Endodontic Radiology

Edited by Bettina Basrani
Endodontic Radiology, Second Edition
“Every great dream begins with a dreamer. Always remember, you have within you the strength, the patience, and the passion to reach for the stars to change the world.”

Harriet Tubman

This book is dedicated to my children, Jonathan and Daniel, to encourage them to follow their dreams with conviction and hard work, and especially with love.
Contents

About the Editor ix
Contributors x
Foreword xiv
Preface xvi
Acknowledgments xvii

Part 1: General Principles and Techniques

1 General Principles of Radiology in Endodontics 5
   Anda Kfir and Bettina Basrani

2 Intraoral Radiographic Principles and Techniques 18
   Mindy Cash and Bettina Basrani

3 Special Situations 39
   Bettina Basrani

4 Intraoral Digital Imaging 43
   Ernest W. N. Lam

5 Radiographic Considerations Before the Endodontic Treatment Is Initiated 49
   Calvin D. Torneck

6 Radiographic Analysis of Anomalous Tooth Forms and Morphological Variations Related to Endodontics 54
   Jeffrey M. Coil

Part 2: Endodontic Disease 79

7 Radiographic Expression of Endodontic Disease 81
   Calvin D. Torneck

8 Image Interpretation of Periapical Abnormalities 101
   Ernest W. N. Lam

9 Radiographic Interpretation of Traumatic Injuries 129
   Nestor Cohenca

10 Radiographic Analysis of Acquired Pathological Dental Conditions 153
    Amir Azarpazhooh

11 Radiographic Analysis of Periodontal and Endodontic Lesions 166
    Jim Yuan Lai and Bettina Basrani
<table>
<thead>
<tr>
<th>Part 3: Sequence of Endodontic Treatment</th>
<th>191</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 Radiographic Considerations during the Endodontic Treatment</td>
<td>193</td>
</tr>
<tr>
<td>Bettina Basrani</td>
<td></td>
</tr>
<tr>
<td>14 Electronic Apex Locators and Conventional Radiograph in Working Length Measurement</td>
<td>218</td>
</tr>
<tr>
<td>Gevik Malkhassian, Andres Plazas, and Yosef Nahmias</td>
<td></td>
</tr>
<tr>
<td>15 Vertical Root Fractures: Radiological Diagnosis</td>
<td>235</td>
</tr>
<tr>
<td>Anil Kishen and Harold H. Messer</td>
<td></td>
</tr>
<tr>
<td>Part 4: Teaching and Research</td>
<td>267</td>
</tr>
<tr>
<td>17 Radiographic Consideration for Endodontic Teaching</td>
<td>269</td>
</tr>
<tr>
<td>Bettina Basrani</td>
<td></td>
</tr>
<tr>
<td>18 Micro-Computed Tomography in Endodontic Research</td>
<td>278</td>
</tr>
<tr>
<td>Mana Mirfendereski and Ove Peters</td>
<td></td>
</tr>
<tr>
<td>Part 5: Advanced Techniques</td>
<td>285</td>
</tr>
<tr>
<td>19 Alternative Imaging Systems in Endodontics</td>
<td>287</td>
</tr>
<tr>
<td>Elisabetta Cotti and Girolamo Campisi</td>
<td></td>
</tr>
<tr>
<td>20 Introduction to Cone Beam Computed Tomography</td>
<td>304</td>
</tr>
<tr>
<td>Ernest W. N. Lam</td>
<td></td>
</tr>
<tr>
<td>21 Interpretation of Periapical Lesions Using Cone Beam Computed Tomography</td>
<td>307</td>
</tr>
<tr>
<td>Carlos Estrela, Mike Reis Bueno, and Ana Helena Gonçalves Alencar</td>
<td></td>
</tr>
<tr>
<td>Part 6: Clinical Cases</td>
<td>329</td>
</tr>
<tr>
<td>22 Clinical Cases</td>
<td>331</td>
</tr>
<tr>
<td>Le O’Leary</td>
<td></td>
</tr>
<tr>
<td>23 Clinical Impact of Cone Beam Computed Tomography in Root Canal Treatment</td>
<td>367</td>
</tr>
<tr>
<td>Carlos Bóveda Z.</td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td>416</td>
</tr>
</tbody>
</table>

To download figures and tables from this book, please visit www.wiley.com/go/basrani.
Dr. Bettina Basrani is Tenured Associate Professor and Co-Director, MSc Program in Endodontics on the Faculty of Dentistry, University of Toronto, in Ontario, Canada. Dr. Basrani received her D.D.S. degree from the University of Buenos Aires and a Specialty Diploma in Endodontics and Ph.D. from Maimonides University in Buenos Aires, Argentina. A long-time educator and researcher, she began her teaching career at the University of Buenos Aires. In 2000, she moved to Canada to serve as Head of the Endodontic Program at Dalhousie University, Halifax, Nova Scotia. In 2004, she moved to Toronto, where she has continued her academic and clinical work, nurturing two careers in parallel—those of educator/researcher and practicing clinician. Internationally recognized as a leading authority in endodontics and as an excellent lecturer, effectively combining clinical and scientific information, Dr. Basrani has received many teacher awards throughout her career and has international courses and lectures, over 30 peer-reviewed scientific publications, textbook chapters, and abstracts to her credit. She serves as an Editorial Board Member for the *Journal of Endodontics* and *International Endodontic Journal*. Dr. Basrani is a member of many endodontics societies around the world, and also serves on the special committee to develop researchers of the American Association of Endodontics. She makes her home in Toronto, where she is married to Canadian psychiatrist Dr. Howard Alter and spends her leisure time taking their sons, Jonathan and Daniel, to soccer practices, chess tournaments, skating lessons, and piano recitals.
Contributors

Ana Helena Gonçalves
Alencar, DDS, MSc, PhD
Professor of Endodontics
Department of Oral Science
Federal University of Goiás
Goiânia, GO, Brazil

Amir Azarpazhooh, DDS,
MSc, PhD, FRCD(C)
Assistant Professor
Discipline of Dental Public
Health and Discipline of
Endodontics
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada

Carlos Bóveda Z.
DDS, Specialist in
Endodontics
Private Practice
Limited to Endodontics
Centro de Especialidades
Odontológicas
Caracas, Venezuela

Mike Reis Bueno, DDS,
MSc, PhD
Professor of Semiology and
Stomatology
University of Cuiabá
Cuiabá, MT, Brazil
Contributors

Girolamo Campisi, MD
Specialist in Radiology
University of Cagliari
Italy

Mindy Cash, BSc, DDS
Lecturer
Oral and Maxillofacial Radiology
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada

Nestor Cohenca, DDS
Diplomate, American Board of Endodontics
Associate Professor,
Department of Endodontics
Adjunct Associate Professor,
Department of Pediatric Dentistry
School of Dentistry
University of Washington
Seattle, WA, USA

Jeffrey M. Coil, DMD, MSD, PhD, FRCD(C), FADI, FACD
Diplomate, American Board of Endodontics
Director of Graduate Endodontics
Department of Oral Biological & Medical Sciences
Faculty of Dentistry
University of British Columbia
Vancouver, British Columbia, Canada

Elisabetta Cotti, DDS, MS
Professor and Chairman
Department of Conservative Dentistry and Endodontics
University of Cagliari
Italy

Carlos Estrela, DDS, MSc, PhD
Chairman and Professor of Endodontics
Department of Oral Science
Federal University of Goiás
Goiânia, GO, Brazil

Anda Kfir, DMD
Lecturer
Specialist in Endodontics
Coordinator, Department of Endodontology
School of Dental Medicine
Tel-Aviv University
Tel-Aviv, Israel

Anil Kishen, BDS, MDS, PhD
Associate Professor
Discipline of Endodontics
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada
Jim Yuan Lai, DMD, MSc(Perio), MEd, FRCD(C)
Assistant Professor and Discipline Head
Periodontology
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada

Ernest W. N. Lam, DMD, MSc, PhD, FRCD(C)
Diplomate, American Board of Oral and Maxillofacial Radiology
Associate Professor and Head Discipline of Oral and Maxillofacial Radiology
Faculty of Dentistry
University of Toronto
Toronto, Canada

Gevik Malkhassian DDS, MSc, FRCD(C)
Assistant Professor Discipline of Endodontics
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada

Harold H. Messer, MDSc, PhD
Emeritus Professor
Melbourne Dental School
University of Melbourne
Melbourne, Australia

Mana Mirfendereski, BSc, DMD, MSc, FRCD(C)
Discipline of Endodontics
University of Toronto
Toronto, Ontario, Canada

Yosef Nahmias, DDS, MSc
Private Practice
Oakville, Ontario, Canada

Le O’Leary, DDS
Private Practice
Plano, TX, USA

Dag Ørstavik, dr. odont.
Professor and Chairman
Department of Endodontics
Institute of Clinical Dentistry
Faculty of Dentistry
University of Oslo
Oslo, Norway
Ove Peters, DMD MS PhD
Diplomate, American Board of Endodontics
Professor and Co-Chair
Department of Endodontics
University of the Pacific,
Arthur A. Dugoni School of Dentistry
San Francisco, CA, USA

Calvin D. Torneck DDS, MS, FRCD
Diplomate, American Board of Endodontics
Professor Emeritus
Discipline of Endodontics
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada

Andres Plazas DDS,
Endodontist
Assistant Professor
Discipline of Endodontics
Faculty of Dentistry
University of Toronto
Foreword

The new edition of *Endodontic Radiology* represents a change of generations and the evolutionary process this change encompasses.

The first edition of *Radiologia en Endodoncia* was a unique textbook published in Spanish in 2003. It was edited by Prof. Enrique E. Basrani, Dr. Ana Julia Blank, and Dr. Maria Teresa Cañete, all from the Maimonides University in Buenos Aires, Argentina, and included contributions from 21 prominent educators and clinicians from Latin America and beyond. It was the first textbook to provide readers with a comprehensive digest of all aspects of radiology related to endodontic therapy. It explained radiology from the endodontic perspective, and it explained many aspects of endodontics through the radiology perspective. It captured the state-of-the-art radiographic technologies available to clinicians at the beginning of the 21st century. In addition to a comprehensive, detailed description of the basic “bread-and-butter” applications of radiology in endodontics, the first edition included at its end several brief chapters featuring the “cutting edge” technologies of that period, including digital radiography, electronic image processing, and digital subtraction. Little could be known at that time that within one decade, what was cutting edge would become the bread and butter, and that newer technologies would emerge that would revolutionize the applications of radiology in endodontics.

The second edition of *Endodontic Radiology* in front of you has been authored by Dr. Bettina Basrani, the late Prof. Basrani’s daughter. She is the representative of the younger generation, but she remains her father’s daughter. An experienced endodontist, she is as dedicated to endodontics and to education as her father was throughout his illustrious career. While in the first edition she coauthored a short chapter with colleagues, she
has since taken it upon herself to update her late father’s labor of love and to make it current for the contemporary clinician. True to her generation, she has been able to expand international and interdisciplinary collaborations, allowing the reader to benefit from contributions by 19 foremost educators, researchers, and clinicians from Australia, Brazil, Canada, Israel, Italy, Norway, the United States and Venezuela, spanning across four different disciplines of dentistry. With access to this collective international expertise, the reader gains an in-depth and wide-ranging insight into the current state of radiology applications in endodontics.

With the change of generations in authorship, the second edition’s content also has evolved greatly from the original published in less than one decade ago. In this respect it provides the clinician an updated, current, and thorough reference to the critical role of radiology in all steps of endodontic therapy. Accurate diagnosis of endodontic diseases and sequelae after traumatic injury to teeth, appreciation of the sites and extent of associated bone loss, insight into the anatomy of teeth, morphology of the endodontic system and resorptive defects, precise execution of endodontic treatment procedures, assessment of treatment outcome, documentation and effective communication of treated cases among dental professionals, all require sophisticated use of radiology at each step. The second edition of *Endodontic Radiology* will guide the clinician toward achieving the required sophistication in applying the most current radiological tools to benefit their patients.

Another aspect of the generation change and evolution is extension of the availability of the information to a much wider readership. Whereas the first edition could only benefit readers versed in Spanish, the second edition of *Endodontic Radiology* published in English will benefit numerous clinicians all over the world.

All clinicians, both general dentists and specialists in different disciplines of dentistry including endodontists, will acquire critical knowledge by reading this current textbook. The acquired knowledge, in turn, will provide the clinicians with the basis for sophisticated use of radiological tools when providing endodontic care to their patients, resulting in upgraded quality of treatment.

**Prof. Shimon Friedman**
Head, Discipline of Endodontics
Director, MSc Program in Endodontics
Faculty of Dentistry
University of Toronto
Toronto, Ontario, Canada
Radiology is an indispensable tool in endodontic practice and provides the clinician with information that is not otherwise accessible. It is also an ever-expanding field driven exponentially by constant changes in technology. It is for these reasons that this textbook, devoted to achieving a mastery of radiographic techniques and understanding in radiographic interpretation as applied to endodontic, is of particular importance to those who teach, study, and practice in this field.

There has been only one textbook dedicated entirely to endodontic radiology that has been published up to now, Radiología en Endodoncia, by my father, Professor Emeritus Dr. Enrique Basrani (1928–2001) in collaboration with his colleagues, Dr. Teresa Cañete and Dr. Ana Blank. Published in Spanish in 2001, it gained wide academic acceptance in many Spanish-speaking countries. This English revised version on the same topic both fills an academic void for those who practice endodontics in non-Spanish-speaking countries and satisfies my personal wish to continue the work originally undertaken by my father. Radiología en Endodoncia was his sixth and last book. He was a pioneer of our specialty, internationally recognized for his ability to inspire and motivate others to love what he loved: The art of endodontics. Now, eleven years after his untimely death, he is still remembered by his colleagues, peers, and students for his unique vision and passion for knowledge.

The field of endodontic imaging is changing and expanding rapidly, and it is for this reason that several chapters incorporating the application of the newer technologies and the information gained through them have been included in this edition.

This book is not intended to cover in detail every aspect of dental radiology; its purpose is directed toward improving endodontic treatment outcomes by identifying and expanding the link between endodontic practice and radiographic imaging.

Clarity in endodontics is comprehended through the shadows. As Leonard Cohen put it: “That’s how the light gets in.” Enjoy the book, and I welcome your feedback at any time.

Bettina Basrani
I would like to thank the Dean of the University of Toronto, Faculty of Dentistry, Dr. David Mock, for granting me a sabbatical from my position at the Department of Endodontics to pursue writing this book. This decision was enthusiastically supported by the Head of the Endodontic Department, Dr. Shimon Friedman, who has always been ahead of his time and who constantly inspires all of us who work around him with his knowledge and wisdom.

Special recognitions to my collaborators on this project, all keen, clever, and dedicated specialists who contributed the highest quality of knowledge. Some of the collaborators have a lifetime of experience and others are recent graduates; some are pure academicians while others are pure clinicians. I thank them all for the enthusiasm they brought to the project.

I want to acknowledge Dr. Lyon Schwartzben for his invaluable help in editing the early manuscript.

Special thanks to Andrea Cormier and James Fiege from the Media Services Department at the Faculty of Dentistry for their beautiful photographs and diagrams.

My gratitude to Rick Blanchette, Melissa Wahl, and all the team from Wiley-Blackwell, who trusted and honored me with this project and helped me throughout the process.

My final thanks are to my family, starting with my parents Clarita and Enrique Basrani for providing me with the opportunity to be where I am today. They have always been my biggest fans and gave me motivation and inspiration to follow my academic career without limits and with unconditional love. My brother, Dr. Damian Basrani, for his care and support throughout my entire personal life and professional career. To my dear and extraordinary husband, Dr. Howard Alter, for keeping me grounded, and because his encouragement, input, and constructive criticism have been priceless.

Finally, I’d like to conclude by thanking you, the reader of *Endodontic Radiology, Second Edition*, for reading this book, and hope that it has served its purpose of enhancing your clinical practice. Enjoy!
Endodontic Radiology, Second Edition
Part 1

General Principles and Techniques

Chapter 1  General Principles of Radiology in Endodontics
Chapter 2  Intraoral Radiographic Principles and Techniques
Chapter 3  Special Situations
Chapter 4  Intraoral Digital Imaging
Chapter 5  Radiographic Considerations before the Endodontic Treatment Is Initiated
Chapter 6  Radiographic Analysis of Anomalous Tooth Forms and Morphological Variations Related to Endodontics
General Principles of Radiology in Endodontics

Anda Kfir and Bettina Basrani

“. . . And God said: Let there be light. And there was light. And God saw the light, which it was good; and God divided the light from the darkness . . .” (Genesis 1:3–4, The Bible, King James version)

Endodontics is the branch of dentistry in which radiology plays a critical indispensable role. Radiology illuminates what otherwise would be dark and hidden zones and allows the dentists to visualize areas not accessible by other diagnostic means. It is the use of oral radiographs which enables visualization of the bone around the apices of the teeth, as well as the results of the root canal treatments, and as such it has allowed turning endodontics into a scientific professional entity (Grossman, 1982).

History of dental radiology

The many developments over the years in the field of dental radiology cannot be adequately appreciated without looking back to the discovery of X-radiation.

The cathode tube

The first step occurred in 1870. Wilhelm Hittorf found that a partially evacuated discharged tube could emit rays able to produce heat and cause a greenish-yellow glow when they strike glass. By placing a magnet within easy reach and changing the path of the rays Varley determined that these rays were negatively charged particles and they were later called electrons. It was Goldstein from Germany who called the streams of charged particles “cathode rays.” He was followed by William Crooks, an English chemist, who redesigned the vacuum tube which subsequently was known as Hittorf–Crookes tube. In 1894, Philip Lenard studied the cathode rays’ behavior with the aid of a tube with an aluminum window. He placed screens with fluorescent salts outside the aluminum window and found that most of the rays could penetrate the window and make the fluorescent screen glow. He noticed that when the tube and screens were separated, the light emitted decreased. When they were separated by 8 cm, the screens would not fluoresce.
Radiographs

Dr. Wilhelm Conrad Roentgen from Würzburg, Germany, studied rays emitted from a tube in a darkened room; he noticed that some crystals of barium platinocyanide from a table nearby became fluorescent. The observation was made on the evening of Friday, November 8, 1895. Roentgen understood that the tube was emitting some hitherto unknown kind of ray which produced the fluorescence and called this rays “X-rays” because the nature of the rays was unknown and uncertain. He also noticed that if a metallic object was placed between the tube and screen, it cast a shadow, and he reported a number of “shadow-pictures” he had photographed. One was the shadow of a set of weights in a closed box; another was a piece of metal whose homogeneity was revealed by the X-rays. But the most interesting picture was of the bones of his wife’s hand which was exposed to the rays for 15 minutes. This was the first radiograph taken of the human body and represented the beginning of practicing radiology in medicine and dentistry.

Roentgen continued to study the X-rays and found that the beam could be diminished in relation to what was placed in its path. The only material that completely absorbed the beam was lead. He went on with his experiments and finally defined the following features of X-rays: (1) they are able to distinguish between various thicknesses of materials; (2) they cause certain elements to fluoresce; (3) they are made of pure energy with no mass; (4) they go in straight lines; and (5) they are not detectable by human senses. Roentgen’s great work revolutionized the diagnostic capabilities of the medical and dental professions, and he was awarded with the first Nobel Prize in Physics in 1901. In modern terms, X-ray radiation is a form of electromagnetic radiation with a wavelength from 0.01 to 10 nm. It is emitted from a metal anode (usually tungsten, molybdenum, or copper) when subjected to a stream of accelerated electrons coming from the cathode.

Dental radiographs

It was Otto Walkhoff, a German dentist, who made the first dental radiograph 14 days after Roentgen’s discovery.

He placed a glass photographic plate wrapped in black paper and rubber in his mouth and submitted himself to 25 minutes of X-ray exposure. In that same year, W.J. Morton, a New York physician, made the first dental radiograph in the United States using a skull and also took the first whole body radiograph. A dentist from New Orleans, Dr. C. Edmund Kells, made the first intraoral radiograph on a patient in 1896. Kells exposed his hands to X-rays every day for years by holding the plates and trying to adjust the quality of the beam in order to achieve clear images. Unfortunately, this exposure led to the development of cancer in his hand which resulted in the amputation of his arm, demonstrating the potential risk and harmful effects of X-rays. Three years later (1899), Kells used the X-ray to determine tooth length during root canal therapy.

Radiograph machines

William H. Rollins, a Boston dentist, developed the first dental X-ray unit in 1896, as well as intraoral film holders. He was the first one to publish a paper on the potential dangers of X-rays. Rollins proposed the use of filters to suspend the dangerous parts of the X-ray beam, the use of collimation, and the practice of covering the patient with lead to prevent X-ray penetration. Rollins also pointed out the importance of setting safe and harmful dose limits. In 1913, William D. Coolidge, an electrical engineer, developed a high vacuum tube that contained a tungsten filament, which became the first modern X-ray tube. Further in 1923, Coolidge and the General Electric Corporation immersed an X-ray tube, in oil, inside the head of an X-ray machine. This eliminated the accidental exposure to high voltage shock, cooled the tube, and served as a model for all modern dental X-ray machines. From that time on, the dental X-ray machine did not change much until 1957 when a variable kilovoltage dental X-ray machine was introduced, followed by the long-cone head in 1966.

Dental X-ray film

Dental X-ray films also changed through the years; from the original glass photographic plates,
General Principles of Radiology in Endodontics

than those that are less active. Susceptible cells include hematopoietic cells, immature reproductive cells, young bone cells, and epithelial cells. The more radiation-resistant cells include the cells of bones, muscles, and nerves. Ionizing radiation has the effect of increasing the incidence and severity of DNA defects during mitotic division of cells and also interferes with the normal process of repair of these defects. As a consequence, the behavior of the cells may be altered and predispose them to malignant changes. To protect radiation exposure for patients and operators, the use of radiation is governed by state, national, and international agencies. Based on recommendations of the International Commission for Radiation Protection (ICRP), many countries have introduced the following regulation form on radiation protection: (1) doses should be kept as low as reasonably achievable (ALARA); (2) there should be a net benefit for the patient from the use of radiation; (3) radiation doses should not exceed limits laid down by the ICPR; (4) a shield or lead apron should always be used to protect the thyroid and the pelvis; (5) only dental X-ray equipment that is properly collimated, adequately filtered, and well calibrated should be used; and (6) the X-ray operator shall stand outside the path of the useful X-ray beam or behind a suitable barrier, and should not hold the film in place for the patient during exposure (NCRP Report, 1970, 1989, 1990, 1988; Richard and Colquit, 1981).

Objectives of dental radiography

Dental radiographs are an essential part of the dental diagnostic process, as they enable the practitioner to see many conditions that are not apparent clinically and which could otherwise go undetected. An oral examination without dental radiographs limits the practitioner to what is seen clinically—the surfaces of teeth and soft tissues. Numerous conditions of the teeth and jaws can only be detected on dental radiographs. Missing teeth, extra teeth, and impacted ones, dental caries, periodontal disease as well as root canal fillings, periapical lesions, cysts, and tumors are among the most common conditions that cannot otherwise be diagnosed or properly detected. Suspected pathological conditions can often be confirmed only on

---

Table 1.1 Milestones in the history of dental radiography.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Manufacturer/Inventor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1895</td>
<td>Discovery of X-rays</td>
<td>W.C. Roentgen</td>
</tr>
<tr>
<td>1896</td>
<td>First dental radiograph</td>
<td>O. Walkhoff</td>
</tr>
<tr>
<td>1901</td>
<td>First paper on risks of X-radiation</td>
<td>W.H. Rollins</td>
</tr>
<tr>
<td>1913</td>
<td>First prewrapped dental films</td>
<td>Eastman Kodak Company</td>
</tr>
<tr>
<td>1913</td>
<td>First X-ray tube</td>
<td>W.D. Coolidge</td>
</tr>
<tr>
<td>1923</td>
<td>First dental X-ray machine</td>
<td>Victor X-ray Corporation</td>
</tr>
<tr>
<td>1947</td>
<td>Introduction of long-cone Paralleling technique</td>
<td>F.G. Fitzgerald</td>
</tr>
<tr>
<td>1957</td>
<td>First variable kilovoltage dental X-ray machine</td>
<td>General Electric</td>
</tr>
</tbody>
</table>

hand-wrapped dental X-ray packets in 1896, to the prewrapped intraoral films manufactured by the Eastman Kodak company which were first introduced in 1913. The current high-speed, double-emulsion films require a very short exposure time and were designed to further reduce X-ray exposure.

The bisecting oral radiographic technique was first introduced in 1904 by Weston Price, and the bite-wing technique was introduced by H. Raper in 1925. The paralleling technique was originally introduced in 1896 by C.E. Kells and reformed in 1947 by F.G. Fitzgerald with the introduction of the long-cone (see Table 1.1) (Cieszynski, 1925).

Hazards of X-ray radiation

Ionizing radiation can have harmful effects. The largest man-made source of exposure of radiation to humans is from medical and dental radiographic examinations. Yet one should keep in mind that we are also exposed to other sources and types of radiation. These include radiation from building materials and luminous goods (i.e., television, computer), as well as natural sources (i.e., cosmic rays, soil).

The risk effects depend on the dose received, the frequency of exposure, and the type of tissue irradiated. In general, tissues whose cells divide frequently are more sensitive to the effects of radiation than those that are less active. Susceptible cells include hematopoietic cells, immature reproductive cells, young bone cells, and epithelial cells. The more radiation-resistant cells include the cells of bones, muscles, and nerves. Ionizing radiation has the effect of increasing the incidence and severity of DNA defects during mitotic division of cells and also interferes with the normal process of repair of these defects. As a consequence, the behavior of the cells may be altered and predispose them to malignant changes. To protect radiation exposure for patients and operators, the use of radiation is governed by state, national, and international agencies. Based on recommendations of the International Commission for Radiation Protection (ICRP), many countries have introduced the following regulation form on radiation protection: (1) doses should be kept as low as reasonably achievable (ALARA); (2) there should be a net benefit for the patient from the use of radiation; (3) radiation doses should not exceed limits laid down by the ICPR; (4) a shield or lead apron should always be used to protect the thyroid and the pelvis; (5) only dental X-ray equipment that is properly collimated, adequate filtered, and well calibrated should be used; and (6) the X-ray operator shall stand outside the path of the useful X-ray beam or behind a suitable barrier, and should not hold the film in place for the patient during exposure (NCRP Report, 1970, 1989, 1990, 1988; Richard and Colquit, 1981).
General Principles and Techniques

Dicular tissue as a consequence of pulpal infection and necrosis. The irritants exiting the infected root canal to the periradicular tissues activate both nonspecific inflammatory reactions and specific immune reactions. These not only prevent the spread of infection to the surrounding bone and to remote sites but also result in local bone resorption that can be visualized by radiographic techniques (Stashenko et al., 1998).

The use of radiographs in endodontics is intensive and not limited to the above. They are used to define anatomical features of the roots, such as numbers of roots, their locations, their shape and size, as well as the presence of root canal space. Technical aspects of root canal treatment are greatly assisted by radiographs. These include confirming the length of root canals before instrumentation, determining position of instruments during the procedure and of master cones at the obturation stage. Evaluation of the quality of the root canal filling is based mainly on its radiographic appearance and so is the evaluation of the result of treatment during the follow-up that takes place later. Traumatic injuries to the dentition also make use of radiography for the diagnosis of fractures in the roots and/or the alveolus or for examining the soft tissues for teeth fragment that may have been embedded in them during the traumatic incident. One can hardly imagine endodontic treatment without the assistance of radiography (Cotti and Campisi, 2004; Nair, 1998a; Torabinejad et al., 1985).

X-rays and endodontics

Endodontics is the branch of dentistry that has benefited the most from the introduction of X-rays into everyday dental practice. X-rays allow dentists to visualize areas not accessible by any other diagnostic means such as changes that occur in the bone surrounding the apices of nonvital teeth, intricate root canal anatomy, as well as the ability to follow up the results of endodontic treatment (Gröndahl and Huumonen, 2004). Due to introduction of X-rays, endodontics could turn from an empirical pursuit to a soundly based scientific discipline. Intraoral periapical, occlusal, and panoramic radiographs form the backbone of the endodontic diagnostic process, treatment procedures, and follow-up routine in most of endodontic cases.

Most osteolytic lesions in the jaws result from the pathological changes occurring in the periradicular tissue as a consequence of pulpal infection and necrosis.

The irritants exiting the infected root canal to the periradicular tissues activate both nonspecific inflammatory reactions and specific immune reactions. These not only prevent the spread of infection to the surrounding bone and to remote sites but also result in local bone resorption that can be visualized by radiographic techniques (Stashenko et al., 1998).

The use of radiographs in endodontics is intensive and not limited to the above. They are used to define anatomical features of the roots, such as numbers of roots, their locations, their shape and size, as well as the presence of root canal space. Technical aspects of root canal treatment are greatly assisted by radiographs. These include confirming the length of root canals before instrumentation, determining position of instruments during the procedure and of master cones at the obturation stage. Evaluation of the quality of the root canal filling is based mainly on its radiographic appearance and so is the evaluation of the result of treatment during the follow-up that takes place later. Traumatic injuries to the dentition also make use of radiography for the diagnosis of fractures in the roots and/or the alveolus or for examining the soft tissues for teeth fragment that may have been embedded in them during the traumatic incident. One can hardly imagine endodontic treatment without the assistance of radiography (Cotti and Campisi, 2004; Nair, 1998a; Torabinejad et al., 1985).

Figure 1.1 (a) Tooth #48 presenting apical lesion. (b) Tooth #48 after root canal treatment presenting healed periapex.
**Limitations of X-rays in endodontics**

With all its benefits, one has to keep in mind that conventional dental radiograph represents merely a two-dimensional (2D) shadow of a three-dimensional (3D) structure (Bender and Seltzer, 1961). As such, it has substantial limitations that should be recognized and taken into consideration when interpreting such records. The buccolingual dimension is not represented in conventional radiographs, thus limiting their interpretation as to the actual 3D size of the radiolucent lesions and their spatial relationship with anatomic landmarks (Cotti and Campisi, 2004; Gröndahl and Huumonen, 2004; Huumonen and Orstavik, 2002). It should also be kept in mind that radiographs do not provide information as to the true nature of the tissue that replaced the bone. Chronic inflammatory lesions cannot reliably be differentiated from cysts or from scar tissue that also mimic osteolytic lesions (Nair, 1998b; Simon, 1980).

For a radiolucent lesion to appear in the radiograph, a substantial amount of bone must have been resorbed; thus, the lack of radiolucency should not be interpreted as absence of bone resorbing process. Furthermore, bone resorption of the cancellous bone surrounding the apex may not be recognized in a periapical radiograph as long as a substantial part of the covering cortical bone has not been resorbed as well (Gröndahl and Huumonen, 2004; Marmary et al., 1999).

**Observer bias**

Radiographic interpretation is prone to observer bias. Goldman has found that when recall radiographs of endodontic treatment were assessed for success and failure by different radiologists and endodontists, there was more disagreement than agreement between the examiners (Goldman et al., 1972).

Since radiographs are an essential tool in the diagnostic process, they should be carefully analyzed and interpreted with caution.

**Digital radiography systems (DRS)**

Oral radiographic sensors capable of providing instant images were introduced in 1984 by Dr. Francis Mouyen from Toulouse, France, and formed the basis for the DRS (Mouyen, 1991). Various digital imaging modalities are available today based on sensors using solid-state technology, such as charge-coupled device (CCD), complementary metal oxide semiconductor (CMOS), or photostimulable phosphor (PSP) technology (Nair and Nair, 2007; Naoum et al., 2003; Wenzel and Gröndahl, 1995). Digital radiography has become an indispensable diagnostic tool in daily dental practice. Requiring a lower radiation dose and providing instantaneous high-resolution digital images make digital radiography especially useful when providing endodontic treatment. Manipulation or processing of the captured image to enhance diagnostic performance makes digital radiography even more versatile in this particular use as it greatly reduces the need to re-expose patients for retakes. In an era of digital archiving, transmission, and long-distance consultation, digital radiography becomes more and more popular. Nevertheless, one should keep in mind that the image is generated using a software program, and as such, it may be subjected to adding or deleting relevant information. The widespread use of these systems, each using their own software, made it important that one software package will be able to adequately handle images produced using another package. The Digital Imaging and Communications in Medicine (DICOM) Standard has therefore been introduced and accepted as the universal standard for digital image transmission and archiving (Calberson et al., 2005; Farman and Farman, 2005). This standard ensures that all images are readable with any viewing software without loss of fidelity or diagnostic information.

Digital images have been shown to perform comparably with conventional intraoral film for a variety of diagnostic tasks (Farman and Farman, 2005; Wenzel and Gröndahl, 1995). However, with continuous upgrading of both software and hardware, and especially with the great advances being made in sensor technology, one may expect great improvement in image quality in the near future.

**Characteristics of the radiograph**

Radiographic examination is carried out to provide maximum differentiation of tissue structures. A high-quality radiograph is characterized by details
which are defined as delineation of the minute structural elements and borders of the objects in the image, by its *density* or the degree of “blackness” on a radiographic film that depends on the amount of radiation reaching a particular area on the film, and by its *contrast* or the ratio between black and white and the different shades of gray on proximate areas of the film. *Distortion* or an unequal magnification of the object causing changes in its size and shape may be another factor affecting the quality of a given radiograph (Anderson, 1974).

**Characteristics of a correct radiograph**

The requirements for achieving a correct radiograph are as follows:

1. It should record the complete area of interest. The full length of the root and at least 2 mm of periapical bone must be visible.
2. If pathology is evident; the complete rarefaction plus normal bone should be present in the film. In some cases of large areas, an occlusal radiograph or a panoramic radiograph (PAN) maybe needed.
3. Films should have the minimal amount of distortion.
4. Films should have optimal density and contrast.

**Defective radiographs**

Errors in improperly exposing or processing dental films can produce dental radiographs of nondiagnostic quality. These are known as defective radiographs (Free-Ed.Net, 2006). The dental X-ray specialist should be familiar with the common causes of faulty radiographs and how to prevent them.

1. **Underexposed image** (Figure 1.2): An image that is too light which may be caused by not enough exposure or not enough development time.
2. **Overexposed image** (Figure 1.3): An overexposed image, an image that is too dark, may be caused by very long exposure, or long development time.
3. **Blurred image** (Figure 1.4): A blurred image is easily recognized by the appearance of more than one image of the object, or objects, on the film. It may be caused by movement of the patient, film, or tube during exposure.
4. **Partial image** (Figure 1.5): Also known as colimation. A partial image may be caused by failure to immerse the film completely in the developing solution, contact of the film with another film during developing, or improper alignment of the central ray.