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From the Origin up to the Recent X-Ray Applications in Dental Imaging

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An accidental discovery and its pioneering application in dentistry

On 8 November 1895 Wilhelm Conrad Röntgen was working with a cathode-ray tube in his laboratory in Germany and accidentally discovered a green coloured fluorescent light generated by a material located a few feet away from the tube. A new type of ray was being emitted from the tube [1,2]. A week after the discovery, Röntgen obtained a picture of his wife's hand on a photographic plate formed due to unknown radiation, which he decided to call like an unknown-ray, exact X-rays. The image obtained clearly revealed her wedding ring and her bones and so Röntgen realized the potential medical use of its discovery [1,3].

The discovery of X-rays represented one of the most revolutionary events in the history of medicine which opened up an exciting field for doctors making possible to explore the human body from inside, without cutting and open the body [1,2]. The news of Röntgen discovery had soon travelled around the world. Doctors soon picked up on the advantageous uses of the X-ray photography and started in using them to diagnose health complaints. Even dentists very quickly recognised the diagnostic advantage for their own special medical field. Especially in dental surgery, significant progress was achieved through the new opportunities of a radiological examination [1].

The first original dental roentgenogram, the first intraoral X-ray from a portion of a glass plated with photographic emulsion was taken by Dr. Otto Walkhoff in January 1896 in his own mouth for an exposure time of 25 min [3-5]. In his report he described "it was a true torture, but I felt a great joy at the sight of the results when I become aware of the importance of the Roentgen rays for dentistry" [1].

One month later, Wilhelm Koenig obtained 14 radiograms from his own teeth using an exposure time of 9 min/tooth and in his publication emphasised that "... the X-rays of the teeth are not only able to prove the position and the form of the fillings in the teeth but we are also able to examine parts of the teeth which are sticking into the jaw bones..." [1,2].

In England, utilization of X-rays was concurrent with Germany; Frank Harrison was the first English dentist who used X-rays and published the first article about the adverse effects of radiation in July 1896. Also, William Herbert Rollins, American scientist and dentist who conducted an intensive work of research on equipment and the use of X-rays in dentistry, was among the first to warn about the adverse effects of radiation [1,2].

In the United States, William James Morton Junior was the first user of the X-rays in the early spring of 1896 while Dr. Charles Edmund Kells, a dentist practicing in the deep South, became a pioneer in the profession of Dentistry and Medicine with his numerous inventions and publications [1,2]. Kells was also one of the first dentists to make use of a female dental assistant and the first to expose a dental radiograph in the United States [1].

The first commercial dental radiographic apparatus was introduced in 1905 in Germany while the Indiana University became the first dental school to install X-ray equipment as promoted by Howard Riley Raper who was the first educator to bring radiology into a dental school clinic for regular daily use in 1909, convincing his dean of the importance of X -rays to the dental profession. Raper wrote the first textbook in oral radiology in 1913 [2].

X-ray imaging in dentistry

Since the pioneering employment of X-rays, radiographic methods have seen considerable progress along with their applications in various fields of dentistry [3]. Broadly, X-ray imaging methods used in dentistry can be categorized as: analogue and digital, intra-oral and extra-oral, two-dimensional (2-D) and three-dimensional (3-D) imaging [3,6].

The film-based radiography, which is a technique using films, cassettes and wet film processing for long time, has some disadvantages such as need and maintenance of darkroom, chemical handling and associated processing errors which have been proven unnecessary with the advent of digital radiography [3,5,7].

With the advancement in electronic systems, innovation in image acquisition processes and the development of networked computing systems, equipment's have been produced to achieve a radiographic image in a digital format [3,5,7]. Digital radiography refers to a method of capturing a radiographic image using a solid-state technology sensor, breaking it into electronic pieces and presenting and storing the image using a computer. Digital images are in numeric format and differ from conventional radiographs in terms of pixels and the different shades of grey given to these pixels [7].

The first system introduced in digital radiography in dentistry was radio-visio-graphy (RVG, formerly Trex-trophy Radiology Inc., Marietta, GA) by Trophy in France in 1987 [3,5]. Changing from analogue to digital radiography has not only made the process simpler and faster but also made image storage, manipulation (bright ness/contrast, image cropping, etc.) and retrieval easier [3]. In addiction, one of the most positive features of digital radiography is the radiation dose reduction up to 80%, when compared with conventional plain film radiography [3].

2-D imaging

Intra-oral and extra-oral radiographic examinations are 2-D imaging techniques. Intra-oral radiographic examination includes periapical, bitewing and occlusal projections, while extra-oral imaging includes panoramic and cephalometric projections [3,7]. These both were performed with conventional radiography, but nowadays with the introduction of digital systems they could be achieved with digital imaging [7].

Panoramic radiography has been one of the most common imaging method among dentists which has become a popular and important diagnostic tool since its introduction in the 1950s [3,7]. Digital extra-oral and panoramic systems have not been widely adopted since their first introduction in the dental market due to their very high costs. Sometime after their invention, relatively cost effective systems with improved computer settings (computer speed, data storage capacities) have been produced and they have been started to be adopted in dental practice [7].

Since their initial introduction 2-D digital imaging systems have been considerably improved. This improvement in type, size, shape, radiation effective dose and resolution of the sensors led to their routine use in dental clinics [7].

Intra-oral and extra-oral radiographs provide a two-dimensional image of a three-dimensional object. This results in the fact that relationship of the tooth to the surrounding anatomical structures cannot be assessed accurately. Moreover, the anatomic structures can be visualized in the mesial-distal and apical- coronal plane but the buccal-lingual plane is not possible to assess. Radiographs do not reveal the soft-tissue to hard-tissue relationships. Anatomical structures surrounding the teeth may superimpose causing anatomical or background noise, leading to difficulty in interpreting periapical radiographs; the superimposition of unwanted structures in 2-D imaging is the main problem in capable of decision-making for correct diagnosis and treatment planning [3,7].

3-D imaging

In case of diagnostic dilemma and treatment planning of special cases, advanced 3-D imaging modalities are required to reveal additional information [3]. 3-D imaging gives the opportunity to the practitioner to examine the dento-maxillofacial region without superimposition and distortion of the image [7]. Various techniques have evolved in the recent past changing the diagnostic approach and treatment planning in dentistry including computed tomography (CT), tuned aperture computed tomography techniques (TACT) and cone-beam computed tomography (CBCT) [3,7].

The first commercial CT scanner was developed in 1972 by Sir Godfrey Newbold Hounsfield, an engineer at EMI, Great Britain. Since then, the introduction of clinical X-ray CT has transformed medical imaging and may be described as the greatest advancement in radiology, since the discovery of X-rays. CT scans were used in medicine since 1973 but it became available for dental application only in 1987 [3].

CT uses a narrow fan-shaped X-ray beam and multiple exposures around an object producing images that reflect internal structure of the object according its density, depicting its morphology in three-dimensions. CT has the ability to acquire multiple, non- superimposed cross-sectional images and it allows the visualization of the mesio-distal as well as the bucco-lingual extent of the pathology overcoming the drawback of 2-D imaging [3,6]. The greatest disadvantage of CT imaging is the high radiation exposure. Other disadvantages of CT include high costs of the scans and scatter because of metallic objects besides the poor resolution compared to conventional radiographs [3].

TACT was developed in 1994 for dental application by the American dentist and physicist Richard L. Webber and colleagues based on the concept of tomosynthesis and optical-aperture theory. TACT uses 2-D periapical radiographs acquired from different projection angles as base images and produces true 3-D data from any number of arbitrarily oriented 2-D projections. The overall radiation dose of TACT is not greater than 1 to 2 times that of a conventional periapical X-ray film. The resolution is stated to be similar with 2-D radiographs. Artefacts associated with CT, such as starburst patterns seen with metallic restorations, do not exist with TACT [3,6]. However, the advent of CBCT and its successful marketing up to now impeded the further development and clinical application of the technique.

CBCT was initially developed for angiography in 1982 and was applied to dental imaging some after. The CBCT system works with a flat panel 2-D detector and special scanner using collimated X-ray source that produces a cone-or pyramid-shaped beam of X-radiation [3,7]. It performs a single full or partial circular rotation around the object and produces a series of 2-D images which are reconstructed in 3-D volume using a modification of the original cone-beam algorithm developed by Aboudara., *et al.* in 1984 [3,7]. Scan times for CBCT are lengthy at 15-20 s and require the patient to stay completely still [3].

Multiplanar and 3D images could be achieved with this technique with lower radiation dose, as little as 3%-20% that of a conventional CT scan. Other advantages of CBCT over CT are represented by the less expensive cost of X-ray tubes of cone-beam scanning and higher spatial resolution relative to CT providing better visualization of structures with mineralized tissue [3,7]. Although CBCT images have high spatial resolution, image quality and diagnostic accuracy of CBCT is affected by the scatter and beam hardening artifacts caused by high density structures such as enamel and radiopaque materials, metal posts and restorations. Scatter radiation reduces the contrast and limits the imaging of soft tissues. Thus, soft tissue contrast in CBCT images is inferior to that in CT images. Because of distortion of Hounsfield Units, CBCT cannot be used for estimation of bone density [3,7].

Compared with 2-D imaging, the effective radiation dose can be higher in CBCT depending on the machine, field of view and the resolution of the image. Therefore, the selection criteria of the CBCT examination should weigh potential patient benefits against the risks associated with the level of radiation dose. This could be achieved by appropriate clinical usage and optimizing technical factors [3,7].

Conclusion

Tremendous advances have been made for improvements of digital imaging systems since their initial introduction on the market and it seems that their adaption will be increasing in the future. From the simple intra-oral periapical X-rays, advanced imaging techniques like CT and CBCT have found place in modern dentistry and there is no denying to the fact that dental imaging remains the backbone of dentistry in terms of investigation, treatment planning as well as follow up. Dentists should have knowledge of the working principles, requirements, clinical benefits and hazardous effects of these systems for proper usage [3,7,8].

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