Literature review Digital Subtraction Radiography in Dentistry

E. Hekmatian DDS. MSc*, S. Sharif DDS, N. Khodaian DDS

Introduction

Radiography is a main diagnostic tool for detecting dental and maxillofacial lesions[1, 2, 3]. Radiologic images have two dimension of three dimensional reality, hence, the images of different anatomical structures are superimposed on each other and, thus, make it difficult to detect the lesions [2, 4, 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 and discrepancies of the same evaluator's interpretation at different times. Secondly, dental and maxillofacial lesions often progress slowly, so they can not be easily evaluated with sequentially obtained radiographs, and thirdly, structural 'noise' produces visual confusion and limits the detection of small lesions.[6,7,8,9]The strength of Digital Subtraction Radiography (DSR) is because it cancels out the complex anatomic background, against which the subtle changes occurs. As a result, the conspicuousness of the changes is greatly increased (figure 1). Subtraction images are well-suited for acquiring quantitative information such as linear, area, and density measurements. Methods used to make such measurements range from visual

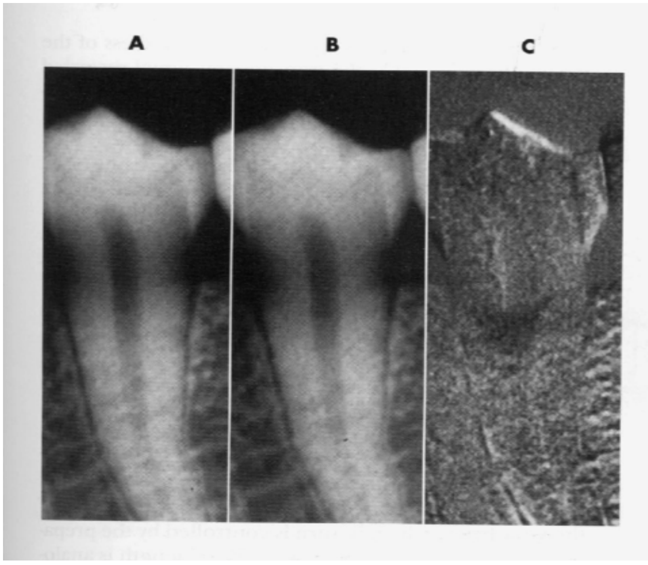

Figure 1: Digital subtraction radiographs. Subtraction radiography requires two images (A&B), which are exposed with the same geometry. In this instance the loss of alveolar bone in "B" is too subtle to be seen, however the subtracted image(C) displays the differences between A&B; the bone loss is seen as a dark structure superimposed over the pulp.(courtesy DR. H. G. Grondahl, Gotenborg, Sweden)

*Assitant Professor. Radiology Department, Faculty of Dentistry, Isfahan University of Mecdical Sciences, Isfahan, Iran.
Address: Radiology Department, Faculty of Dentistry, Isfahan University of Medical Sciences, Hezarjerib Ave., Isfahan. Iran.
E-mail: hekmatian@dnt.mui.ac.ir

interpretation and manual measurements to computer-aided image analysis.[10]

History and Definition

Digital Subtraction Radiography (DSR) is a method that can resolve deficiencies and increase the diagnostic accuracy [11,12,13]. Subtraction methods were introduced by B.G.Zeides des Plantes in the 1920s. Subtraction image is performed to suppress background features and to reduce the background complexity, compress the dynamic range, and amplify small differences by superimposing the scenes obtained at different times [14, 15].

Subtraction radiography was introduced to dentistry in 1980s [11, 16, 17, 18]. 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 [19, 20, 21].

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, specially video fluoroscopy, are used to subtract diagnostic images [15].

Methods and Applications

Temporal subtraction and energy subtraction are two considerable methods in digital fluoroscopy, each has distinct advantages and disadvantages (table 1).

Table 1: Comparison of "Temporal" and "Energy" subtractions

Temporal Subtraction	Energy Subtraction
-A single KVP is used	-Rapid KVP switching is required
-Normal x-ray beam filtration 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
-Simple arithmetic image subtraction is necessary	-Complex image subtraction is necessary
-Motion artifacts are a problem	-Motion artifacts are greatly reduced
-Total subtraction of common structures is achieved	-Some residual bone may survive subtraction
-Subtraction possibilities are limited by the number of images	-Many more types of subtraction images are possible

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 [22]. 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 (figure 2) [10].

Figure 2: Application of digital subtraction radiography for detection and quantification of periodontal bone healing. A, Base line image. B, Standardized 1-year follow-up image. C, Subtraction image showing increase in bone(arrow).

DSR has made a significant improvement in detection of dental and maxillofacial lesions [1]. It improves the detection of density changes in bony structures, and significantly, the sensitivity and accuracy of the evaluations[23]. With conventional radiography, a change in mineralization of 30-60% is necessary to be detected by an experimented radiologist, [2,3,24,25,26] also the lesions restricted to cancellous bone could not be detected because of it's less mineral contents than the cortical bone, [2,27,28,29,30,31] 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 [32,33,34].

This technique is used in periodontal diagnosis because of its potentially high sensitivity to detect of bone changes as little as 1% [4,12,36,37] and changes in the third dimension (bone density, bone thickness). Also defects of at least 0.49 mm in depth of cortical bone can be detected whereas a lesion must be at least three times larger to be detectable with the conventional radiography techniques [4, 34]. Furthermore, it can be used to assess the bone at each of three phases of implant treatment, evaluation, and maintenance [19, 23].

Another application of DSR is in Tempro Mandibular Joint (TMJ), imaging, especially with panoramics. TMJ imaging programs allowed imaging of the right and left mandibular condyles in the open and closed positions on a single film, but the condylar head and intra-articular space were not depicted clearly because of the superimposition of surrounding structures and the oblique projection of the joint. So, elimination of the superimposed structures with digital subtraction technique improves the visualization of condyl [38, 39, 40, 41].

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 [20, 21, 42, 43]. Subtraction consists of subtracting the pixel values of the baseline image from the pixel values of the second image. When nothing has happened, the result is zero. When caries regression or progression has occurred in the mean time, the result will be different from zero. When there is caries regression, the outcome will be a value above zero. in case of caries progression, the result is opposite and the outcome will be a value below zero. Because the negative values can not be displayed on the screen, usually an offset of 127 is added to the outcome of the subtraction process [44]. In addition it is used for evaluation of endodontically treated teeth [45, 46, 47] 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[48].

Limitations and Resolves

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, 49, 50] and even minor changes leads to large errors in the results [51]. Such artifacts are often difficult to be distinguished from biologic changes, [52] hence the Projection Geometry (PG), and contrast and density should be standardized by a step wedge, to avoid misinterpretation of the subtracted images [3, 14, 52]. Although exact reproduction of the projection geometry is not strictly necessary, some form of mechanical standardization will increase the reliance of image processing and will generally produce better results. Differences in image contrast and intensity between the baseline and the follow-up images can hamper the detection task and make the quantitative measurements unreliable [10]. Density and contrast of radiographs are influenced by processing time, temperature of developer, and exhaustion of developer caused by aging and depletion, [3, 53] so a step wedge or other devices must be incorporated into the imaging system to allow correction of differences between radiographs, after they have been indirectly digitized by desktop scanner or digital camera [48, 54]. Various methods have been used to match the intensities of baseline and follow-up images. All methods rely on either external or internal calibration[10.] This calibration can be accomplished by changing contrast, brightness, and gamma values. 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. Adjustment of brightness, contrast, and gamma values changes the original intensity values of the image (input) to new values (output) (figure 3) [10].

Projection artifacts can be caused by misangulation of the central beam in relation to the film holder and the film, itself while it is held in consistent geometry, and also when the film angulation is changed while the X-ray beam is held constant, [19, 55] the misangulation between the central beam and film holder and thus the film is of high importance[14, 55, 56]. 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]. To address the need for reproducible positioning, numerous methods have been proposed; in one of these methods customized occlusal stents[14, 57]. made of cold-cured acrylic or impression materials, are used to align the film's reproducibility to the dentition. Application of the stent method is possible for a limited number of patients and also teeth may move over time, making the stent unusable, [1, 23] so the stents can be used for follow-up durations of less than two years. Other difficulties in using stents are limitation of usage in edontulous areas, different patient's bite hardness in each exposure, high costs, maintaining the contaminated stents between the exposures and infection control issues, and also, the construction of individualized stents is very time consuming[58].

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. However, this method is not an effective solution for the general application, because the cephalostat is expensive and also it needs adequate space to accommodate the long source-to-patient distance.

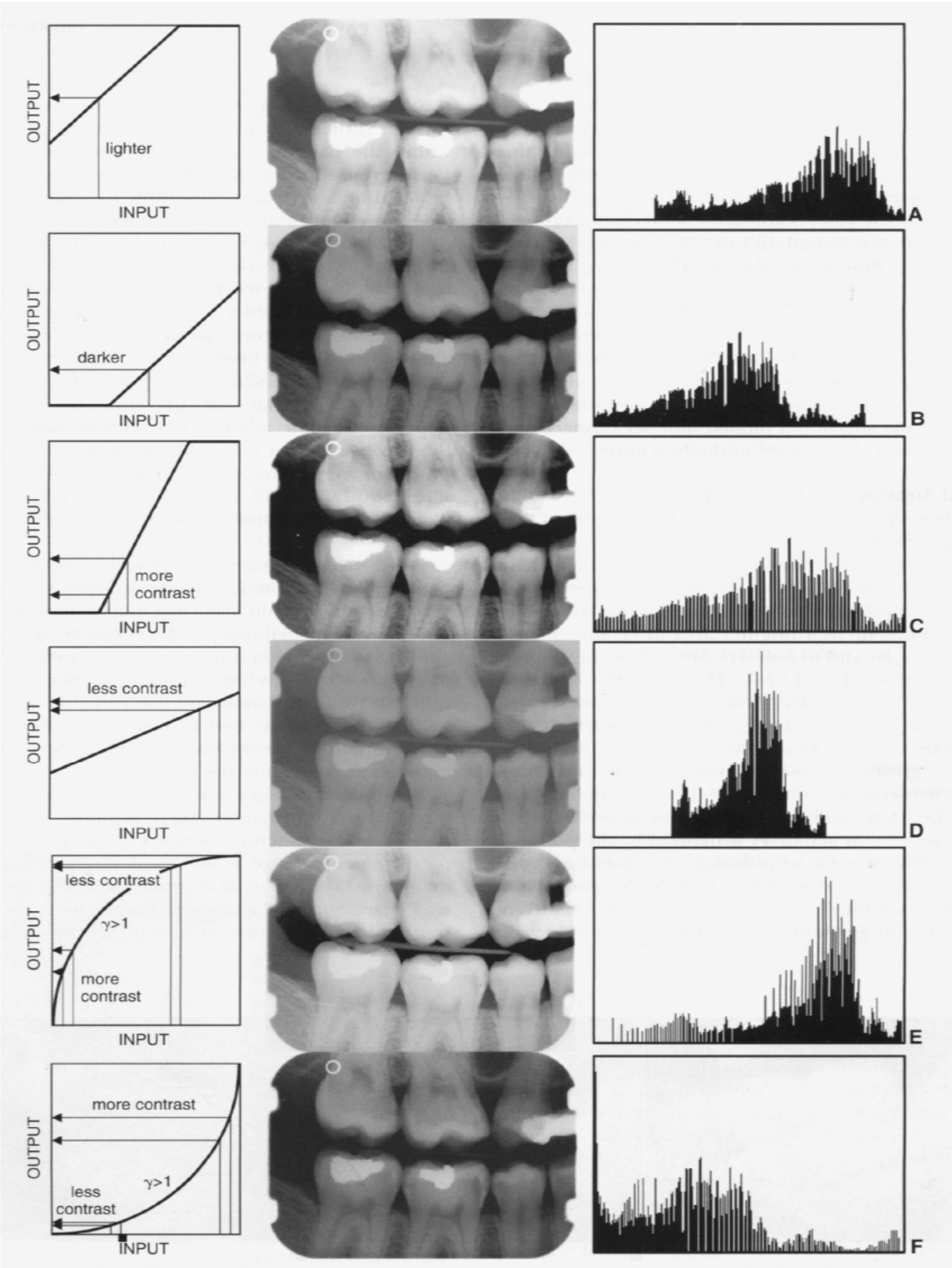

Figure 3: Effect of brightness, contrast, and gamma adjustment as illustrated by image transformation graphs(left), digital images(middle), and image histograms(right). A, Increase in brightness. B, Decrease in brightness. C, Increase in contrast. D, Decrease in contrast. E, Increase in gamma. F, Decrease in gamma.

Advances and Future

Recently a new system has been introduced, which consists of an aiming device, a high resolution X-ray film scanner and a computer software. With use of this aiming device, the "Projection Geometry" will vary no more than ten degrees in the horizontal or vertical dimension between the exposures; also a conventional long cone(40cm) is used with the system, and these overcome the two important limitations of previous systems to control "PG": a rigid linkage of the X-ray source, patient, and film, and a long source-to-object distance used in conjunction with the cephalostat [1].

Nowadays with the progress in the personal computers processing capability and also development of soft wares, adjusting serial images with discrepancies of more than ten degrees has become possible [23]. With computer soft wares used to align the pairs of images the same reference points are selected, compared and then the images are moved vertically, horizontally and rotationally until the pairs of images are matched [14].

Despite all these efforts, 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 [59].

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