

# A COMPARISON OF CONVENTIONAL RADIOGRAPHS AND DIGITALLY ENHANCED IMAGES FOR CARIES DETECTION USING RECEIVER OPERATING CHARACTERISTIC ANALYSIS

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## REZUMAT

**Obiectiv:** Scopul prezentului studiu in vitro a fost investigarea posibilităților de prelucrare digitală a imaginii radiologice în detectarea și evaluarea profunzimii cariilor proximale simple pe baza performanței diagnostice a unor observatori analizate prin curbe ROC. **Material și metode:** 90 de fețe proximale aparținând la 25 de dinți anteriori și 20 de dinți posteriori extrași au fost radiografiate standardizat prin tehnica paralelă, obținându-se radiografiile care au fost ulterior scanate. Imaginile rezultate, prelucrate digital cu un editor de imagine, au fost utilizate în diagnosticarea proceselor carioase proximale. Standardul de aur utilizat în analiza statistică este reprezentat de imaginile obținute la microscopul scanning ale zonelor de interes, iar observatorii implicați prezintă experiență variată în domeniul radiologiei stomatologice. **Rezultate:** Valoarea medie a performanței diagnostice  $A(z)$  pentru imaginea radiologică pe film este de 0,638, iar valoarea medie pentru performanța cea mai mare rezultată în urma prelucrării digitale a imaginilor este de 0,750 ( $p > 0,05$ ). În baza rezultatelor acestui studiu se poate stabili o legătură între profunzimea leziunii carioase și tipul de comandă utilizată cu care s-a înregistrat performanță diagnostică bună. Variațiile interobservator au fost mari în cazul cariilor în smalt, în timp ce, în cazul cariilor în dentină, acestea au înregistrat valori mai mici. **Concluzii:** Studiul demonstrează creșterea performanței diagnostice pentru toți observatorii în cazul imaginilor radiologice digitale prelucrate cu editorii de imagine comparativ cu radiografiile convenționale. Comenzile alese au variat în funcție de tipul de leziune carioasă analizată precum și de caracteristicile observatorilor (experiența clinică, radiologică și de utilizare a unui program de manipulare digitală a imaginii).

**Cuvinte cheie:** prelucrare digitală a imaginii radiologice, performanță diagnostică

## ABSTRACT

**Objective:** The aim of this in vitro study was the investigation of the possibilities of digital manipulation of the radiological images in the detection and evaluation of the depth of proximal caries using a receiver operating characteristic analysis. **Material and methods:** 90 proximal surfaces belonging to 25 anterior extracted teeth and 20 posterior extracted teeth were radiographed using the parallel technique. The radiographs were, then, scanned and the resulted images were digitally processed and enhanced. The gold standard was represented by the images of the fragments of interest viewed at the scanning electronic microscope. The observers had variable degrees of experience in dental radiology. **Results:** The mean value of the diagnostic performance  $A(z)$  was 0.638 for the images on film and 0.750 for the processed and enhanced images ( $p > 0.05$ ). After results analysis, we established a link between the type of caries and the type of commands used to improve the quality of the radiological digital image. The interobserver agreement was higher for the dentin caries than for the enamel caries. **Conclusions:** The study demonstrates the power of the digitally processed images over the improvement of the diagnostic performance for all observers. The selected commands varied according to the characteristics of the observers (clinical and radiological experience, computer skills).

**Key Words:** digitally processed image, diagnostic performance

## INTRODUCTION

The indirect digital radiographic techniques (scanning of conventional films and digitally enhancement using image editors) have issued several contradictions among specialists. The disagreements

implied that scanned and enhanced radiological images distort reality and do not improve diagnosis. This is the reason why we feel that this field needs further exploration.

Indirect digital techniques with scanning methods implies a conventional radiograph whose quality depends on the radiological geometry and processing steps of the film. It is understandable therefore that digital enhancement can't make miracles and transform a low quality image into a very good one with a high diagnostic potential.<sup>1,2</sup>

Still, proper enhancing of low quality radiographs with high tech image editors may lead to a significant rise of the diagnostic accuracy, due to the potential advantages of the digital manipulation.<sup>3-11</sup>

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Although these digital programs have many interactive options, most of the users limit their activities in image manipulation to the automatic functions, due to ease, habits and lack of computer experience. That's why, a correct and quick use of an image editor program requires serious knowledge in this field, on one hand and computer skills, on the other hand. Obviously, the secrets are not mentioned in books and this method requires patience and a lot of hard work. Of course, computer and image editor skills do not complete the picture as long as there isn't clinical and radiological experience.

Image enhancement should be performed within certain limits because, otherwise, the result may be highly distorted and without diagnostic value. A beautiful image, from the optical point of view, doesn't necessarily provide real radiological information.<sup>12,13</sup> Several studies even support the idea that the conventional radiograph gives the most reliable and correct diagnostic information.<sup>14,15</sup>

The aim of this *in vitro* study is to establish the influence of digital enhancement of radiological images on the diagnostic accuracy.

## **MATERIAL AND METHODS**

The study used AGFA Dentus M 2 Comfort film, whose processed radiographs were scanned and then digitally enhanced. Automatic commands (autobalance, autolevels, autocontrast) and manual commands (levels, brightness/contrast, accented and illuminated edges, sharpen edges, unsharp mask, emboss) commands were used by the observers to manipulate the set of digitized images. Receiver operating characteristic curves were generated for comparison of diagnostic efficacy of the two examination modalities. Ground truth was established with a gold standard represented by microscopic evaluation.

Forty-five extracted teeth were selected on the basis of radiographs on plain films and scanning microscope examinations in order to provide a variety of proximal carious lesions and statistical power. A total of 90 proximal surfaces (25 anterior and 20 posterior teeth) were evaluated. The clinical status of the carious lesions was either cavitation, stain or chalky appearance for all lesions microscopically detected.

All images were obtained in a standardized way having the teeth in a geometrical stable position using identical projections rules. The teeth mounted on film holder devices (ENDOPRO, USA) by bonding in the apical region with light cured resin were positioned at a 25 cm source-to-object distance. Tissue equivalent

material was used to simulate x-ray scatter of soft tissue. The X-ray source was a Toshiba B082D unit with long cone and rectangular collimation, operated at 70 kV for 0.2 seconds.

After the radiographs were obtained (using AGFA Dentus M 2 Comfort, No 2, speed E/F films; Heraeus Kulzer GmbH, Germany), the entire set was processed manually by a single technician, in order to avoid objective and subjective variations.

The digitized images were obtained using a commercial device – a flatbed scanner with transparency adaptor Genius HR-7 (resolution 1200/2400dpi) connected to a personal computer, at a scanning resolution of 400 dpi. The optimum resolution and the necessity of scanner calibration for digitizing intraoral radiographs were subject of analysis for various studies.<sup>16-18</sup>

The original films and the digitized images were distributed for examination to six observers with different degrees of radiological experience: two senior students, two general dentists and two radiologists. A computer randomized process of observer viewing was used to ensure a balanced distribution of images.

The viewing conditions for the films were made as similar as possible using constant room lighting and a masked view box. The digitized images were examined using the same settings for the display.

Each of the six observers was trained in the assessment of digital images so as to be familiar with the presentation format. All observers were trained in using the Adobe Photoshop® 6.0 software as an image editor.

Oral and written instructions about the method protocols were provided. In addition, the project coordinators were available to answer any of the observers' questions.

The observers were told to optimize the image using the digital commands (automatic or manual) according to what they considered to be best way of improving the quality of the radiological image in order to give a diagnostic score as good as possible in their opinion. So, they had to identify the presence or absence of carious lesion as no caries, caries in enamel, caries in internal dentin and external dentin.

### **Statistic analysis**

There are studies which advise the use of equal numbers of caries-free and penetrated surfaces in ROC analysis for preventing degenerated data sets.<sup>19,20</sup>

The scores of the observers were statistically analysed using the comparison with the gold standard imaged by the microscopic results. The ROC curves

were then completed and the next step was to analyse the data provided by the areas under these curves.

The five point confidence scale counts as standard for any ROC analysis:

- 1 - Caries definitely absent;
- 2 - Caries probably absent;
- 3 - Undecided;
- 4 - Caries probably present;
- 5 - Caries definitely present.

The gold standard or ground truth was given by the microscope examination. We have made sections of the area of interest (caries-free or not) and we have viewed them at the scanning electronic microscope. The study processed the statistical data using MedCalc 2005® for Windows 8.1 (Belgium).

## RESULTS AND DISCUSSION

Based on the received data, the diagnostic accuracy for enamel caries on conventional film was calculated. The accuracy is indicated through the value of the areas under the ROC curves (Table 1). The observers were chosen as following: first and second observers - the senior students, third and fourth observers - the general dentists and the fifth and sixth observers - dental radiologists.

**Table 1.** A(z) values for enamel caries on film; A(z) = 0.638 (mean).

	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
<b>A(z)</b>	0.545	0.583	0.621	0.621	0.727	0.693

For each of the 6 observers the A(z) values for enamel caries evaluated on digitally enhanced images were established. (Table 2)

**Table 2.** A(z) values for enamel caries on digitally enhanced film (the most efficient commands).

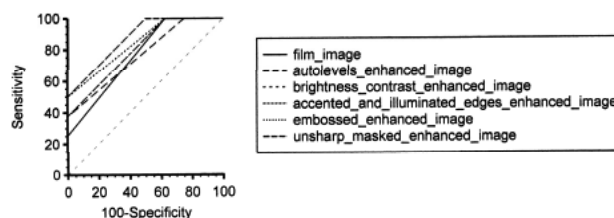
Command	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
Autolevels	0.583	0.621	0.679	0.687	0.727	0.727
Brightness Contrast	0.659	0.697	0.777	0.727	0.814	0.806
Accented and illuminated edges	0.659	0.679	0.786	0.732	0.761	0.758
Unsharp mask	0.727	0.727	0.786	0.732	0.886	0.866
Emboss	0.693	0.727	0.761	0.758	0.864	0.777

The diagnostic accuracy was quite low for enamel caries evaluations, with the radiologists having the best results. The best results were obtained using the

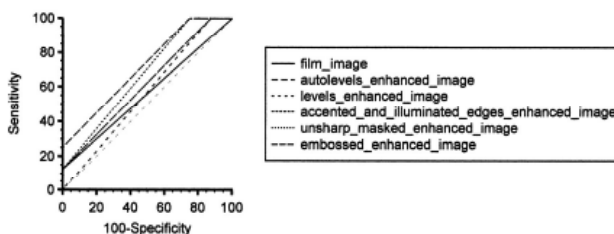
unsharp mask and emboss commands.

The p-values (indicating whether there is a normal distribution of data or not) were 0.13 for unsharp mask and 0.08 for emboss.

The ROC curves for best and worst observers for enamel examinations are significant regarding the efficiency of different commands. (Figs. 1, 2)



**Figure 1.** ROC curves for best observer.



**Figure 2.** ROC curves for worst observer.

The highest accuracy for these observers was obtained using the unsharp mask and the lowest performance was given by autolevels. Good values of A(z) (not impressive for some of them) were also obtained with emboss, illuminated and accented edges and brightness-contrast. The p-value was higher than 0.05 for the unsharp mask and emboss.

After receiving the observers' scores, the values of A(z) for dentin caries on conventional film were calculated. (Table 3)

For each of the 6 observers the A(z) values for enamel caries evaluated on digitally enhanced images were validated. (Table 4)

**Table 3.** The A(z) values for dentin caries on film; A(z) = 0.666 (mean).

	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
<b>A(z)</b>	0.583	0.621	0.659	0.679	0.727	0.727

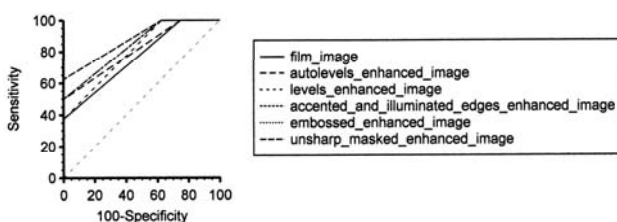
**Table 4.** A(z) values for dentin caries on digitally enhanced film (the most efficient commands).

Function	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Obs 6
Autolevels	0.621	0.659	0.697	0.679	0.687	0.758
Levels	0.659	0.679	0.777	0.721	0.732	0.814
Unsharp mask	0.727	0.758	0.786	0.844	0.821	0.886
Emboss	0.758	0.777	0.821	0.839	0.866	0.886
Accented and illuminated edges	0.697	0.697	0.786	0.732	0.777	0.814

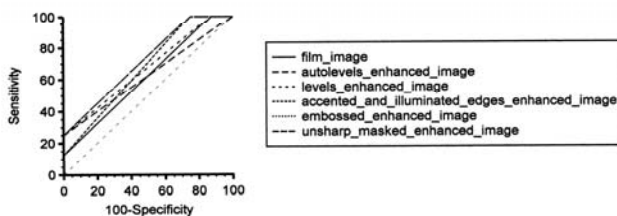
The diagnostic accuracy improved for dentin caries and didn't involve important interobserver agreement variations. The commands varied according to different reasons but some of them indicated themselves as being quite efficient for certain type of carious lesions.

The most efficient commands were emboss, the unsharp mask, the accented and illuminated edges, invert and brightness/contrast (different succession than commands used for improving A(z) for enamel caries detection).

The ROC curves for the best and worst observers are important for the analysis of the final results. (Figs. 3 and 4)



**Figure 3.** The ROC curves for worst observer.



**Figure 4.** The ROC curves for best observer.

The highest diagnostic accuracy was obtained with emboss, unsharp mask and accented and illuminated edges. The p-values were statistical significant: 0.06 for illuminated and accented edges, 0.08 for emboss and

0.013 for the unsharp mask.

The accuracy variations for both enamel and dentin caries evaluations had different reasons. Two significant cases in order to explain the reasons that drove to the results above were chosen.

Case 13 represents a distal external enamel caries of 47 considered as a challenge even for the radiologists. (Fig. 5) The tooth was mesio-distal sectioned, the histological analysis proving the existence of the enamel carious lesion. (Fig. 6) The observers digitally improved the scanned radiographs and the most efficient commands proved to be emboss, unsharp mask and accented and illuminated edges. (Figs. 7- 10)



**Figure 5.** Distal enamel carious lesion of 47.

The automatic commands are simple to use but they are not proper for low loss of substance lesions. These functions were chosen, at first, by all observers but the radiologists were the only ones that obtained good results due, of course, to their radiological experience. On the other hand, the manual commands are pretentious, laborious and need experience in using image editors. The general dentists and even some of radiologists were, at first, reluctant in choosing these functions but the insatisfying results drove them,

finally, into using manual commands.



**Figure 6.** Mesio-distal section evidencing the external enamel carious lesion of 47.



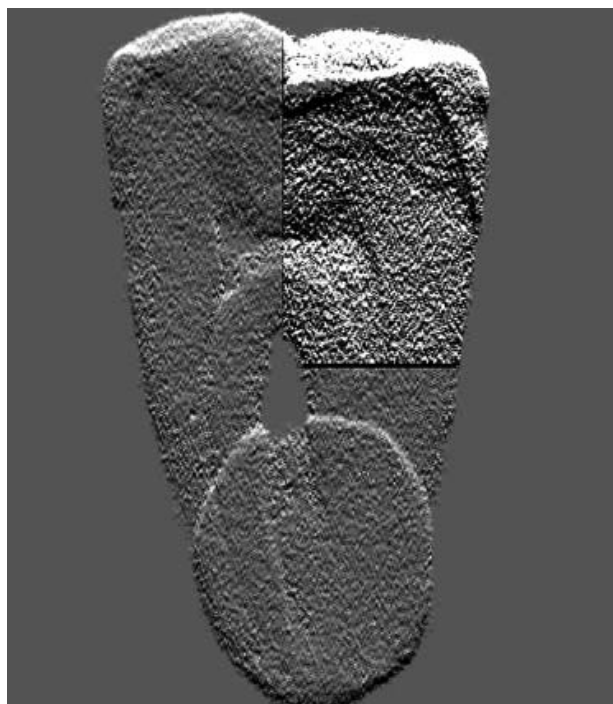
**Figure 7.** Scanned image.

Technical problems occurred frequently, but the results depended on the clinical and radiological experience of the observers.

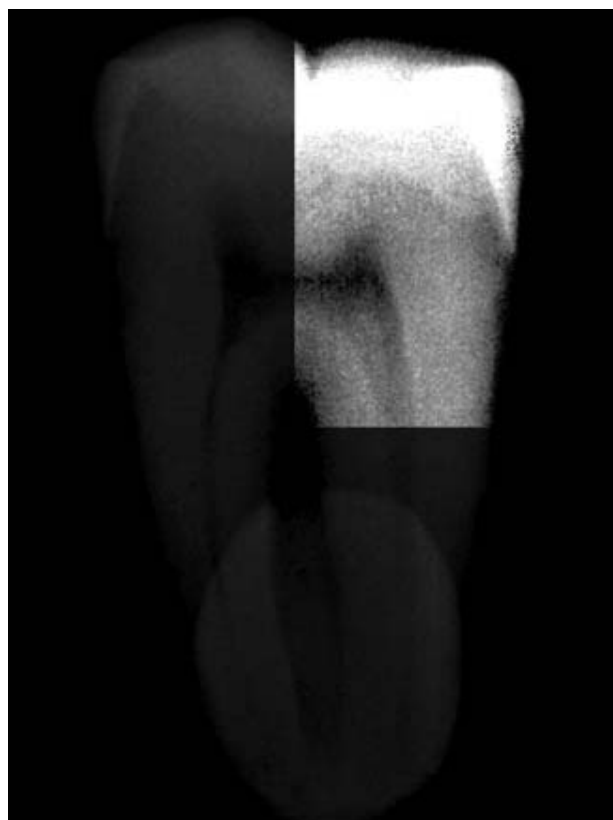
Case 57 represents a distal intern dentin carious lesion of 44. (Fig. 11) The mesio-distal section of the tooth proves the existence of the lesion. (Fig. 12)

The best diagnostic accuracy was achieved using emboss, unsharp mask and illuminated and accented edges commands. (Figs. 13-16)

Due to the low quality of the scanned radiograph, the case involved the highest examination time for all observers, in order to get the best results.



**Figure 8.** Embossed digital image.

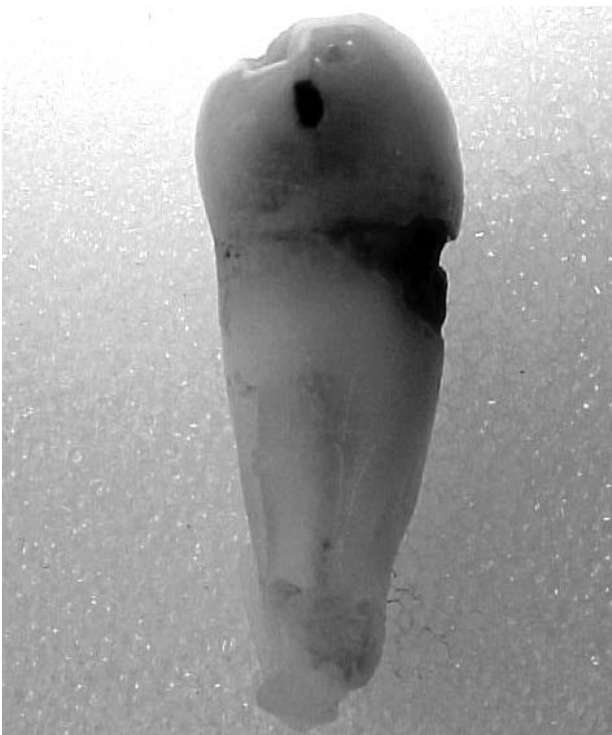


**Figure 9.** Unsharp masked digital image.

Students were very open, from the beginning, to use manual commands due to their good computer skills and to their eagerness to explore new imaging techniques. Adobe Photoshop 6.0 is very performant, but needs a lot of patience in order to obtain good results.



**Figure 10.** Illuminated and accented edges digital image.



**Figure 11.** Distal dentin carious lesion of 44.

The apparent difficulty dissipated at the beginning our young observers, and this was the reason why they have adopted, at first, the automatic commands. Fortunately, the uncertain results forced them into adopting the challenge of the manual digital functions.

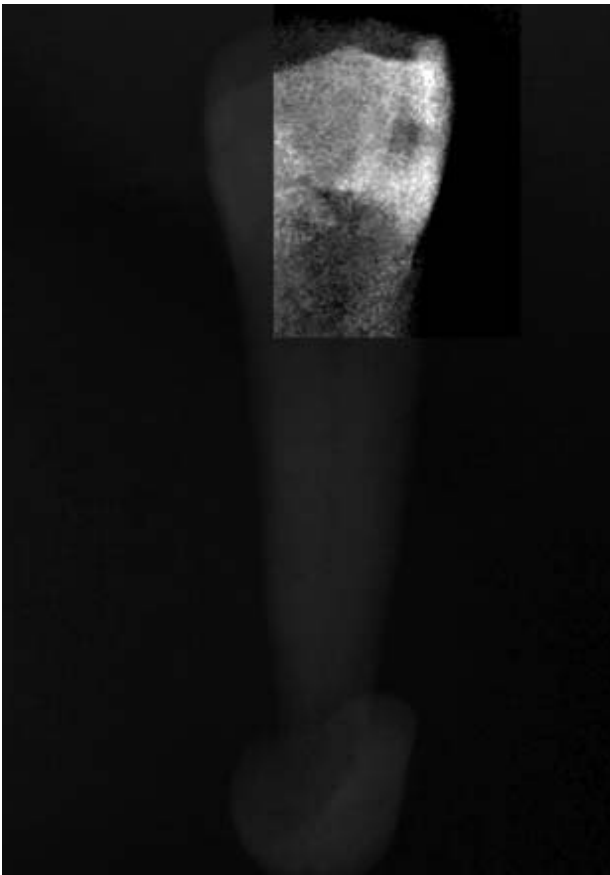


**Figure 12.** Mesio-distal section evidencing the internal dentin carious lesion of 44.

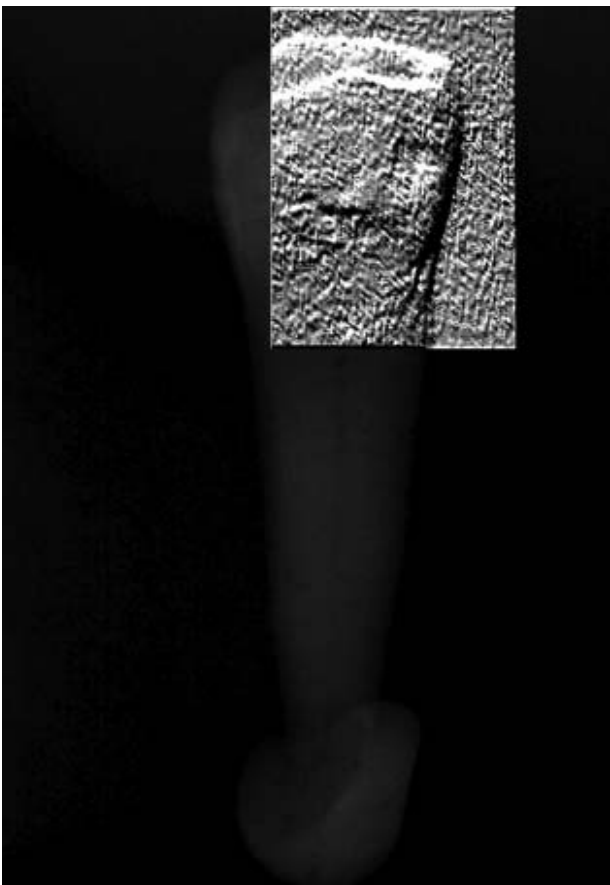


**Figure 13.** Scanned image.

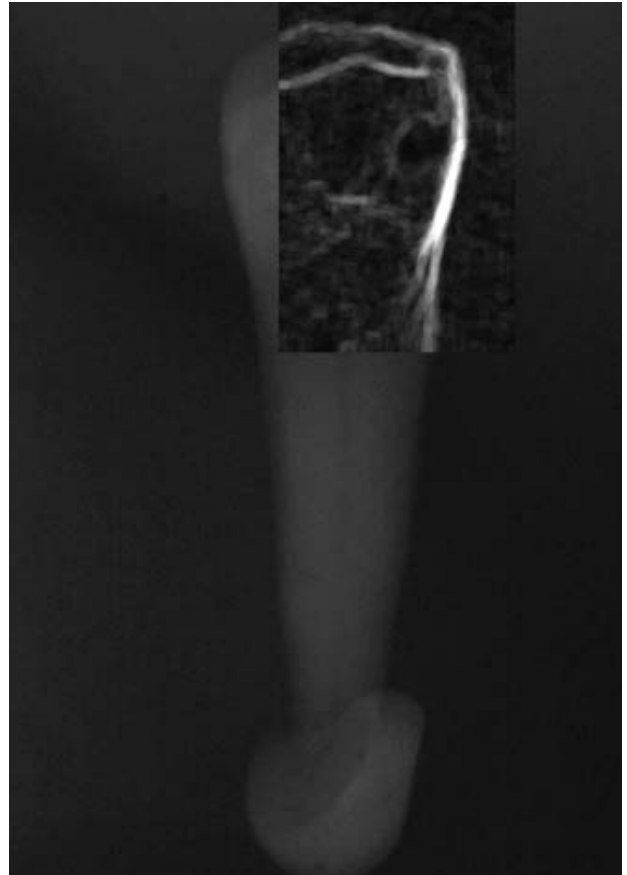
The results prove that there isn't a miraculous way of transforming a low quality radiological image into a „beauty princess” image which helps to get a quick



**Figure 14.** Unsharp masked image.



**Figure 15.** Embossed image



**Figure 16.** Illuminated and accented edges image.

and correct diagnosis even for the low experienced observers. This is why the optical experience of the radiologists had a high impact over the final results in all situations.

The analysis of the observers' answers showed that there is an important variation between the average of the areas under the ROC curves for film (0.638) and the one for digitally enhanced radiological images (0.750). These values are not significantly different from those published by other studies in the field. The p-value was also higher than 0.05 for the situations when efficient commands had been involved.

The results of this study have confirmed that there are possibilities of establishing a certain link between the type of caries and the command of an image editor which leads to a high performance accuracy.

So, unsharp mask, emboss and brightness/contrast were the best for improving enamel caries on radiological images. These caries are very difficult to be detected especially on in vitro radiographs (even for the experienced observers), therefore they implied harder and more cautious work.

Emboss, unsharp mask and accented and illuminated edges commands were most capable for rising the quality of dentin caries on radiological images.

The interobserver agreement had higher values for evaluating enamel caries than dentin caries.

## **CONCLUSIONS**

This study undoubtedly proves the advantages of enhanced digital images on the diagnostic accuracy in caries detection. We believe this represents a reliable comparison between the influence of conventional radiographs and digitally enhanced images on diagnosis.

The commands belonging to the image editor varied according to the type of caries and the features of the observers (clinical and radiological experience, computer skills).

## **REFERENCES**

1. Analoui M. Radiographic image enhancement. Part I: spatial domain techniques. *Dentomaxillofac Radiol* 2001;30(1):1-9.
2. Analoui M. Radiographic digital image enhancement. Part II: transform domain techniques. *Dentomaxillofac Radiol* 2001;30(2):65-77.
3. Farman AG. Fundamentals of image acquisition and processing in the digital era. *Orthod Craniofac Res* 2003;6(Suppl 1):17-22.
4. Brennan J. An introduction to digital radiography in dentistry. *J Orthod* 2002;29(1):66-9.
5. Pharoah MJ, White SC. *Oral radiology - Principles and interpretation*. 4th Edition, Mosby - Zear Book Inc., St. Louis, 2000.
6. Roman EC. Rolul prelucrării imaginilor radiologice digitale în diagnosticul odontal. *Revista Națională de Stomatologie*. 2005;III(1-2):59-64.
7. Baștan EC. Studiu comparativ privind calitatea și cantitatea informației furnizate de examinările radiologice clasice și digitale indirecte în terapia leziunilor coronare la dinți vitali. *TMJ* 2004;54(Suppl. 2):61-2.
8. Roman EC, Bodnar D, Vârlan C. Radiodiagnosticul digital indirect al leziunilor carioase coronare. 8th Romanian National Dentistry Congress. First International Esthetic Dentistry, Bucharest, 18-22 August, 2004.
9. Shrout MK, Russell CM, Potter BJ et al. Digital enhancement of radiographs: can it improve caries diagnosis? *J Am Dent Assoc* 1996;127(4):469-73.
10. Smith KE. Caries detection: At best an inexact science: Part II. *Global Dental News Journal* 2002.
11. Lehmann TM, Troeltsch E, Spitzer K. Image processing and enhancement provided by commercial dental software programs. *Dentomaxillofac Radiol* 2002;31(4):264-72.
12. Boscolo FN, Oliveira AE, de Almeida SA et al. Clinical study of the sensitivity and dynamic range of three digital systems, eE-speed film and digitized film. *Braz Dent J* 2001;12(3):191-5.
13. Li G. Comparative investigation of subjective image quality of digital intraoral radiographs processed with 3 image-processing algorithms. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2004;97(6):762-7.
14. Parisis N, Kondylidou S, Tsirlis A, et al. Conventional radiographs vs digitized radiographs: image quality assessment. *Dentomaxillofac Radiol* 2005;34(6):353-6.
15. Guneri P, Lomcali G, Boyacioglu H, et al. The effects of incremental brightness and contrast adjustments on radiographic data: a quantitative study. *Dentomaxillofac Radiol* 2005;34(1):20-7.
16. Chen SK, Hollender L. Digitizing of radiographs with a flatbed scanner. *J Dent* 1995;23(4):205-8.
17. Janhom A, van Ginkel FC, van Amerongen JP, et al. Scanning resolution and the detection of approximal caries. *Dentomaxillofac Radiol* 2001;30(3):166-71.
18. Carroll L, Kimmes N, Saini T, et al. Interpretative agreement during visualization of conventional and scanned bitewing radiographs. *IADR/AADR/CADR 83rd General Session*, March 9-12, 2005, Radiological Diagnostics.
19. Metz CE. Some practical issues of experimental design and data analysis in radiological ROC studies. *Invest Radiol* 1989;24:234-45.
20. Metz CE. Basic principles of ROC analysis. *Semin Nucl Med* 1978;8:283-98.