dental radiology

Editor:
JOHN W. PREECE, D.D.S.
American Academy of Dental Radiology
Department of Dental Diagnostic Sciences
School of Dentistry, The University of Texas Health Science Center at San Antonio
7703 Floyd Curl Dr.
San Antonio, Texas 78284

A study of the radiographic aluminum equivalent values of the mandible

W. Th. Trouerbach, W. H. A. Steen, A. W. Zwamborn, and H. J. A. Schouten, Rotterdam, The Netherlands

DEPARTMENTS OF EXPERIMENTAL RADIOLOGY AND BIOSTATISTICS, ERASMUS UNIVERSITY, UNIVERSITY HOSPITAL "DIJKZIGT" ROTTERDAM, AND DEPARTMENT OF PROSTHETIC DENTISTRY, STATE UNIVERSITY OF UTRECHT, THE NETHERLANDS

A longitudinal study of bone changes in the mandible was conducted. Duplicate radiographs were taken at 3-month intervals with the use of a positioning instrument, which included an aluminum calibrating wedge. The in-duplicate values obtained over the investigation period made it possible to assess the precision of the method and to analyze effects that take place with time. Significant bone changes were observed in seven volunteers between various observation periods at intervals of 6 and 9 months.
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A radiograph not only provides a picture of the bone morphology but also permits a microdensitometric quantitative analysis of bone minerals.

Microdensitometry has a distinct advantage over the more traditional visual method as a basis for the investigation of bone mineral changes. Since visual diagnosis is possible only in cases of substantial bone loss (30%) and visual radiographic criteria are not precise, it is desirable to identify a measuring technique that is useful with routine clinical radiographs. Computer processing makes it possible to store the data and to study the changes in certain areas that take place with time. This type of technique could be of special interest in the improvement of diagnostic procedures in clinical longitudinal investigations.

A record of bone mineral content and bone mineral distribution, for instance, can be very helpful in an evaluation of periodontal therapy or in a study of the changes in the residual alveolar ridge after tooth extraction. The literature concerning microdensitometry can be divided into two basic types of investigations, those carried out in the laboratory and those conducted on patients. Many experiments have been conducted in order to register the bone mineral content equivalent (BMC eq) in the mandible.[1, 4, 6, 8-10, 12, 19, 20] All of these investigators have demonstrated that the aluminum equivalent values of bone in the mandible can be measured, but the method proved time-consuming in practice. Several areas of medicine and dentistry, such as internal medicine, pathology, radiology, and surgery, are interested in bone or bone mineral from different points of view. This explains the variety in the bones chosen for evaluation and listed in Table I.

In an earlier study Trouerbach[22] described a computerized technique for measuring routine clinical radiographs, including the procedure for the determination of the aluminum equivalent values. Until now no conclusive answers were available to the questions concerning how long an observation period should be and how many samples in an observation period need to be made in order to follow changes in bone mineralization. The aim of this investigation was to analyze the aluminum equivalent values from radiographs of the mandibles of healthy subjects with time.

Table I. Sites of bone mineral determination

Investigator	*Site*
Balz and Birkner (1956)	Thumb
Bentley (1967)	Femur, hand, and lumbar spine
Vose (1969)	Bone phantom
Nagel et al. (1974)	Calcaneum
Melsen and Melsen (1976)	Iliac crest
Wing and Birring (1976)	Maxilla and phalanx, digit III
King (1977)	Bone phantoms
Pullan and Roberts (1978)	Animal experiments
Lindsay and Anderson (1978)	Third metacarpal midshaft
Castells et al. (1979)	Phalanx
Paice (1979)	Hands, phalanx, and metacarpal
Parker et al. (1979)	Animal bone experiments

METHODS

Twenty individuals (ten men and ten women volunteers) were investigated: The men had an average age 43.7 years, with a SD of 11.0 and a range of 28 to 61 years. The average age of the women was 39.3 years, with a SD 13.6 and a range of 21 to 60 years. None of these volunteers suffered from detectable or diagnosed diseases of the skeleton. Radiographs of the mandible were studied at 3-month intervals over a period of 9 months.

In longitudinal studies, the reproducibility of radiographs and identification of the same area for measurement may pose a problem. The technique used here was relatively simple and did not require great skill or complicated equipment; nor did it cause inconvenience to the patient. In each period, a pair of mandibular radiographs was made with a positioning instrument, which included an aluminum calibrating wedge to aid in minimizing variations in the radiographic exposure, energy spectrum, and developing procedure.

RADIOGRAPHIC PROCEDURE

Radiographs may be considered identical when they can be perfectly superimposed. To test the reproducibility of the technique, two radiographs of the same subject were taken during each session. Individual bite blocks were used to obtain identical radiographs of the volunteers. An autopolymerizing, acrylic resin bite block was made on a plaster model of each mandible, avoiding impressions of undercuts. These bite blocks snapped into a slot prepared in the positioning instrument and were interchangeable.

After the film was placed parallel to the axis of the teeth, the patient held the positioning instrument in place with a finger. Sometimes a cotton roll was used to secure the object-film relationship (Fig. 1). The bite block and film holder were adapted for the first radiograph and then removed. For the second radiograph they were repositioned in the same way. Most of the volunteers tolerated the radiographic investigation with minimum inconvenience.

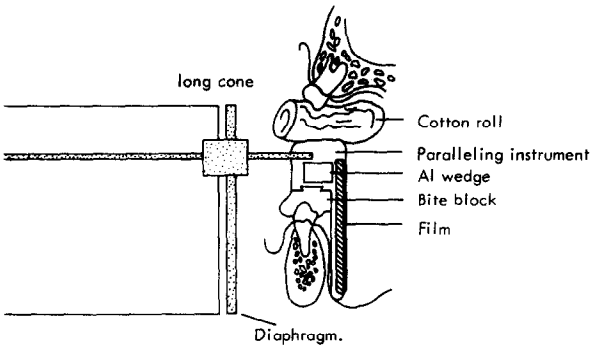

Fig. 1. Schematic representation of the method to obtain standardized radiographs.

The films were developed immediately in freshly prepared solutions with a Siemens Pantomat automatic processor, according to a standard procedure (Fig. 2).

DENSITOMETRIC PROCEDURE

A microdensitometer* was used to measure the optical densities in the radiograph. The recording shows an average of the attenuation coefficients for all the materials present (that is, soft tissue and mineral) in the bone along the line scanned by the densitometer (scan trajectory).

The computation of the mineral content was made with the use of equations that transformed the raw transmission densities from the radiographs with high and low densities into aluminum equivalent values.

The duplicate radiographs of each region from the patient were studied in order to compare the aluminum equivalent values from previously localized regions obtained on the first radiograph. Scan trajectories of these specific areas of the radiographs were examined to determine the reproducibility of the radiographs, together with possible changes in the aluminum equivalent values with time. The areas studied were situated in the apical third of each radiograph, and sharply defined points such as the roots of molars were used for identification of the densitometer tracing path. Microdensitometer tracings were made parallel to a common reference line to permit easy identification of the area under investigation.

*Gamma Scientific, San Diego, Calif. Model 2900 HR,

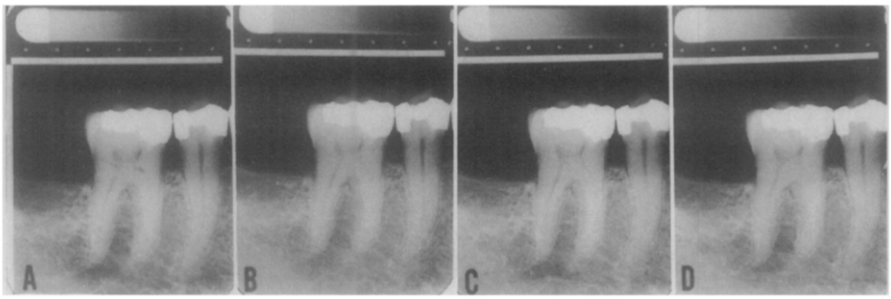

Fig. 2. Four radiographs taken at intervals of 3 months (with images of a stepless aluminum wedge, measuring points, and two perpendicular wires to start the computer).

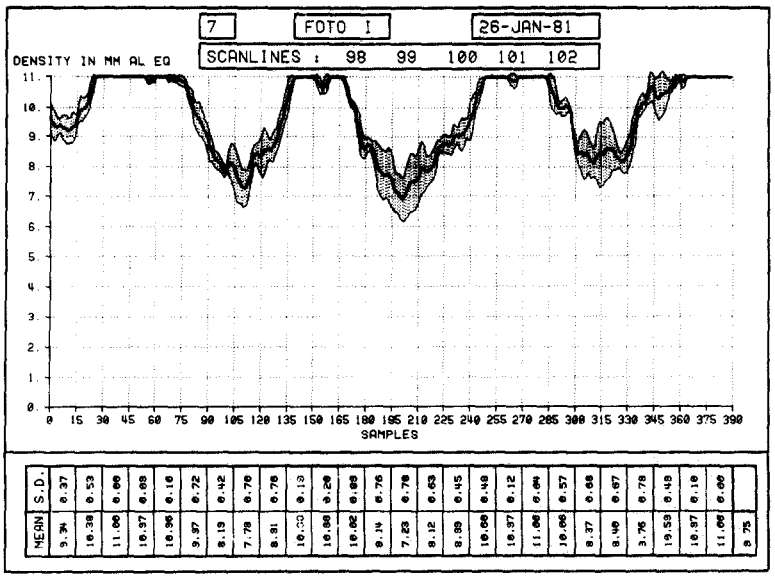

Fig. 3. Example of the spread of five horizontal trajects of 0.2 mm and the average value (mean) in one radiograph.

A series of five consecutive scans in the field of interest were made, each measuring 0.2 mm. All values were stored and available for subsequent calculations and plottings by means of a computer (Fig. 3). The mean aluminum equivalent value over a scan length of 1 mm (fifteen samples) and the standard deviation of the five scans were determined.

Measurements of the same scan in both radiographs of one session were taken to evaluate their reproducibility. The reproducibility error (precision of the method) was determined by evaluating the differences between the mean of five bone scans of each pair of radiographs. These differences were calculated and plotted (Fig. 4). The appendix details the statistical methods used to obtain densitometric and corresponding aluminum equivalent values from measured values of radiographs.

RESULTS

One hundred sixty radiographs of the twenty volunteers were suitable for radiographic investigation (4 × 2 per person).

Measurements of the duplicate radiograph were omitted in cases in which one scan did not cover the second one.

The densitometric measurements in four sessions at intervals of 3 months are shown in Table II.

For each session the standard deviation of the random error (S_2) and the corresponding 95% confidence interval were computed. These confidence intervals are rather wide, since the small sample sizes caused great sampling fluctuations. A standard deviation of the random error (S_2) was also computed from all 76 duplicate radiograph measurements: $S_2 = 0.16$, with a 95% confidence interval of 0.14 to 0.19. Using the S_2 value of 0.16, conclusions were

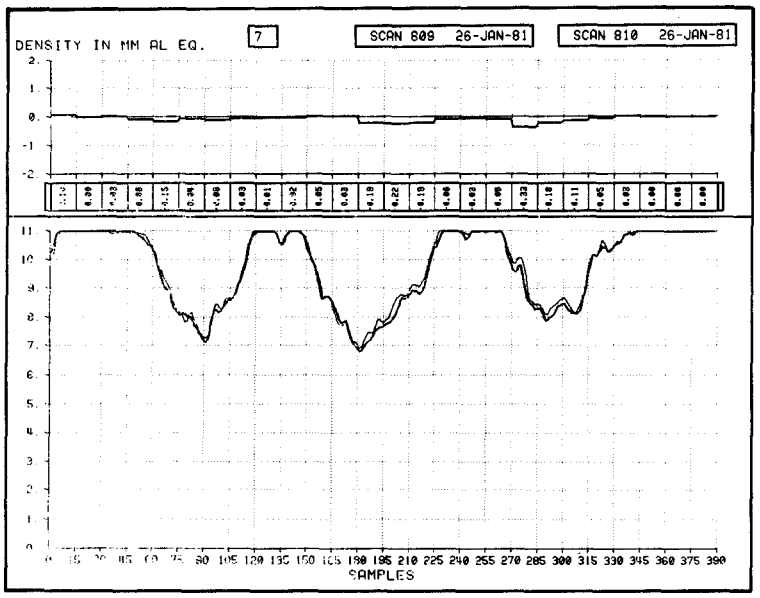

Fig. 4. The mean values, each representing the mean of five scans on two radiographs used to analyze the precision between exposures taken during one session.

Table II. Mean aluminum equivalent values of five scantrajects on duplicate radiographs taken during the investigation

Volunteer No.	*Age*	*Session I radiograph*			*Session II radiograph*			*Session III radiograph*			*Session IV radiograph*		
		I	*II*	*Difference*	*I*	*II*	*Difference*	*I*	*II*	*Difference*	*I*	*II*	*Difference*
1	28	7.50	7.65	0.15	7.89	7.64	0.25	7.16	6.76	0.60	7.19	7.25	0.06
2	43	7.52	7.37	0.15	7.70	8.16	0.46	7.19	6.88	0.31	7.26	6.95	0.31
3	34	6.09	6.31	0.22	5.69	6.16	0.47	5.75	5.78	0.03	6.09	5.87	0.22
4	40	7.04	7.25	0.21	7.44	*	*	7.14	6.86	0.28	7.21	7.28	0.07
M 5	33	6.91	7.18	0.27	6.76	6.84	0.08	6.64	7.21	0.57	6.78	7.33	0.55
a 6	61	9.06	9.16	0.10	9.34	9.40	0.06	8.53	8.39	0.14	8.30	*	*
l 7	54	9.93	9.81	0.12	9.83	9.77	0.06	9.49	9.90	0.41	9.81	9.85	0.04
e 8	55	9.05	9.14	0.09	8.90	8.63	0.27	8.40	9.14	0.74	8.38	9.10	0.72
9	51	7.51	7.52	0.01	6.32	7.30	0.98	6.43	6.58	0.15	6.30	6.67	0.37
10	38	9.22	8.91	0.31	8.79	9.26	0.47	9.03	8.68	0.35	8.68	*	*
		S_2	0.09			0.22			0.21			0.19	
95% confidence interval		0.06-0.16			0.15-0.40			0.15-0.37			0.13-0.36		
11	34	6.51	6.55	0.04	6.15	6.33	0.18	5.79	5.60	0.19	5.70	5.62	0.08
12	21	7.60	7.92	0.32	7.62	7.74	0.12	*	7.52	*	6.89	7.16	0.27
13	28	7.24	7.13	0.11	6.76	7.26	0.50	6.99	6.64	0.35	5.93	6.09	0.16
F 14	60	8.40	8.58	0.18	8.41	8.04	0.37	8.41	8.13	0.28	8.50	7.92	0.58
e 15	52	5.50	5.09	0.41	4.69	4.76	0.07	5.04	4.80	0.24	4.73	4.56	0.17
m 16	50	7.46	7.16	0.30	6.98	7.06	0.08	7.21	7.02	0.19	6.90	6.97	0.07
a 17	47	5.95	6.42	0.47	6.09	6.44	0.35	5.95	6.04	0.09	6.23	6.08	0.15
l 18	25	6.94	7.05	0.11	7.28	7.24	0.04	7.17	7.50	0.33	7.30	7.52	0.22
e 19	28	9.31	9.20	0.11	8.96	8.47	0.49	8.68	9.09	0.41	9.12	9.02	0.10
20	48	8.12	8.16	0.04	7.59	7.26	0.33	7.53	7.97	0.44	7.48	7.43	0.05
		S_2	0.13			0.15			0.15			0.12	
95% confidence interval		0.09-0.22			0.11-0.27			0.10-0.27			0.08-0.21		

*Measurement of duplicate radiograph omitted when one scan did not cover the second one.

Table III. Mean aluminum equivalent values of five scan trajects on duplicate radiographs over four sessions and differences after 6 and 9 months

	Session Month				*Difference between various sessions at 6 and 9 months*		
	I	*II*	*III*	*IV*			
Volunteer no.	*0*	*3*	*6*	*9*	*I-III*	*II-IV*	*I-IV*
Males							
1	7.57	7.76	6.96	7.22	−0.61*	−0.54*	−0.35
2	7.45	7.93	7.03	7.11	−0.42	−0.82*	−0.34
3	6.20	5.92	5.77	5.97	−0.43	+0.05	−0.23
4	7.15	7.44	7.00	7.24	−0.15	−0.20	+0.09
5	7.04	6.80	6.93	7.06	−0.11	+0.26	+0.02
6	9.11	9.37	8.46	8.30	−0.65*	−1.07*	−0.81*
7	9.87	9.80	9.70	9.83	−0.17	+0.03	−0.04
8	9.09	8.77	8.77	8.74	−0.32	−0.03	−0.35
9	7.52	6.81	6.51	6.48	−1.01*	−0.33	−1.04*
10	9.06	9.03	8.86	8.68	−0.20	−0.35	−0.38
Females							
11	6.53	6.24	5.69	5.66	−0.84*	−0.58*	−0.87*
12	7.76	7.68	7.52	7.02	−0.24	−0.66*	−0.74*
13	7.18	7.01	6.82	6.01	−0.36	−1.00*	−1.17*
14	8.49	8.22	8.27	8.21	−0.22	−0.01	−0.28
15	5.29	4.72	4.92	4.64	−0.37	−0.08	−0.65*
16	7.31	7.02	7.12	6.94	−0.19	−0.08	−0.37
17	6.19	6.26	6.00	6.16	−0.19	−0.10	−0.03
18	7.00	7.26	7.34	7.41	+0.34	+0.15	+0.41
19	9.25	8.72	8.89	9.07	−0.36	+0.35	−0.18
20	8.14	7.42	7.75	7.46	−0.39	+0.04	−0.68*

*Significant difference in aluminum equivalent values between indicated observation periods.

made with regard to measurements obtained for individuals within the experimental group.

For each volunteer the differences between two sessions may be considered a significant difference, as shown in Table III, if it is greater than 0.64 when one measurement per session is taken, greater than 0.45 when two measurements per session are taken, or greater than 0.55 when there are two measurements in the one session and one measurement in the other session. Significant differences were observed for individual volunteers between various observation periods and are indicated by an asterisk in Table III.

DISCUSSION AND CONCLUSIONS

Studies of the mandible[1, 6, 8, 9, 10, 20] recognize the difficulty in observing changes in the structure of spongy bone. Many authors have mentioned the fact that cortical bone must be affected in order to make it possible to detect changes. In the literature there are some data concerning the quantity of bone mineral in the mandible,[4] but no estimates of the physiologic changes of bone mineral in healthy volunteers exist.

The information obtained here was limited to a relatively small series in which sex, age, and case history were not given sufficient consideration. One female (No. 12) for instance, started using contraceptive tablets, and this was probably the cause of bone diminution. In normal women bone diminution in the skeleton did not occur until the age of 45 years (1% each year). In normal men, bone diminution with age was minimal or insignificant (0.3% each year).

Bone diminution in the mandible with aging has not been assessed until now. We found a quantitative difference in the bone diminution between men and women, but we cannot exclude the possibility of an effect on the bone that may have occurred in the time span (39 years for females and 37 years for males) that separated the youngest and the oldest volunteers in our sample. The experiments described were carried out to test *the developed method* in a longitudinal study of healthy volunteers. The series of radiographs did not show any changes related to dental illness, and bone lesions were not noticed during the investigation period.

In this investigation, mean aluminum equivalent values of a 1 mm track containing roots and bone together were calculated, and these values were used to determine the precision of the method by measuring two radiographs made during one investigation

session. The reproducibility must be taken into account in order to be able to detect the real bone mineral changes which take place. The average aluminum equivalent value of the investigated tracks in the alveolar process was 8 mm.

Differences between the average of duplicate measurements which exceed 0.45 mm aluminum are significant. This implies that discrimination of differences <0.45 is not possible. In other words, small bone mineral changes cannot be detected. It should be noted that about 5% of the differences compared will show significant differences purely by chance; these will be erroneously interpreted as real differences (false positives).

When the differences between sessions I and IV in Table III are considered, it is probable that one of the seven significant differences is erroneously judged significant.

The precision assessed for the total mineral content was calculated for all subjects considered together. Bone without roots, based on trabecular and compact bone densities together, can be considered. If a specific bone mineral change at a more precise level must be analyzed, additional measurements are required and computer software must be modified to eliminate the contribution of the roots. This approach provides us with a quantitative method and can be used as one of the features that allow measurements of bone resorption in the alveolar crest.

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Reprint requests to:
Dr. W.Th. Trouerbach
Department of Experimental Radiology
Erasmus University
Postbox 1738
3000 DR Rotterdam, The Netherlands

APPENDIX

STATISTICAL PROCEDURE

Precision

The measured value from a radiograph may be written as:

Measured value = True value + random error

Since measured values are to be compared with one another, it is not necessary to take a possible bias into account. The true value may be considered as the mean of a great many measured values, if these could be obtained. An estimate of the standard deviation of the random error is

$$S_1 = \frac{\sqrt{\Sigma\Delta^2}}{2n}$$

where the sum is taken over n patients and is the difference between the values of two radiographs in one session. This means that the difference between measured value and true value is about S_1, and this difference is smaller than $2 \times S_1$ in about 95% of the cases.

An estimate of the standard deviation of the random error in the mean of two measured values from two radiographs is

$$S_2 = \frac{\sqrt{\Sigma\Delta^2}}{4n}$$

The difference between this mean measured value and the true value is about S_2, and this difference is smaller than $2 \times S_2$ in about 95% of the cases. Thus, S_1 and S_2 indicate the order of magnitude of the random error.

The 95% confidence interval around S_2 is defined by the lower and upper bound

$$n\,S_2/\sqrt{\chi^2 0.975^{(n)}} \text{ and } nS_2/\sqrt{\chi^2 0.025^{(n)}}$$

where $\chi^2 0.975^{(n)}$ and $\chi^2 0.025^{(n)}$ are the 0.975 and 0.025 fractiles of the chi-square distribution on n degrees of freedom.

Difference between two sessions

When there is one measurement per session, the individual difference between two sessions contains a random error with standard deviation about:

$$\sqrt{S_1^2 + S_1^2} = \sqrt{2} \times S_1 (= 2\,S_2)$$

Consequently, such a difference may be considered a significant difference if it is greater than $2\sqrt{2} \times S_1$ $(= 4S_2)$. When patients do not change with time, about 5% of the differences are erroneously considered as real differences ($\alpha = 0.05$).

When there are two measurements per session, the individual difference between two sessions may be considered a significant difference if it is greater than $2\sqrt{2} \times S_2$.

When there are two measurements in the one session and one measurement in the other session, the individual difference between those two sessions may be considered a significant difference if it is greater than

$$2 \times \sqrt{S_1^2 + S_2^2} = 2\sqrt{3}\,S_2$$