



A GLIMPSE INTO THE ERA OF RADIOVISUOGRAPHY WITH COMPARATIVE ANALYSIS TO CONVENTIONAL IMAGING

Radiology

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ABSTRACT

History doesn't change the past but likely it changes the future. A dive into the history of Digital imaging is a necessity as it is a boon in the digital era. Dawn of the digital era in dental radiology came in 1987 when a French company Trophy Radiology in Europe launched the first digital system-Radiovisulography (RVG). Dr. Francis Mouyen, (1989) used fibre optics to narrow down a large radiographic image onto a smaller size that could be sensed by a sensor chip which was made by Finnish Engineer Paul Suni. This review article discusses the historical review and technological evolution, various generation of the radiovisulography and summarizes the various studies for the comparison with the conventional imaging.

KEYWORDS

Conventional imaging, Digital imaging, Radiovisulography

INTRODUCTION

In 1895, German physicist, Sir Wilhelm Conrad Roentgen discovered the X-ray. Within two weeks after Roentgen made his discovery public, the first dental radiograph was made by German dentist Otto Walkoff, which helped in emerging of Oral Radiology.^{1,2} The characteristics, the sensitivity of film have improved considerably in the intervening 110 years but a very attractive alternative to film-based imaging is the Digital radiography due to its most commonly cited positive feature "Radiation Dose Reduction". The first considerations about high precision and quality of computer analyses of radiographic images were presented in 1968 by Ando et al. Realizing the advantages of computerized radiographic system, soon in 1973 Robb et al. worked on specialization on operator-interactive, computer controlled system for high fidelity digitalization and analysis of biomedical images (FIGURE 1).^{3,4} After about nine decades, Radiovisulography (RVG) marked the starting point of intraoral digital radiographic techniques in dentistry by Dr. Francis Mouyen (1989).¹

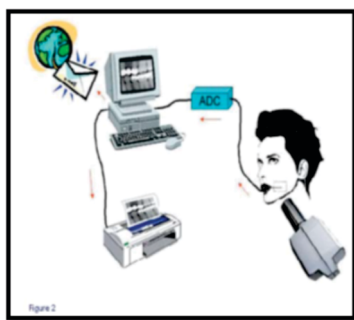


FIGURE 1: A flow chart showing the digital imaging

Historical Review And Technological Evolution

1984- Radiovisulography (RVG) was invented by Dr. Frances Mouyens.⁵

1987 – Trophy Radiology contracted Fairchild CCD Imaging Company in Silicon Valley, California, USA to develop the actual CCD imaging chips.⁵

1988- Trophy Radiology made the first radiographic image capturing device, an image sensor based on a large silicon matrix integrated circuit.⁵

1989 – RVG was described in the USA dental literature.⁵

1992 – Sens-a-Ray of Regam Medical System (Sundsvall, Sweden) is introduced. The company went out of business and their technology was purchased by Dent-X, recently renamed to Image Works (USA). First distributor in North America was Video Dental Concepts 1992.⁶

1993- A pioneer in the field of Digital Radiography, Mr. Paul Suni, Finnish Physicist developed the world's first set of X-Ray film-sized digital radiography sensors at Fairchild and made RVG digital radiography system a reality.⁶

1993 – The first computer-linked system, VisualX of Gendex-Italy was launched by subsidiary of USA company.⁶

1994 – CDR of Schick Technologies, USA was introduced.⁶

1994 – Introduction of a prototype ink-jet printer for printing by Kirkhorn et al.⁷

1995 – SIDEXIS of Sirona, DEXIS of ProVison Dental Systems (renamed following its acquisition by Danaher Corporation), DIGORA (PSP solution) of Soredex (Finland) was introduced.⁶

1998 - Schick were the first company to offer three film-like sizes of sensor.⁶

1999 - Schick Technologies, USA laid down the first USB connectivity in the computer linked system.⁶

2002- Funke et al used wet or dry radiographic laser printers for hardcopies of digital mammography.⁶

2003 - Schick Technologies, USA introduced the first sensors without cables.⁶

2006 - Schick merged with Sirona (Germany) and is now part of Sirona Dental Systems.⁶

2008 - Schick Technologies, USA introduced the first sensors with replaceable cables.⁶

2008 – Schulze et al used glossy paper for the first time with the use of thermo-sublimation printers.⁷

2009 - Schick Technologies, USA launched their second generation of CMOS-APS chips.⁶

2013 – Gerrard used the first normal paper and Epson Stylus ink-jet

printer to print a digital panoramic image.⁸

GENERATIONS

Nagalaxmi V, Goyal S (2013)¹ has reviewed the generations of radiovisuography as follows.

The First Generation:

The first commercial generation of the RVG, was introduced in Europe in 1987. It provided a basic grey scale image display without image processing capabilities

The Second Generation:

The second generation included software driven central processing unit. Due to insufficient memory for storage and display of full resolution images, a four to one pixel averaging compression was utilized for display. Furthermore, the display reduced the internal 8-bit capacity to 6-bit.^{1,9}

The Third Generation:

The third generation, RVG 32000 incorporated modifications which increased the sensitivity and dose dynamics of the sensor. In this model, the sensor was sealed and colour coded to indicate the X-ray sensitive side. It also provided image enhancement features including gradient contrast adjustment and black/white reversal, but added a steep gradient enhancement with only 8 grey levels displayed and the choice of full resolution image acquisition. Only four 'normal' images or one high resolution zoom image could be held in the RVG buffer without storage in an attached computer. Images were therefore printed using a thermal printer and archived as analogue 'hard copies'. The characteristics and diagnostic accuracy of this version of the RVG system reflected a reduction of two to three fold over the second generation.^{1,9}

The Fourth Generation:

The fourth generation RVG-S has a more compact and ergonomic keyboard, a super Video Graphic Array (VGA) colour monitor, a more powerful CPU and a more streamlined and visually presentable overall appearance. Twenty images can be stored in the buffer without down loading to the storage device. The personal computer based version (RVGPC) includes a sensor, image acquisition board and application software which allows image capture and acquisition by any 386 or 486 IBM personal computer. Versions are now available which allow the use of any X-ray generator. These are designated by the suffix i (for example, RVG-PCi). The fourth generation RVG had an option of automatic exposure compensation, which compensated for exposure errors by stretching the pixel value range to increase the contrast of structures within the images.^{1,9}

The Fifth Generation:

RVG-ui and the Dexis are the examples of this generation. The RVG-ui is a solidstate system for dental x-ray imaging combining a CCD of small pixel size (19.5µ) with a caesium iodide scintillator. It features two sizes of sensor with receptive areas that approach the size of No. 1 and No. 2 periapical x-ray films. The spatial resolution of the RVGui

exceeds 20 lp/mm, rivaling conventional intra-oral x-ray film when the latter is optimally exposed and processed.^{1,10}

The Sixth Generation:

The RVG 5000 System incorporates innovative KODAK sensor technology, the RVG 5000 System combines the best attributes of CCD and CMOS (Complementary Metal Oxide Semiconductor) sensors in a single component, allowing for the capture of high-quality radiographs at exceptional speed. It features excellent contrast perceptibility to support high standards of diagnostics and patient care.¹

The Seventh Generation:

KODAK RVG 6100 has rounded corners which help make the sensor more comfortable for patients. It has also introduced new size 0 sensors for pediatric examinations and shock absorbing material protects the sensor from damage. It's fiber optic technology provides high resolution digital images enabling clinicians to make swift and accurate diagnoses. The system also employs a sensor remote control, allowing clinicians to capture and display images chair side in less than two seconds.¹

RVG VERSUS CONVENTIONAL IMAGING

Digital imaging is not simply the display of filmless radiographs. More importantly, the images are captured in a computer and can be displayed almost instantaneously, facilitating operative procedures that now can be image-guided.⁵

Walker A, Homer K, Czajka J, Shearer C, Wilson H. F (1991)¹¹

has reviewed a description of the system and an assessment of the original model in terms of patient dose (relative to film systems), resolution (limiting resolution and modulation transfer function), distortion and image noise (amplitude). They concluded that the system does offer the possibility of reduced patient exposure and minimal distortion, although resolution and latitude are inferior to standard dental film.

Wenze A I, and Mùystad A (2001)¹² conducted a study to evaluate Norwegian general dental practitioners' decision criteria and characteristics for choosing digital radiographic equipment. A questionnaire was sent to 3940 dental practitioners in Norway. They were categorised on the basis of their responses as either a digital radiography or non-digital radiography dentist. Demographic, clinical, and electronic technology variables were recorded. On a six-point scale the Dentists ranked their reasons for choosing or not choosing digital radiography. Their responses were analysed by logistic regression. They concluded that working in a private or group practice or using multiple computers were significant factors in choosing digital radiography.

Edwin T Parks, Williamson Gail.F (2002)⁵ has reviewed the basic feature differences between film based imaging and digital imaging (TABLE 1)

TABLE 1: The difference between film and digital based imaging

Film based imaging	Digital imaging
Density – the overall degree of darkening of an exposed film	Brightness – digital equivalent to density or overall degree of image darkening
Latitude – measure of the range of exposures that will produce usefully distinguishable densities on a film	Dynamic range – the numerical range of each pixel; in visual terms it refers to the number of shades of gray that can be represented
Film speed – amount of radiation needed to produce a standard density; refers to the sensitivity of the film to radiation. The faster the film, the less radiation required.	Linearity – linear or direct relationship between exposure and image density; contrast is not affected but density can be altered after image acquisition
Contrast – the difference in densities between various areas on a radiograph; high contrast images have few shades of gray between black and white while low contrast will demonstrate more shades of gray.	Contrast resolution – the ability to differentiate small differences in density as displayed on an image
Resolution – ability to distinguish between small objects that are close together, measured in line pairs per millimeter.	Spatial frequency – measure of resolution expressed in line pairs per millimeter
Radiographic mottle(noise) - appearance of uneven density of an exposed film or graininess	Modulation transfer function - measure of image fidelity as a function of spatial frequency; how close the image is to the actual object
Sharpness - ability of a radiograph to define an edge or display density boundaries	Background electronic noise – small electrical current that conveys no information but serves to obscure the electronic signal
	Signal to noise ratio – ratio between the fraction of the output signal(voltage or current or charge) that is directly related to the diagnostic information(signal) and the fraction of output that does not contain diagnostic information(noise)

Berkhout WER, Sanderink GCH, Van der Stelt PF (2002)¹³ conducted a study to assess the experiences of general dental practitioners (GDPs) with solid-state and storage phosphor digital sensors compared to film. In a mail survey 578 questionnaires were sent to Dutch GDPs who were users of digital X-ray detectors and @Im. The questionnaire requested for the demographic data, information about the digital system used and the user-friendliness of the X-ray detector system. The data were analysed using descriptive statistics, variance-analysis (One-Way ANOVA) and nonparametric tests (Kruskal ± Wallis, Mann ± Whitney and Wilcoxon) (SPSS 9.0). In the analysis of the data these variables were related to the type of system used and the demographic data. They concluded that the user-friendliness was best for film pre-exposure and digital sensors post-exposure.

Brian JN and Williamson GF (2007)¹⁴ has conducted a study to assess the number of Indiana dental practices that utilize digital radiography and to identify the reasons for using or not using digital radiography. A questionnaire was sent to a random sample of 300 licensed dentists in the State of Indiana. Demographic, clinical and digital technology responses were obtained. The data were analysed using SPSS 12.0 (Statistical Package Social Sciences) software; t-tests and Pearson's x 2 test were performed on several variables with significance levels set at P, 0.05. They concluded that digital radiography is more commonly used by general dentists in group practices. Several findings suggest that instruction in digital radiography needs to be improved through formal education, continuing education and manufacturer training and services.

T Nyathi et al. (2010)¹⁵ conducted a study to assess radiographer familiarity and preferences with digital radiography in four teaching hospitals and thereafter make recommendations in line with the migration from screen film to digital radiography. A questionnaire was designed to collect data from either qualified or student radiographers from four teaching hospitals. From the four teaching hospitals, there were a total of 205 potential respondents. Among other things, responses regarding experiences and preferences with digital radiography, quality control procedures, patient dose, advantages and disadvantages of digital radiography were sought. The information collected was based on self-reporting by the participants. The study was exploratory in nature and descriptive statistics were generated from the collected data using Microsoft Excel 2007 and Stats Direct software. They concluded that the participants are familiar with digital radiography and have embraced this relatively new technology as shown by the fact that they can identify both its advantages and disadvantages as applied to clinical practice. However, there are minimal quality control procedures specific to digital radiography being undertaken as such there is need for formal education, continuing education and manufacturer training with respect to quality control as institutions make the transition from conventional screen film radiology to digital radiology. They also concluded the advantages and disadvantages of digital radiography which are highlighted as follows (TABLE 2.)

TABLE 2: The advantages and disadvantages of digital radiography

ADVANTAGES	DISADVANTAGES
Increased dynamic range.	Poorer spatial resolution.
Linear response of images.	Artefacts due to the imaging plate.
Availability of post-processing functions.	Non-availability of post-processing functions.
Easy to archive since images are in digital format.	Increased sensitivity to scattered radiation.
Leads to a higher patient throughput.	More expensive than screen-film radiography.
Separation of image capture, processing, storage and display processes which means they can be optimized individually.	Lack of familiarity to radiologists and radiographers.

Nagalaxmi V, Goyal S (2013)¹ has reviewed the differences between RVG and conventional imaging in a more elaborative form as follows.

1. Acquisition of images: Film-based imaging consists of X-ray interaction with electrons in the film emulsion, production of a latent image, and chemical processing that transforms the latent image into a visible one. Based on the continuous density scale film-based images are called analogue images. The final result is a fixed image that is difficult to manipulate once captured. Digital imaging is the result of

X-ray interaction with electrons in electronic sensor pixels conversion of analog data to digital data, computer processing, and display of the visible image on a computer screen.¹

2. Rigidity: The property of rigidity prevents distortion of the image, which is present in conventional imaging due to bending of the film intraorally. But this at the same time can be considered as a disadvantage as the rigidity may cause improper placement and pain to the patient.¹

3. Radiation dose: Radiation safety is an important issue in dental radiography. The desired amount of information must be obtained with the smallest possible amount of radiation. The dose per exposure is generally lower in digital intraoral radiography than in conventional film-based radiography. According to few articles the reduction in radiation offered by digital radiography is usually 70 to 80 percent, and at times even more-allows multiple periapical images for the same radiation exposure involved in a single periapical image obtained via conventional radiography. This reduction in radiation is especially important in implant placement or difficult endodontic therapy, in which multiple images frequently are needed. Radiation exposure is reduced by 50% to 90% when compared with D-speed conventional film-based technology. The surface exposed with the CCD is approximately 50% less than what is exposed using film for a single image the total patient dose depends on the number of exposures required to cover the area.¹

4. Image display: The digital image is displayed on a monitor screen in much greater dimensions than the film image that is read on a viewing box. It allows for manipulation of the grey scale for variation in image presentation. Moystad et al demonstrated that high zooming sizes gave inferior detection levels of proximal caries and that one has to be aware of an upper limit of displayed image size.¹

5. Image characteristics: Brightness, contrast and many other image characteristics can be manipulated with digital radiographs, while contrast and density of a conventional radiograph is determined during the exposure and film processing procedure and cannot be corrected afterwards. Film displays higher resolution than digital receptors (6-10 lp/mm) with a resolving power of about 16 lp/mm. The direct digital receptors have a wider dynamic range than that of film. Dynamic range or latitude is the range of exposures that will produce images within the useful density range. Alternatively it is also defined as the range of exposures that result in a diagnostically acceptable image. This reduces the number of retakes. Digital radiography allows the clinician to change contrast (to lighter or darker), enlarge images, place color enhancements or superimpose various textures on images. All of these changes of the original image facilitate easier detection of any pathology that is present, and they also allow immediate and effective patient education.¹

6. Working time: In conventional radiographic techniques, the delay in reading the image usually forces the clinician to change gloves and do something else as the radiograph undergoes development. On returning to the patient, the clinician must wash his or her hands, don new gloves and reorient himself or herself to the clinical procedure at hand e.g.: endodontic therapy, implant surgery etc. RVG uses less time (0.5-2 min) and manpower when compared to the conventional imaging (6 min).¹

7. Image storage, Image retrieval and Communication: Pulling up specific stored radiographic images from a computer database is easy because of the highly organized nature of computer file storage. This form of storage also aids in electronic communication between dentists, which is made easier with digital networking. Also the patient education is highly improved and simplified with this modality. But the lack of universal use of digital imaging in the present scenario can be a hindrance to this form of communication.¹

8. Added features: Conventional radiography do not have any added features which can allow for post manipulation.. But RVG has many added tools (Brightness and Contrast Adjustments, Black/White Reversal, Pseudocolor Application, Sharpening, Zoom and Digital Subtraction).^{1,4}

9. Cost of RVG: The Cost of conventional radiography set up is definitely lower than RVG but it requires only a high initial investment and eliminates the recurring expenses of film and processing solutions

thereafter .At the same time it also eliminates the problem of disposal of spent solutions.¹

10. Initiation:Conventional radiography do not require any software but RVG requires initial education and training to begin with and regular upgradation of the software from time to time.¹

11. Problems with Sensors:Conventional radiography uses film that are flexible and free of wires which makes the procedure simple and easy to handle. With wired sensors in RVG, the presence of a wire attached to the sensor allows immediate observation of the image but initially the clinician needs to work around the wire. Careful handling of the sensor is paramount as breakage of the sensor can significantly affect the image quality.¹

12. Infection Control:One and the same digital image receptor will be used in a dental clinic for years for all patients who need to have a radiograph, in contrast to film packages where a new package is used for every radiograph that is made. Therefore digital image receptors should be covered to prevent cross contamination.¹

13.Questionable use as an evidence in medico-legal case:Currently juries view radiographs as photographs i.e., real evidence offered for jury inspection. Since a digital radiograph can be altered or manipulated, it is questionable whether digital radiograph can be used as legal evidence in a lawsuit. It is a possibility that digital radiographs can be manipulated to suggest pathological conditions when no pathology exists. Water marking a digital radiograph can prevent this manipulation to an extent.¹ Digital watermarking is the process of embedding information into digital multimedia content such that the information (which we call the watermark) can later be extracted or detected for a variety of purposes including copy prevention and control.¹⁶

CONCLUSION

Theodore Roosevelt once said “the more you know about the past, the better you are prepared for the future”. Digital imaging is a boon in the digital era. A glimpse into the history and technological evolution are the blueprints of the past with more studies and development in the future.

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