Quantitative assessment of vertical heights of maxillary and mandibular bones in panoramic radiographs of elderly dentate and edentulous subjects

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The clinical applicability of vertical measurements of the mandible and maxilla in panoramic radiographs was studied by assessing the variety of vertical heights among 91 elderly dentate subjects. Measurements in each jaw and calculations of a maxillary ratio were made at five sites. Variations in measurements of the dentate subjects were small: 9–11% for vertical measurements in the mandible, 6–11% for vertical measurements in the maxilla, and 8–10% for the maxillary ratios. These findings suggest that it is possible quantitatively to assess heights of the mandibular and maxillary bones in panoramic radiographs. Reductions in the edentulous jaws were assessed by comparing the heights of jaws of elderly dentate subjects with those measured in 177 elderly edentulous subjects. Significant differences in heights of the mandibular body and maxilla were found between the dentate and the edentulous ($P < 0.001$). Edentulous women had greater values for percentage reduction in the mandibles than did the men ($P < 0.01$; $P < 0.001$ in various locations). □ *Aging; maxillary ratio; residual ridge resorption; vertical measurement*

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Resorption of the residual ridge has been estimated with various radiographic techniques: lateral cephalometric radiographs (1–5) and panoramic radiographs (6–10). In longitudinal studies of edentulousness, Mercier & Lafontant (1), Tallgren et al. (2), and Habets et al. (4) have used lateral cephalometric radiographs to quantify reduction in the alveolar ridge. Because vertical and horizontal magnification factors in the lateral cephalometric radiographs are known, and images of the maxilla and mandible are also well reproduced, measurements made from the radiographs are preferred. However, the alveolar ridges on the two sides are superimposed on each other in the lateral radiograph. An oblique cephalometric technique has solved this problem (3, 5), but four radiographs have to be taken for one patient if measurements are made in the anterior region and posterior regions on both sides.

The panoramic radiograph is widely used and is often a tool in the routine examination, especially for edentulous patients before the construction of a complete denture. It is also a convenient radiologic approach to survey dental condition by providing information about most aspects of dentistry with only one panoramic film. Assessing residual ridge resorption with panoramic radiographs is practical for examination of large samples of patients.

In studies of residual ridge resorption, problems due to distortion of images, variation in the magnification factor at different object depths (11, 12), and difficulty in standardizing the head position among various patients limit the use of the panoramic radiograph. The panoramic radiograph has been used in the mandible mostly for classifying residual ridge resorption by means of the mandibular ratio presented by Wical & Swoope (6). In this method the height of the mandibular body at the site of the mental foramen is divided by the distance from the lower margin of the mental foramen to the lower border of the mandibular body. Since the image of the mental foramen is invisible in some of the radiographs, the ratio could not be calculated in 17% of the radiographs studied in the investigation of Packota et al. (13). Moreover, the mandibular ratio serves as the indicator of residual ridge resorption only at the site of the mental foramen and does not take into account other regions of resorption in the mandible. The panoramic radiograph is seldom used for studying the edentulous maxilla (13), since no reliable maxillary ratio is available for clinical studies.

On the basis of studies on the precision of measurements of tooth length and mandibular linear dimensions in panoramic radiographs, Larheim et al. (14, 15) have indicated that the variability of vertical measurements made from repeated panoramic radiographs is small when patients are properly positioned in the panoramic apparatus. Our previous study of the effect of head position in the panoramic radiograph on vertical measurement (16) showed the possibility of making accurate vertical measurements in both jaws, particularly in the lower jaw. If reference lines and measured points are located in the same vertical plane or in approximately the same plane as the teeth, variations in vertical measurements in the mandible and the posterior regions of the maxilla fall within a small range.

The aims of this study were to explore whether any

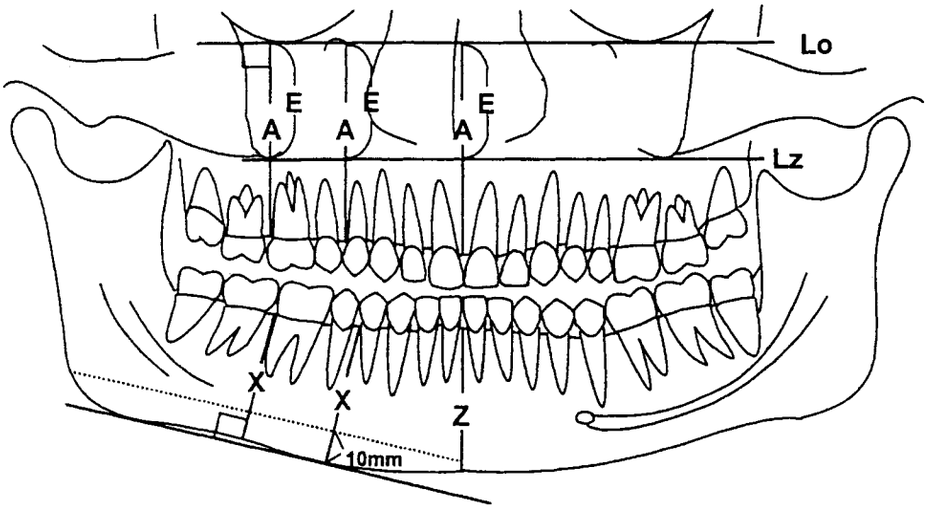

Fig. 1. Reference lines and measured heights and sites in dentate jaws. In the mandible, X distances were measured at distal surfaces of first premolar (FP) and first molar (FM); the tangent and X measurements were made on both sides. The Z measurement was recorded in the midline. In the maxilla, A and E measurements were made in the midline and at FP and FM on both sides. X, Z, and A distances were measured at 2.0 mm apically from the cementoenamel junction. A dotted line shows mandibular length used for assessing measurement sites at FP and FM in the edentulous mandible.

clinically applicable maxillary ratio is available, to examine the variation of the vertical measurements in the mandible and maxilla made from clinical patients' panoramic radiographs, and, furthermore, to assess quantitatively differences in measurements between dentate and edentulous jaws.

Materials and methods

Subjects

The elderly dentate group consisted of 91 subjects with a mean age of 65 (range, 52–81) years: 46 men and 45 women. Fourteen of the subjects came from the

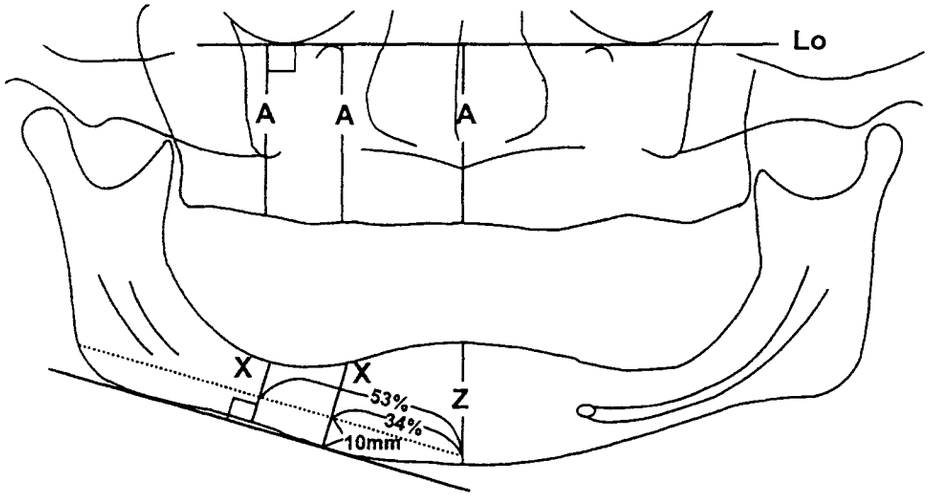

Fig. 2. Reference lines and measured heights and sites in edentulous jaws. In the mandible, a dotted line shows mandibular length; X distances were measured at 34% and 53% of the length; the tangent, the dotted line, and X measurements were made on both sides. The Z measurement was recorded in the midline. In the maxilla, the A measurement was made in the midline and along the infraorbital and zygomatic vertical lines on both sides.

sample of a dental survey concomitant with the Helsinki Aging Study (HAS) (17) and 77 from the patient pool of the Institute of Dentistry, University of Helsinki.

Criteria for selection of the subjects were as follows: 1) age older than 50 years; 2) occluding teeth present at the anterior or at the posterior measurement site; 3) at least 20 teeth remaining; 4) no history of diseases impacting on bone such as hyperparathyroidism, osteoporosis, thyroid disease, diabetes, or chronic renal disease, and no severe attrition of the occlusal surface and the incisal edge of the teeth; and 5) a panoramic radiograph taken with a PM 2002 CC panoramic apparatus (Planmeca Co., Helsinki, Finland).

Criteria for selection of the radiographs were as follows: 1) radiologic images of anatomic landmarks such as the inferior and posterior borders of the mandible, the most inferior points of both orbital margins, the most inferior margins of the zygomatic processes of the maxilla, and the infraorbital foramen distinct at least on one side; 2) no gross distortion of images of the maxilla and mandible; and 3) space between maxillary and mandibular teeth forming an approximately horizontal space or a gentle arch with the midpoint lower than the ends.

The one subject with a radiograph suitable for analysis of one jaw but not the other was still included in the study.

The elderly edentulous group came from the sample of the dental surveys of HAS and consisted of 185 subjects aged 76, 81, and 86 years (mean age, 80 years). Of these 185, 130 had edentulous mandibles and 179 had edentulous maxillae. All edentulous subjects had complete medical and oral examination records. Panoramic radiographs of the elderly edentulous subjects were taken with the same panoramic equipment as the one used for the elderly dentate subjects. Criteria for selection of the radiographs of this group were those stated above as 1 and 2, and the image of the edentulous mandible had to be slightly U-shaped. Four radiographs of subjects with an edentulous mandible and 11 of subjects with an edentulous maxilla were excluded because of image distortion or the lack of radiologic images of anatomic landmarks, and consequently, 177 edentulous subjects' radiographs, 126 (31 male and 95 female) edentulous mandibles and 168 (40 male and 128 female) edentulous maxillas, were measured.

Methods

Dentate jaws. Ten sites were measured on every radiograph whenever possible, five sites in each jaw: the midline and the distal surfaces of the first premolar (FP) and first molar (FM) on both sides. In the mandible, X and Z distances were measured (Fig. 1). A line was drawn tangential to the most inferior points at the mandibular angle and the lower border of the mandibular body on each side: X = distances from 2.0 mm below the cementoenamel junction (CEJ) to the lower border of the mandible and perpendicular to the tangent, and Z = vertical distance from 2.0 mm below the CEJ to the lower border of the mandible in the midline. In the maxilla, A and E distances were measured (Fig. 1). A reference line (Lo) was drawn joining the inferior points of both the orbits, with the other line (Lz) joining the inferior margins of the zygomatic processes of the maxilla. A = vertical distance from the Lo to 2.0 mm apically from the CEJ; E = vertical distance from Lo to Lz. The X, Z, and A distances were measured only when occluding teeth were present at the measurement site.

To determine the measurement sites in the edentulous jaws, horizontal locations of the first premolars and first molars in the dentate jaws were assessed. In the mandible the horizontal lengths of the dentate mandible were measured parallel to the tangent at 10 mm above the lower border of the mandible (Fig. 1). Proportions were calculated by the length of the mandibular body, from the midline to the posterior border of the ramus, divided by the length of the distal surface of the lower first premolar from the midline and the length of the distal surface of the first molar from the midline. In the maxilla, one vertical line was drawn through the mesial margin of the infraorbital foramen to the dentition (the infraorbital vertical line) and another through the inferior margin of the zygomatic process of the maxilla to the dentition (the zygomatic vertical line). Relationships of FP with the infraorbital vertical line and of FM with the zygomatic vertical line were examined individually and on both sides of the maxilla.

Edentulous jaws. A line tangent to the mandibular border and the reference line Lo in the maxilla were drawn as in the dentate jaws. According to results from the dentate subjects, 34% of the length of the mandibular body from the midline was approximate to FP and 53% to FM in the mandible (Fig. 2); the infraorbital vertical line and the zygomatic vertical line were approximate to FP and FM, respectively, in the maxilla. The midline was determined by images of the nasal septum, anterior nasal spine, and lingual foramen. The X, Z, and A vertical measurements were made from the alveolar crest. X indicates distances from the alveolar crest to the lower border of the mandible at 34% and 53% of the length of the mandibular body and perpendicular to the tangent; Z is the vertical distance from the alveolar crest to the lower border of the mandible in the midline; A is the vertical distance from Lo to the alveolar crest. Measurements were performed at the five sites for each jaw.

Each radiograph was viewed on a standard light box. After the points and lines to be measured were marked manually with a pencil, the radiographs were scanned, digitized, magnified, and measured with a scanner and a personal computer (16). One investigator (Q. Xie) was responsible for selecting the panoramic radiographs and performing the measurements. If there was any doubt in

Table 1. Means (mm) and standard deviations (s) of radiologic heights in elderly dentate jaws

	Dentate men				Dentate women				
	n	Mean	s	CV (%)	n	Mean	s	CV (%)	P
Mandible									
Z (midline)	32	42.2	3.9	9	36	38.1	3.5	9	<0.001
X (first premolar)	71	41.3	3.6	9	73	37.5	3.5	9	<0.001
X (first molar)	43	36.4	4.0	11	39	31.5	3.1	10	<0.001
Maxilla									
A (midline)	24	51.0	3.0	6	35	45.9	3.6	8	<0.001
A (first premolar)	34	48.3	3.1	6	45	43.7	3.5	8	<0.001
A (first molar)	32	44.0	3.4	8	46	41.1	3.6	9	<0.001
E (midline)	28	24.6	2.4	10	38	22.9	2.4	11	<0.01
E (first premolar)	34	24.7	2.5	10	45	23.0	2.4	10	<0.01
E (first molar)	32	24.1	2.6	11	46	22.9	2.5	11	<0.05

Z = distance from 2.0 mm below the cementoenamel junction (CEJ) to the lower border of the mandible in midline; X = distance from 2.0 mm below the CEJ to the lower border of the mandible at distal surfaces of the first premolar and first molar; A = distance from the line joining inferior points of orbits to 2.0 mm apically from the CEJ; E = distance from the line joining inferior points of orbits to the line joining the inferior margins of the zygomatic processes. n = Number of measurements; CV = coefficient of variation. Statistical evaluation with unpaired t test.

determining the measurement point, the radiograph was examined by an experienced radiologist (J. Wolf); this involved 50 radiographs. Agreement was achieved after discussion. In the dentate group, out of 910 measurement points, 400 could not be measured because of invisible CEJ or missing teeth.

According to the manufacturer, the magnification factor of the PM 2002 CC panoramic apparatus is 1.2. In this study it was not necessary to correct the radiologic heights for the magnification factor, because all radiographs were taken with the same panoramic apparatus.

Of the radiographs, 10% were randomly selected, re-marked and re-measured at an interval of 1 month for an intra-examiner test.

The maxillary ratio was calculated as the distance A divided by the distance E.

Since no significant difference was found in the X, A, and E measurements between the left and right sides of the dentate and edentulous jaws, data from FP and FM of both sides were pooled. The extent of variation in the measurements was shown by the coefficient of variation (CV), which was calculated by the formula $CV = 100 \times s/\text{mean}$ % (s = standard deviation). Differences in the mandibular and maxillary heights between dentate and edentulous subjects were expressed as percentages and calculated with the formula 100 × (Hod-He)/Hod % (Hod ≒ height of old person's dentate jaw; He = height of edentulous jaw). The percentage of the difference was named percentage of reduction in the edentulous jaws, because the edentulous jaws had much smaller heights than the dentate jaws. The percentages were calculated separately for the different measurement sites and for the two sexes.

Statistical analysis of differences between men and women, between dentate and edentulous subjects, and between the mandible and maxilla was performed with the t test. Analysis of variance and pairwise comparisons were used to examine differences among measurement sites. Intra-examiner difference was tested with the paired t test. Differences at the 5% level were accepted as significant.

Table 2. Means and standard deviations (s) of maxillary ratios (A/E), assessed for elderly dentate subjects

	n	Mean	s	CV (%)
A/E (midline)	59	2.04	0.20	10
A/E (first premolar)	79	1.94	0.17	9
A/E (first molar)	78	1.82	0.17	9

A/E = radiologic height A divided by radiologic height E. The measurements A and E are as defined in the footnote to Table 1. CV = coefficient of variation.

Results

Variations in vertical measurements

Among elderly dentate subjects variations (CV) in heights of the mandibular body (X and Z) varied from 9% to 11% and those in the maxilla from 6% to 9% for measurement A and 10% to 11% for E (Table 1).

No significant difference in the maxillary ratio was found between the elderly dentate men and women, and the values were very similar. The variations in the maxillary ratios (A/E) of all the dentate subjects were from 9% to 10% (Table 2).

Dentate subjects

The heights of the mandibular body and the maxilla were significantly greater in the elderly dentate men than in the elderly dentate women at all sites measured (Table 1).

Table 3. Comparison of means (mm) and standard deviations (*s*) of radiologic heights of the mandible and maxilla between elderly dentate and edentulous men

	Dentate men		Edentulous men	
	n	Mean (*s*)	*n*	Mean (*s*)
Mandible				
Z (midline)	32	42.2 (3.9)	31	28.5 (4.7)
X (first premolar)	71	41.3 (3.6)	62	26.7 (7.3)
X (first molar)	43	36.4 (4.0)	62	22.4 (5.4)
Maxilla				
A (midline)	24	51.0 (3.0)	39	41.2 (5.2)
A (first premolar)	34	48.3 (3.1)	80	41.0 (5.1)
A (first molar)	32	44.0 (3.4)	80	39.0 (5.1)

The measurements Z, X, and A in dentate jaws are as defined in the footnote to Table 1, and those in edentulous jaws refer to Fig. 2. $P < 0.001$ for all comparisons between dentate and edentulous men and for the difference in decrease of height between the edentulous mandible and maxilla.

The elderly dentate subjects who had a zygomatic process directly above or a little anterior or posterior (one-third of the crown) above the distal surface of the first molar accounted for 82% of the subjects, and 93% of the elderly dentate subjects had the mesial margin of the infraorbital foramen directly above or a little anterior or posterior (half the crown) above the distal surface of the first premolar. The average length from the midline to the distal surface of the first premolar made up 34% ($s = 3.9$) of the length of the mandibular body, and the corresponding figure for the first molar was 53% ($s = 4.4$).

Edentulous subjects

Tables 3 and 4 show highly significant ($P < 0.001$) differences in the heights of the mandibular body and maxilla between the elderly dentate and edentulous subjects of both sexes, with the edentulous having much smaller heights of the mandibular body and maxilla than the dentate. The decreases in heights were greater ($P < 0.001$) in the edentulous mandible than in the edentulous maxilla.

Table 4. Comparison of means (mm) and standard deviations (*s*) of radiologic heights of the mandible and maxilla between elderly dentate and edentulous women

	Dentate women		Edentulous women	
	n	Mean (*s*)	*n*	Mean (*s*)
Mandible				
Z (midline)	36	38.1 (3.5)	95	22.9 (5.1)
X (first premolar)	73	37.5 (3.5)	190	18.7 (6.1)
X (first molar)	39	31.5 (3.1)	190	16.8 (4.5)
Maxilla				
A (midline)	35	45.9 (3.6)	126	37.6 (5.1)
A (first premolar)	45	43.7 (3.5)	256	38.1 (5.0)
A (first molar)	46	41.1 (3.6)	256	36.1 (5.2)

The measurements Z, X, and A in dentate jaws are as defined in the footnote to Table 1, and those in edentulous jaws refer to Fig. 2. $P < 0.001$ for all comparisons between dentate and edentulous women and for the difference in decrease of height between the edentulous mandible and maxilla.

The average percentages of reductions in the edentulous mandible were 44% ($s = 14$) including both the posterior and anterior regions, 46% ($s = 16$) in the posterior regions, and 38% ($s = 13$) in the anterior mandible. The corresponding figures for the edentulous maxilla were 14% ($s = 12$), 12% ($s = 11$), and 18% ($s = 11$). Elderly edentulous women had a more pronounced reduction in the height of the mandible than did the men (Table 5). The differences between elderly edentulous men and women in percentages of reductions in heights of the maxilla were not, however, significant.

There were significant differences in percentage reductions of heights between different measurement sites in both the mandible and the maxilla (Table 5). In the mandible the reduction was more severe at the first premolar and first molar sites for women and at the first molar site for men than was the reduction in the anterior area. In the maxilla the percentage of reduction was more pronounced in the midline for both sexes.

The mean of the difference in re-measurements was 0.06 mm ($s = 0.55$), which was not statistically significant in the test of intra-examiner error.

Discussion

The maxillary ratios (A/E) in the present study seem to be the first such ratios in the maxilla applicable for clinical study. Packota et al. (13) tried to establish a maxillary ratio in their dentate subjects, but the difference of as much as 25% among individuals was too great for this to serve as an indicator of change in alveolar bone height in a cross-sectional study. This study's dentate subjects had a range of only 8% to 10% difference in the maxillary ratios in posterior regions and the midline. These variations were similar to those in the mandibular ratio, 8%, presented by Wical & Swoope (6), and 12% by Packota et al. (13); therefore these maxillary ratios were also suitable for a clinical investigation with panoramic radiographs. The smaller the maxillary ratio, the greater the extent of alveolar resorption that can be graded.

In a study of the reproducibility of panoramic radiographs (15), panoramic radiographs were exposed under different clinical radiographic conditions. The method error for assessment of vertical distances in the mandible fell mostly within 3% of total variance. The effect of head positioning in panoramic radiography on vertical measurements was further investigated by means of sagittal shifting and tilting (16). The effect was small and accounted for only 1–2% of the measurements in the mandible and 1–3% in posterior regions, and 3.7% in the midline for measurement A in

Table 5. Comparison of average percentages (%) of reductions in radiologic heights of the mandibular body and maxilla between elderly edentulous men and women

	First molar, mean (s)	First premolar, mean (s)	Midline, mean (s)
Mandible			
Men (n = 31)	39† (15)	35 (18)	32 (11)
Women (n = 95)	47‡ (14)	50‡ (16)	40 (13)
P	<0.001	<0.001	<0.01
Maxilla			
Men (n = 40)	11‡ (12)	15‡ (11)	19 (10)
Women (n = 128)	12‡ (13)	13‡ (12)	18 (11)
P	NS	NS	NS

† $P < 0.01$, difference in mean percentage between the first molar site and the midline.
‡ $P < 0.001$, differences in mean percentages between the first molar site and the midline, and between the first premolar site and the midline.

the maxilla. In clinical patient radiographs the variations in the vertical measurements, 9–11% in the mandible and 6–9% in measurement A at FP and FM of the maxilla, were mostly caused by morphologic deviation in each individual. With a minor amount of influence of head positioning and a small range of morphologic deviation among individuals, the vertical measurements in both jaws are therefore considered to be clinically applicable, except for measurement A in the midline of the maxilla, which is relatively sensitive to head positioning.

The mandibular ratio presented by Wical & Swoope (6) represents change in alveolar bone height only in the region of the mental foramen, and thus it cannot be used for any mandible in which the mental foramen is invisible or is resorbed due to progression of residual ridge resorption. Compared with the variations in the vertical measurements (A), the variations in the maxillary ratios (A/E) were slightly greater due to greater morphologic deviation and a greater effect of head positioning in the E measurements than in the A measurements. Thus, in this investigation, vertical measurements in the edentulous mandible and maxilla rather than mandibular and maxillary ratios were used.

In the great majority of the dentate elderly, progressive periodontal disease increases the distance from the CEJ to the alveolar crest. In the present study the distance between the CEJ and the intact crest of the alveolar bone was first measured for teeth without radiologic evidence of periodontitis in 13 panoramic radiographs of elderly dentate subjects. The average of the distance was 1.8 mm, with a standard deviation of 0.3 mm. Thus, in the absence of periodontal disease, the distance from the CEJ to the alveolar crest in panoramic radiographs is still considered to be about 2 mm in these elderly dentate subjects, like the distance in younger adults (18). This distance was used to estimate the original level of the alveolar crest in our whole group of elderly dentate subjects.

In the edentulous mandible, because of the lack of a landmark for indicating the fist molar site, and because the images of the mental foramen are invisible in some patients' panoramic radiographs, the proportions of the horizontal lengths were used to locate the measurement sites. Absolute horizontal measurement in a panoramic radiograph must be abandoned owing to inherent distortion of image and unlinear change of magnification (12). The proportions of the lengths represent the relative locations of the first premolar and first molar to the midline of the mandible. The measurement sites in the edentulous mandible could be determined with these proportions obtained from the elderly dentate, while the same panoramic machine was used in both groups, and no obvious distortion was observed in the images of the upper and lower jaws.

In a cephalometric follow-up study, Tallgren (19) reported that during a 25-year period of complete denture wear, the average reduction in anterior height of the mandibular ridge was about 9 to 10 mm, and the reduction in the maxilla about 2.5 to 3 mm. The reduction of the anterior ridge height was greater in the mandible than in the maxilla. In the present study the average duration of complete denture wear was 31–40 years in the mandible and the maxilla for women, and the average duration 21–30 years in the both jaws for men. Compared with the edentulous maxilla, a much greater reduction in radiologic heights was observed in the edentulous mandible for both sexes. The finding is considered to be in agreement with the study of Tallgren (19).

Residual ridge resorption is usually more rapid in the premolar and molar region than the anterior region of the mandible, due to the lower position of the reversal line in the posterior region (20). The reversal line on the lingual side occurs along the mylohyoid ridge, which is the limit between the resorptive alveolar field and depository field of the basal bone (21). Furthermore, the inner aspect of the anterior area of the mandible provides attachment for the genial muscles. These attachments, due to the functional forces of the genial muscles, probably protect this area from extreme alveolar bone loss and reduction in vertical height. This may explain our finding that the most pronounced percentage reduction in total height of the mandibular body was found at the first premolar and first molar sites.

By means of vertical measurement, highly significant differences in the heights of the mandible and maxilla were found between dentate and edentulous subjects of both sexes. Comparison of the extent of residual ridge resorption was made between men and women by means of percentages of reduction. The decrease in the height of the edentulous mandible was more pronounced in women than in men, a finding identical to that in the studies by Ortman et al. (22) and de Baat et al. (23). In postmenopausal women, deficiency of estrogen hormone accelerates skeletal bone loss and

may result in rapid alveolar bone resorption (24). However, this difference between the genders was not obvious in the maxilla. The explanation may lie in different bone quantities between the mandible and maxilla; trabecular bone is more often looser in the edentulous maxilla than in the edentulous mandible (25). Other possible factors associated with residual ridge resorption will be analyzed in continuing studies.

In conclusion, reduction in the edentulous mandible was more pronounced in women than in men. The variations in maxillary ratios and vertical measurements made from the patients' panoramic radiographs fell within small ranges and were mainly caused by morphologic deviation among individuals. The vertical measurement in panoramic radiographs used in this study was clinically applicable in quantitative assessment of alveolar bone resorption in the mandible and maxilla.

References

1. Mercier P, Lafontant R. Residual alveolar ridge atrophy: classification and influence of facial morphology. J Prosthet Dent 1979;41:90–100.
2. Tallgren A, Lang BR, Walker GF, Ash MM. Roentgen cephalometric analysis of ridge resorption and changes in jaw and occlusal relationships in immediate complete denture wearers. J Oral Rehabil 1980;7:77–94.
3. Freihofer HPM, Hoppenreys TJM. Mandibular ridge augmentation by visor osteotomy combined with a subperiosteal rib graft. J Maxillofac Surg 1986;14:301–7.
4. Habets LLMH, Bras J, van den Akker HP, Bormeryer-Hoelen AMMJ, van Ooij CP. Mandibular atrophy and metabolic bone loss. Mandibular ridge augmentation by combined sandwich-visor osteotomy and resorption related to metabolic bone state. A 5 year follow-up. Int J Oral Maxillofac Surg 1987;16:540–7.
5. Jonkman REG, van Waas MAJ, Plooij J, Kalk W. Measuring mandibular ridge reduction on oblique cephalometric radiographs. J Craniomaxillofac Surg 1991;19:27–30.
6. Wical KE, Swoope CC. Studies of residual ridge resorption. I. Use of panoramic radiographs for evaluation and classification of mandibular resorption. J Prosthet Dent 1974;32:7–12.
7. van Waas MAJ. Ridge resorption in denture wearers after vestibuloplasty and lowering of the floor of the mouth, measured on panoramic radiographs. Dentomaxillofac Radiol 1983;12: 115–21.
8. Swart JGN, Allard RHB. Subperiosteal onlay augmentation of the mandible: a clinical and radiographic survey. J Oral Maxillofac Surg 1985;43:183–7.
9. Wilding RJC, Levin I, Pepper R. The use of panoramic radiographs to measure alveolar bone areas. J Oral Rehabil 1987;14:557–67.
10. Humphries S, Devlin H, Worthington H. A radiographic investigation into bone resorption of mandibular alveolar bone in elderly edentulous adults. J Dent 1989;17:94–6.
11. Tronje G, Eliasson S, Julin P, Welander U. Image distortion in rotational panoramic radiography. II. Vertical distances. Acta Radiol [Diagn] (Stockh) 1981;22:449–55.
12. McDavid WD, Tronje G, Welander U, Morris CR, Nummikoski P. Chapter 4. Horizontal and vertical magnification. In: Imaging characteristics of seven panoramic x-ray units. Dentomaxillofac Radiol 1985; Suppl 8:29–34.
13. Packota GV, Hoover JN, Neufeld BD. A study of the height of intact alveolar bone on panoramic radiographs of adult patients. J Prosthet Dent 1988;60:504–9.
14. Larheim TA, Svanaes DB, Johannessen S. Reproducibility of radiographs with the orthopantomograph 5: tooth-length assessment. Oral Surg 1984;58:736–41.
15. Larheim TA, Svanaes DB. Reproducibility of rotational panoramic radiography: mandibular linear dimensions and angles. Am J Orthod Dentofac Orthop 1986;90:45–51.
16. Xie Q, Soikkonen K, Wolf J, Mattila K, Gong M, Ainamo A. Effect of head positioning in panoramic radiography on vertical measurements: an in-vitro study. Dentomaxillofac Radiol 1996; 25:61–6.
17. Ainamo A, Soikkonen K, Wolf J, Siukosaari P, Erkinjuntti T, Valvanne J. Dental radiographic findings in the elderly in Helsinki, Finland. Acta Odontol Scand 1994;52:243–9.
18. Kaimenyi JT, Ashley FP. Assessment of bone loss in periodontitis from panoramic radiographs. J Clin Periodontol 1988;15:170–4.
19. Tallgren A. The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years. J Prosthet Dent 1972;27:120–32.
20. Mercier P. Ridge reconstruction with hydroxylapatite. I. Anatomy of the residual ridge. Oral Surg Oral Med Oral Pathol 1988;65:505–10.
21. Enlow DH, Bianco HJ, Eklund S. The remodeling of the edentulous mandible. J Prosthet Dent 1976;36:685–93.
22. Ortman LF, Hausmann E, Dunford RG. Skeletal osteopenia and residual ridge resorption. J Prosthet Dent 1989;61:321–5.
23. de Baat C, Kalk W, van't Hof MA. Factor connected with alveolar bone resorption among institutionalized elderly people. Community Dent Oral Epidemiol 1993;21:317–20.
24. Devlin H, Ferguson MWJ. Alveolar ridge resorption and mandibular atrophy. A review of the role of local and systemic factors. Br Dent J 1991;170:101–4.
25. Desjardins RP. Tissue-integrated prostheses for the edentulous patients: Brånemark (Nobelpharma) system. In: Caswell CW, Clark AE, editors. Dental implant prosthodontics. Philadelphia: J. B. Lippincott Company; 1991:1–57.

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