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Digital Subtraction Radiography in Dentistry: A Literature review

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Abstract: DSR has made a significant improvement in the detection of dental & maxillofacial lesions. The Digital Subtraction Radiography is used to compare standardized radiographs taken at sequential examination visits. All unchanged structures are subtracted and these areas are displayed in neutral gray shade in the subtraction image; while regions that have changed are displayed in darker or lighter shades of gray. This article reviews the literature of digital subtraction radiography in dentistry.

Keywords: Digital subtraction, Digital dental imaging, bone change.

Introduction

Radiography is the main diagnostic tool for detecting dental & maxillofacial lesions [1, 2, and 3]. Radiologic images have two dimensions of three dimensional realities; hence, images of different anatomical structures are superimposed on each other &, thus, make it difficult to detect the lesions [2, 4, and 5]. Radiographic examination is still left much to be desired as a diagnostic tool: First of all, because of frequent disagreement among evaluators on its interpretation & discrepancies of same evaluator's interpretation at different times. Secondly dental & maxillofacial lesions often progress slowly, so they cannot be easily evaluated with sequentially obtained radiographs, & thirdly, structural 'noise' produces visual confusion & limits detection of small lesions [6, 7, 8, and 9]. The strength of Digital Subtraction Radiography (DSR) is because it cancels out complex anatomic background, against which the subtle changes occur. As a result, conspicuousness of the changes is greatly increased. Methods used to make such measurements range from visual interpretation and manual measurements to computer-aided image analysis [10]

History

Subtraction methods were introduced by B. G. Zeides des Plantes in the 1920s. Subtraction radiography was introduced to dentistry in 1980s [11, 12, 13, and 14]. It was used to compare standardized radiographs taken at sequential examination visits. All unchanged structures were subtracted and these areas were displayed in neutral gray shade in the subtraction image; while regions that had changed, were displayed in darker or lighter shades of gray [15, 16, 17].

Digital subtraction of images has been applied to dental radiography for more than 20 years. Film subtraction was the established standard method for cerebral angiography and was widely used until digital subtraction fluoroscopy became available in the late 1970s. Nowadays, filmless' photoelectronic imaging systems, especially video fluoroscopy, are used to subtract diagnostic images [18].

The detection of small changes in serial radiographs using subtraction methods introduced by Zeidses des Plantes is so-called 1st generation of subtraction systems and it employs photographic techniques for the subtraction of a priori registered radiographic films that are aligned manually.

The 2nd generation performs digital subtraction by means of computer. One of the earliest methods in dental radiology was reported by GroÈ ndahl et al. in the early 1980s (GroÈ ndahl's method[13]). Based on standardized radiographs, the reference (baseline) radiograph is digitized, converted to an exact positive image by the computer and displayed on a television (TV) screen. A TV-camera is then connected to the same screen and the subsequent (follow-up) image in its negative modality is superimposed on the positive reference image. By means of a device permitting rotation and translation of the subsequent radiograph, it is aligned and then digitized[13]. Ortman et al. added a second stage to this manual adjustment procedure where both images are presented sequentially in a ‘Flicker-mode’. Bragger and coworkers suggested the use of three stages to register the images during digitization. Coarse registration is done by a `chessboard'-mode. Numerous studies, starting in the early 1980s, have proven that digital subtraction radiography is capable of exquisite sensitivity to small changes, provided that the experimental conditions can be held constant.

The 3rd generation of subtraction systems based on direct digital radiography[11] with either CCD or storage phosphor receptors, was introduced in the late 1980s. Even though imaging geometry still is controlled mechanically, an alignment procedure, at least for compensation of the planar rigid transforms (i.e. translations and rotations), is required after the digitization or digital acquisition of radiographs. Hence, all 3rd generation systems perform the a posteriori registration by means of computer software. Furthermore, they are not restricted to rigid geometric transforms.

Methods and Applications

There are two considerable methods in digital fluoroscopy viz. "temporal subtraction" and "energy subtraction" [TABLE 1].

Table 1: Comparison of Temporal & Energy subtractions

Temporal subtraction	Energy subtraction
Normal x-ray beam filterate is adequate	x-ray beam filter switching is preferred
A contrast resolution of 1mm at 1% is achieved	Higher x-ray intensity is required for comparable contrast resolution
A single KVP is used	Rapid KVP switching is required
Simple arithmetic image subtraction is necessary	Complex image subtraction is necessary
Total subtraction of common structures is achieved	Some residual bone may survive subtraction
Motion artifacts are a problem	Motion artifacts are greatly reduced
Subtraction possibilities are limited by the number of images	Many more types of subtraction images are posssible

When the two techniques are combined, the process is called "Hybrid Subtraction". Image contrast is still enhanced further by hybrid subtraction because of reduced patient motion between taking subtracted images. Temporal subtraction techniques are more often used because of limitation of high voltage generators in the energy subtraction techniques [19]. When the two images of the same object are registered and intensities of corresponding pixels are subtracted, a uniform difference image is produced. If there is a change in the radiographic attenuation between the baseline and follow-up examination, this change shows up as a brighter area, when the change represents gain, and as a darker area when, the change represents loss [10].

Role of Digital Subtraction Radiography in Dentistry

DSR has made a significant improvement in the detection of dental & maxillofacial lesions [1]. With conventional radiography, a change in mineralization of 30-60% is necessary to be detected by an experimented radiologist [2, 3, 20, 21, 22] also the lesions restricted to cancellous bone could not be detected because of its less mineral contents than cortical bone [2, 23, 24, 25] but with DSR the alveolar bone changes of 1-5% per unit volume and significant differences in crestal bone height of 0.78 mm can be detected [26, 27, 28]. Also, defects of at least 0.49mm in depth of cortical bone can be detected whereas a lesion must be at least 3 times larger to be detectable with the conventional radiography techniques [4, 28]. Furthermore, it can be used to assess the bone at each of three phases of implant treatment, evaluation & maintenance [15].

Another application of DSR is in Temporomandibular Joint imaging, esp. with panoramics. The TMJ imaging programs allowed imaging of the right & left mandibular condyles in the open & closed positions on a single film, but the condylar head & intra-articular space were not depicted clearly because of the superimposition of the surrounding structures & the oblique projection of the joint. So, elimination of the superimposed structures with digital subtraction technique improves the visualization of condyle [29, 30, 31, and 32].

DSR has also been used in the evaluation of the progression, arrest, or regression of caries lesions. The caries lesions are not well-defined radiolucencies, thus the measurement of their extent is difficult in conventional radiography [16, 17]. In addition it is used for evaluation of endodontically treated teeth [33, 34]. And has the ability to detect root resorption as low as 0.5mm [6] and when underexposed radiographs are used, it can detect even soft tissue changes. So any lesion (including bony cysts or tumors) with potential of change over time can be studied in this technique [35].

Digital radiography also offers useful advantages in cephalometric analysis and growth prediction of the facial structures.

DSR also has a role in research purpose as the nature of digital images itself renders the technique very useful for a variety of scientific research approaches. Since digital images come as pure mathematical information, modern data processing can easily be applied making digital radiography an enormously useful source for scientific purposes

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Advantages

- Lower dose of radiation: Digital imaging requires lower dose of radiation as compared to conventional radiography.
- Computer manipulation: Computer manipulation is useful to modify contrast, colour, size of images as well as the visibility of the structures. .
- Image analysis: Automated image analysis may be performed by means of modern data processing. This is a particularly promising feature of digital radiography for the (near) future.
- No film processing: No need for conventional processing, thereby avoiding all film processing errors and hazards associated with handling the chemical solutions.
- Time reduction: Digital radiographs are acquired almost in real time (solid state detector systems)
- Storage: Due to legal requirements in many countries, radiographs have to be stored over a long period of time. Digital radiographs can easily be stored on various digital storage media in a space saving manner. However it should be kept in mind that change in digital file formats and operating systems may pose hazards in opening older files.
- Easy and quick image transfer: Digital images may be easily and quickly transmitted between institutions or offices, i.e. simply to avoid additional exposure for the patient.

Limitations and Resolves

- Cost: Purchasing digital radiographic systems is expensive, particularly panoramic systems.
- Storage capacity: The larger the image, the more storage space is required.
- Handling problems: Rigid direct digital receptors may induce patient discomfort and correct positioning in the hard palate region is beset with difficulties.
- Loss of resolution: Particularly most storage phosphor systems offer a lower optimal resolution when compared to radiographic film. If at all, however, this may only be relevant for high-resolution intraoral radiography where fine detail such as the tip of a very thin endodontic file has to be visualized.
- Image manipulation: Digital image may be more easily prone to intentional manipulation.

For a successful DSR, reproducible exposure geometry, and also identical contrast and density of the serial radiographs, are essential prerequisites, and long experience shows that this technique is very sensitive to any physical noise occurring between the radiographs [4] and even minor changes leads to large errors in results. Hence, the projection geometry & contrast & density should be standardized by a step wedge, to avoid misinterpretation of the subtracted images [3]. Differences in the image contrast and intensity between the baseline and the follow-up images can hamper the detection task and make the quantitative measurements unreliable [10]. Digital imaging soft-wares commonly include a histogram tool, as well as tools for the adjustment of brightness and contrast. Some tools also allow adjustment of the gamma value. Projection artifacts can be caused by misangulation of the central beam in relation to the film holder and the film. Grondahl showed that angulation discrepancies less than three degrees can produce interpretable subtraction images; Ruttiman et al reported that angulation errors should be limited to two degrees [1]. Customized occlusal stents can be used to align the film’s reproducibility to the dentition. But, stents can be used for a follow up period of less than 2 years and also they can be used in limited number of patients. In 1987, Jeffcoat et al described a method based on the use of cephalostat to maintain the position of the patient's head and a long source-to-object distance (more than 50 inch). In this method, the patient could be reproducibly placed within the cephalostat with less than 0.33 degrees of difference between the exposures and a non-divergent X-ray beam would pass through the patient and will be captured by an intra-oral film but cephalostat is expensive and also it needs adequate space to accommodate the long source-to-patient distance.

Conclusion

The digital subtraction radiography technique accommodating a digital dental imaging system should be acknowledged as a reliable method for quantitatively & longitudinal assessing any lesion with a potential of change over time. DSR has made a significant improvement in the detection of dental & maxillofacial lesions, in Temporomandibular Joint imaging and evaluation of the progression, arrest, or regression of caries lesions. But still there is no definite and accurate simple solution to control projection geometry and correct the discrepancies due to that, so this technique has still not been widely adapted to dental profession and the efforts are underway to solve these problems.

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