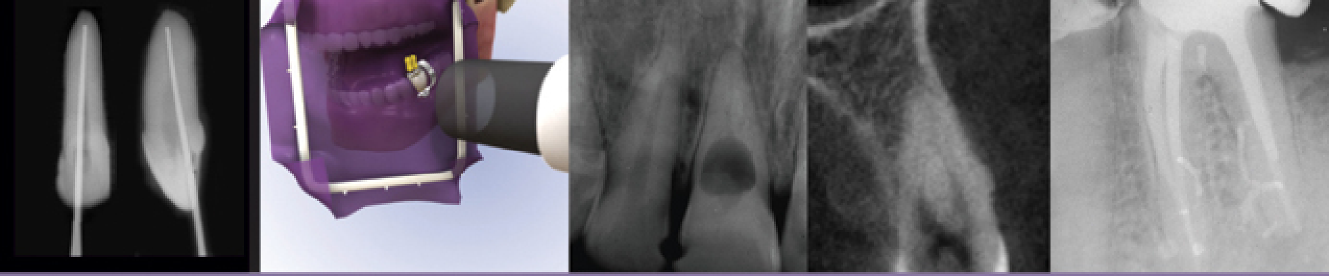
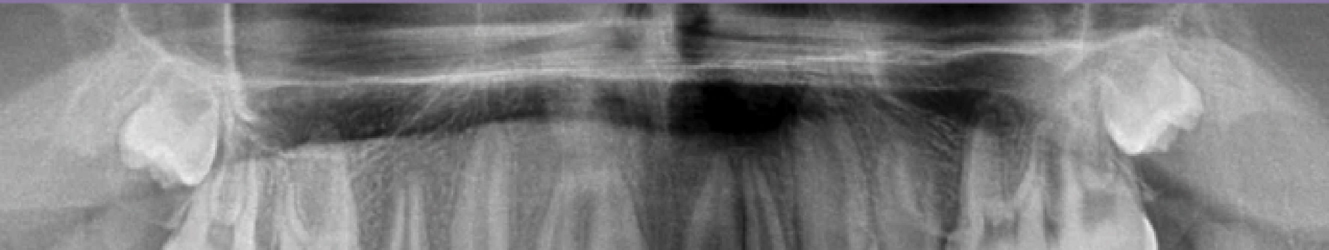


Second Edition

Endodontic Radiology

Edited by Bettina Basrani



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Endodontic Radiology, Second Edition

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Edited by

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> *"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

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.

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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


Professor Emeritus Enrique E. Basrani

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 sequellae 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.

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Preface

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, *Radiologia 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. *Radiologia 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

Acknowledgments

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

1 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.

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Radiographs

Dr. Wilhelm Conrad Roentgen from Würzberg, 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,

Table 1.1 Milestones in the history of dental radiography.

1895	Discovery of X-rays	W.C. Roentgen
1896	First dental radiograph	0. Walkhoff
1901	First paper on risks of X-radiation	W.H. Rollins
1913	First prewrapped dental films	Eastman Kodak Company
1913	First X-ray tube	W.D. Coolidge
1923	First dental X-ray machine	Victor X-ray Corporation
1947	Introduction of long-cone Paralleling technique	F.G. Fitzgerald
1957	First variable kilovoltage dental X-ray machine	General Electric

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 filtrated, 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

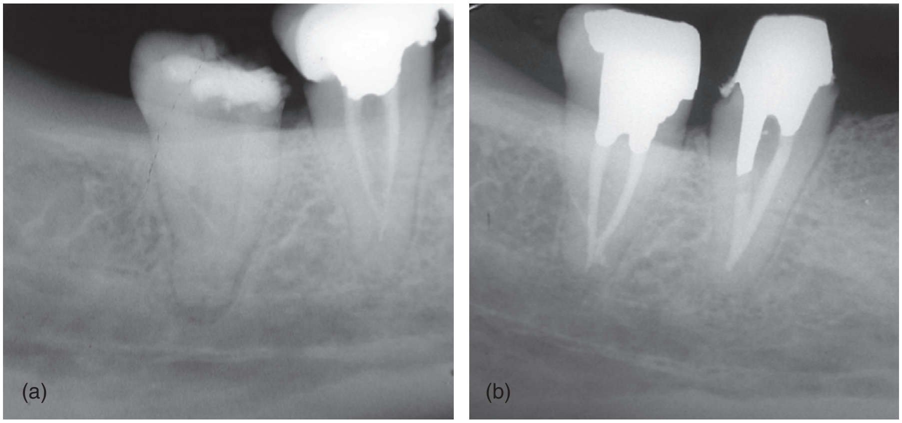

Figure 1.1 (a) Tooth #48 presenting apical lesion. (b) Tooth #48 after root canal treatment presenting healed periapex.

using radiographs. Radiographs often contain a huge amount of information, far more than a written record will usually include. Therefore, initial radiographic examination may provide valuable baseline information about the patient. Follow-up radiographs can then be used to detect and evaluate subsequent changes resulting from treatment, trauma, or disease (Figure 1.1a,b). Patient communication may also greatly benefit from the use of dental radiographs (DeLyre and Johnson, 1995; Haring and Lind, 1996).

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).

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 cancelous 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 collimation. 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.

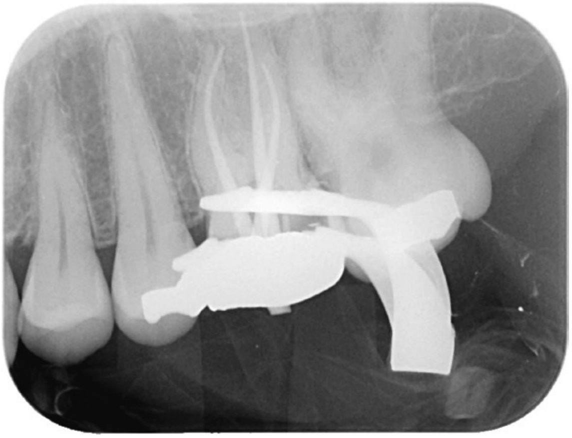

Figure 1.2 Underexposed radiograph.

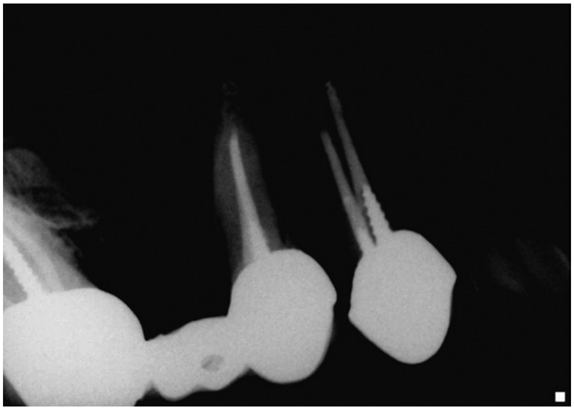

Figure 1.3 Overexposed radiograph.

Figure 1.4 Blurry radiograph.

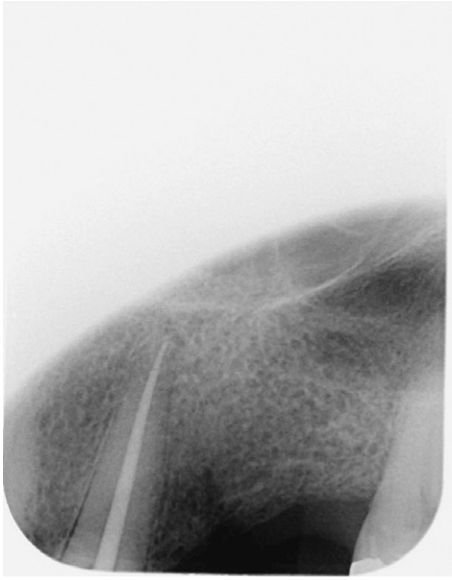

Figure 1.5 Collimated radiograph.

Figure 1.6 Elongated radiograph.

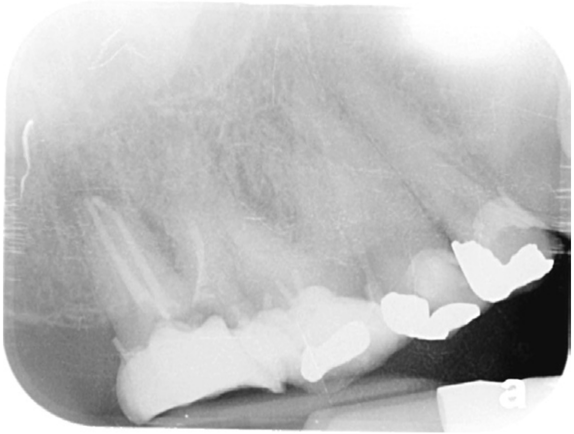

Figure 1.7 Fogged radiograph.

5. Distorted image (Figure 1.6): A distorted image may be caused by improper angulation of the central ray due to bending of the film or sensor.
6. Fogged image (Figure 1.7): A fogged film can be caused by exposure of film to light during storage, or leaving film unprotected (i.e., outside the lead-lined box or in the X-ray room during operation of the X-ray machine) or use of film that has been exposed to heat or chemical fumes, use of improperly mixed or contaminated developer, or defective safelight.
7. Stained or streaked film: Stained or streaked film may be caused by dirty solutions, dirty film holders or hangers, incomplete washing, or solutions left on the workbench.

8. Scratched film: When a film is scratched by film holders or hangers during the development process or when the digital PSP sensor needs to be replaced (Figure 1.8).
9. Lead-foil image (Figure 1.9): A lead-foil image occurs when the embossing pattern from the lead-foil backing appears on the radiograph. The embossing pattern consists of raised diamonds across both ends of the film. This happens when the film is placed in backwards.
10. No image: No image may result if no current was passing through the tube at the time of exposure or if the film was placed in the fixing solution before it was placed in the developing solution.

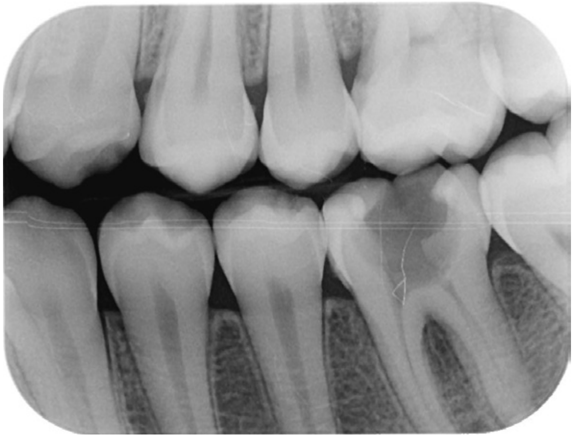

Figure 1.8 Scratched image.

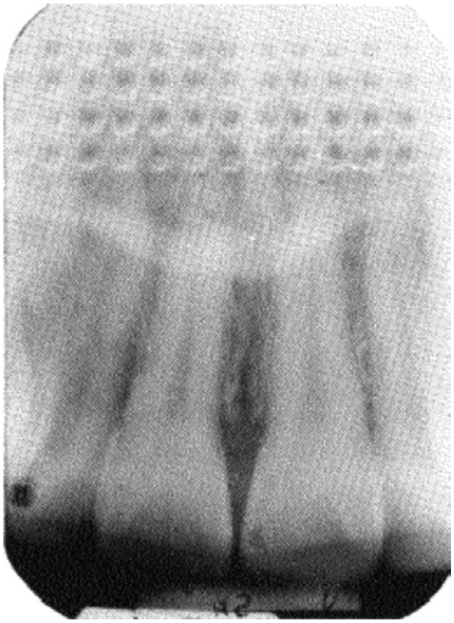

Figure 1.9 Lead foil image.

Control and characteristics of the X-ray machine

The X-ray beam emitted by the generating tube can be controlled and modified by the operator. The milliamperage or the amount of electric charge flowing past a circuit point at a specific time may affect the time required to generate a radiograph. High milliamperage is preferable in order to reduce the exposure time and limit radiation exposure; kilovoltage or the electrical potential difference between the anode and cathode of an X-ray tube is set for dental radiographs in the range between 65 and 90 kVp. Radiographs generated with high kilovoltage will show increased density and reveal more details and information. Exposure time is the parameter most frequently controlled by the operator. It is equivalent to the amount of light allowed to fall on the photographic film or sensor during the process of taking a photograph. Longer exposure time provides denser and darker radiographs. The spread of the X-ray beam is controlled by the collimator which consists of a barrier containing an aperture in the middle. It narrows the X-ray beam and minimizes the formation of secondary diffuse radiation. The collimator thus reduces exposure to excessive ionizing radiation and improves film quality. A filter made as an aluminum barrier is interposed in the path of the beam to eliminate X-rays with low penetrating power and low diagnostic benefit. The distance between target and object is yet another parameter that controls the intensity of the X-ray beam (Anderson, 1974).

Radiographic processing

One of the processing methods in dental radiography is the automatic processor. Most dental facilities use this processing method. With automatic processors, exposed films are immediately loaded to the processors by unwrapping films in the dark room. These processors are equipped with rollers and compartments filled with chemical solutions through which the film advances. At the end of the processing cycle, the film releases.

Another processing method in dental radiography is the manual process. This is done by using the standard time temperature method and a small container consisting of various solutions. The film has to pass through different solutions including developing, rising, fixing, washing, and drying in a temperature-controlled environment. These steps will give better dental radiographic image.

Table 1.2 Published guidelines on radiological image viewing conditions.

Source of guidelines	Brightness of viewing box (cd m^{-2})	Uniformity of viewing box (%)	Ambient lighting (lux)
WHO (WHO, 1982)	1500–3000	≤15	≤100
CEC (CEC, 1997)	≥1700	≤30	≤5

WHO, World Health Organization; CEC, Commission of European Communities.

Viewing conditions for radiographs

Accurate diagnosis from radiographs depends upon optimal viewing conditions.

A magnifier-viewer and adequate light are of the utmost importance (Brynolf, 1971). Sensitivity and specificity has been shown to be reduced with inappropriate illumination (Patel et al., 2000). To maximize visual acuity, it is important that the retinal cones of the human eye receive an incident luminance of 100 candela per meter (cdmJ) (CEC, 1990). In diagnostic radiology, viewing boxes with low brightness will reduce the light reaching the eye, limiting visual acuity, and thus reducing the ability to carry out adequate assessment of radiographs. A good viewing box should also demonstrate consistent spatial illumination; otherwise, areas of the image will transmit less light than adjacent areas even when optical densities in the two areas are the same. Also, ambient lighting should be minimized (see Table 1.2) (Abildgaard and Notthellen, 1992).

Radiographic interpretation

Finally, the clinical information that can be derived from a radiograph depends on interpreting what is seen on the film. Such interpretation should be performed systematically. An organized method for evaluation and interpretation of all types of radiographs should be applied on a series Wuehrmann (1970). One structure should be reviewed at a time. For example, the lamina dura is followed around the first tooth on the left and then around the next tooth and the next, until the full mouth is scanned. Attention is then turned to the next structure, root form, tooth crowns, and so on. Much of radiographic interpretation is based on differentiation of normal versus abnormal conditions. Radiographical interpretation requires a comprehensive knowledge and familiarity of normal radiographic anatomy and of the oral cavity. Accurate interpretation requires the integration of clinical data, and information provided by the patient with the radiographic data is mandatory.

New horizons in endodontic imaging

Alternative imaging techniques have been introduced over the years to overcome the existing limitations of intraoral radiographs (Abrahams, 2001; Cohenca et al., 2007; Nair and Nair, 2007; Patel et al., 2007, 2009).

Computed tomography (CT)

Computerized axial tomography was first introduced by Hannsfield during the l970s. CT is an X-ray imaging technique that produces 3D images of an object by using a series of 2D sets of image data and mathematically reconstructing the part under observation in a series of cross sections or planes: axial, coronal, and sagittal (Hannsfield, 1973). CT is exceptional in that it provides imaging of a combination of soft tissues, bone, and blood vessels, and the technique became widely used for the diagnosis of pathologic conditions in maxillary and mandibular bones (Cotti and Campisi, 2004). CT provides valuable information regarding anatomy of the roots and their relation to adjacent anatomical structures such as the maxillary sinus or the inferior alveolar nerve. Information about the thickness of the cortical plates in a given area and their relation to the root apices is of particular interest when endodontic surgery is concerned (Nair and Nair, 2007).

CT also has several drawbacks. On the one hand, it requires high radiation doses and on the other hand, it has a limited low resolution as far as endodontic diagnostic needs are concerned. Scatter from metallic objects presents yet another technological drawback. The high cost of the CT machines which is reflected in the cost of the scans and their limited availability are factors that limit the use of CT in endodontics (Patel, 2009; Patel et al., 2007).

Cone beam computed tomography (CBCT)

The CT is being greatly replaced in endodontics by CBCT (Figure 1.10) (Hashimoto et al., 2003, 2006, 2007). This technology was developed during the 1990s to produce 3D scans of the maxillofacial frame at a considerably lower radiation dose than the CT (Arai et al., 1999; Mozzo et al., 1999). The reduced radiation dose is a result of the rapid scan time, pulsed X-ray beam, and special image receptor sensors. CBCT differs from CT imaging in that the whole volume data are acquired by a single round of the scanner, rotating around the patient's head 180–360 degrees, depending on the CBCT properties. One rotation results in up to 570 projections or exposures. The X-ray beam is cone-shaped (hence the name of the technology) and captures a cylindrical or spherical volume of data called field of view (Patel, 2009; Patel et al., 2007). Voxel size used in CBCT ranges between 0.08 and 0.4 mm^3. The radiation dose may be further reduced by decreasing the size of the field of view, increasing the voxel size, and/or reducing the number of projection images during the rotation of the X-ray beam around the patient.

CBCT is usually served by unique software in which the images are displayed simultaneously in the three planes: axial, saggital, and coronal. Moving the cursor on one image simultaneously enables reconstruction in all three planes, allowing for dynamic evaluation of the area involved

CBCT is increasingly used in endodontics, allowing for the earlier detection of periapical disease as compared to conventional radiographs and in assessing the true size, extent, nature, and position of periapical and other resorptive lesions. Diagnosing root fractures and evaluation of root canal anatomy are also greatly enhanced by CBCT (Bartling et al., 2007; Estrela et al., 2008; Huumonen et al., 2006; Mora et al., 2007; Patel and Dawood, 2007; Rigolone et al., 2003; Velvart et al., 2001). It is extremely useful when planning apical microsurgery.

This new technology is still far from being perfect. At present, the spatial resolution of CBCT images is at the range of 2 line-pairs per millimeter, compared to that of conventional radiography which is in order of 15–20 line-pairs per millimeter (Patel, 2009).

Scattering caused by high-density neighboring structures such as enamel, gutta-percha, metal posts, and restorations is another unsolved problem with CBCT images, together with the need to perfectly stabilize the patient for as long as 15–20 seconds (Estrela et al., 2008; Minami et al., 1996).

Magnetic resonance imaging (MRI)

MRI combines the use of a magnetic field and radio waves. During an MRI exam, a magnetic field is created. Different atoms in the body absorb radio waves at different frequencies under the influence of the magnetic field. The absorption is measured and reconstructed by the software into images of the area examined (Haring and Lind, 1996). MRI is a completely noninvasive technique, since it uses radio waves and is not affected by metallic restorations (Abildgaard and Notthellen, 1992; Hashimoto et al., 2003). MRI was used in dentistry to investigate the tissues of the temporomandibular joint and salivary glands (Goto et al., 2007). It may also help to determine the nature of the tissue in periapical lesions when planning surgical inter-

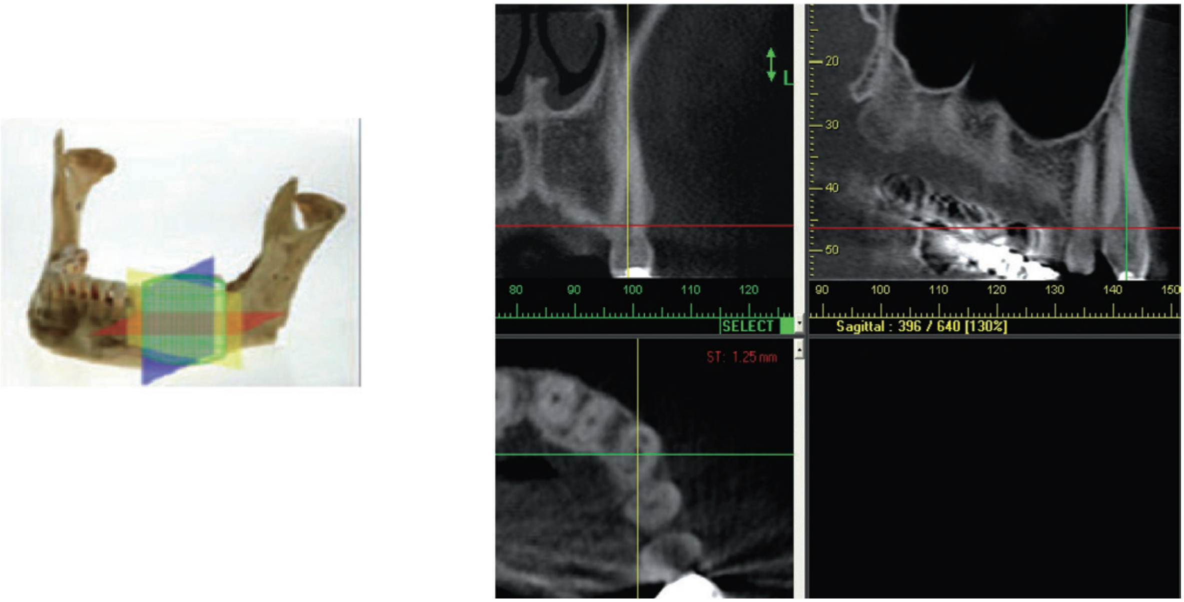

Figure 1.10 3D+cross sections of CBCT.

vention (Cotti and Campisi, 2004; Goto et al., 2007; Minami et al., 1996). The high cost of the unit scans, the limited availability, and the poor resolution of the scans limit the use of this technology in endodontics.

Ultrasound

Ultrasound is an imaging technology based on the reflection of ultrasound waves called "echos," generated by a synthetic crystal. When the ultrasound beam comes across the interface between tissues possessing different acoustic properties, the echo is reflected back to the crystal. The echoes are then transformed into light signals and then into moving images on a monitor. Ultrasound imaging is considered to be a safe technique and is easy to perform. Its use in endodontics may allow detection of periapical lesions and in determining whether vacuolization exists within the lesion, thus possibly allowing for differentiation between cysts and granulomas. Interpretation of the results of this diagnostic technology requires extensive experience.

References

The Bible. King James version. Genesis. Chapter 1:3–4.

CEC. (1990) Quality criteria for diagnostic radiographic images. Working document (2nd ed.), XII/173/90: CEC, Brussels, Belgium.

Abildgaard, A. and Notthellen, J.A. (1992) Increased contrast when viewing radiographic images. *Radiology*, 185, 475–478.

Abrahams, J.J. (2001) Dental CT imaging: a look at the jaw. *Radiology*, 219, 334–345.

Anderson, P.C. (1974) *Dental Radiology*. Delmar Publishers, Albany, NY.

Arai, Y., Tammisalo, E., Iwai, K., Hashimoto, K., and Shinoda, K. (1999) Development of a compact computed tomographic apparatus for dental use. *Dentomaxillofac Radiol*, 28, 245–248.

Bartling, S.H., Majdani, O., Gupta, R. et al. (2007) Large scan field, high spatial resolution flat-panel detector based volumetric CT of the whole human skull base and for maxillofacial imaging. *Dentomaxillofac Radiol*, 36, 317–327.

Bender, I.B. and Seltzer, S. (1961) Roentgenographic and direct observation of experimental lesions in bone. *J Am Dent Assoc*, 87, 708–716.

Brynolf, I. (1971) Improved viewing facilities for better roentgenodiagnosis. *Oral Surg Oral Med Oral Pathol*, 32, 808–811.

Calberson, F., Hommez, G., and De Moor, R. (2005) Fraudulent use of digital radiographs: secret reality or fiction? *Rev Belge Med Dent*, 60, 58–67.

CEC. Criteria for acceptability of radiological (including radiotherapy) and nuclear installations. Radiation Protection No. 91. Luxembourg, 1997. Commission of the European Communities.

Cieszynski A. (1925) The position of the dental axis in the jaws and the exact adjustment of the chief ray in the intraoral method with regard to maxillary irregularities: Table of angle dimensions for the chief ray. *Int J Orthod*, 11, 742.

Cohenca, N., Simon, J.H., Roges, R., Morag, Y., and Malfaz, J.M. (2007) Clinical indications for digital imaging in dento-alveolar trauma: Part 1. Traumatic injuries. *Dent Traumatol*, 23, 95–104.

Cotti, E. and Campisi, G. (2004) Advanced radiographic techniques for the detection of lesions in bone. *Endod Top*, 7, 52–72.

DeLyre, W.R. and Johnson, O.N. (1995) Patient education. In: M. Cohen, ed., *Essentials of Dental Radiography for Dental Assistance and Hygienists*, 5th ed., pp. 365–371. Julie Levin Alexander, Norwalk, CT.

Estrela, C., Bueno, M.R., Leles, C.R., Azevedo, B., and Azevedo, J.R. (2008) Accuracy of cone beam computed tomography and panoramic radiography for the detection of apical periodontitis. *J Endod*, 34, 273–279.

Farman, A.G. and Farman, T.T. (2005) A comparison of 18 different x-ray detectors currently used in dentistry. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 99, 485–489.

Free-Ed.Net. (2006) Fundamentals of dental radiography. Accessed October 26, 2011. www.free-ed.net/free-ed/MedArts/DentalRad01.asp

Goldman, M., Pearson, A.H., and Darzenta, N. (1972) Endodontic success—who's reading the radiograph? *Oral Surg Oral Med Oral Pathol*, 33, 432–437.

Goto, T.K., Nishida, S., Nakamura, Y. et al. (2007) The accuracy of three-dimensional magnetic resonance 3D vibe images of the mandible: an in vitro comparison of magnetic resonance imaging and computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 103, 550–559.

Gröndahl, H.-G. and Huumonen, S. (2004) Radiographic manifestations of periapical inflammatory lesions. *Endod Top*, 8, 55–67.

Grossman, L.I. (1982) A brief history of endodontics. *J Endod*, 8, Special Issue, 36.

Hannsfield, G.N. (1973) Computerized transverse axial scanning (tomography) 1. Description of system. *Br J Radiol*, 46, 1016–1022.

Haring, J.I. and Lind, L.J. (1996) *Dental radiography: Principles and Techniques*. W.B. Saunders Company, St. Louis, MO.

Hashimoto, K., Yoshinori, Y., Iwai, K. et al. (2003) A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 95, 371–377.

Hashimoto, K., Kawashima, S., Araki, M., Sawada, K., and Akiyama, Y. (2006) Comparison of image performance between cone-beam computed tomography for dental use and four-row multidetector helical CT. *J Oral Sci*, 48, 27–34.

Hashimoto, K., Kawashima, S., Kameoka, S. et al. (2007) Comparison of image validity between cone beam computed tomography for dental use and multidetector row helical computed tomography. *Dentomaxillofac Radiol*, 36, 465–471.

Huumonen, S., Kvist, T., Grondahl, K., and Molander, A. (2006) Diagnostic value of computed tomography in re-treatment of root fillings in maxillary teeth. *Int Endod J*, 39, 827–833.

Huumonen, S. and Orstavik, D. (2002) Radiological aspects of apical periodontitis. *Endod Top*, 1, 3.

Marmary, Y., Kotler, T., and Heling, I. (1999) The effect of periapical rarefying osteitis on cortical and cancellous bone. A study comparing conventional radiographs with computed tomography. *Dentomaxillofac Radiol*, 28, 267–271.

Minami, M., Kaneda, T., Ozawa, K., Yamamoto, H., Itai, Y., Ozawa, M., Yoshikwa, K., and Sasaki, Y. (1996) Cystic lesions of the maxillomandibular region: MR imaging distinction of odontogenic keratocysts and ameloblastomas from other cysts. *Am J Roentgenol*, 166, 943–949.

Mora, M.A., Mol, A., Tyndall, D.A., and Rivera, E. (2007) In vitro assessment if local tomography for the detection of longitudinal tooth fractures. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 103, 825–829.

Mouyen, F. (1991) Evaluation of the new radiovisiography system image quality. *Oral Surg Oral Med Oral Pathol*, 72, 627–631.

Mozzo, P., Procacci, C., Tacconi, A., Martini, P.T., and Andreis, I.A. (1999) A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. *Eur Radiol*, 8, 1558–1564.

Nair, M.K. and Nair, U.P. (2007) Digital and advanced imaging in endodontics: a review. *J Endod*, 33, 1–6.

Nair, P.N.R. (1998a) Pathology of apical periodontitis. In: D. Orstavik and T.R. Pitt Ford, eds., *Essential Endodontology: Prevention and Treatment of Apical Periodontitis*. Blackwell Science Ltd, Oxford.

Nair, P.N. (1998b) New perspectives on radicular cysts: do they heal? *Int Endod J*, 31, 155–160.

Naoum, H.J., Chandler, N.P., and Love, R.M. (2003) Conventional versus storage phosphor-plate digital images to visualize the root canal system contrasted with a radiopaque medium. *J Endod*, 29, 349–352.

NCRP Report. National Council on Radiation Protection and Measurements, Bethesda, MD Dental X-Ray Protection, No. 35, 1970.

NCRP Report. Quality Assurance for Diagnostic Imaging Equipment, No. 99, 1988.

NCRP Report. Radiation Protection for Medical and Allied Health Personnel, No. 105, 1989.

NCRP Report. Implementation of the Principle of as Low as Reasonably Achievable (ALARA) for Medical and Dental Personnel, No. 107, 1990.

Patel, N., Rushton, V.E., Macfarlane, T.V., and Horner, K. (2000) The influence of viewing conditions on radiological diagnosis of periapical inflammation. *Br Dent J*, 189, 40–42.

Patel, S. (2009) New dimensions in endodontic imaging: part 2. Cone beam computed tomography. *Int Endod J*, 42, 463–475.

Patel, S. and Dawood, A. (2007) The use of cone beam computed tomography in the management of external cervical resorption lesions. *Int Endod J*, 40, 730–737.

Patel, S., Dawood, A., Whaites, E., and Pitt Ford, T. (2007) The potential applications of cone beam computed tomography in the management of endodontic problems. *Int Endod J*, 40, 818–830.

Patel, S., Mannocci, F., Wilson, R., Dawood, A., and Pitt Ford, T. (2009) Detection of periapical bone defects in human jaws using cone beam computed tomography and intraoral radiography. *Int Endod J*, 42, 507–515.

Richard, A.C. and Colquit, T.W.N. (1981) Reduction in dental x-ray exposures during the past 60 years. *J Am Dent Assoc*, 103, 713.

Rigolone, M., Pasqualini, D., Bianchi, L., Berutti, E., and Bianchi, S.D. (2003) Vestibular surgical access to the palatine root of the superior first molar:"low-dose cone-beam" CT analysis of the pathway and its anatomic variations. *J Endod*, 29, 773–775.

Simon, J.H. (1980) Incidence of periapical cysts in relation to the root canal. *J Endod*, 6, 845–848.

Stashenko, P., Teles, R., and D'Souza, R. (1998) Periradicular inflammatory responses and their modulation. *Crit Rev Oral Bio Med*, 9, 498–521.

Torabinejad, M., Eby, W.C., and Naidorf, I.J. (1985) Inflammatory and immunological aspects of the pathogenesis of human periapical lesions. *J Endod*, 11, 479–488.

Velvart, P., Hecker, H., and Tillinger, G. (2001) Detection of the apical lesion and the mandibular canal in conventional radiography and computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*, 92, 682–688.

Wenzel, A. and Grondahl, H.G. (1995) Direct digital radiography in the dental office. *Int Dent J*, 45, 27–34.

WHO (1982) *Quality Assurance in Diagnostic Radiology*. World Health Organisation, Geneva, Switzerland.

Wuehrmann, A.H. (1970) Radiation hygiene and its practice in dentistry as related to film viewing procedures and radiographic interpretation. Council on Dental Materials and Devices. *JADA*, 80, 346–356.