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Review Article

Subtraction Radiography

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Digital Subtraction Radiography in Dentistry: An Overview

Dr. Prasanna R. Sonar[1*], and Dr. Aarati S. Panchbhai[2]

[1]Sharad Pawar Dental College & Hospital, Datta Meghe Institute of Higher education & Research (Deemed to be university), Sawangi-Meghe, Wardha (Maharastra), India.*

[2]Prof, Department of Oral Medicine and Radiology, Sharad Pawar Dental College & Hospital, Datta Meghe Institute of Higher education & Research (Deemed to be university), Sawangi-Meghe, Wardha (Maharastra), India.

Abstract: Digital imaging has transformed the field of medical and dental imaging by overcoming many of the drawbacks of conventional film-based radiographs. These alterations, however, are hidden behind a background of typical anatomical features and are not readily visible, making it difficult for the human eye to discern them. One image-enhancing method or tool that solves this issue is digital subtraction radiography, which has recently found usage in a number of dental specialties. Quantitative measures from digital subtraction pictures have been validated as a result of the development of digital imaging technology. Moreover, changes made to computer software have made the clinical use of subtraction imaging more adaptable. Digital subtraction radiology has significantly improved the ability to find oral and maxillofacial lesions. Comparing standardised radiographs acquired during successive examination sessions is done using digital subtraction radiography. Any structures that have not changed are removed, and these regions are shown in the subtraction picture as neutral grey areas, whilst parts that have altered are shown as deeper or brighter shades of grey. Yet, there is not much analysis of this often used method in the literature. The purpose of this article is to examine this technology, its applications in different areas of dentistry, and its potential for detecting a range of disorders. This review article highlights its basic principles, applications, technique, advantages, disadvantages and future scope of digital subtraction radiography in dentistry.

Key words: Subtraction radiography, radiography, digital imaging, digital subtraction, digital radiography

***Corresponding Author**

Dr. Prasanna R. Sonar , Sharad Pawar Dental College & Hospital, Datta Meghe Institute of Higher education & Research (Deemed to be university), Sawangi-Meghe, Wardha (Maharastra), India.

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1. INTRODUCTION

For detection of oral and maxillofacial lesions, radiograph is considered to be a diagnostic tool[1-3]. Because of its two dimensional nature, it is quite difficult to detect the lesions since various anatomical structures are superimposed over each other[2,4,5]. Radiographic examination still cannot be considered an ideal tool because of the discrepancies in the interpretation by different evaluators and at different times by same evaluators. Also, due to the slow progression of oral and maxillofacial lesions, it is difficult to assess them using radiographs that were taken sequentially.[6,7,8] The another term named as structural 'noise' creates the visual confusion restricting the scope of small lesions' detection[9,10].

2. HISTORICAL REVIEW

B. G. Zeides des Plantes introduced subtraction methods in 1920s. In dentistry, it was introduced in the year 1980[11]. One of the methods that can resolve the limitations of conventional radiography to raise the diagnostic accuracy include the Digital Subtraction Radiography (DSR)[11-13]. By removing the static backdrop disturbances, DSR improves visibility of radiographic changes between two radiographs. To subdue the background features or to eliminate the background complexness the subtraction image is carried out. This technique compresses the dynamic range and enhances the slight differences as well by superposing the scenes achieved at various times[14,15]. Dental radiography has used digital image subtraction since more than 20 years. Film subtraction was the universally accepted standard procedure for cerebral angiography. Later on, digital subtraction fluoroscopy came out in the late 1970s. These days, the diagnostic images are subtracted using filmless photoelectronic imaging technique or systems, particularly video fluoroscopy[15]. It uses comparison of standardized radiographs achieved at sequential visits of examination. The unmodified structures are removed or subtracted, and the resulting image shows these regions in a subtraction image with a neutral grey tone. Whereas the areas' modifications are shown in lighter or deeper grey tones[16,17,18]. Since digital subtraction radiography eliminates the complicated anatomic backdrop that the small changes occur against, digital subtraction radiography is effective. The alterations become far more obvious as a result. Such measures can be made manually or with the use of computer-aided image processing, visual interpretation, and measurements. This review article highlights its basic principles, applications, technique, advantages, disadvantages and future scope of digital subtraction radiography in dentistry[19-21].

3. DIGITAL INTRAORAL IMAGE RECEPTOR

When subjected to a stimulus, namely energy in the form of x-rays, radiographic film receptor acts as a recording medium on which pictures are captured. The device that blocks the X-ray beam after it has travelled through the patient's body and creates a digital picture, or a matrix of pixels with numerical values, is known as a digital image receptor. It takes the place of the cassette used in traditional film screen radiography, which contained intensifying screens and films[22]. A matrix of individual pixel components makes up a digital image receptor, and technologies like solid state technology and photostimulable phosphor (PSP) plate technology are used to make them function. After travelling through the patient's body and exposing a pixel region, an electrical signal is created when X-ray photons are absorbed. Analog data from this signal is first transformed into a digital number and then saved as one pixel in a picture. Charge Couple Device (CCD), Complementary Metal Oxide Semiconductor (CMOS), and Thin Film Transistor are the three types of solid state sensors now in use (TFT)[22]. PSP is made up of a plate with phosphor coating on top of which a latent picture develops following exposure to X-rays. A scanning gadget stimulates a latent picture into a digital image using laser light. On the grounds that image generation is thought to be momentarily stored inside the phosphor, it is sometimes referred to as storage phosphor. In order to distinguish it from films and solid state detectors, it is referred to as picture plates. Computed radiography is the term used to describe the use of PSP plates in medical radiology[22].

4. FILM-BASED AND DIGITAL IMAGING PRINCIPLES

In film-based imaging, X-rays interact with the electrons in the film emulsion to create a latent picture, which is then converted into a visible image by chemical processing. Radiographic film serves as a platform for capturing, presenting, and storing diagnostic data as a result. Analog pictures are those produced using film. Continuous grayscale between the extremes of black and white is a distinctive feature of analogue pictures. Every shade of grey has an optical density (darkness) that corresponds to how much light can enter the picture at a given location. Film has a resolving capability of around 16 lp/mm, which is better resolution than digital receptors. Yet because film is such a poor radiation detector, it needs to be exposed to a lot of radiation. Less radiation exposure can be achieved by using rectangular collimation and the fastest film available, however private dental offices seldom employ these technologies. Chemicals, which are necessary for image processing but frequently the cause of mistakes and retakes, are to blame. A fixed image that is challenging to edit after being recorded is the end result[23]. Digital imaging is the process of converting analogue data to digital data, computer processing, and displaying the visible image on a computer screen as a result of X-ray interaction with electrons in electronic sensor pixels (picture components). Analog information obtained by the sensor is sent to the computer. The binary number system, which uses the digits 0 and 1 to represent data, is the one used by computers. These two characters are known as bits (binary digits), and together they make words called bytes that are eight bits or longer. There are 28 = 256 potential bytes in an 8-bit language. Analog data is converted to numerical data using the binary number system using an analog-to-digital converter. According to the voltage's strength, the output signal's voltage is measured and given a value from 0 (black) to 255 (white). These number designations correspond to 256 different colours of grey. The human eye can distinguish between about 32 different shades of grey. Certain digital systems sample the raw data with a resolution of 10 bits or 12 bits, which is higher than 256 grey levels. The advantage of regulating underexposed or overexposed photos comes from the reduction of the many grey values to 256 shades of grey[23]. Direct digital imaging systems provide a dynamic image that allows for instantaneous display, image augmentation, storage, retrieval, and transfer. Film sensors are less sensitive than digital ones, which need far less radiation exposure[23].

5. DIRECT DIGITAL IMAGING

Direct digital image production needs a lot of different elements. A computer with an analog-to-digital converter (ADC), a screen monitor, software, a printer, and an X-ray source are some of these components. Generally, systems are PC-based and include a high-resolution monitor, an SVGA graphics card with 640 KB of internal memory, and a higher processor. Charge-coupled devices (CCDs) or complementary metal oxide semiconductor active pixel sensors (CMOS-APS) are both examples of direct digital sensors[23]. In direct digital imaging, a sensor which will be exposed to radiation is put in the patient's mouth. The radiographic picture is captured by the sensor, which then transmits it to a computer monitor. A few seconds later, the image is shown on the computer screen. Potentially groundbreaking technology for measuring oral hard tissue has recently been introduced in the form of direct digital radiography equipment for oral usage. Photostimulable phosphor radiography (PPR) devices feature decent imaging qualities and reasonable resolution, much like films. The phosphor plates, in contrast to films, provide a repeatable, linear response over several orders of magnitude and are thus ideally suited for quantitative measurement[24].

6. DIAGNOSTIC UTILITY

Studies have compared the effectiveness of digital imaging against film-based imaging for a range of diagnostic tasks, including the identification of caries, periodontal disease, and periapical lesions. The results show that film and digital imaging modalities do not significantly differ in their capacity to capture oral disease states and are generally consistent. The radiograph picture that has been digitally enhanced is clearly superior than the original film. Images that have been converted to digital format may be archived and shared more easily. Digital pictures have the potential to improve dental diagnosis, treatment planning, and follow-up procedures because to the technical opportunities provided by digital software[25].

7. BASIC PRINCIPLE

The idea behind digital subtraction is rather straightforward. Before and after the course of therapy, two radiographs are taken, and they are compared pixel by pixel. The components of the photos that haven't altered are removed, revealing the minor modifications that have taken place. If there has been a change in the follow-up photograph, it will appear as a brighter or darker region depending on whether the change reflects gain or loss. The histogram of the final image—a visual representation of the distribution of grey levels—can also be used to gauge the size of the alterations. In order to conduct the digital subtraction, each pictures must contain the same amount of pixels. It will be challenging to see the difference in a perfect subtraction when there is no difference between the pictures since every pixel would have a value of 0 (black). So, in order to solve this issue and improve visualisation, an offset grey value of 128 is applied to provide a grey backdrop that will make any overlaid alteration or lesion easier to see[26].

8. APPLICATIONS

DSR is sensitive and accurate in the evaluation of bony changes[27]. (Figure 1) It detects the changes in the density of bone efficiently thus improving the identification of dental as well as maxillofacial lesions. (Figure 1)

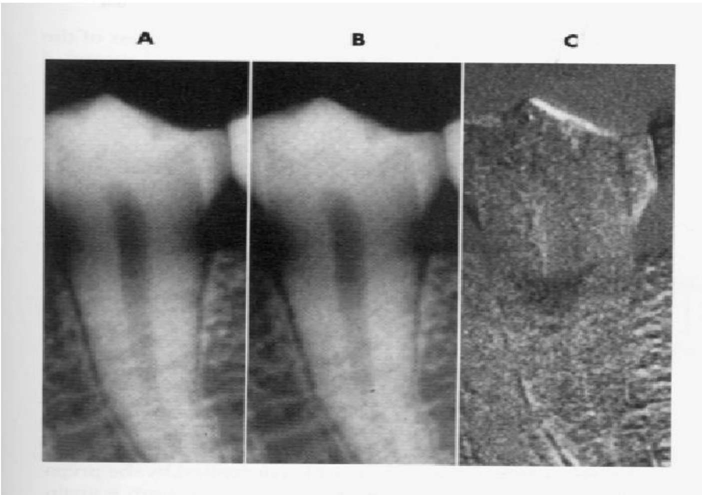

Fig 1: Digital Subtraction radiography showing three images (A, B and C). The difference between A&B may be detected in the subtracted picture (C), where the loss of alveolar bone in "B" is too slight to be seen. A black structure superimposed on the pulp represents the bone loss.[63]

A change in mineralization of atleast 30-60% is required for its detection in case of conventional radiography whilst with DSR, it must have bony variations of 1–5% per unit volume in order to be obvious. DSR allows for the detection of 0.78 mm in crestal bone height changes that are significant [28,29,30]. Digital Subtraction Radiography helps in panoramic imaging and TemperoMandibular Joint (TMJ) assessment of the right and left mandibular condyle[31-33]. A highly significantly better observer agreement was achieved by digital subtraction radiography during the evaluation of the outcome of root canal treatment on periapical lesions, occult bone cavites, detachability of artificial marginal bone lesions[34,35,36]. DSR allows for the detection of defects in cortical bone that are 0.49 mm deep, but traditional conventional radiography requires lesions to be at least three times bigger to be detectable[37-39]. The diagnosis of periodontal diseases with this technique is sensitive enough for detecting bony changes as in its density as well as thickness as little as 1%[40,41]. In TMJ imaging, intra-articular space was obscured by the superimposition of surrounding structures and the oblique joint projection. By removing overlaid structures, this technique enhances condyle visibility[42-44]. (Figure 2)

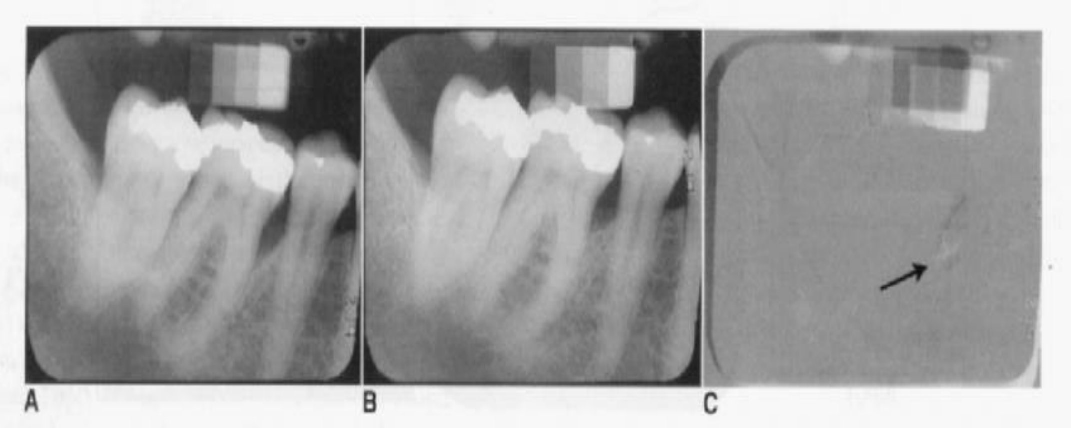

Fig 2: Digital subtraction radiography is used to identify and measure periodontal bone healing. A, 1st image. B, standardised image from a 1-year follow-up. D, Subtraction image demonstrating bone growth (arrow).[63]

Digital Subtraction Radiography along with the use of contrast media can be used to assess the arrest, progression or regression of caries. (Figure -3) Because of ill-defined radiolucencies of carious lesions, their extent in conventional radiography is difficult to measure[45, 46]. Using this technique, the pixel values of the 2nd picture are subtracted from the 1st image's pixel values. In case of no change in regression or progression of caries, it appears as zero whereas when there is caries regression or progression in the meantime, the result appears other than zero. If the caries rate declines, the value above zero will be the outcome while in case of caries progression, the result will be opposite and the value below zero will be the outcome. The result of the subtraction method has a "offset" of 127 added since the screen cannot display negative values[47]. This technique can also evaluate the condition of endodontically treated teeth[48-50]. Moreover, it may spot root resorption as low as 0.5 mm[6]. It has the ability to detect soft tissue changes when underexposed radiographs are used. This method can be used to study bony tumours or cysts that have the ability to alter over time[51].

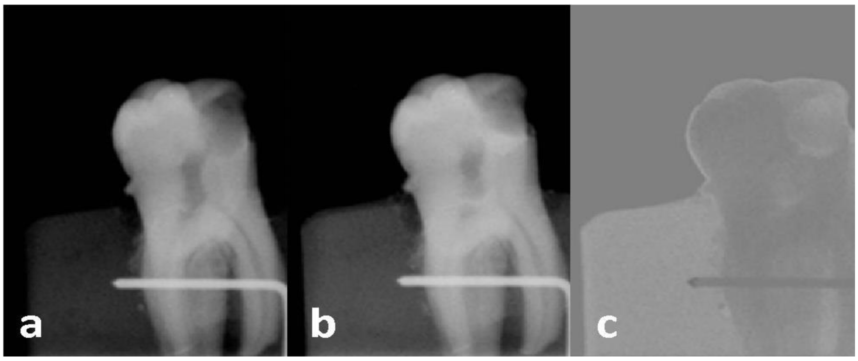

Fig 3: Use of contrast material in conjunction with digital subtraction radiography for the identification and progression of caries.

9. TECHNIQUES/ METHODS

Hybrid subtraction is a term used when the two methods namely 'temporal' subtraction and 'energy' subtraction are combined. The advantages of both the methods are combined in digital fluroscopy. As there is decrease in the patient motion while undertaking subtracted images, there is significant enhancement in the image contrast in hybrid subtraction. Owing to limitations in energy subtraction techniques and methods caused by high voltage generators, the temporal subtraction techniques are more commonly used[52]. An even difference image is developed when more than one images of the same object are recorded and their intensities of corresponding pixels are subtracted. The change shows up as brighter region when there is a gain whereas it shows darker in case of loss if the radiographic attenuation differs between the baseline and follow-up exams[10].

10. ADVANTAGES

DSR raises the conspicuousness of the changes by removing the complicated backdrop that tiny changes occur against. It is advantageous above other methods also as it is able to acquire quantitative information like as measurements of area, linear as well as density. These measurements can be carried out using visual or manual aids as well as with the aid of computer[10].

11. DISADVANTAGES AND SOLUTIONS

This method has certain limitations like it is very sensitive to the physical interference or noise between radiographs[4,53,54]. So the minor changes can lead to significant discrepancies in the results[55]. These artifacts can be tough to differentiate from biologic changes. Thus the most crucial prerequisites for succesful Digital Subtraction Radiography is that misinterpretation of the subtracted images should be avoided[56,57]. For this, it requires uniform density and contrast of the serial radiographs and also the projection geometry should be reproducible. If the picture density and contrast between the baseline and follow-up images are not uniform due to differences in processing time, developer temperature, and developer exhaustion (caused by ageing and depletion), it will make the quantitative measurements unreliable and will hamper the detection task[10]. To correct the disparities between distinct radiographs following their digitalization by desktop scanner or digital camera, the imaging system can incorporate a step wedge or other devices[51,58]. The standardization of projection geometry though not always essential and possible has the ability to produce good results. Different techniques are available for matching baseline and follow-up images and these techniques depend upon the change in the brightness, contrast, and gamma values[10]. The image's initial intensity values which are termed as input changes to new values or output with the adjustment of gamma values, brightness and contrast[10]. Digital image software includes options for gamma value, brightness, and contrast alterations. The miss angulation of the film holder and centre beam as well as film can cause artifacts, thus it is important to keep check on the angulations even when the X-ray beam is held constant[58,59,60]. Grohndahl suggested that subtraction images are interpretable if the angulation discrepancies are less than three degrees. While Ruttiman et al stated that angular deviations shouldn't be more than 2 degrees. As reproducible positioning is crucial to avoid errors, customized occlusal stents made of impression materials or cold-cured acrylic are used[14,61]. Stents, however, can be utilised for a small number of patients with follow-up intervals of less than 2 years since tooth movement occurs over time. Stents posses' other limitations like its customized construction is time consuming, their high costs and limited usage as in edentulous areas, infection control issues etc[62]. Use of cephalostat method for maintaining the reproducible position of patient's head and a long i.e more than 50 inches of distance between source and object was advocated by Jeffcoat et al in 1987. However, this method requires more space for its accomodation and is also expensive thus minimizing its uses and applications.

12. SCOPE AND FUTURE

With the emerging developments in the technologies and soft-wares, recently a brand-new method was introduced. This system consists of a high resolution radiographic film scanner, an aiming device as well as a computer software. In this system, the variations in the projection geometry is unable to exceed more than 10 degrees in vertical and horizontal dimension between the exposures. A long cone of around 40 cm is used that control the limitations of cephalostat. With this technique, adjusting serial images with variations of more than 10 degrees has become possible because of continuosly progressing processing capabilities of computers and the developing technologies and softwares[27]. These software applications line the images up in pairs. In these images, the same reference points are chosen for comparison and differentiation. After this, the images are moved in different directions, for example vertical, horizontal and rotational, until these pairs of images are co-ordinated[14]. Regardless of all the efforts, the control of projection geometry as well as the correction of the discrepancies has been difficult to achieve. Various attempts are underway to solve the issues pertaining to this.

13. CONCLUSION

By removing the static backdrop disturbances, digital subtraction radiography improves visibility of radiographic changes between two radiographs. In order to identify oral and maxillofacial lesions, image the temporomandibular joint, and assess whether caries lesions are progressing, stopping, or regressing, DSR has achieved considerable advancements. The dentistry industry has not yet adopted this procedure widely, and attempts are being made to find a solution since there is yet no clear-cut, precise, easy way to regulate projection geometry and repair the errors caused by it.

14. AUTHORS CONTRIBUTION STATEMENT

Dr. Aarati S. Panchbhai conceived of the presented idea and encouraged Dr. Prasanna R. Sonar for this work. Dr. Prasanna R. Sonar wrote the manuscript with input from Dr. Aarati S. Panchbhai. Dr. Aarati S. Panchbhai helped for overall guidance and editing this manuscript.

15. CONFLICT OF INTEREST

Conflict of interest declared none.

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