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A Method to Evaluate and Compare Two Different Intraoral Radiographs of the Same Patient

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A B S T R A C T

Objective of this study was to determine the accuracy of the method of the clinical intraoral densitometry, to compare differences in the calculation with or without subtraction of the background adjacent soft-tissues from the stepwedge (SW) and to verify which regression model best fitted the experimental data in order to express the measured values in equivalents of SW thickness. Two intraoral radiographs, one after another, were made for each of 6 patients. A copper SW (6 steps, thickness 0.05–0.3 mm) was attached to each radiograph, trying to avoid the superimposition of the bony structures. Films were processed and digitized. Grey levels were measured on each step of the SW, on the background of the SW and on the same 3 randomly chosen regions of interest (ROIs) on each digitized image. The measurement with and without the subtraction of optical densities of the background around the SW from the optical densities of the SW was performed. For the calculation of the SW thickness equivalents, the regression analysis was performed by using different regression models. The best fitting regression model was the 3rd degree polynomial. The results were more precise when using the subtraction of the background overlapping the SW.

Introduction

The radiographic image is the most common way to evaluate relationships between different regions of the skeleton, to distinguish the diseased from the normal state, and to monitor bone-mass changes of disease progress or treatment.

When the qualities of radiographs are evaluated, two parameters are generally considered: a) the radiographic density (or optical density (OD)) at the darkest

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site of the radiograph); and b) the radiographic contrast (or the capacity to sharply distinguish different shades of gray on the same radiograph)[1].

However, a minimum bone mass loss of 30%, and sometimes as much as 50–60% is needed before significant loss of bone can be detected using standard visual analysis techniques.

The basic principle for the evaluation and the comparison of the radiographs, even from the same patient, is their standardization[2].

This could be provided with various sorts of materials of a recognizable thickness. A common method for densitometric standardization is to include a stepwedge (SW) with each exposure in order to provide a basis for comparison of the radiographs.

In the manner of the easiest radiograph manipulation, some materials such as aluminium[3,4] copper[5–7], nickel[8,9] of various thicknesses, or some solutions like CsCl or $CaCl_2$[10], ethanol[11] and water[11] are in the use. The most frequently used is aluminum SW, however, the range of thicknesses of aluminum equivalent to typical mandibular bone densities (4.5–8 mm) is likely to be bulky and inconvenient[8].

The SW included with each exposure could reflect the differences between the exposures, film processing[12], and the digitization.

Some investigators attempted to develop a method for the radiograph comparison of ODs without previous standardization with a SW[13].

Recently, a number of papers have been published in the dental literature which demonstrate methods for quantitative assay of osseous lesions based on digital subtraction radiography[14–16].

The aim of this study was to try to improve the accuracy of the method of clinical intraoral densitometry, using a 6 step copper SW, to compare differences in the calculation with or without subtraction of the background overlapping the SW and to find out which regression model best fitted the experimental data.

Materials and Methods

For this purpose, 6 volunteers took a part in this study. Voluntary written informed consent was obtained from each of them. Approval for the study was obtained from the Ethics Committee, University of Zagreb.

Two intraoral radiographs of the right frontal section of the maxilla were taken for each participant, one after another, under almost the same conditions. The X-ray machine (Siemens, Dosimatic Helìodent, Germany) was operated at 56 kVp with a constant current of 2,5 mA/s and an exposure time of 0,7 sec. Images were recorded using the Kodak Ekta speed Plus film (3 x 4 cm). All films were processed together in an automatic dark chamber processor (Dürr Dental XR 24 Nova, Germany) for 12 minutes.

During the exposure, a copper SW was attached coronal to the teeth (trying not to cover any bone structure) to give a reference image on the radiographs. SW was composed of 6 steps of thickness 0.05–0.3 mm.

The ranges of the optical densities of all the steps of the SW were designed to match with the ranges of optical densities of the bone structures of ROIs measured on the digitized images.

Radiographs were digitized using a transparent scanner (Lynotype-Hell, 8-bit, 300 DPI).

Before the measurement of grey levels (GL), black and white shades of the images were inverted in order to measure the blackness or whiteness on a range scale from zero (black) to 255 (white). The measurement was performed using the probe with the dimension of 4 x 4 pixels.

The mean grey levels (GLs) were measured by using Scion image, Beta 4.0.2 software (www.scioncorp.com) on:

– each step of the SW (on the right side, 2 mm above the lower border of SW),
– the immediately adjacent soft-tissue under each step of SW (on the right side, 2 mm below the lower border of SW),
– and on the regions of interest (ROI), (3 ROIs were randomly chosen based upon the criteria to include different ranges of grey levels – periapical region, bony structure 5 mm above periapical region and interdental alveolar crest) (Figure 1).

The same measurement was performed on each digitized image, to determine the reference points on the images providing the same measurement area for the images of the same patient.

As it is not precise enough to compare two different images of the same patient through the mean grey level scale, optical densities for each region of measurement were calculated as follows:

$$OD= -\log Ii/255,$$

OD = optical density and I_i – mean measured intensity of grey levels.

There were neither 0 nor 255 grey level values measured in this study.

The calculations were made in two different ways – with and without subtraction of the immediately adjacent soft-tissue from the SW.

Subtraction of the superimposed background was performed on the level of optical densities.

In the first calculation, optical density values of SW together with the superimposition of the soft tissues were used in the regression curve along with the SW thickness.

In the second calculation, prior to the calculation of the regression formula, each optical density of the background, overlapping next to each step of SW was subtracted from optical density of each step of SW in order to obtain the pure optical density of the SW.

To compare the two images of the same patient, optical density values of the SW, corrected through the regression curve to fit the copper thickness, should be equal. In this way, expressing ODs in equivalents of copper thickness (corrected through the regression curve), two different images are compensated for the eventual difference in exposure, processing and digitisation[17–19].

The next step in this study was to apply a regression test for multiple curves, in order to verify which regression model (linear, polynomial, logarithmic, power or exponential, etc.) better fitted the experimental data for both calculation methods (with and without subtraction of the background).

During the calculation, optical density values of each step of the SW were plotted

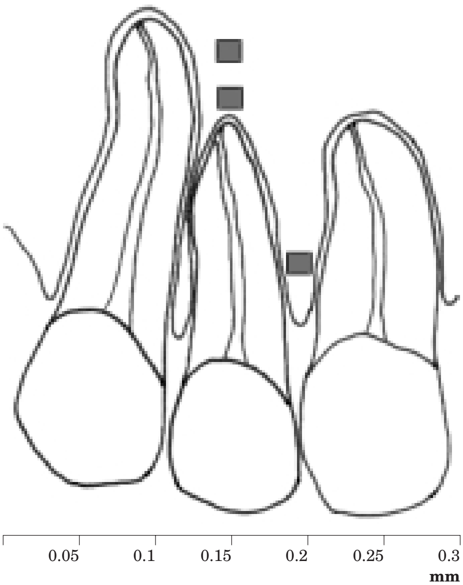

Fig. 1. Six step stepwedge and regions of the interest measured in the study.

on the axis of abscissas and the actual SW thickness (in mm) of the related step on the axis of ordinates.

The regression formula was thus derived, through the different regression models.

Optical density values of the ROIs were also expressed in copper thickness equivalents, through the different regression models.

The differences between each actual SW thickness and its equivalent were calculated (absolute residual errors expressed in mm, and relative residual errors in %).

The differences between the same ROIs (expressed in mm) on two digitized images of the same patient were also calculated (Eq ROI 2 – Eq ROI 1) for all the regression models used in the study. This was done for both, the first and the second radiographs.

Results

Mean values of calculated optical densities for both, stepwedge and regions of interest in the first and second image, with and without subtraction for all the patients are shown in Table 1.

The summary of the mean values and standard deviations of the equivalents of the SW thickness for the measurement of the different regression models (linear, 2nd degree polynomial, 3rd degree polynomial, 4th degree polynomial, logarithmic, power and exponential) without subtracting (in the first image of one of the patients) is presented in Table 2, and the same measurement for the second image in Table 3.

The same regressions were used to express all regions of interest in equivalents of stepwedge thickness (SWT), for the both measurements (Eq ROI) (Tables 2 and 3).

The calculations for the measurement with the subtraction of the background on the first and the second image of 6 patients are shown in Tables 4 and 5.

Each of the equivalents of the SW thickness on the images were subtracted from the actual SW thickness, and the difference between them was presented as the relative as the absolute residual error (in mm).

TABLE 1
MEAN VALUES OF CALCULATED OPTICAL DENSITIES (OD) FOR BOTH, STEPWEDGE (SW) AND REGIONS OF INTEREST (ROI) IN THE FIRST AND SECOND IMAGE, WITH AND WITHOUT SUBTRACTION

x OD SW – first image, without subtraction	x OD SW – second image, without subtraction	x OD SW – first image, with subtraction	x OD SW – second image, with subtraction
0.38	0.37	0.36	0.37
0.34	0.33	0.32	0.33
0.26	0.26	0.25	0.26
0.17	0.18	0.15	0.18
0.09	0.09	0.08	0.09
0.04	0.04	0.02	0.04
x OD ROI	x OD ROI	x OD ROI	x OD ROI
0.29	0.30	0.29	0.30
0.21	0.18	0.21	0.18
0.22	0.21	0.22	0.21

TABLE 2
DIFFERENT REGRESSION MODELS CALCULATED WITH THE SUBTRACTION ON THE FIRST IMAGE OF THE PATIENTS

Linear			2nd degree polynomial			3rd degree polynomial			4th degree polynomial			Logarithmic			Power			Exponential		
Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	EqSWT		Error	EqSWT		Error	EqSWT		Error
X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X
0.29	0.001	–0.01	0.29	0.001	–0.01	0.30	0.00	0.00	0.30	0.00	0.00	0.32	0.002	0.02	0.28	0.002	–0.02	0.33	0.002	0.03
0.26	0.001	0.01	0.26	0.001	0.01	0.25	0.00	0.00	0.25	0.00	0.00	0.31	0.002	0.06	0.26	0.001	0.01	0.27	0.002	0.02
0.21	0.001	0.01	0.21	0.002	0.01	0.20	0.00	0.00	0.20	0.00	0.00	0.30	0.003	0.10	0.21	0.001	0.01	0.19	0.001	–0.01
0.15	0.00	0.00	0.14	0.001	–0.01	0.15	0.00	0.00	0.15	0.00	0.00	0.28	0.003	0.13	0.15	0.00	0.00	0.12	0.002	–0.03
0.09	0.001	0.01	0.09	0.002	–0.01	0.10	0.00	0.00	0.10	0.00	0.00	0.25	0.003	0.15	0.10	0.00	0.00	0.08	0.001	–0.02
0.05	0.00	0.00	0.06	0.001	0.01	0.05	0.00	0.00	0.05	0.00	0.00	0.21	0.004	0.16	0.05	0.00	0.00	0.07	0.001	0.02
Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI		
X	SD		X	SD		X	SD		X	SD		X	SD		X	SD		X	SD	
0.23	0.00		0.23	0.00		0.22	0.00		0.23	0.001		0.30	0.001		0.23	0.002		0.22	0.00	
0.17	0.002		0.17	0.002		0.17	0.002		0.17	0.001		0.29	0.00		0.17	0.002		0.14	0.001	
0.18	0.001		0.17	0.00		0.17	0.00		0.17	0.00		0.29	0.00		0.18	0.001		0.15	0.00	
R^2 = 0.9890–0.9916			R^2 = 0.9890–0.992			R^2 = 0.9990–0.9996			R^2 = 0.9986–0.9990			R^2 = 0.7998–0.9133			R^2 = 0.9687–0.9855			R^2 = 0.9265–0.93		

TABLE 3
DIFFERENT REGRESSION MODELS CALCULATED WITH THE SUBTRACTION ON THE SECOND IMAGE OF THE PATIENTS

Linear			2nd degree polynomial			3rd degree polynomial			4th degree polynomial			Logarithmic			Power			Exponential		
Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	EqSWT		Error	EqSWT		Error	EqSWT		Error
X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X
0.29	0.001	–0.01	0.29	0.002	–0.01	0.30	0.00	0.00	0.30	0.00	0.00	0.32	0.002	0.02	0.28	0.002	–0.02	0.32	0.002	0.02
0.26	0.002	0.01	0.26	0.002	0.01	0.25	0.00	0.00	0.25	0.00	0.00	0.32	0.003	0.07	0.26	0.001	0.01	0.27	0.001	0.02
0.21	0.002	0.01	0.21	0.002	0.01	0.20	0.00	0.00	0.20	0.00	0.00	0.30	0.003	0.10	0.21	0.001	0.01	0.19	0.001	–0.01
0.15	0.00	0.00	0.15	0.00	0.00	0.15	0.00	0.00	0.15	0.00	0.00	0.29	0.004	0.14	0.15	0.00	0.00	0.13	0.002	–0.02
0.09	0.001	–0.01	0.09	0.001	–0.01	0.10	0.00	0.00	0.10	0.00	0.00	0.25	0.004	0.15	0.09	0.002	–0.01	0.08	0.002	–0.02
0.06	0.002	0.01	0.06	0.002	0.01	0.05	0.00	0.00	0.05	0.00	0.00	0.22	0.004	0.17	0.05	0.00	0.00	0.07	0.001	0.02
Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI		
X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.
0.23	0.00	0	0.23	0.00	0	0.22	0.00	0	0.22	0.001	–0.01	0.31	0.001	0.01	0.23	0.003	0.23	0.22	0.00	0
0.15	0.002	–0.02	0.15	0.002	–0.02	0.16	0.002	–0.01	0.16	0.001	–0.01	0.29	0.00	0.00	0.16	0.003	0.16	0.13	0.002	–0.01
0.17	0.002	–0.01	0.17	0.00	0	0.17	0.00	0	0.17	0.00	0	0.29	0.00	0.00	0.18	0.003	0.18	0.15	0.00	0
R^2 = 0.9868–0.9918			R^2 = 0.9878–0.9920			R^2 = 0.9991–0.9995			R^2 = 0.9989–0.9990			R^2 = 0.9242–0.9950			R^2 = 0.9550–0.9855			R^2 = 0.9243–0.9300		

Each of the equivalents of reference points (ROI) measured on the second images were subtracted from the first image of the same patient, and the difference between them was presented in mm (Eq ROI2-Eq ROI1).

The results for both measurements indicated that the best fitting curve was the 3rd degree polynomial (the relative residual error for the SW Eq regression curve was 0%), whose regression equation can be thus expressed:

$$y=ax^3+bx^2+cx+d.$$

The 3rd degree polynomial had also shown the smallest difference (mm) in the calculation of the equivalents of ROIs for the measurement without the subtraction (Table 3) and no difference in the calculation of the equivalents of ROIs for the measurement with the subtraction (Table 5).

The 4th degree polynomial had also shown the smallest relative residual error for the calculation of the equivalents of the SW thickness in both measurements (0%)(Table 3, Table 5), but the differences between the calculated equivalents of the ROIs for the measurements without the subtraction were higher in comparison to the equivalents calculated using 3rd degree polynomial (Table 3).

In the measurement with the subtraction the difference was even higher – mean error was 0.01 mm and 0.02 mm (Table 5).

All the other regression models, for both measurements, presented higher relative and absolute residual errors.

The most inaccurate model for both measurements was the logarithmic one because of the relative residual errors in the calculated equivalents of the SW thicknesses – even up to 74% for the measurements with the subtraction and up to 77% for the measurements without the subtraction on both images.

The highest difference in the calculated equivalents of ROIs for the measurement without the subtraction existed in the linear and the 2nd degree polynomial model (0.02 mm).

The differences in the calculated equivalents of ROIs for the measurement with the subtraction were lower for all the regression models except the 4th degree polynomial.

Table 6 shows the regression line for the curves tested in this study, proving that the 3rd degree polynomial is the best fitting regression curve because of its highest squared correlation coefficient-R^2 (from 0.9990 to 0.9998).

After the same calculation (with the subtraction) for all of the 6 patients, the results for the calculation without the subtraction revealed that the residual errors for the equivalents of the SW thicknesses did not exist using the 3rd degree polynomial, and the differences between the same ROIs on the first and the second digitized image were the lowest.

The results revealed that the residual errors for the equivalents of SW thicknesses did not exist using the 3rd degree polynomial, and the difference between the same ROIs on the first and the second digitized image, calculated with the same regression curve was the lowest.

One-way ANOVA revealed that there was statistically significant difference between 7 different regression models for each step of the SW used in this study ($p<0.01$) (Table 7).

Discussion

It is very difficult to determine bone density of small structures such as those in the maxilla or the mandible, or even to compare differences in their optical densities on two images of the same patient. There are several principles of using the

TABLE 4
DIFFERENT REGRESSION MODELS CALCULATED WITHOUT THE SUBTRACTION ON THE FIRST IMAGE OF THE PATIENTS

Linear			2^{nd} degree polynomial			3^{rd} degree polynomial			4^{th} degree polynomial			Logarithmic			Power			Exponential		
Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	EqSWT		Error	EqSWT		Error	EqSWT		Error
X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X
0.29	0.001	–0.01	0.29	0.002	–0.01	0.30	0.00	0.00	0.30	0.00	0.00	0.29	0.001	–0.01	0.26	0.001	–0.04	0.32	0.001	0.02
0.26	0.001	0.01	0.26	0.001	0.01	0.25	0.00	0.00	0.25	0.00	0.00	0.29	0.002	–0.04	0.25	0.00	0.00	0.27	0.001	0.02
0.21	0.002	0.01	0.21	0.001	0.01	0.20	0.00	0.00	0.20	0.00	0.00	0.28	0.003	–0.08	0.21	0.001	0.01	0.19	0.001	–0.01
0.15	0.00	0.00	0.14	0.001	–0.01	0.15	0.00	0.00	0.15	0.00	0.00	0.26	0.003	–0.11	0.16	0.001	0.01	0.12	0.002	–0.03
0.09	0.001	–0.01	0.09	0.001	–0.01	0.10	0.00	0.00	0.10	0.00	0.00	0.24	0.002	–0.14	0.11	0.001	0.01	0.09	0.001	–0.01
0.05	0.00	0.00	0.06	0.002	0.01	0.05	0.00	0.00	0.05	0.00	0.00	0.19	0.003	–0.14	0.05	0.00	0.00	0.06	0.001	0.01
Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI		
X	SD		X	SD		X	SD		X	SD		X	SD		X	SD		X	SD	
0.24	0.001		0.24	0.001		0.23	0.00		0.22	0.002		0.28	0.002		0.23	0.00		0.23	0.002	
0.18	0.002		0.18	0.002		0.17	0.00		0.18	0.002		0.27	0.001		0.19	0.00		0.16	0.001	
0.19	0.00		0.18	0.002		0.18	0.00		0.18	0.00		0.27	0.001		0.20	0.00		0.16	0.001	
R2 = 0.9886-0.9010			R2 = 0.9897-0.9590			R2 = 0.9990-0.9995			R2 = 0.9984-0.9990			R2 = 0.8523-0.9523			R2 = 0.9520-0.9806			R2 = 0.9144-0.9347		

TABLE 5
DIFFERENT REGRESSION MODELS CALCULATED WITHOUT THE SUBTRACTION ON THE SECOND IMAGE OF THE PATIENTS

Linear			2^{nd} degree polynomial			3^{rd} degree polynomial			4^{th} degree polynomial			Logarithmic			Power			Exponential		
Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	Eq SWT		Error	EqSWT		Error	EqSWT		Error	EqSWT		Error
X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X	X	SD	X
0.29	0.001	–0.01	0.29	0.001	–0.01	0.30	0.00	0.00	0.30	0.00	0.00	0.27	0.002	0.03	0.25	0.002	–0.05	0.32	0.001	0.02
0.26	0.002	0.01	0.26	0.001	0.01	0.25	0.00	0.00	0.25	0.00	0.00	0.27	0.002	–0.02	0.23	0.001	–0.02	0.27	0.001	0.02
0.21	0.001	0.01	0.21	0.001	0.01	0.20	0.00	0.00	0.20	0.00	0.00	0.26	0.002	–0.06	0.21	0.001	0.01	0.19	0.001	–0.01
0.15	0.00	0.00	0.15	0.00	0.00	0.15	0.00	0.00	0.15	0.00	0.00	0.25	0.001	–0.10	0.18	0.001	0.03	0.13	0.001	–0.02
0.09	0.001	–0.01	0.09	0.001	–0.01	0.10	0.00	0.00	0.10	0.00	0.00	0.23	0.003	–0.13	0.12	0.001	0.02	0.08	0.001	–0.02
0.05	0.00	0.00	0.06	0.001	0.01	0.05	0.00	0.00	0.05	0.00	0.00	0.18	0.002	–0.13	0.05	0.00	0.00	0.06	0.001	0.01
Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI			Eq ROI		
X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.	X	SD	Diff.
0.25	0.001	0.01	0.25	0.001	0.01	0.23	0.00	0.00	0.24	0.001	0.02	0.27	0.001	–0.01	0.23	0.00	0.00	0.24	0.001	0.01
0.17	0.001	–0.01	0.17	0.001	–0.01	0.17	0.00	0.00	0.17	0.001	–0.01	0.25	0.001	–0.02	0.19	0.00	0.00	0.15	0.001	–0.01
0.19	0.00	0.00	0.19	0.001	0.01	0.18	0.00	0.00	0.18	0.00	0.00	0.26	0.001	–0.01	0.20	0.00	0.00	0.17	0.001	0.01
R^2= 0.988-0.990			R^2= 0.9890-0.9910			R^2= 0.9989-0.9998			R^2= 0.9989-0.9990			R^2 = 0.7905-0.8992			R^2 = 0.952-0.9740			R^2 = 0.9150-0.9366		

TABLE 6
REGRESSION LINES FOR THE CURVES TESTED FOR ALL PATIENTS

Curve	Equation	R^2 (min – max)
Linear	$y = ax+b$	0.9868 – 0.9918
2nd degree polynomial	$y = ax^2+bx+c$	0.9878 – 0.9920
3rd degree polynomial	$y = ax^3+bx^2+cx+d$	0.9990 – 0.9998
4th degree polynomial	$y = ax^4+bx^3+cx^2+dx+e$	0.9984 – 0.9990
Logarithmic	$y = a \log(x)+b$	0,7905 – 0.9523
Power b of x	$y = ax^b$	0.9520 – 0.9855
Exponential	$y = a e^{bx}$	0.9144 – 0.9366

TABLE 7
STATISTICALLY SIGNIFICANT DIFFERENCE BETWEEN EACH STEP OF THE STEPWEDGE AND 7 DIFFERENT REGRESSION MODELS

	First image, with subtraction			First image, without subtraction		
	df	F	p	df	F	p
Step 1	6	8.76	< 0.001	6	114.808	< 0.001
Step 2	6	5	0.001	6	204.461	< 0.001
Step 3	6	656.242	< 0.001	6	1057.35	< 0.001
Step 4	6	40.057	< 0.001	6	823.409	< 0.001
Step 5	6	62.287	< 0.001	6	668.359	< 0.001
Step 6	6	209.522	< 0.001	6	1001.06	< 0.001
	Second image, with subtraction			Second image, without subtraction		
	df	F	p	df	F	p
Step 1	6	4.4356	0.001	6	4.3138	0.001
Step 2	6	4.5678	0.001	6	201.465	< 0.001
Step 3	6	537.654	< 0.001	6	1032.53	< 0.001
Step 4	6	32.1786	< 0.001	6	832.307	< 0.001
Step 5	6	4.9967	0.001	6	4.5644	0.001
Step 6	6	195.887	< 0.001	6	1003.01	< 0.001

radiographs to analyze, compare, evaluate and interpret the results obtained.

Some authors plotted optical densities against SW thickness and used the linear regression model for the calculation[8,9], some of them plotted measured grey levels against SW thickness and used the 4th degree polynomial[20].

Although some investigators tried to compare optical densities on radiographs without a SW[13], in our study SW was used to compensate the differences between the two or more images of the same object, due to exposure, film processing and digitizing. For example, either through internal hardware or software, scanners will often perform image processing tasks on images to make them appear more visually pleasing. Such alterations in the gray-scale values make any kind of quantitative evaluation problematic or impossible without the use of the SW.

The contribution to the method of clinical intraoral densitometry with the SW are the results obtained in this study, confirming no residual errors using the 3rd degree polynomial as the regression model best fitting the experimental data when plotting optical densities against SW thickness.

According to Campos[21], the best fitting regression model was the logarithmic curve (r=–0.9705), but he suggested to avoid it because the value *y* is already a logarithm, leading to the expression Log(Log(y)), and also Log(x) has an infinite value when x=0. For that reason, he suggested the hyperbolic transformation of the 2nd order to be chosen. The correlation coefficient for the hyperbolic transformation, in his study, was r= 0.9296 for the hyperbola of the 1st order and r= 0.9463 for the hyperbola of the 2nd order proving that the hyperbola of the 2nd order is the best fitting model.

The results in our study show that the highest squared correlation coefficient-R^2 was obtained from the 3rd degree polynomial (R^2=0.9990–0.9998). The real correlation coefficient calculated from R^2 is then r=0.9994–0.9998, which is higher than it is in the study of Campos[21].

The worst fitting model in Campos's study[21] was the linear transformation (r = 0.9161), and in our investigation the worst fitting model was the logarithmic transformation (R^2 = 0,7905–0.9523, r = 0.8891–0.9758).

The results of this study indicate that the odd polynomial transformations better fit than those of even polynomial transformations. The reason for that is the specific shape of the curve expressing the data (moderate shape of the letter *S*).

The next very important fact, obtained in this study, was the subtraction of optical densities of the immediately adjacent soft-tissue from the optical densities of the SW, in the second set of our measurements.

The results of our study indicate that the residual error between the actual SW thickness and the equivalents of the SW thickness, as well as the difference between equivalents of ROIs on the two images of the same patient do not exist when using the 3rd polynomial and the subtraction of the soft tissue overlapping the SW.

This subtraction of the background is concerning soft, as well as possible hard tissue. According to Richards' investigation[22], the lip alone recorded one tenth the density of the lip and the mandible together.

The results of the first and the second measurement are indicating that the subtraction is also an important step in the process of evaluation and comparison of the intraoral radiographs.

Conclusions

To obtain more precise results of the measurement, optical densities of the overlapping background under the SW must be subtracted from the optical densities of each step of the SW.

The best fitting regression model for the experimental data is the polynomial function of the 3rd order, which should be used to express optical densities in SW equivalents.

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METODA ZA PROCJENU I USPOREDBU DVAJU RAZLIČITIH INTRAORALNIH RADIOGRAFSKIH SNIMAKA ISTOG PACIJENTA

S A Ž E T A K

Cilj rada bio je odrediti preciznost metode intraoralne denzitometrije, usporediti razlike u izračunima sa i bez oduzimanja sjena mekih tkiva od bakrenog kalibracijskog klina (BKK-a), te odrediti najbolji regresijski model za prikazivanje izmjerenih vrijednosti u ekvivalentima debljine BKK-a. Svakom su pacijentu izrađene svije intraoralne snimke, jedna za drugom. Na svaki intraoralni film pričvršćen je BKK od 6 slojeva, debljine od 0.05 do 0.3 mm uz nastojanje da se izbjegne superponiranje koštanih struktura. Svi su filmovi razvijeni i digitalizirani. Nivoi sivila mjereni su na svakom sloju BKK-a, u pozadini BKK-a te na 3 nasumce odabrana područja istraživanja na svakoj digitaliziranoj snimci. Sve vrijednosti mjerenja izražene su sa i bez oduzimanja optičkih gustoća pozadine superponirane preko BKK-a od optičkih gustoća BKK-a. Izmjerene vrijednosti izražene su u ekvivalentima debljine BKK-a koristeći različite regresijske modele. Najboljim se pokazao regresijski model polinoma trećeg stupnja. Rezultati su također bili precizniji koristeći metodu oduzimanja sjena mekih tkiva superponiranih preko BKK-a.