Original Article

A Comparison of Radiographic Film Densitometry Using a New Computerized Tool with a Digital Densitometer

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Abstract

Objectives: The purpose of this study was to develop and test a new tool for radiographic densitometry by combining periapical films and aluminum step wedge.

Materials and Methods: We reviewed 50 Kodak E-speed intraoral films. An aluminum step wedge consisting of 16 steps was constructed. Each step was 1mmx3mx10mm. The step wedge was exposed to varying exposure times, ranging from 0.05 second to 0.5 second, increasing in 0.05 second increments. Films were digitalized after processing and the MATLAB software algorithm was ran subsequently. Density of the films was measured again using a digital densitometer. In order to compare the two imaging techniques, three steps were selected. Output data from the MATLAB algorithm were compared with data obtained from the digital densitometer.

Results: The new method could detect significant differences between subsequent exposure times in step 7, while the densitometer did that in steps 7 and 12. The new method's sensitivity in determining density changes was 5.26%, 84.1% and 93.02% in steps 2, 7, and 12 respectively.

Conclusions: Our new method has an acceptable sensitivity for determining density changes of at least 7 mmEq/Al.

Keywords: Densitometry; Image Processing, Computer-Assisted; Aluminum; Phantoms, Imaging

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INTRODUCTION

Bone mineral density (BMD) is defined as the amount of bone tissue in a certain volume [1]. Bone mineral density measurement may be beneficial or even necessary in clinical situations such as diagnosing osteoporosis, intraoral procedures related to dental implants, periodontal treatments, endodontic procedures, or follow up evaluations of such procedures [2, 3]. Several methods are available for BMD measurement. Magnetic resonance imaging, ultrasound, computed tomography, dual energy X-ray absorptiometry (DXA), and radiographic densitometry have been used for medical and dental evaluations [4]. Dual energy X-ray absorptiometry is currently the gold standard for diagnosis and evaluation of bone loss [5]. It can also be used to measure mandibular BMD. Tonguç et al, [6] reported that BMD was significantly lower in patients with moderate to severe chronic periodontitis compared to those with healthy periodontium. Computed tomography is also used to evaluate mandibular BMD.

It determines the general BMD by averaging BMD values obtained from various pixels of the image. However, this modality is not suitable for dental purposes such as implant site determination because surgeons need detailed information regarding quality and quantity of bone in a certain area. In other words, when measuring BMD, the jaws should be divided into small regions of interest compatible with the required accuracy [3]. Conventional film densitometry is an inexpensive tool for assessment of BMD.

Fig. 1: Aluminum step wedge

Fig. 2: Digital densitometer

Panoramic and periapical radiographs, as well as direct digital radiographs are among the other conventional densitometry methods [7-11]. Conventional films can be evaluated with digital densitometers or they can be digitalized and processed using special software programs used for digital radiographs. Using conventional intra-oral films for bone densitometry has some clinical benefits.

It is user friendly, inexpensive, and easily available. In situations like follow up visits, it can be used to monitor the progress of healing or resorption of periapical, pericoronal, or any other inflammatory bone lesion. The purpose of the present study was to develop a method for measurement of film densitometry using conventional periapical films. This method was tested for its potential application in clinical studies. Sensitivity for detecting two consecutive densities was evaluated by a digital densitometer.

MATERIALS AND METHODS

We used an aluminum step wedge (Fig. 1) and Kodak E-speed #2 periapical film (Eastman-Kodak Co., Rochester, NY, USA). The step wedge was made in the Dental Material Laboratory (Science and Technology Research Center, Imam Khomeini Hospital, Tehran, Iran) and was 16 mm in height, 48 mm in length, and 10 mm in width, and consisted of sixteen 1x3mm steps. The step wedge was fixed to intraoral films and a wooden table was used to standardize the projection geometry. Films were exposed with dental X-ray machine with exposure time ranging from 0.05 second to 0.5 second, increasing in 0.05 second increments. The distance between the table and the tube was set at 10cm. The samples included radiographic images, which were processed in an automatic roller transport processor machine (Velopex Extra-X Medivance Instruments Ltd., London, UK), and were subsequently digitalized with Epson 1240U Photo Flatbed Scanner (Seiko Epson Corp., Nagano, Japan). In order to minimize interpersonal variation and exposure, processing and digitalization were performed by one person and to limit the effect of temperature, exposure and processing were done in one day. After digitalization, 1x1mm segments were cropped from the steps of each scanned image and were saved in JPEG format. We used an algorithm from the MATLAB Software (MathWorks Inc., MA, USA) to calculate the intensity of brightness for each cropped segment. Subsequently, the films underwent density measurement using a digital film densitometer (Fig. 2). Statistical analysis was done using SPSS version 20 (SPSS Inc., Chicago, IL, USA). Since the one-way ANOVA test showed a significant interaction between the variables, two-way ANOVA and Tukey's test were applied to compare the results in each step. Statistical significance was set at $P \leq 0.05$.

RESULTS

Relationship between pixel intensity and thickness:

To have an average value for the pixel intensity in the images obtained by the step wedge, we used steps number 2, 7, and 12. The algorithm output showed the mean pixel intensity of each of the three steps in successive exposure times.

Table 1 presents the means and standard deviations of pixel intensity in three selected steps, which encompass 10 exposure times.

Table 1. Descriptive statistics of pixel intensity in three selected steps

Step number	Exposure time (s)	Mean	Standard deviation
2	0.05	2.3054	.0098
	0.1	2.3175	.0090
	0.15	2.3301	.0103
	0.2	2.3155	.0073
	0.25	2.3284	.0076
	0.3	2.3207	.0079
	0.35	2.3313	.0082
	0.4	2.3068	.0263
	0.45	2.3232	.0110
	0.5	2.3101	.0196
7	0.05	2.2780	.0044
	0.1	2.2671	.0208
	0.15	2.2315	.0083
	0.2	2.1405	.0372
	0.25	2.1615	.0166
	0.3	2.0766	.0116
	0.35	2.1347	.0177
	0.4	2.0403	.0455
	0.45	2.0704	.0148
	0.5	2.0170	.0327
12	0.05	2.1758	.0324
	0.1	1.9758	.0241
	0.15	1.9046	.0225
	0.2	1.5669	.1189
	0.25	1.6812	.0143
	0.3	1.4959	.0353
	0.35	1.5887	.0274
	0.4	1.3851	.0967
	0.45	1.4696	.0097
	0.5	1.3983	.0936

Two-way ANOVA and post hoc Tukey's HSD test showed no significant difference in pixel intensity with increasing exposure time for step 2 (P>0.05, Table 2).

Table 2: Relationship between the mean pixel intensity and increase in exposure time in step number 2

Time (s)	Subset for alpha=0.05	
	1	2
0.50	215.7440	-
0.45	216.0200	-
0.40	216.3180	216.3180
0.10	216.6480	216.6480
0.5	217.2780	217.2780
0.25	217.3840	217.3840
0.20	217.5280	217.5280
0.35	217.6080	217.6080
0.15	217.6540	217.6540
0.30	-	219.1880
Significance	0.583	0.100

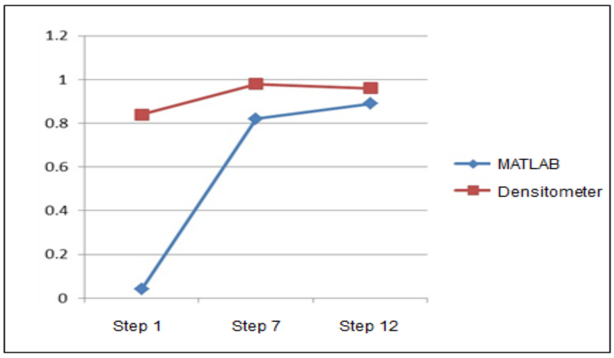

Fig. 3: Relationship between sensitivity of digital densitometer and self-designed algorithm

The relationship between exposure time and pixel intensity for steps 7 (P=0.000) and 12 (P=0.000) was significant (Tables 3 and 4).

The radigraphic density of every step was subsequently measured for every exposure time, using a digital densitometer. These data served as the gold standard against which, we compared our algorithm's output. Descriptive statics for radiographic density results from the digital densitometer are shown in Table 5. Similar analyses were performed for the algorithm output data. The results showed that except in step number 2, there were significant differences in radiographic densities for subsequent exposure times for other steps (P<0.05, Tables 2, 3 and 4).

Sensitivity of technique in detecting density changes:

Sensitivity of each technique in determining changes in radiographic density or mean pixel intensity was calculated with the following equation: The sum of the significant differences between each two successive exposure times for each step was divided by the sum of all multiple comparisons. The calculated sensitivity for each step by each method is shown in Table 6. The proportion of sensitivity in each step is demonstrated in Figure 3. It was 5.26%, 84.1%, and 93.02% for steps 2, 7 and 12, respectively.

DISCUSSION

Changes in crestal and periapical bone mass, together with other clinical features, can be used

Table 3: Relationship between the mean pixel intensity and increase in exposure time in step number 7

Time	Subset for alpha=0.05								
	1	2	3	4	5	6	7	8	9
0.05	20.6667	-	-	-	-	-	-	-	-
0.1	-	26.3333	-	-	-	-	-	-	-
0.15	-	-	31.6667	-	-	-	-	-	-
0.2	-	-	-	35.6667	-	-	-	-	-
0.25	-	-	-	-	40.0000	-	-	-	-
0.3	-	-	-	-	-	44.3333	-	-	-
0.35	-	-	-	-	-	-	50.3333	-	-
0.4	-	-	-	-	-	-	-	55.6667	-
0.45	-	-	-	-	-	-	-	58.3333	-
0.5	-	-	-	-	-	-	-	-	62.6667
Significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.086	0.000

to evaluate healing of periapical lesions, progression of peri-implantitis, follow up of surgical or nonsurgical periodontal treatments and implant osseointegration process, evaluate healing of tooth extraction sites, and detect interproximal caries in restorative dentistry. Evaluation of changes in the bone level can be performed using digital subtraction technique (DSR) [12-21], software programs such as computer assisted densitometric image analysis [22-30], specialized programs for digital radiographic systems like DIGORA, customized software programs such as IDRISI [24, 31-36], and optical densitometry [37-42], which has been used more commonly in the past. The main focus of this study was to evaluate the ability of the algorithm designed by the authors to discriminate between changes in intraoral film density with a step wedge with calibrated steps in vitro.

Numerical values obtained from the algorithm show mean pixel value or brightness intensity, which is the reciprocal of radiographic density. Two variables were used to categorize these data: time and the number of each step.

“Time” was a variable selected in this study to assess the ability of the algorithm to determine changes in pixel values between two subsequent steps. Each step had 1mm thickness of aluminum. “Number” of steps was a variable selected to assess the ability of the algorithm to distinguish between pixel values of two pieces of aluminum with similar thickness but different exposure times. The next step was to determine the density of the samples using a digital densitometer. Our results showed that both methods had significant differences in distinguishing between two images taken in subsequent exposure times.

Table 4: Relationship between the mean pixel intensity and increase in exposure time in step number 12

Time (s)	Subset for alpha=0.05							
	1	2	3	4	5	6	7	8
0.05	26.3333	-	-	-	-	-	-	-
0.1	-	44.0000	-	-	-	-	-	-
0.15	-	-	59.6667	-	-	-	-	-
0.2	-	-	-	75.0000	-	-	-	-
0.25	-	-	-	-	90.6667	-	-	-
0.3	-	-	-	-	-	109.6667	-	-
0.35	-	-	-	-	-	117.3333	-	-
0.4	-	-	-	-	-	-	145.0000	-
0.45	-	-	-	-	-	-	148.0000	-
0.5	-	-	-	-	-	-	-	167.6667
Significance	0.000	0.000	0.000	0.000	0.000	0.544	0.997	0.000

Table 5: Descriptive statistics of radiographic density in three selected steps

Step number	Exposure time (s)	Mean	Standard deviation
2	0.05	19.00	0.00
	0.1	22.00	0.00
	0.15	24.00	1.00
	0.2	25.66	0.57
	0.25	27.00	0.00
	0.3	28.66	0.57
	0.35	32.66	1.15
	0.4	34.66	2.88
	0.45	34.66	0.57
	0.5	36.33	1.15
7	0.05	20.66	0.57
	0.1	26.33	0.57
	0.15	31.66	1.52
	0.2	35.66	0.57
	0.25	40.00	0.00
	0.3	44.33	0.57
	0.35	50.33	1.52
	0.4	55.66	1.52
	0.45	58.33	0.57
	0.5	62.66	1.15
12	0.05	26.33	0.57
	0.1	44.00	1.00
	0.15	59.66	3.78
	0.2	75.00	5.19
	0.25	90.66	0.57
	0.3	109.66	1.52
	0.35	117.33	8.08
	0.4	145.00	7.54
	0.45	148.00	3.00
	0.5	167.66	4.72

Our method failed to determine two subsequent steps as precisely as the digital densitometer did for step 7 and both methods were unable to detect changes in radiographic density or pixel intensity for step 2. This inaccuracy was due to the inability of the conventional films to capture all details of very thin bodies or very short exposure times. Haidekker et al, [43] conducted an animal study, which helped them develop an algorithm for image processing. They concluded that computerized methods, such as quantitative computed tomography and DXA were not suitable for densitometry in small animals while their designed algorithm quantitatively determined BMD in digitalized radiographs and could accurately determine the outline of cortical bone. However, this algorithm had structural difference with ours and measured radiographic density, while our algorithm calculated brightness intensity. Their algorithm could also detect cortical bone outline. Vaccaro et al, [44] evaluated the correlation between the mean gray value obtained from digital radiographs and digital images of conventional films and BMD values from DXA scans of bovine and equine bone. The mean gray values were obtained using a software designed to manipulate digitalized images or digital radiographic images. They concluded that mean gray value analysis is a precise and highly accurate method for assessing BMD and the obtained data were comparable to those of DXA (correlation coefficients of 0.910 and 0.937 for conventional and digital radiography, respectively). Their conclusions were in agreement with ours, and offer an inexpensive and non-invasive method for BMD estimation. In our study, DXA was the gold standard for BMD measurement while digital densitometry was the comparison.

Table 6: Sensitivity of the two methods in steps 2, 7 and 12

	MATLAB			Densitometer		
Step	2	7	12	2	7	12
Sensitivity	2/45	37/45	40/45	38/45	44/45	43/45

Gomes et al, [45] performed a study to compare pixel intensity obtained at different spatial resolutions. In their study an aluminum step wedge was used as the reference and bone chips from two different pig mandibles were used as samples. The images were measured by using a histogram tool provided by the Image Tool program. The results of the study showed that there was no significant difference between pixel intensity of steps 2, 3 and 4 and that of bone chips in spatial resolutions of 150 and 300 dpi. They recommended measuring pixel intensity on digital images of conventional films by using an aluminum step wedge as the reference for density. They also stated that small variations in spatial resolution did not interfere with pixel intensity calculations by computer programs. Gomes et al, [45] confirmed that aluminum step wedge can be used to simulate bone and compare bone densities in-vitro. Steps 2, 3 and 4 in their study were 3.3 mmEq/Al, 3.6 mmEq/Al and 3.9 mmEq/Al, respectively. We also found no significant difference between exposure times in step 2 with 1 mm thickness. Nackaerts et al, [46] developed a densitometry tool for analysis of intraoral radiographs and jaw bone densitometry. That study was performed on adult human cadavers and a step wedge served as the reference. The samples were gradually decalcified and radiographs were taken and analyzed and DXA was performed for all specimens. Direct volumetric measurement was considered the gold standard for determination of accuracy of the new software. With introducing custom designed software, density in mmEq/Al was calculated for all radiographs. The correlation coefficients between density in mmEq/Al and DXA results and the direct density measurements were 0.9 and 0.5, respectively, which suggests that it could potentially be used for clinical evaluation of bone density. Proportion of sensitivity of our method in relation to digital densitometer indicated that this method can calculate changes in density of aluminum in step 2 as 5.26% of digital densitometer. This ratio definitely is inadequate for clinical situations. For aluminum pieces 7 mm and 12 mm thick, this number was 84.1%, and 93.02%, respectively. This suggests that this new method is good for evaluation of hard tissue density and gross masses rather than small changes. To perform density evaluation by special software programs and self-designed algorithms, it is wise to include soft tissue simulator density in the design of the study. In this regard, Schropp et al, [47] used wax and acrylic plates to provide radiographic density similar to that of human cheek. They demonstrated that pieces of wax 13-17 mm thick or 14.5 mm thick acrylic can simulate average human cheek density in radiographic studies in-vitro. A study by de Molon et al, [48] evaluated the effect of soft tissue simulation materials on dental and bone radiographic densities with pixel intensity (PI) and digital subtraction radiography (DSR) analysis. Five types of materials consisting of acrylic, wax, water, wood, and frozen bovine tissue were used as soft tissue simulators and they found that in dental region, analysis by both PI and DSR techniques showed no differences in the density of these materials. However, in the bone region, DSR showed that material type and thickness could influence the gain of density, while PI analysis in bone region showed lower density in the images without soft tissue simulators.

CONCLUSION

This new method of densitometry can distinguish changes in density of aluminum with acceptable proportion in thicknesses of 7 mm and 12 mm. This suggests that with increasing thickness of aluminum for any given exposure time, the sensitivity of the technique becomes closer to that of a digital densitometer.

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