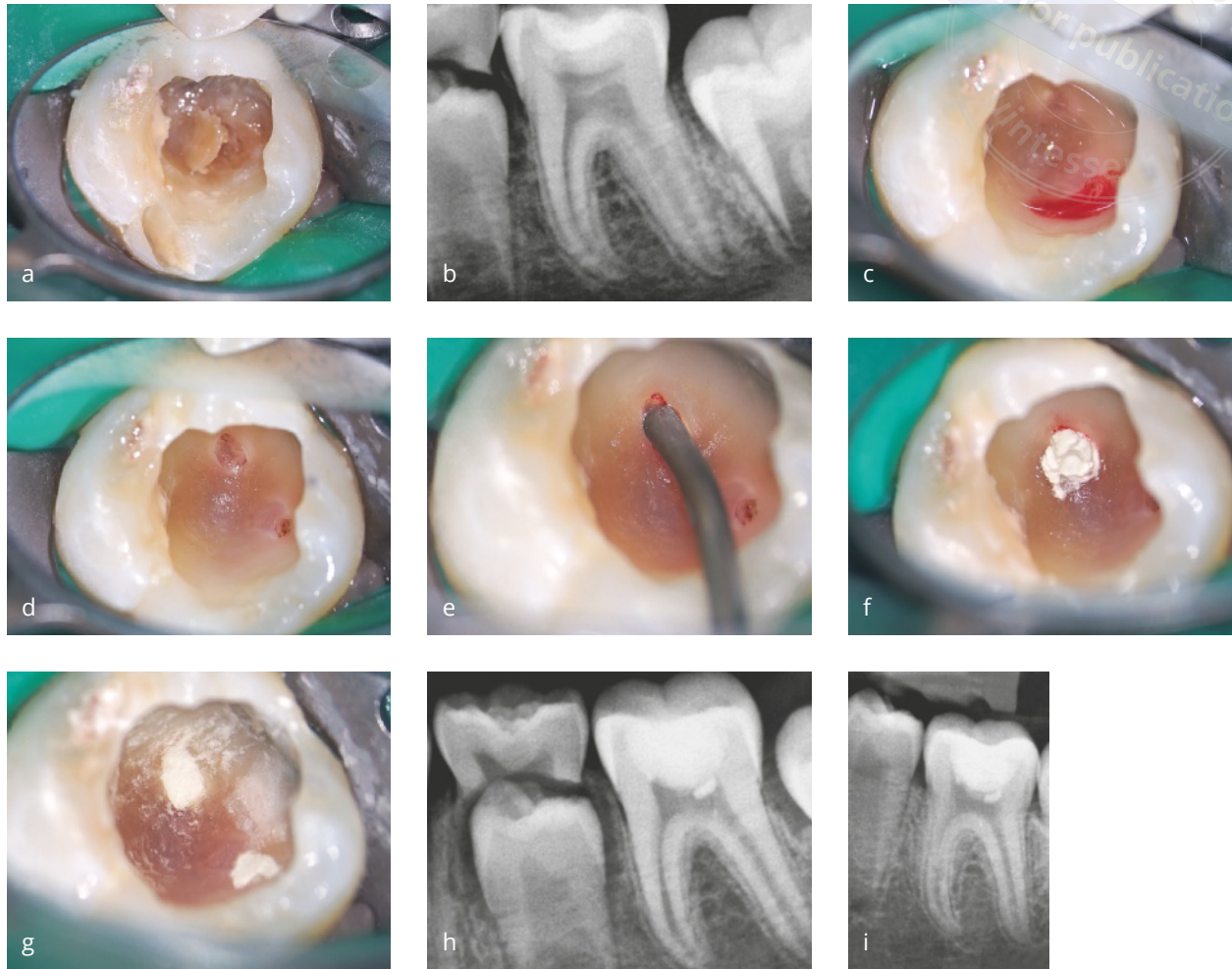


Fig 1-5a to i Step-by-step pulp capping procedure on a mandibular molar of a 12-year-old boy. The patient complained of manageable pain. It was decided to keep the pulp alive and complete a pulp capping. Clinical view before treatment (a). Preoperative radiograph (b). After complete removal of the infected dentin, the cavity is cleaned and disinfected with 2% sodium hypochlorite (c). The clinical view shows two sites of pulp exposure (d). The hemostasis is obtained with gentle compression with a cotton pellet for less than 2 minutes (e). The MAP System is used to place the capping material (f) in direct contact with the pulp tissue. The pulp capping is complete, and the cavity restored with bonded composite resin (g). Postoperative control (h). 14-month postoperative recall – the pulp is still responsive to a cold test (i).

- instance, MAP One; PDSA, Vevey, Switzerland) but do not plug it.
10. Fill the cavity with the same material, for instance, Biodentine. If the pulp is capped with MTA, the bonded restoration can be performed during the same session.
11. Take a postoperative radiograph and check the occlusion.
12. Follow the patient for 1 month, again at 6 to 12 months, and again at 4 years. Check the pulp sensitivity with a cold test; a recall radiograph is also recommended.



Fig 1-6a to h Pulp capping on the maxillary incisors of a 19-year-old patient after a dental trauma. The patient was treated less than 6 hours after coronal fracture. Preoperative radiograph (a). Clinical view (b). After cleaning the pulp wound, the MTA (ProRoot MTA) is gently placed on the pulp tissue (c). Post capping control (d). Coronal fragments are bonded and fixed to the radicular part with a flowable composite resin (e). 9-year recall postoperative radiograph (f). Because the ProRoot MTA is charged with bismuth oxide as a radiopacifier, the tooth staining remains a problem (g). The discoloration is fixed with a polish of the tooth and a minimally invasive restoration with flowable bonded composite resin (h). The tooth still responds normally to cold and an electric pulp test.

1.5.2 Pulp chamber pulpotomy

Pulp chamber pulpotomy is indicated when bleeding control of the exposed pulp site is not possible or when the inflammation status of the pulp is in doubt. In such cases, it is probably safer to perform a deep pulpotomy (Figs 1-7 and 1-8).

Follow Steps 1 to 6 of the pulp-capping procedure above (Section 1.5.1) and then:

1. Use a carbide bur with a low-speed handpiece and copious water cooling to remove the whole coronal pulp from the pulp chamber.
2. Cut the pulp with a sharp and sterile excavator at the entrance of the root canal.

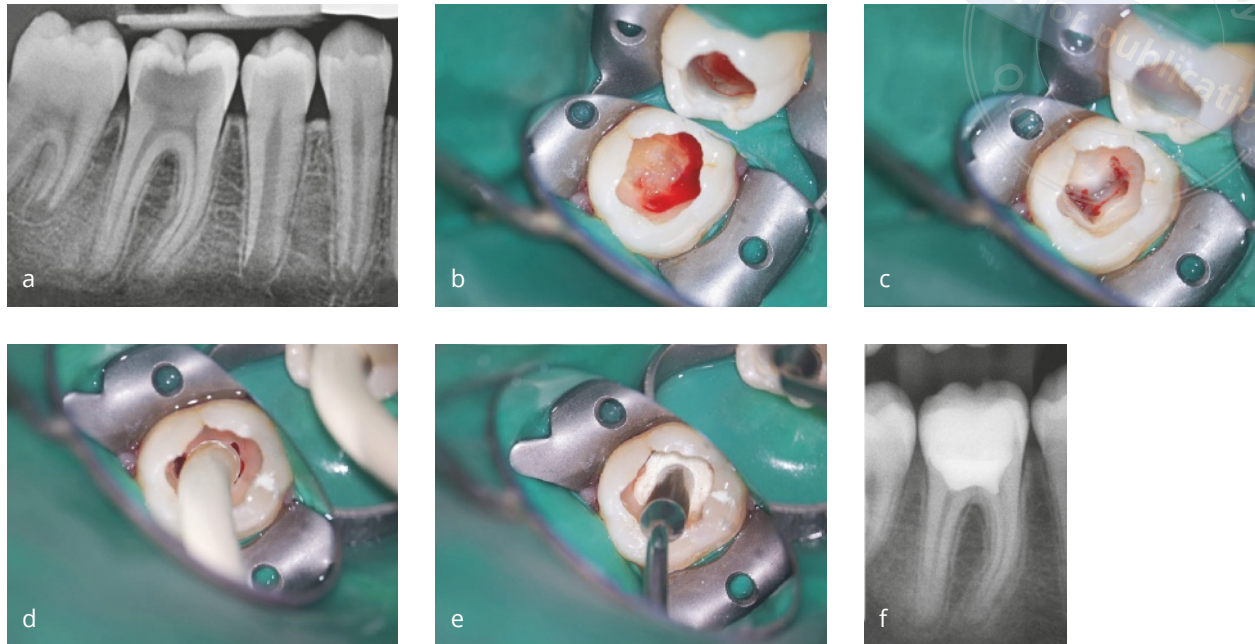


Fig 1-7a to f Treatment of a mandibular molar of a 25-year-old patient with pulp chamber pulpotomy. The patient complained of redundant pain. Pulp capping is contraindicated and it is decided to treat the tooth with pulp chamber pulpotomy. Preoperative radiograph (a). Clinical view showing uncontrollable hemostasis (b). The whole pulp tissue of the pulp chamber is removed (c). After cleaning the cavity with sodium hypochlorite, MTA Aggregate (NeoMTA 2) is placed into the cavity with an amalgam carrier (d and e). Postoperative radiograph after completion of treatment (f).

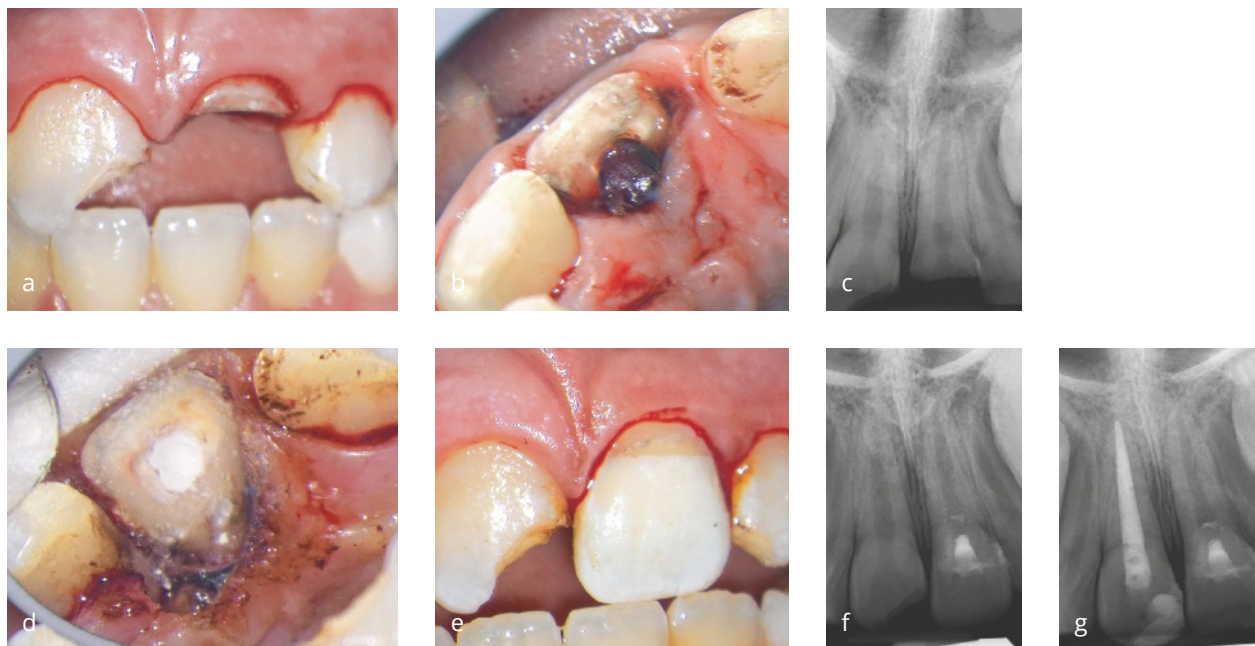


Fig 1-8a to g Treatment by pulpotomy of a maxillary central incisor of a 14-year-old teenager after severe dental trauma. Preoperative clinical views (a and b). Preoperative radiograph (c). The tooth fracture was very deep, and a gingivectomy was performed with an Er:YAG laser (d). The pulp was capped with NeoMTA 2 and the tooth was restored by bonding the missing part of the crown (e). Postoperative radiograph (f). At the 18-month recall, the tooth still responded normally to electric and cold tests (g). Because the right incisor was not treated properly on time, pulp necrosis occurred a few months later. The root canal treatment was then completed.

3. Control the bleeding by applying gentle pressure with a moist cotton pellet.
4. Cap the root canal pulp stump with capping material (as described in Section 1.5.1, Step 9).
5. Fill the rest of the coronal cavity with the same material (for instance, Biodentine) or with a bonded composite resin.
6. Take a postoperative radiograph and check the occlusion.

Recall the patient for short- and long-term follow-ups. Note that in the case of a pulp chamber pulpotomy, sensitivity tests are not reliable.

1.6 Pulp capping and bioproducts to stimulate regeneration

The extracellular matrix (ECM) of dentin contains a variety of molecules involved in regulating dentinogenesis. Several ECM proteins (expressed in recombinant bacteria) have been studied for their capacity to stimulate pulp regeneration.²⁷ For example, dentonin, a synthetic peptide derived from matrix extracellular phosphoglycoprotein (MEPE), and A+4 and A-4, two splice products of the amelogenin gene, each induced regeneration of a superficial pulp.²⁸ Such studies are helping to elucidate the biologic events that occur during pulp capping and regeneration. However, further investigations are necessary to confirm any advantages, as well as the safety, of such bioproducts versus mineral hydraulic cements.

1.7 Short- and long-term future developments

Recent developments in biomaterials for capping have helped to stimulate interest in approaches to preserve pulp vitality. As our understanding of pulp biology continues to improve, the reasons behind certain treatment failures are being clarified, and often they are related to the state of inflammation of the pulp. Clinically, it remains difficult to know exactly how much pulp tissue deep within the chamber needs to be

removed to eliminate the risk of leaving behind any inflamed tissue. Thus, taking additional pulp, short of a complete pulpectomy, may be the best way to ensure that all the inflamed tissue has been eliminated.

Until recently, this treatment option was limited to primary teeth or certain immature teeth. However, going forward, pulp chamber pulpotomies might become an endodontic therapeutic alternative to pulpectomies and root canal treatment. In pulpotomies, the entire tissue of the pulp chamber is removed, and the radicular stumps are topped with a capping material (Fig 1-5). Several studies have shown promising results,^{29–33} but these must be bolstered by formal studies of efficacy and safety.

1.8 Conclusions

Eliminating bacterial infection of the tooth pulp is the central challenge in endodontic healing and regeneration. Pulp capping and pulp chamber pulpotomy effectively prevent bacterial penetration and colonization by simply placing a biocompatible barrier material in direct contact with the pulp connective tissue. This material seals off the wound in a matter of minutes or hours and creates a double protective layer over the pulp tissue. Thus, partial- and full-chamber pulpotomies, followed by pulp capping, must be considered as minimally invasive endodontic treatments. Furthermore, new methods for coronal restoration with bonded composite resins, or bonded prosthetic restorations, will lessen the need for root canal procedures as a treatment option, at least for restorative reasons.

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Chapter 12

Cleaning and shaping the root canal system

Arnaldo Castellucci

12.1 Introduction

The need for some manner of root canal preparation prior to root canal filling has long been recognized as an essential step in endodontic treatment. Concepts concerning the role and purpose of this canal preparation, however, have differed remarkably at different times in the development of endodontics and in the hands of different practitioners and teachers.

Initially, root canals were manipulated primarily to allow placement of intracanal medicaments, with little attempt made to completely remove the organic contents of the root canal system. In time, the concept of modifying root canal preparations to facilitate the placement of root canal filling became part of accepted endodontic practice. However, the methods employed for these procedures remained, for the most part, unrelated both to the true anatomy of root canal systems and to the physical nature of the materials with which the root canals were presumed to be filled. For many decades, the concepts for root canal preparation remained empirical, and essentially ignored the physical and biologic requirements for endodontic success.

Over the years, canal preparation has been described by a variety of names, including “enlargement,” “mechanical preparation,” and “instrumentation.” These descriptions are not precise, because the root canals are not simply “enlarged” or “instrumented;” nor is the goal of “preparation” to reproduce in the canal the shape of the instrument being used. In modern endodontics, which emphasizes the related biologic and anatomical problems, “cleaning” and “shaping” are more correct terms.¹

Schilder introduced these terms to the endodontic vocabulary in 1974. Since then, they have been universally used to indicate the principal goals of canal preparation.

To achieve predictable success in endodontic practice, root canal systems must be cleaned and shaped, cleaned of their organic remnants, and shaped to receive a three-dimensional hermetic filling of the entire root canal space. When “preparing” a root canal system, it is, in fact, cleaned of all inor-

ganic debris, organic substrates, and microorganisms, and it is shaped to facilitate the placement of a permanent three-dimensional filling. The two procedures of cleaning and shaping are intimately related, both conceptually and mechanically—temporally. When one of the two is performed well, the other will also be correctly performed: shaping facilitates cleaning!

In preparing the root canals, one must ensure that no trace of organic or inorganic material, which could contribute to the growth of bacteria or generate products of tissue decomposition, is left in the root canal system, and that any microorganisms that might be present are removed or destroyed. At the same time, one must plan and prepare within each root canal the cavity form or shape that is appropriate for the simplest and most effective three-dimensional obturation:¹ shaping facilitates obturation! If the root canal is shaped well, every clinician could compact the gutta-percha in root canals in three dimensions.²

It is important to appreciate that files produce shape, but it is essential to understand that irrigants clean a root canal system.

Since shaping facilitates cleaning and cleaning is completed after a complete shaping is achieved – shaping allows a deeper and more apical penetration of the irrigating solutions, and a deeper and more complete dissolution of the existing organic material – today it is preferred to speak in terms of “shaping” first and “cleaning” later. Furthermore, taking into consideration the results obtained with the new rotary nickel titanium (NiTi) instruments, which allow the clinician to ideally shape relatively easy root canals sometimes in just a few minutes, while the cleaning of the same system needs much more time, today it is considered more appropriate to speak in terms of “shaping and cleaning,” since in chronological order the root canal system is first shaped and then later becomes adequately cleaned, if irrigation protocols are followed. Nevertheless, for practical reasons, in this chapter we will keep the old sequence, describing the cleaning principles first and the shaping objectives later.

A controversial issue in endodontics is: Is it possible to thoroughly clean the root canal system? Some dentists think it is impossible, and in order to be as close as possible to the ideal result, it is necessary to enlarge the root canal with large-size instruments, as a deeper cleaning is only obtainable with more enlargement. Many dentists, on the other hand, correctly believe that it is possible to clean into all aspects of the root canal anatomy.³ This is obviously not just with files, which can only take care of the negotiable part, but mainly with irrigants, which can take care of the unnegotiable and inaccessible aspects of the root canal system: isthmus, resorptions, lateral canals, bifidities, fins, and so on. As already stated, one concept must be clear: files shape and irrigants clean, and this is demonstrated by many accredited studies.^{3,4} Now, the question is: How do we know when a root canal is totally cleaned? The answer is: When the apical foramen has been enlarged to a minimum size of 0.25 and the taper developed is between 0.05 and 0.06.⁵ Numerous studies have demonstrated that there is no need to develop a bigger taper⁶ or to over-enlarge the root canal.^{7,8} It is well established that, being “minimally invasive,” we can obtain the same results and at the same time save a lot of tooth structure.

The old axiom that what comes out is as important as what goes into the canal is not intended to minimize the importance of three-dimensional obturation of the root canal system and, on the other hand, it is true that complete root canal filling cannot be achieved unless the canals have been properly cleaned and prepared to receive the filling material.

12.2 Cleaning

The purpose of cleaning is to remove all intracanal material, whether of pulpal origin, vital or necrotic, or microorganisms, from the root canal system.

12.2.1 The removal of vital pulp tissue

In sufficiently wide and straight canals, broaches are recommended to withdraw the pulp tissue all in one piece. Broaches are very delicate instruments that fracture very easily. They are designed only to hook

and twist the pulp filament around itself in order to extract the pulp from the root canal. Used properly and safely, the instruments should never come into contact with the canal walls; therefore, they should never be used in narrow or calcified canals or around canal curvature.

Today, the removal of vital pulp tissue is enormously facilitated by the use of NiTi instruments, like PathFile or ProGlider (Dentsply Sirona, Bensheim, Germany; Fig 12-1).⁹ It is almost an everyday experience in treating vital cases that the pulp is entirely removed with the first or second rotary file.

12.2.2 The removal of necrotic pulp tissue and microorganisms

Pulp tissue that is necrotic or in an advanced state of degeneration cannot be removed with a broach. This is obviously even truer where microorganisms are concerned.

The removal of this material is achieved by using irrigating solutions and the mechanical action of the endodontic instruments.

Irrigating solutions

The root canal instruments must never be used in dry canals, but should always be completely immersed in irrigating solutions that completely fill the root canal and the pulp chamber.

Irrigating solutions for endodontic use must meet precise requirements. They must:

- be able to digest proteins and dissolve necrotic tissue;
- have a low surface tension to reach the apical delta and all the areas that cannot be reached by the instruments;
- have germicidal and antibacterial properties;
- be non-toxic and non-irritating to the periapical tissues;
- keep the dentinal debris in suspension;
- lubricate the canal instruments;
- prevent discoloration of the tooth – indeed, they should bleach the tooth;
- be relatively harmless to the patient and dentist;
- be readily available and inexpensive.

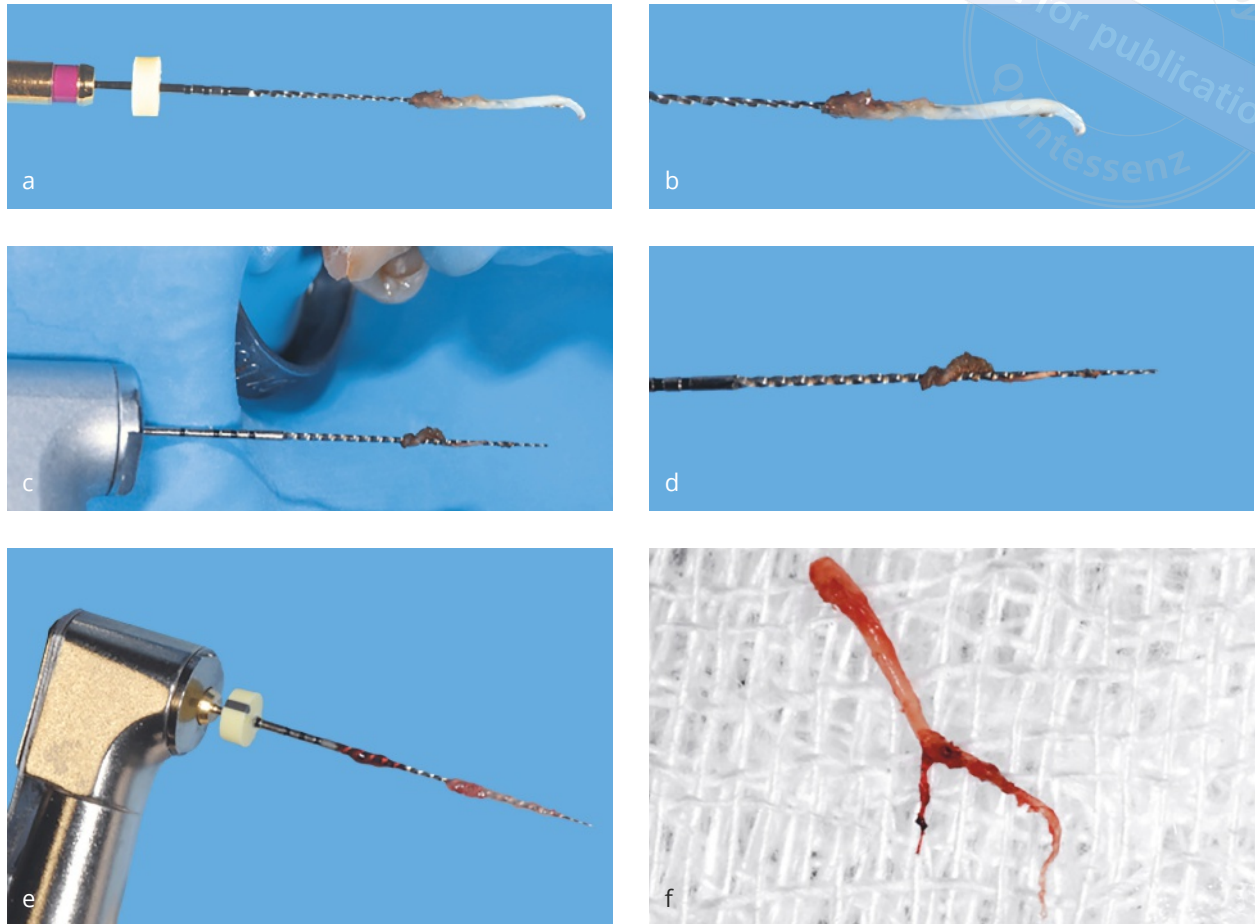


Fig 12-1a to f Several examples of the total removal of the pulp tissue during the utilization of rotary NiTi PathFiles in the preliminary enlargement of the glide path.

In 1915, Dakin¹⁰ reported the use of 0.5% sodium hypochlorite for the irrigation of wounds sustained by soldiers in the First World War. Taylor and Austin¹¹ tested the solvent activity of Dakin's solution in vitro and in vivo in non-vital tissues. In 1936, Walker¹² found that a solution of 3% sodium hypochlorite and sodium chloride was a good solvent for organic substances. He was the first to recommend its clinical use as a root canal irrigant. In 1941, Grossman and Meiman¹³ demonstrated in vitro the solvent activity of this solution on a pulp that had just been extracted. In the same year, Grossman recommended irrigation with alternating solutions of NaOCl and 3% hydrogen peroxide. Finally, in 1954, Lewis¹⁴ suggested Clorox (5.25% commercial bleach) as a source of sodium hypochlorite for endodontic use.

Chelating agents

The use of chelating solutions in endodontic procedures is suggested by the capacity of these substances to combine chemically with the calcium ion (Ca^{2+}) and thus, possibly, soften the dentin. The substance most commonly used for this purpose is ethylenediaminetetraacetic acid (EDTA), which, on combining with Ca^{2+} , causes the hydroxyapatite crystals to transform into the calcium salt of ethylenediaminetetraacetate.

EDTA was introduced in endodontics for the first time by Nygaard-Ostby¹⁵ in 1957 to facilitate the preparation of the root canals, particularly in the case of narrow, calcified canals.

Stewart et al¹⁶ found that, in combination with urea peroxide, EDTA very effectively removes debris within the canal, owing to its bubbling action, and improves the cutting capacity of canal instruments.

Chelating agents are used in endodontics for several purposes such as lubrication, emulsification, and flotation. They are available in either a viscous suspension or an aqueous solution.

12.2.3 Activation of irrigants: apical negative pressure and ultrasonic activation

In the syringe–cannula classic irrigation method, irrigants are delivered deeply into the canal space using positive pressure irrigation through a cannula connected to a syringe via applying finger pressure on the syringe plunger, which pushes the irrigant solution through the cannula into the canal space by directly injecting the solution. Originally, open-ended cannulas were used, with a high risk of extrusion periapically, resulting in tissue damage and postoperative pain. This is the reason why most clinicians often avoid a closer approach to the working length while irrigating with NaOCl solution, and, consequently, a large amount of debris remains clogged in the irregularities of the root canal system and does not efficiently deliver the irrigant solution into the apical one-third of the canal.¹⁷

Furthermore, due to the interaction between the air bubbles caused by the irrigation distribution (positive pressure) and the gas production created by the chemical reaction of NaOCl with organic tissue, an “apical vapor lock” will act as an embolism and will block the irrigant from reaching the apical one-third.

The only method capable of removing the air bubble, allowing a continuous exchange of irrigants throughout the entire length of the root canal and eliminating completely any risk of extrusion, is the apical negative pressure irrigation method, introduced by Dr John Schoeffel in 2007 and called EndoVac.¹⁸ With this system, the irrigants circulate through the canal by creating a negative apical pressure in the working length and generate a rapid apical-oriented fluid stream that allows the use of a greater volume of the solution compared with the conventional irrigation, and a perfect control of the apical extrusion. However, EndoVac had some design drawbacks that limited its clinical practice use: The

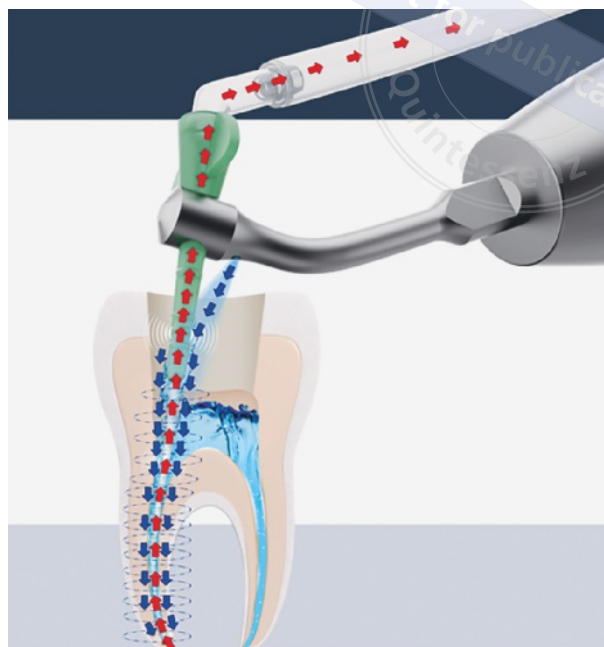


Fig 12-2 Schematic representation of the new method to activate the irrigating solutions: apical negative pressure and concomitant ultrasonic activation.

12 microports of the microcannula were too narrow and frequently remained clogged due to dental pulp fragments and dentin debris.

A method of potentiating the action of irrigants is by using ultrasonics to activate them.

The iVac system (PacDent, Brea, CA, USA) (Fig 12-2) brings a completely new approach to address some of the limitations of the irrigation/activation systems previously described. The method continuously delivers the irrigant to the entire working length without any apical pressure, alongside concomitant ultrasonic activation and a safe evacuation via negative pressure. The iVac system consists of a non-tapered 0.35- or 0.50-mm diameter polymer cannula self-threaded to a piezo ultrasonic connector. The connector is coupled to a piezoelectric ultrasonic handpiece, providing vibrations to the iVac cannula and delivering concomitant irrigation from the reservoir. The connector has a “water-port” that provides continuous flow of irrigant to the pulp chamber and root canal. The vibration helps to carry the irrigant throughout the canal extension,

alongside the external cannula surface, and be recollected via the apical opening. The irrigant follows the external surface of the ultrasonically activated polymer cannula, reaches the working length, and is then aspirated via the apical opening, while the other end of the cannula is connected to the evacuation tubing, creating apical negative pressure.¹⁷

The iVac system features continuous flush irrigation, providing an uninterrupted supply of fresh solution during the procedure and achieving better results in removing debris from the apical third. The iVac cannula provides the same level of ultrasonic vibration as the metal tip used in passive ultrasonic irrigation (PUI). However, the cannula is much more flexible and does not break during use. In addition, metallic inserts for PUI are usually designed using a K-file as a base, resulting in unintentional dentin removal.

In conclusion, the iVac system represents the state-of-the-art method for delivering irrigating solution in the root canal system:

- apical negative pressure;
- ultrasonic activation of the irrigants;
- continuous flow of irrigants to the entire working length;
- no risk of extrusion.

12.3 Shaping

On account of the activity of the irrigating solutions and endodontic instruments, the fragments of pulp tissue, the microorganisms and their toxins, and all the infected material that may be contained within are removed from the root canal system during the cleaning procedure. Simultaneously, the instruments give the canal such a shape that the space obtained within may then be easily filled three-dimensionally.

In the same way that Black,¹⁹ at the beginning of the last century, described the principles that regulate the preparation of the various cavities in restorative dentistry, Schilder,¹ in 1974, listed the “mechanical” and “biologic” objectives of the shaping of the root canal to receive the warm gutta-percha obturation. However, clinicians must always try to be as

minimally invasive as possible so as to save as much tooth structure as possible in order not to weaken the root and not to predispose it to fracture.

12.3.1 Mechanical objectives

A continuously tapering preparation

The canal must be uniformly and progressively conical or in the shape of a truncated cone, without ledges on its walls, with the thinnest section of the cone positioned apically and the widest coronally (Fig 12-3a).

The truncated cone shape permits more thorough cleaning, better contact between the endodontic instruments and dentinal walls, better removal of all the pulp debris, and better penetration of the irrigating solutions. The truncated cone, therefore, increases the probability of obturating the important lateral canals.² The conicity of the canal allows the endodontic instruments to reach the critical area of the apical third to perform an adequate preparation and obturation.¹

Finally, it must be noticed that this objective, like all the others, was described by Schilder in 1974, when only hand instruments were used. Today, using the NiTi rotary or reciprocating files, the final shape is much more conservative, since the instruments are specifically designed to remove less dentin in the coronal portion of the root canals in order to be minimally invasive. Consequently, the continuously tapering preparation is only, or is mainly, present where it is needed, which is the apical one-third, and the mechanical objective is still respected (Fig 12-3b).

Cross-sectional diameters diminish in a coronapical direction

In other words, each cross-sectional diameter is smaller than the one immediately more coronal and greater than the one immediately more apical (Fig 12-4).

The concept of cross-sectional diameters has an important practical implication that becomes evident on obturation of the canal. The gutta-percha cone will be chosen, measured, and positioned slightly shorter than the performed canal preparation (Fig 12-5a). The diameter of the tip of the gutta-percha cone is therefore greater than the diameter of the more apical

Fig 12-3a and b During the shaping of the root canal (**a**), the dentin must be removed (red in the illustration) in such a way that the final shape of the apical preparation is a truncated cone, with continuous tapering and without ledges (**b**). Note how today the conical preparation is performed in a minimally invasive manner and the taper is limited to the most apical portion of the canal, while the middle and coronal thirds remain almost cylindrical in section.

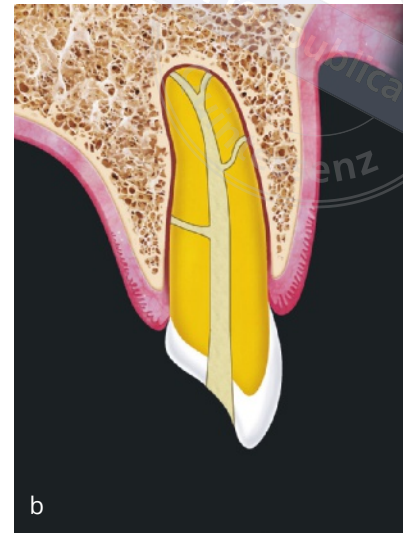
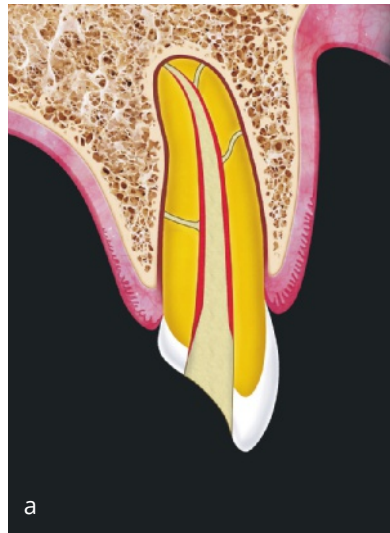


Fig 12-4a and b The transverse diameters of the apical tapering cone preparation diminish in a coronal direction (**a**). Note that in the coronal portion, the diameters remain about the same and the preparation is more or less cylindrical, to be minimally invasive and to save dentin (**b**).

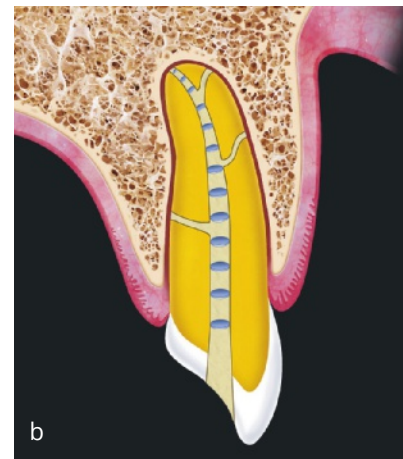
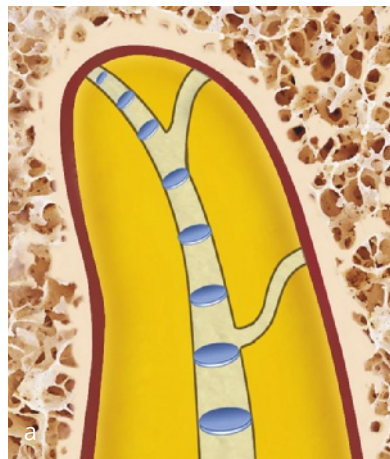
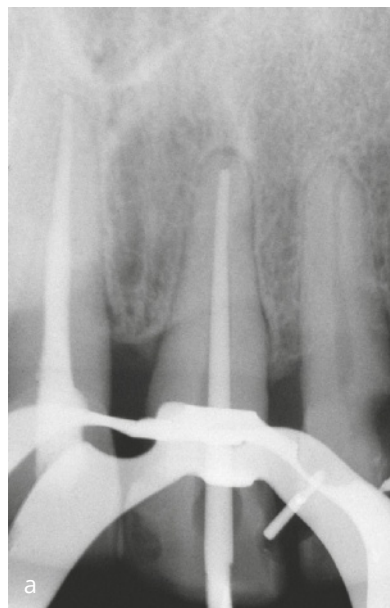


Fig 12-5a and b The gutta-percha cone to obturate the root canal must be slightly shorter than the canal preparation (**a**). During compaction, the cone will move apically, and its tip will be engaged through zones of progressively decreasing diameters. This forces the cone to deform, and this deformation assures a tight apical seal and good control of the material (**b**).



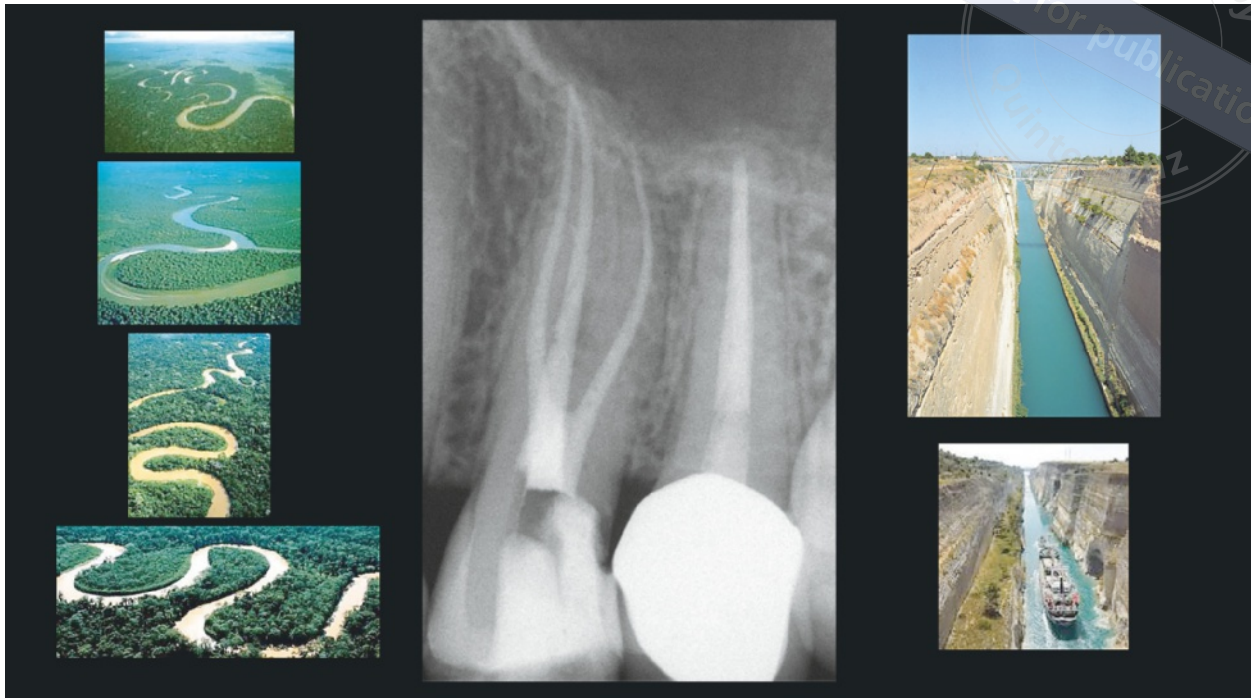


Fig 12-6 In postoperative radiographs, the course of the root canals should resemble that of a natural river course and not of a human-made canal.

small portion of the root canal. When the gutta-percha cone is heated and compacted, thanks to a vertical push, it moves apically and fills those empty apical portions (Fig 12-5b). To do this, it must deform to pass through progressively smaller sections. This deformation assures better adaptation of the gutta-percha, which assumes the shape of the canal, a better seal of the obturation, and better apical control of the material

Conicity must exist in multiple planes and give a sense of flow

The tapering conical preparation must not exist only in two planes but in all planes of the space. The apical part of the root canal must be conical both in a mesiodistal plane (the sides of the tapering conical form will be one mesial and one distal) and in a buccolingual plane (the sides of the tapering conical form will be one buccal and one lingual or palatal). Obviously, the first form can be appreciated on the radiograph, while the second one only on the extracted tooth.

In a postoperative radiograph, the course of the root canals should resemble that of a river seen from

the altitude of an airplane; it should not have the appearance of a human-made canal (Fig 12-6).

Apical foramen should be preserved in its original position and shape

Respect for the apical curvature of the canal also implies respect for the foramen, which remains in its original position and shape.

External transportation

This consists of transporting the apical foramen onto the external surface of the root, either by the formation of an elliptical, teardrop foramen or by direct perforation.

Teardrop foramen

A teardrop foramen is obtained when one uses straight, non-precurved instruments in curved canals. All the instruments are flexible and elastic. As one gradually passes from small instruments to larger ones, the instruments' flexibility decreases, while their elastic memory increases. Thus, the instruments can be bent, but they have an increasing tendency to return to their original, straight shape.

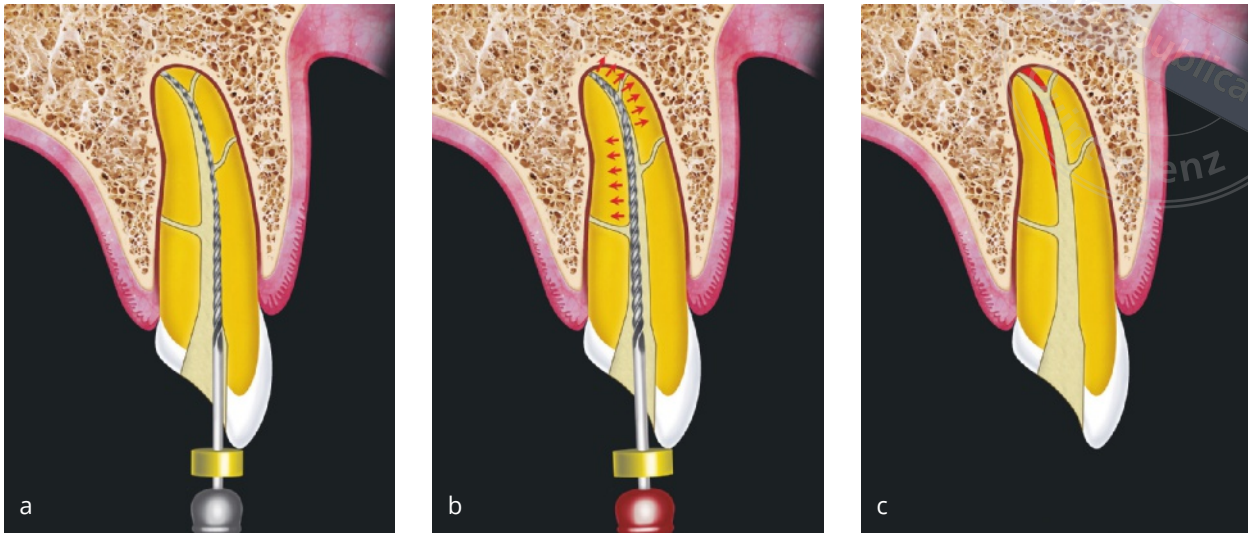


Fig 12-7a to c A small, straight file introduced into a curved canal deforms and follows the canal curvature (a). The elastic memory, which is always greater in instruments of increasing size, tends to cause the instruments to straighten and to make them work particularly in the zones indicated by the arrows (b). This involves greater removal of dentin from the external zone of the curve in the apical one-third and from the internal zone of the curve in the middle one-third (red in the illustration) (c).

Their action is therefore exerted only at the points of the root canal where they make contact, rather than on the entire canal circumference. This means that the external side of the curve close to the apex and the internal side of the curve in the intermediate portion of the canal are instrumented excessively (Fig 12-7).

At the apex, the result of such instrumentation is eccentric enlargement of the apical foramen, which assumes an elliptical or teardrop shape (Fig 12-8). The narrow part corresponds to the original foramen, while the wider portion is where the larger instruments have performed their work.

In the middle third, the thinning of the dentin can be so marked as to lead to perforation or “stripping.”

The clinical consequences of the teardrop foramen depend both on the periodontal damage that has been caused by the instruments and from the irregular shape that has been given to the apical foramen. The foramen will be very difficult to seal and will be the cause of the “inexplicable” gross extrusion of obturating material, which, in these cases, includes not only sealer, but also gutta-percha. Not only is the foramen elliptical (much more difficult to seal) but, most of all, the root canal has the shape of an hour-glass in the last millimeters (Fig 12-9a). Apical control of the obturating material is not possible

(Fig 12-9b). Many authors are convinced that the extruded gutta-percha is the only reason responsible for the failure of these cases, and they speak in terms of “foreign body reaction.”²⁰ Actually, the real reason responsible for these failing cases is not the extruded gutta-percha but rather the lack of apical seal.

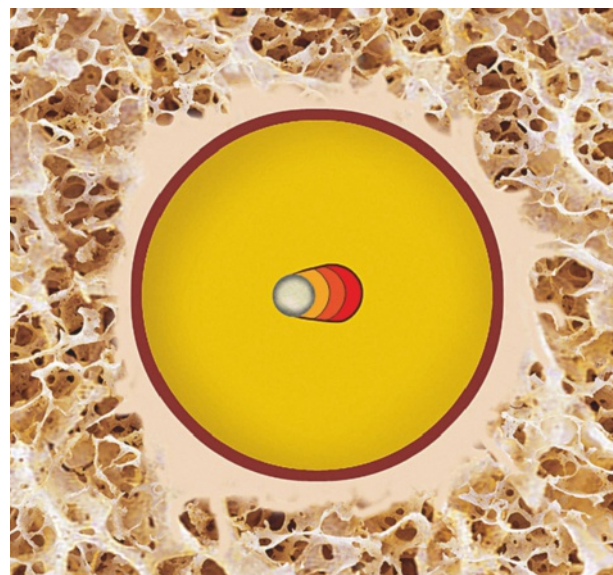


Fig 12-8 Schematic representation of a cross-section of the root at the level of the apical foramen after cleaning and shaping with straight, non-precured instruments, showing the teardrop foramen. The original foramen is light blue; the dentin removed by a non-precured instrument, increasing in size, is yellow, orange, and then red.

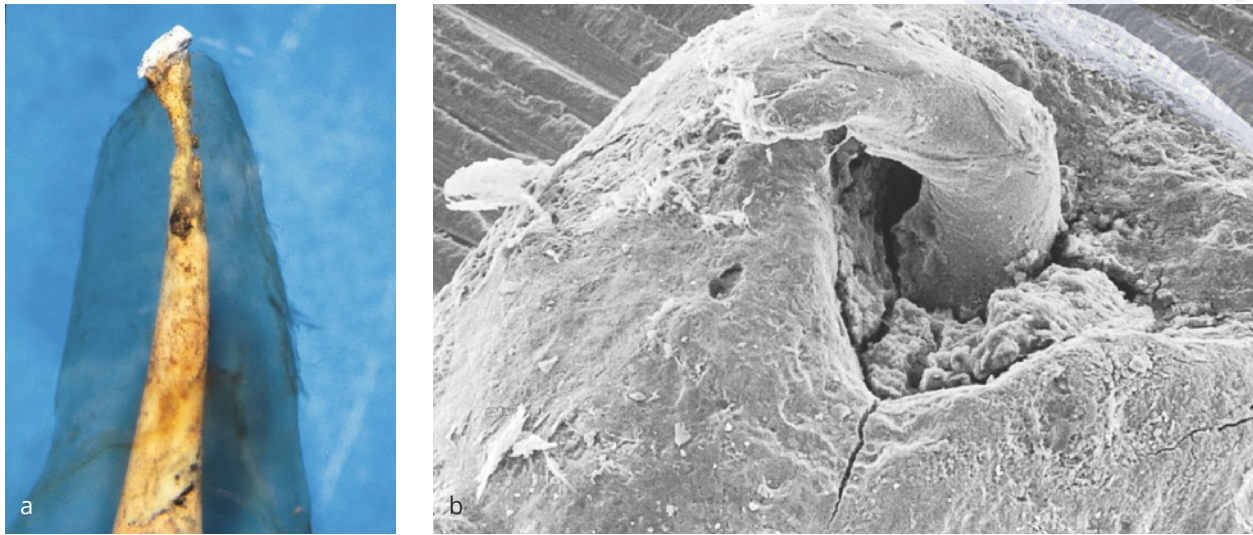


Fig 12-9a and b The transparent tooth shows the hourglass shape of the apical one third, due to the teardrop foramen (a). SEM image of a teardrop foramen with extrusion of obturating material (65x) (b).

Direct perforation

Direct perforation occurs when straight, large-size hand instruments are used in curved canals. The instruments are forced into the canal and screwed into the dentin in an attempt to cause the instrument to emerge radiographically “at the apex” (Fig 12-10). To avoid this adverse outcome, one should always begin the instrumentation with small, precurved files. The instrument should adapt itself to the anatomy of the canal, which must be respected as much as possible, especially in the most delicate zone, the apical one-third.

Internal transportation

This consists of transportation of the apical foramen within the root canal and can be performed within the original canal or within the dentinal walls.

Within the original canal

This occurs when one is working intentionally (at the so-called cementodentinal junction²¹) or inadvertently “short” without being concerned with keeping patent the most apical portion of the canal using the patency file. In this segment, collagenous tissue, debris, and dentin mud accumulate easily, blocking the canal as far as the apical foramen,

which, therefore, is occluded (Fig 12-11). Working arbitrarily short of the real terminus of the canal (that is, the foramen) based on statistical averages, and not keeping the foramen patent, encourages the accumulation and retention of debris and dentin mud, which may result in apical blocks that predispose the patient to the next type of transportation: ledges, false paths, and perforations.³

Within the dentinal walls

In certain situations, the instrumentation may terminate 2 to 3 mm, or more, short of the apex, after having begun the canal instrumentation at 0.5 mm from the apex, and having created an internal transportation by blocking the canal with dentin mud. In the attempt to re-establish the lost path, one tries to advance in the canal with the last instrument used, screwing it into the dentin in the conviction that one is removing the dentin mud from the apex. In fact, one is creating a new path in the “wrong” direction: One is making a “false canal” or “ledge” (Fig 12-12).

Apical foramen kept as small as practical

The apical foramen must be kept as small as practical to obtain a better seal and to prevent extrusion of the gutta-percha filling.¹ In other words, the foramen

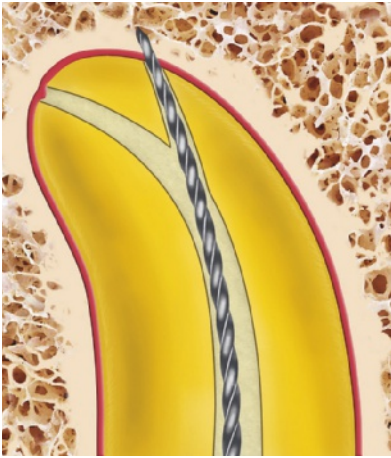


Fig 12-10 Schematic representation of a direct perforation. The straight, large-size instrument has been forced within a curved canal until it appeared radiographically "at the apex."



Fig 12-11 Schematic representation of an internal transportation. The last millimeters of the root canal are blocked by dentin mud.

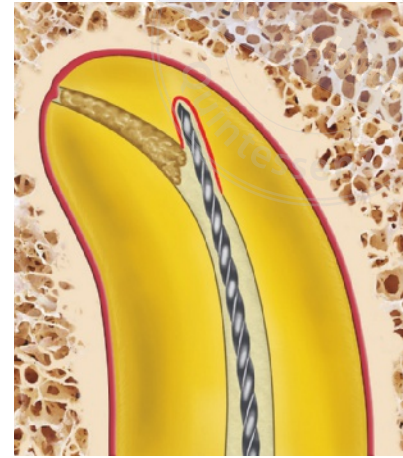


Fig 12-12 Schematic representation of a false canal (ledge). In the attempt to re-open the original canal, which was blocked by dentin mud, the instrument is actually opening an artificial canal.

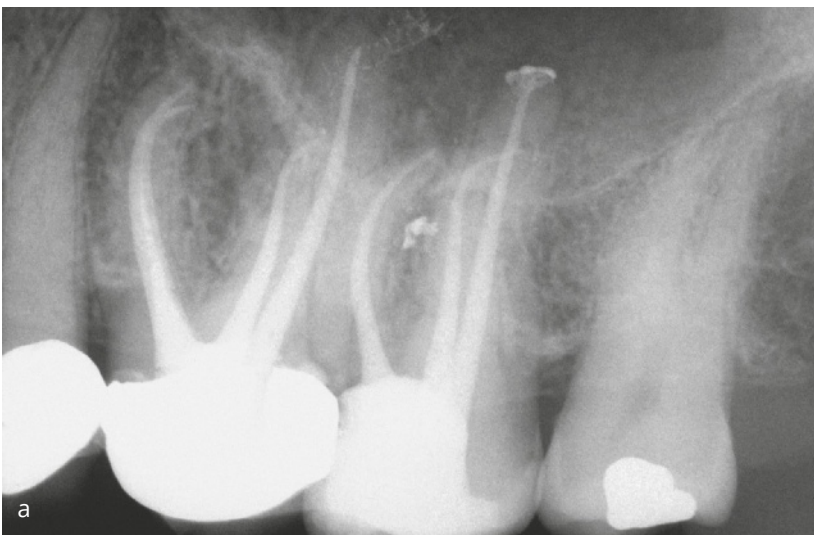


Fig 12-13a and b The apical foramina of these maxillary left molars have been enlarged to receive a no. 25 K-type file (**a**). The apical foramen of this maxillary left central incisor has been cleaned only with irrigating solutions, without any enlargement (**b**).

should be enlarged to a size that will allow deep penetration of irrigants and deep penetration of obturating materials and instruments.

The apical foramen of a narrow canal will have to be enlarged to at least the size that corresponds to a no. 25 ISO file (Fig 12-13a), while the apical foramen of an already-wide canal will only have to be cleaned, without any enlargement: It should remain the same original shape and size (Fig 12-13b).

12.3.2 Biologic objectives

Since lesions of endodontic origin are caused by the presence of infected material within the root canal system, the earlier it is removed, the sooner the healing process will begin.

The extraction of a tooth with periradicular pathology leads to a successful outcome and healing of the lesion by the simple fact that, together with the

tooth, the infected contents of its canal system have also been extracted.

The same degree of healing may be obtained by accurately removing the pulp debris and the micro-organisms, naturally without extracting the tooth.

This is obtained during the very important phase of cleaning and shaping, which has to be performed with respect to the abovementioned mechanical objectives and the following biologic objectives:¹

1. Limit the instrumentation to within the root canal. The endodontic instruments must not be introduced beyond the foramen, to avoid damaging the periodontium and important nearby structures (for example, maxillary sinus, nasal floor, mandibular canal, mental nerve). To prevent such injury, it is necessary to accurately check the working length of the instruments by using electronic apex locators, paper points, and by radiographic means as well as to pay attention to correct positioning of the rubber stops of the various instruments.
2. An exception to this rule is the use of the “patency file,” the small file used to check that the foramen is patent and not blocked. Patency is an extremely important concept in endodontics and can make the difference between success and failure.
3. Do not force necrotic material beyond the foramen. Careful use of the hand instruments within the root canal, in such a way that they are made to work only on withdrawal (and do not exert a piston-like action), will avoid pushing infected material beyond the apex.
4. On the other hand, inadequate instrumentation, with the consequent introduction of necrotic and infected material of pulpal origin into the periapical tissues, can have outcomes ranging from simple periodontitis to an acute alveolar abscess.
5. Today, thanks to the use of rotary NiTi files, the risk of extrusion during the shaping procedure is almost eliminated. The rotary files rotate clockwise, and all the debris is carried in a coronal direction by the flutes of the instruments.
6. Scrupulously remove all tissue debris. If the etiology of the lesion happens to be endodontic, the importance of total removal of all tissue debris to prevent this debris from acting as a substrate for bacterial growth is clear. This removal is performed with the use of endodontic instruments, but it is well known that even in the simplest, straightest, round canals there are areas that remain untouched by the instruments. In these zones, the complete removal of tissue debris is assured by the digestive activity of 5% to 6% sodium hypochlorite.
7. One should not forget that while endodontic instruments shape, the irrigating solutions clean.
8. Complete the cleaning and shaping of individual canals in a single visit.
9. When treating a root canal, it must be completely cleaned and shaped, so that it is ready to receive the obturation, even if this is planned for a subsequent appointment. This concept applies not only to single-rooted teeth – in which it may seem logical to prepare the canal completely in a single visit – but also to multirrooted teeth, whose several canals must be individually and completely prepared. And every root canal can be considered completely cleaned and shaped when it is ready to fit the gutta-percha cone.
10. It is thus a mistake to jump from one canal to another with the same instruments, and it is likewise a mistake to simultaneously prepare the three or four canals of one molar. The canals should always be prepared individually and completely.
11. If the time available does not permit complete cleaning and shaping of all the root canals of a multirrooted tooth, one should clean and shape some of them in one visit and postpone the negotiation and preparation of the others to a subsequent visit.
12. During the enlargement of the canals, maintain the foramen patent and create a space sufficient to contain any exudate that may form.

In the past, the space obtained by enlarging a canal served to introduce medications that could thus carry out their pharmacologic function. Modern practice, in contrast, tends to leave this space as empty as possible, so it can contain an exudate that might ac-

cumulate as a result of the clinician's nonetheless delicate and careful instrumentation. Therefore, if the canal is empty, and, especially if the apical foramen has remained "patent," the exudate can spill into the canal before accumulating in the space of the periodontal ligament (PDL), stretch its fibers, and give rise to periodontitis.

Today, therefore, less and less importance is given to canal medications that can also act as irritants.

Today, the only indications for the use of calcium hydroxide ($\text{Ca}(\text{OH})_2$) as an intracanal medicament are the following:

- Perforation repair with MTA in a case with a persistent sinus tract. It is well known that MTA does not set in the presence of a low pH. Therefore, for the only purpose of raising the level of pH, one week's medication with calcium hydroxide is highly recommended.
- When treating a tooth whose apex is surrounded by a large cystic lesion, the canal is continuously draining so that it is impossible to have it dry to hermetically obturate it. In such a case, it is highly recommended to fill the canal with $\text{Ca}(\text{OH})_2$ after having cleaned and shaped it, and to leave the medication as long as 1 or 2 months. The healing process will start, and after that time – after removal of the medication – it will be possible to have a very dry canal. As a matter of fact, to obturate a root canal, it has to be asymptomatic and "dry."

12.4 Basic concepts for root canal shaping

12.4.1 Glide path and preliminary enlargement

In recent years, endodontics has undergone a complete revolution with the introduction of the NiTi alloy used to produce first hand instruments and then rotary endodontic instruments. In fact, the instruments in NiTi have made it possible even for less-expert operators to produce perfectly truncated cone shaping that is in harmony with the original anatomy, notably improving the prognosis even in more complex cases.

Once the NiTi alloy became commercially available, it became the alloy of choice that allowed even less-expert operators to achieve excellent results.

The only true difficulty with canal preparation that one encounters nowadays is with the initial negotiation of the canal with a narrow and precurved stainless steel file. All the rest can be done with ease by careful use of the NiTi rotary/reciprocating instruments.

The initial probing is the only moment when it is still necessary to use stainless steel alloy, for the simple reason that an instrument in stainless steel, being different from an instrument in NiTi, can be precurved and, therefore, can be used to explore the canal – avoiding eventual obstacles that may be present such as ledges or calcifications – to be able to reach the working length.

While years ago, using hand stainless steel files, one had to do many steps and recapitulations, at the end of which it was impossible to know which taper had been developed – indispensable for choosing the correct gutta-percha cone for obturation. Nowadays, the shaping is standardized and repeatable because it is automatically created by the NiTi instruments.

The NiTi systems are matched to the paper points for drying the canals and to the gutta-percha cones to then be able to obturate the canals.

Obviously, to do this and to use the NiTi instruments safely, one must follow precise rules to avoid the big risk that goes with their use, which is instrument fracture.

To be able to work safely with the rotary/reciprocating NiTi instruments requires understanding of the following three concepts:

The glide path

The glide path is nothing other than a smooth wall along which the NiTi instruments slide to reach the working length. NiTi instruments cannot be precurved. However, they can follow the curvature of the root canal and reach the working length thanks to two characteristics: the instrument having a blunt and non-aggressive tip, capable of sliding along the canal walls, which have to be smooth. Therefore, the

glide path is the essential requirement that the canal must have for the clinician to be able to use NiTi instruments.

Preliminary enlargement

All around the world there are still dentists reluctant to use NiTi alloy because they are afraid that these instruments, which rotate inside the canal at a certain speed, could fracture. In fact, since the use of NiTi has become widespread, one sees many more fractured instruments than when only stainless steel was used.

In fact, the use of NiTi has one serious drawback in that it carries a higher risk of the instrument breaking compared with stainless steel, and we know that breakage usually depends on torsional and bending stresses.²²

Bending stress fundamentally depends on the original canal anatomy and occurs essentially because the instrument rotates inside the curvature of the canal, and its blades are subjected to tension when they are against the external part of the curve, as well as to compression when they are against the internal part of the curve. If the instrument rotates at 300 revolutions a minute, the alternation of tension/compression occurs an equal number of times, with a resultant accumulation of stress that may cause it to fracture. The operator can do very little to reduce this type of stress – which cannot be eliminated, in as much as one cannot change the original anatomy nor straighten the curvature. One can, however, reduce the risk of fracture by distributing the stress over a larger number of blades. The latter can be done simply by not staying at the same working length, but by moving the instrument up and down in the canal. As a secondary issue, it is recommended to consider the instruments as “single use” or, at least, “single patient use,” and not to abuse their longevity and apparent integrity.

Torsional stress depends on numerous factors, but mainly on the cross-section of the root canal compared with the cross-section of the rotating instrument. In other words, it is due to the friction that the instrument encounters while rotating in the canal

and cutting the surrounding dentin. The narrower the canal, the more fatigue the instrument will accumulate cutting a path to reach the working length. Breakage occurs if the canal section is smaller than the tip of the instrument that cannot cut the dentin, and what is known as “taper lock” occurs. The tip of the NiTi instrument, in fact, is its most fragile part, and if the canal surrounding it is tight, the tip can bind in the canal while the motor continues to run, after which the tip deforms, and then, after exceeding the elastic limit, it fractures.

To mitigate this risk, the only thing to do is to make sure that the tip encounters a canal having the same caliber, if not even bigger. In other words, to eliminate the risk of fracture due to torsional stress (the most frequent cause of fracture), all one has to do is to pre-enlarge the apical third and increase the foramen size to the same caliber as the tip of the first NiTi instrument that is used at the working length to shape the canal. Therefore, it is highly recommended that its use is preceded by preliminary enlargement of the existing “glide path.”

Coronal preflaring

This term refers to the slight pre-enlargement of the coronal and middle third of the canal, necessary for two reasons: removal of the coronal interferences to have straight-line access to the apical third, and to have space to maintain the precurvature given to the stainless steel hand instrument to be able to probe an accentuated curvature in the apical third, or to surpass an existing ledge in that spot.

12.5 Use of the patency file

The patency file is a small, flexible K-File (usually size 08 or 10) that will passively move through the foramen without widening it, to keep it clean and free of debris.²³ This step has been suggested for most rotary techniques but should be used for any system, including, and maybe mainly, for hand instrumentation. In fact, rotary systems rotate in a clockwise direction so that the debris is constantly carried in a coronal direction, and then it is more

difficult for the debris to accumulate apically and thereby block the canal. On the other hand, stainless steel hand files are mostly moved with a filing push-pull motion, which means they cut the dentin, produce debris, and quite easily push the debris apically, risking the blockage of the foramen. If this happens in a vital case and sterility is maintained, there might not be a consequence, but if this happens in a necrotic and infected case, the blockage of the foramen with dentin mud full of bacteria is the guarantee for failure.

Therefore, the small patency file is used to remove accumulated debris, to help maintain the working length, and to achieve more predictable results.

The patency file should always be the smallest file size possible, used carefully and passively, and every time the operator is afraid of blocking the canal, or any time a decrease is observed in the working length of the instruments.

The use of the patency file is a very controversial topic, and some authors disagree with its use.²⁴ The main concern with the patency file is that, instead of having a cleaning effect, the file may push contaminated debris through the foramen. Izu et al,²⁵ in an *in vitro* study, demonstrated that the risk of pushing debris was minimal when the canal was filled with sodium hypochlorite. Arias et al,²⁶ in a recent article, suggested that maintaining apical patency throughout an endodontic procedure does not increase the incidence, degree or duration of postoperative pain. On the contrary, maintaining apical patency is associated with significantly less postoperative pain severity scores in molars with necrotic pulp and apical periodontitis.²⁷

The foramen must remain patent. It must not be obstructed by dentin mud, and the dentist should theoretically be able to introduce a small-size instrument beyond the foramen at any point in the cleaning and shaping procedure.

Using small-size files connected to the apex locator, fine and flexible all the way to the “electronic apex,” facilitates the elimination of the pulp residues, various irritating substances, and dentin mud. Maintaining the terminus of the canal patent avoids blockages, ledges, and perforations.^{28,29}



Fig 12-14 The Endo Radar (Woodpecker) has the apex locator incorporated so that one can constantly check on the working length during the mechanical instrumentation.

On the other hand, according to Vera et al,³⁰ maintaining apical patency and then using passive ultrasonic irrigation improves the delivery of irrigants into the apical third of human root canals.

Taking into consideration the rich collateral blood supply and the elevated healing potential of the attachment apparatus, it is illogical to think that extending a small file passively and accurately beyond the apex will compromise the final result or cause an irreversible condition for the patient.

The patency of the foramen will permit the accumulation of any exudate (which may form in the apical tissues in spite of careful shaping) within the canal rather than among the fibers of the PDL. This prevents the development of periodontitis postoperatively.

Finally, the patency file must always be used connected to the apex locator in order to have an idea of the extension of the small-size file beyond the foramen. This can be done also when using rotary NiTi files, since many motors have the apex locator incorporated (Fig 12-14). On the other hand, according to Abdelsalam and Hashem,³¹ the root canal blockage has a negative influence on the accuracy of apex locators. Foramina patency could be considered as a prerequisite for a reliable working length determination with apex locators.

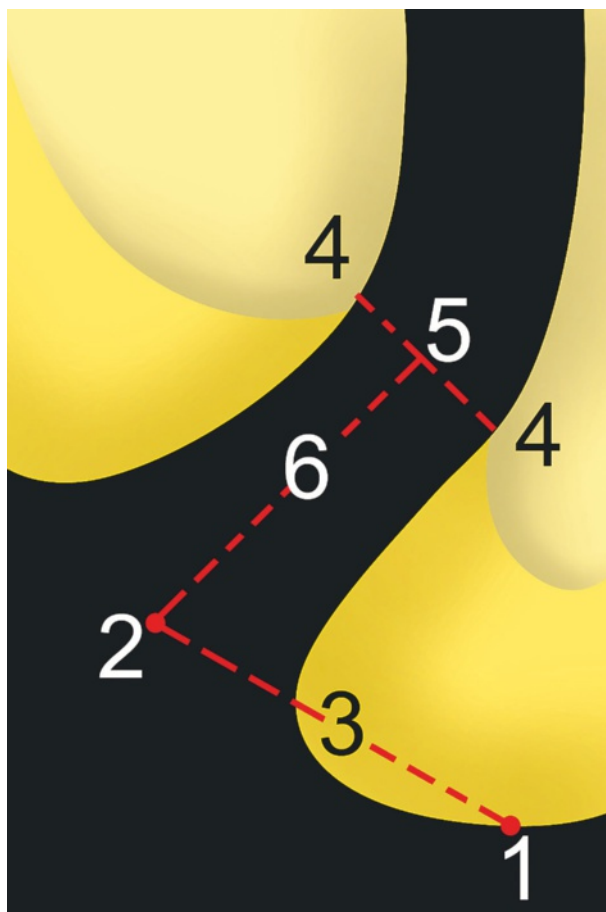


Fig 12-15 Schematic representation of the root apex, according to Kuttler.³⁸ Anatomical apex, geometric apex or vertex of the root (1). Center of the foramen (2). Distance between the vertex and the center of the foramen (3). Cementodentinal junction (4). Canal diameter at the level of the cementodentinal junction (5). Distance between the center of the foramen and the apical constriction (6). (Images adapted from Kuttler.³⁸)

12.6 Determination of the instrument's working length

A much-discussed topic that, perhaps, will always be disputed, is where to end the preparation – and thus, the obturation – of the root canal.

One view, held by many, maintains that instrumentation and root canal obturation must stop at the cementodentinal junction, near which the apical constriction is maximal (Fig 12-15). At this point, the pulp tissue ends, and the endodontium yields to the periodontium. The canal walls are no longer formed of dentin, but cementum.

Theoretically, this view is more than correct, since the apical constriction ensures a good stopping point for preparation and canal obturation, which must maximally respect the periodontium and periapical tissues.

In practice, however, the facts are quite different. As Coolidge³² maintained as long ago as 1929, the site of the cementodentinal junction is so variable that trying to use it as a marker during pulp removal and canal obturation is of little help. This junction often has indistinct borders, and it may be found at different levels within the root canal (Fig 12-16). Still, according to Coolidge, "... the dividing line between the pulp and the periodontal tissue is not a fixed point to be used as a guide in operating. Not only is the dentinocemental junction an imaginary dividing line, but the conception also is erroneous and may be misleading. It would be more accurate to speak of this area as the area of the apical foramen and disregard the variable position of the junction between cementum and dentin."

One must bear in mind that, practically speaking, identification by tactile means of the cementodentinal junction as the site of maximal apical constriction may often be misleading.

The "constriction" encountered by the instruments can be due to a calcification (Fig 12-17a) or a narrowing of the canal space, which can be close to or far from the real endodontic terminus (Fig 12-17b); therefore, the tactile sensation used to determine the working length can be considered unreliable. On the other hand, it is well known that at the origin of all endodontic failures is a short preparation and a short obturation.³ Therefore, the arbitrary rule that canal preparation should terminate 1 mm (or more) short is unacceptable in modern endodontic therapy because it increases the likelihood of failure.^{33,34}

Even if it were desirable, it is not possible to terminate the canal preparation and obturation at the cementodentinal junction, for histologic reasons (ie, the irregularity and inconsistency of the cementodentinal junction and the lack of differentiation of the pulp neurovascular bundle before and after its entry in the



Fig 12-16 The cementum may rise within the canal, so that, even histologically, the cementodentinal junction is not easy to locate.

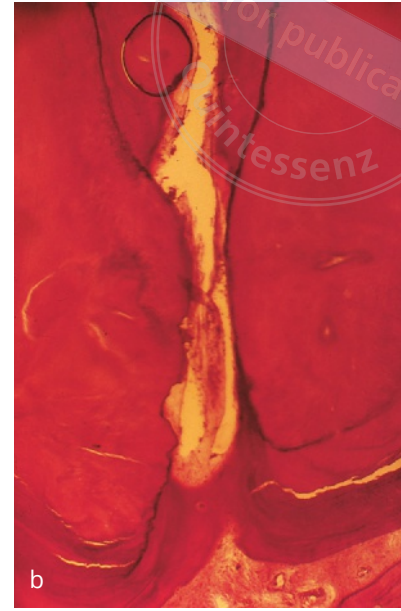
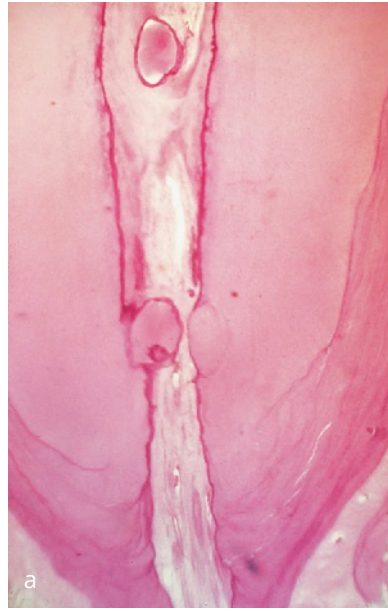


Fig 12-17a and b In this case, the apical constriction or "minor diameter" corresponds to a calcification situated coronally to the cementodentinal junction (**a**). In this case, the apical constriction does not correspond to the cementodentinal junction, but is more coronal, where the canal walls almost contact each other (**b**).

apical foramen), and for clinical reasons (ie, the impossibility of identifying and locating the cementodentinal junction, the unreliability of tactile sensation in identifying the point of maximal apical constriction, and the unreliability of pain sensation in the patient).

Other investigators make use of mathematical formulae and statistics to locate the junction, but even these methods cannot be considered rigorous since they must obviously be considered approximate and arbitrary.³⁵ Also, statistics work in big numbers and not in single cases.

According to Stein and Corcoran,^{34,35} Kuttler³⁸ studied the average distance between the major and minor diameters of the apical foramina in 268 teeth. He found the average distance to be 0.507 mm in patients 18 to 25 years of age, and 0.784 mm in patients older than 55 years of age.

Green³⁷ claims that the point of maximal apical constriction is, on average, 0.75 mm from the foramen.

In a recent article, Rosenberg³⁹ said that the distance to be subtracted from the radiographic apex is based on studies where the average distance of the apical foramen from the radiographic apex has been

measured. Then an average length discrepancy with a standard deviation is determined. The problem with this approximation technique is that the teeth we treat are not average, but unique.

Other authors feel that canal preparation and obturation should be performed slightly short of the apical foramen for yet another reason: the lack of correspondence between the radiographic apex and the anatomical apex.

However, because there is much confusion regarding the terminology, some clarification is in order. Apical constriction³⁹ refers to the apical portion of a root canal having the narrowest diameter. It may be associated with the cementodentinal junction, with cementum alone, or with dentin alone. The position may vary, but is usually between 0.5 and 1.0 mm short of the center of the apical foramen.

Anatomical apex³⁹ refers to the tip or end of the root of a tooth as determined morphologically, or, in other words, the vertex of the root, and is also called "geometric apex."

Radiographic apex³⁹ refers to the tip or end of the root of a tooth as seen on a radiograph: in other words, it is the anatomical apex as seen on the radiograph.

Apical foramen³⁹ refers to the opening of the root canal on the external surface of the root and does not necessarily coincide with the anatomical apex, depending on the apical curvature of the canal inside the root. Since the cementodentinal junction cannot be chosen as the terminal point of canal preparation and obturation, because it is not possible to determine its location either clinically or histologically – given that the distance by which one falls short is a rather arbitrary and subjective choice (between 0.5 mm, 0.75 mm, and 1 mm, up to 3 mm), depending on the authorial source the clinician decides to follow – it is necessary to establish another marker for the determination of the instrument's working length.

Schilder¹ states that canal preparation and obturation must be performed to the “radiographic terminus of the canal,” meaning to the point where the canal radiographically meets the external profile of the root surface. This derives from the following considerations:

1. Its determination is not arbitrary or subjective, nor is it dictated by statistics.
2. Clinically, it is easily identifiable by dentists, even those with differing opinions, by simply examining a properly performed intraoperative radiograph.
3. In 50% of cases,^{33,40} the canal ends at the anatomical or geometric apex or vertex of the root and is thus identifiable radiographically. In these cases, using the radiographic terminus of the canal entails neither over-instrumentation nor overfilling.
4. If the emergence from the canal is not at the geometric apex of the root but in a lateral position, it will always be identifiable radiographically if situated mesially or distally, as often happens^{33,40,41} (about 40% of cases).
5. If, instead, the foramen is displaced buccally or lingually, it obviously will not be radiographically identifiable.

A recent study by Olson et al³⁴ on 305 anterior and posterior root canals further demonstrated that the apical foramen can be accurately located by a good

radiographic study alone (paralleling technique) in a good 82% of cases. A similar study by Castellucci et al⁴¹ on 227 teeth with a total of 342 canals led to even more reassuring conclusions. In 48% of cases, the file appeared to exit at the radiographic apex, while 40.9% of the files appeared to exit elsewhere along the root surface (mesial or distal). In 11.1% of cases, the file appeared short of the root surface on the radiograph. Some important conclusions:

- In 88.9% of cases, it is possible to accurately determine the location of the apical foramen by the use of a radiograph.
- If one wants to consider the choice of the radiographic terminus of the canal to be approximate (given that this sometimes involves preparation and obturation slightly beyond the foramen), it cannot be considered any more approximate than the choice of staying 0.5 mm, 0.75 mm, 1 mm (or even more)⁴² short of the radiographic apex.

However, even in the 11.1% of cases in the previous study, today “long” preparations and obturations are not carried out because the electronic apex locators inform us of the true position of the apical foramen and therefore the correct working length. We can conclusively say that the reference point of the apical depth of our preparation and obturation is represented by the “electronic apex,” which coincides, in about 90% of cases, with the radiographic terminus of the canal.

In about 10% of cases disagreement exists between the apex locator – which informs the operator that the instrument is exactly at the foramen – and the radiograph, which shows an instrument radiographically short. Of course, the operator must rely on the electronic apex locator and not on the radiograph, and in the patient's chart, the dental assistant must write “electronic apex,” which means that the treatment looks “radiographically short,” but is “exactly at the foramen.”

Furthermore, seeing that the reason for endodontic failures is due to persistence of bacteria that have been left in a portion of the canal that is incompletely cleaned and unsealed, seeing that the canal ends at the apical foramen, and seeing that the

foramen can open on any side of the root apex, what sense is there in taking as the reference point of the working length, a point chosen at random, which is more or less far from the radiographic apex, where the radiographic apex could have nothing to do with the true end of the canal?

As already stated above, the arbitrary rule that canal preparation should terminate 1 mm (or more) short is unacceptable in modern endodontic therapy, and root canal length should be determined by employing a combination of methods – electronic, radiographic, and, finally, the consistent drying point.^{33,38}

12.6.1 Electronic apex locators

Currently, the use of the electronic apex locator represents a reliable method of measuring the working length for our instruments, which, as mentioned above, takes the electronic apex as their reference point.

These instruments are based on the principle that the electrical resistance between one electrode in the root canal and another applied to the oral mucosa registered consistent values. This was demonstrated in a study by Suzuki⁴⁴ in 1942, but had already been suggested by Custer⁴⁵ in 1918.

Sunada⁴⁶ was the first to take advantage of this principle to measure the length of root canals. He concluded that when an endodontic instrument was inserted into the canal and the ohmmeter registered 40 mA, the instrument tip was exactly in contact with the PDL at the apical foramen of the root canal.

The first generation of electronic apex locators had the disadvantage of requiring the canal to be free of pulp tissue, exudate, pus, blood, electrolytes, and sodium hypochlorite – in other words, any substance that could act as a conductor. This, of course, represented a great limitation.

The applications and possible uses of electronic apex locators have evolved significantly in recent years as revolutionary new instruments have become available to the dental profession. Their use is not influenced by the contraindications and disadvantages that are true limitations to the use of the instruments previously discussed.

These instruments make use of a different principle and are not at all affected by the contents of the root canal, whether blood, vital or necrotic pulp, pus, RC Prep or (most of all) sodium hypochlorite.⁴⁶ In other words, the instruments can perform accurately even in moist conditions and in the presence of mineral salts. Moreover, they may be used with small-size files immersed in sodium hypochlorite and in contact with organic fluids. It is thus possible to obtain an accurate measurement of the working length from the first probing of the root canal.

The instruments yield inaccurate responses only if the shaft of the file used for the measurement comes into contact with the metal of a coronal restoration, or if there is a previous obturation within the canal that impedes contact of the endodontic file with the surrounding dentin. The reading is also inaccurate if the file is too small a size compared to the size of the apical foramen, or if the conductive liquid is in contact with the metallic restoration. In the first situation, an accurate reading can be obtained using an endodontic instrument of a proper size (the readings are more accurate the more the size of the instrument is close to the size of the foramen), while, in the second case, the length of the root canal can be accurately measured by simply removing the electrolyte from the access cavity with a suction tip, and, if necessary, from the root canal with a paper point.

The physical principle on which their function is based differs from that of the above instruments, inasmuch as they do not give the impedance measurement value for the periodontium and the measuring needle, but rather the difference in the impedance responses for two different frequencies (1 and 5 kHz) in the Apit/Endex (“the relative values of frequency response method”⁴⁷), and the ratio in the impedance for two different frequencies (400 Hz and 8 kHz) in the Root ZX (“the ratio method”⁴⁸) at differing points in the root canal.

This ratio gives a very precise value, one that represents the position of the electrode inside the canal, independently of the type of electrolyte contained in



Fig 12-18 Apex locator of the third generation by Woodpecker: Ai-Pex.

it.⁴⁸ This value diminishes as the file nears the foramen, until it becomes zero upon reaching it. This principle, therefore – not being influenced by the canal contents – reduces to a minimum the error caused by the conditions of the canal itself and of the measuring instrument.

Recent studies^{49,50} have shown that the Root ZX gives readings that are 100% accurate with a clinically acceptable margin of error of ± 0.5 mm: the average distance of the file tip from the apical foramen was 0.2 mm. The same authors^{49,50} have also emphasized the fact that the Root ZX can be used with confidence to localize the apical foramen, not the apical constriction, referred to by other authors.⁴² This is obvious if we take into account the physical principle on which it is based and on the role the instrument has in diagnosing the site of the radicular perforation.⁵¹ Therefore, contrary to what its manufacturers say, the Root ZX must not be utilized to determine the site of the point that is 0.5 mm from the foramen, but to locate the actual foramen, which is reached when the digital scale is on the “Apex” sign and when the wording flashes. Only then, if desired, can one measure 0.5 mm from the foramen on the scale.

Third generation of electronic apex locators

Recently, the third generation of electronic apex locators has been introduced and patented by Dr Carlos Ramos Spironelli (Fig 12-18).^{52–54} The instrument, called Ai-Pex (Woodpecker, Guangxi, China), determines the foramen location by measuring the thickness of the dentin. The thickness of the dentin in the root canal is the same until the most apical 4 mm, when it decreases. Dentin is an excellent thermal and electrical insulator, so when a file is inserted into the root canal and sparks an electronic signal, the signal will try to pass through the dentin and reach the PDL and bone. However, where the dentin is thick, only half or less of the signal (50% of those “ohms”) will likely pass through. An apex locator can detect the electronic signal that the dentin impedes from passing through. In the most apical millimeters, the thickness of the dentin will also impede the passage of some electronic signals. Still, some of it will go back to the lip clip and the device, informing the dentist about the related distance from the end of the root canal.

As the instrument penetrates deeper into the root canal, the thickness of the dentin reduces. This allows more electronic signals to pass through and

reach the device, which informs the dentist that the instrument is closer to the end of the root canal. Thus, the lower the impedance, the deeper the instrument goes. At the final part of any dentin wall, the foramen equator, the thickness of dentin, and impedance will be almost zero, because there is little isolation. This is why the “00” point is the most accurate measurement point, as it is the most apical part of the root canal, the foramen.⁵⁵

12.7 Conclusions

Not even the latest generation of electronic apical locators can be considered a radiographic substitute since radiographs provide the operator with other information that electronic measuring equipment is unable to provide: canal width; degree and direction of curve; position of the foramen; dentin thickness; and relationship between canals, which might be in the same root. Furthermore, these instruments are able not only to inform the operator about the location of the foramen, but also to reveal the opening of any other foramen such as that of a lateral canal (Fig 12-19) or a perforation^{46,50} (Fig 12-20).

If, once the radiograph has been taken, a variance occurs between the radiographic image (which shows a “short” file with respect to the radiographic terminus of the canal) and the apex locator (which has just indicated that we have reached the foramen), then one must consider the locator reading as valid⁵¹ since, evidently, the foramen is in an area (buccal or lingual/palatal) not radiographically identifiable. Our therapy will therefore be based on a measurement carried out by an electronic apex locator (at the electronic apex and not just 0.5 mm from the radiographic apex), and we will know from the beginning that in the postoperative radiograph, the canal obturation will appear “short,” but will, instead, be accurate at the apical foramen. Not taking the radiograph – as some do – and believing blindly in an electronic instrument, our “short” obturation will be a postoperative surprise and we will never know whether we are truly short.

12.7.1 Ten rules to follow

1. Do not begin endodontic therapy unless a recent preoperative radiograph is available.
2. The initial hand instruments must always be pre-curved and equipped with a directional rubber stop.
3. Do not begin to work at the foramen without first having radiographically ascertained the position of the instrument in the canal.
4. The endodontic instrument does not work for itself but prepares the canal for the following instrument.
5. All endodontic instruments work on withdrawal, arriving where the canal will accept them: “Take what the canal will give you.”
6. In multirrooted teeth, one always performs the cleaning and shaping of one canal at a time, always starting from the easiest.
7. Each root canal deserves a series of new instruments.
8. The instruments’ working length must always be checked electronically first and then radiographically: never take a radiograph without consulting a reliable electronic apex locator.
9. It is advisable not to trust one’s tactile sense.
10. Never progress to the next step unless the preceding step has been completed. This means:
 - Never introduce an instrument into any root canal if the access cavity has not been completed.
 - Never start working in the second canal of the multirrooted tooth if the first canal is not ready to fit the cone.
 - Never obturate any root canal if all the root canals of the multirrooted tooth have not been completely cleaned and shaped and if they are not ready to fit the cone.

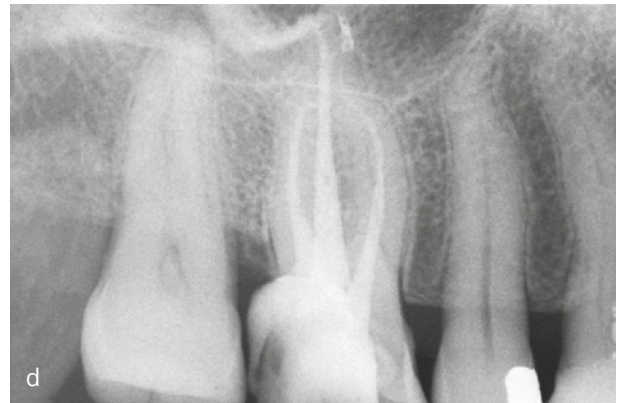
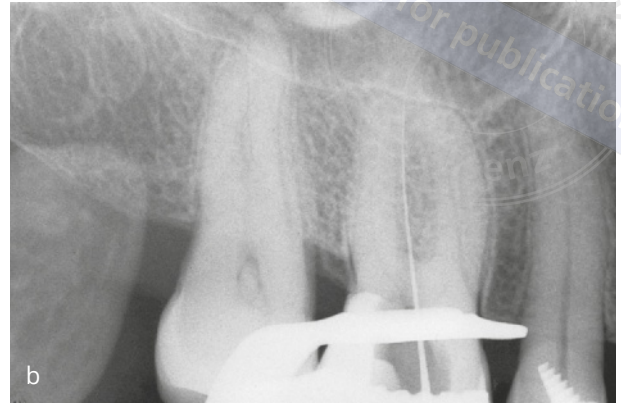
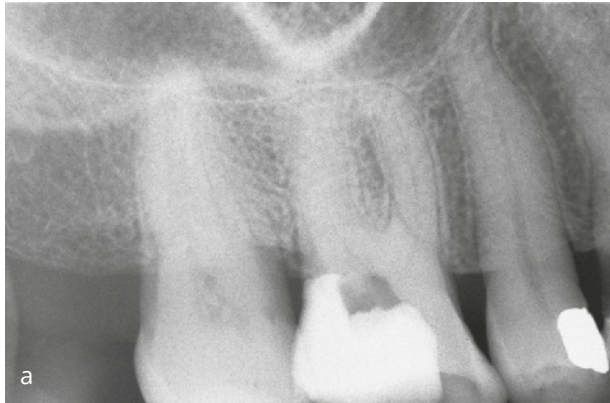


Fig 12-19a to e Preoperative radiograph of a maxillary right first molar (a). The electronic apex locator indicates that the instrument is at the foramen and the radiograph shows that the foramen belongs to a lateral canal (b). The file has been withdrawn and reintroduced more apically: the electronic apex locator indicates that a new foramen has been reached, and the radiograph shows the file at the apical foramen (c). The postoperative radiograph shows that both canals have been three-dimensionally obturated (d). 3-year recall (e).



Fig 12-20 The apex locator indicates that the instrument has reached the foramen; however, the radiograph shows that it has entered a perforation.

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