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Gerodontology

Original article

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doi: 10.1111/j.1741-2358.2011.00589.x

Residual ridge atrophy in complete denture wearers and relationship with densitometric values of a cervical spine: a hierarchical regression analysis

Background: The rate of residual ridge atrophy (RRR) and its association with mineral density of other bones have not yet been fully explained.
Objective: To measure RRR over a 5-year period in complete denture wearers and relate it to the density of a cervical spine (CSBD).
Materials and methods: Sixty-two patients (different gender, age, body mass index, duration of edentulousness (DE) and different denture-wearing habits) participated. A copper stepwedge was attached to the cassette, and 50 lateral radiograms met the criteria to be included.
Results: A significant decrease in vertical height was observed in all measured sites. The amount of RRR was highest in frontal areas of both jaws and decreased gradually towards lateral regions. Hierarchical regression analysis revealed that the amount of RRR in the maxillary frontal area could be explained up to 48.4% by the variable DE and only up to 6.1% by the CSBD, while gender had almost no influence (1%). Similar results were obtained for the lateral maxillary RRR (33.9%; 7%; 2%), frontal mandibular RRR (40; 8.4; 0.4%) and lateral mandibular RRR (31.5%; 3.4%; 7.7%).
Conclusion: Skeletal bone density, reflecting systemic and hereditary factors, is weakly related to RRR (3.4–8.4%).

Keywords: residual ridge resorption, complete dentures, cervical spine bone density, 5-year follow-up, hierarchical regression analysis.

Accepted 4 August 2011

Introduction

Following tooth loss, the bone of the residual alveolar ridge is continuously reduced, resulting in a decrease in the denture-bearing area, a decrease in the vertical size of the lower third of the face and a contraclockwise rotation of the mandible[1–4]. The extent of the residual ridge reduction (RRR) is especially marked in anterior parts of the maxillary and mandibular ridges. According to Atwood[1], continuous reduction in alveolar ridges is regarded as a ‘major oral disease’ including anatomical, metabolic, prosthetic and functional factors. A significantly reduced alveolar ridge creates a number of problems complicating prosthodontic rehabilitation and a construction of complete dentures (CD)[2–4]. Understanding the causative factors affecting the RRR would be of great help both in the possible prevention of extensive alveolar ridge resorption and in designing complete dentures that provide a proper functioning of the masticatory apparatus, delaying bone resorption. Some studies revealed that dental implants and overdentures prevent alveolar bone reduction at the implant site and reduce RRR posteriorly of the implant site[5,6]. One study covering a period of 10 years of denture wearing revealed that patients rehabilitated with implant-retained mandibular overdentures were not subjected to more RRR in the anterior maxilla when compared to patients wearing a conventional

CDs, but regarding the mandibular posterior residual ridge, resorption was irrespective of wearing an implant-retained mandibular overdenture or a conventional mandibular denture[7]. A two-implant or even a one-implant overdenture for the edentulous mandible is increasingly regarded as a minimum standard of care for edentulous patients in many developed countries, but its routine prescription for the majority of the world is unrealistic; for them, even 'low-tech' therapies such as conventional CDs are beyond their reach. Improving the conventional management of edentulous patients is a necessity and requires a keener focus by researchers, educators and clinicians in the developed world on the needs of populations with fewer resources[8]. However, reducing and delaying the RRR in edentulous patients would enhance their satisfaction owing to better retention and stability of CDs[9–16].

Numerous factors have been mentioned as causative factors contributing to RRR, such as gender, age, duration of edentulousness (DE), denture-wearing habits, number of dentures worn by each patient, oral hygiene habits, oral parafunction and occlusion, quality of dentures, distribution of occlusal forces, denture-bearing area loading, drug use or abuse, systemic diseases such as osteoporosis, and hormone imbalance[17–20]. The potential causative factors can be generally divided into two major groups: the systemic factors depending on hereditary and general health conditions and the local factors depending on denture construction, chewing habits, denture-bearing area loading and local forces. However, it is difficult to specify the most important factor(s) affecting individual variations in RRR[21,22].

It is well known that human bone mass declines with age. It starts around the age of 35 and continues throughout life[23,24]. Measurements of BMD in different parts of the human skeleton have already been described in detail in several studies[25–29] and correlated with a local bone loss of the alveolar ridge. The BMD of forearm[26,27], femur[28], vertebrae[28] and wrist bones[27] have been examined.

However, many previous studies had no precise data on the exact duration of the local alveolar bone reduction or the precise extent of the RRR, as the baseline data had often not been reported. Several studies suggested that the skeletal low BMD can be accepted as the important predisposing factor for rapid RRR[23].

In the last three decades, prosthodontists have been mostly concerned with research related to implants and implant-supported overdentures, and there is a lack of reported long-term observations concerning CDs[29]. Yet, many countries face an ageing population, with almost a quarter of the population above 65 years of age being edentulous[30]. Many of them will not be able to afford any implant therapy, and CD treatment will still be the only possible choice. Therefore, understanding problems associated with CD wearing would be helpful.

The aim of this study was to analyse the extent of an RRR through a 5-year period of denture wearing and to relate it to various local and general contributing factors, including the BMD of the C3 cervical spine, which mostly reflects the influence of general factors[31,32].

Patients and methods

Sample

The subjects who participated at baseline of the study were 110 fully edentulous patients with a need for new dentures. All of them received new complete dentures at the Department of Prosthodontics, Dental Polyclinic, Split, Croatia, within a period of 10 months. The Ethics Committee of the School of Dental Medicine approved the study.

All dentures were made following the same criteria [preliminary impression, individual impressions, semi-adjustable articulator, semi-anatomical artificial teeth (25°–33° artificial tooth-cusp inclination), lingualised occlusion with no attempt of occlusal balance]. During the process of denture fitting, the occlusion was checked and adjusted if necessary. Retention and stability of both dentures were also verified. Only patients with satisfactory occlusion and retention and stability of new CDs participated, so at the stage of denture delivery, 10 patients were excluded and 100 patients remained. Two experienced observers assessed 15 sets of CDs for occlusion, retention and stability. The weighted kappa statistics showed satisfactory agreement between the observers ($\kappa = 0.865$). Because the reliability of the measurements and the agreement were satisfactory, further assessment was made by one observer.

During the 5-year observation period, the dentures have not been relined. However, at the 5-year observation stage, only 62 of 100 patients responded, and only these were included in the final analysis. Patients were divided into three groups in relation to their age [<65 years ($n = 24$), ≤65–75 years ($n = 28$) and >75 years (10 patients)]. There were 30 men (mean age 64 ± 6.87 years, age range 58–80 years) and 32 women (mean age 68 ± 6.56 years, age range 56–83 years). Patients were also asked about night-time denture wearing and were divided into two groups; 50 of them had been wearing their dentures only during the day, and 12 of them were wearing their dentures during both day and night. At the denture delivery, patients were also asked about the time that had elapsed from the last tooth/teeth extraction(s) (DE) and were divided into three groups: <1 year (n = 14), 1–10 years (n = 14) and >10 years (n = 34). All of the patients also provided data about their height and weight, and body mass index (BMI) was calculated using a formula: weight (kg)/ height × height (m^2). All of the patients were within normal BMI limits and were divided into two groups: BMI ≤24 and BMI > 24.

Radiographs

Two lateral cephalometric radiographs were obtained for each patient: the first radiograph was obtained at the time of the delivery of CDs, while the second radiograph was obtained 5 years later. Lateral cephalograms were obtained with the dentures in the mouth, in the position of maximal intercuspation during the exposure.

All radiographs were produced using the same equipment (Siemens Roentgen Kugel 2E:220 V, 15 mA, 70 kV), and the exposition varied between 1.2 and 1.6 s. During the exposure, the head position was fixed in a standard position using a cephalostat.

Measurement of the residual ridge height

Measurements of the residual maxillary and mandibular processes were taken using an original, already described approach[33,34]. Briefly, a shaped calibrated grid was placed over the residual ridges (Fig. 1). The horizontal line of the calibrated grid placed over the maxillary edentulous alveolar ridge correlated with a line connecting two distinct maxillary bony features; *anterior nasal spine* (ANS) and *posterior nasal spine* (PNS). The first reference point determining the height of the ridge was the intersection of the first line (perpendicular to the horizontal line) and the most anterior aspect of the maxillary alveolar crest (U1). Successive reference points were placed at a distance of 1 cm from each other at the intersection of the perpendicular lines and the alveolar process (U2–U5). The perpendicular line of the grid had graduations of 0.2 mm. To measure the height of the mandibular alveolar ridge, the horizontal line of the grid was placed parallel to the mandibular plane [line connecting *gonion* (Go) and *gnation* (Gn)]. Again, the first

Figure 1 Lateral cephalogram with a Cu stepwedge included for the cervical spine bone density measurement.

reference point determining the height of the ridge was the intersection of the first line (perpendicular to the horizontal line) and the most anterior aspect of the mandibular alveolar crest (L1). Successive reference points were placed at a distance of 1 cm from each other posteriorly from L1 (L2–L5).

In some cases where the margins of the left and the right sides of the jaws differed in lateral radiograms (as they were superimposed), the mean value between the upper and the lower margins was taken into account for further statistical analysis. In a pilot study, two experienced observers measured a total of 15 lateral radiographs for vertical alveolar heights in each of the five points of measurements. The independent t-test revealed no significant differences between the observers (p = 0.71). Therefore, one experienced observer completed the measurements.

The amount of RRR of both the maxillary and the mandibular alveolar ridges was determined by calculating the difference in height of the ridges between the two stages of radiographic observation.

BMD assessment

During the exposure at the 5-year observation stage, a copper stepwedge was attached to the bottom of the film cassette to give a reference intensity value on the radiographs. The stepwedge was composed of nine copper steps ranging in thickness from 0.05 to 0.8 mm (0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 and 0.8 mm). The last (the tenth) step was made of lead and was not used for scaling.

All radiographs were digitised using a scanner (ScanMaker i900; Microtech Lab Inc., Hsinchu, Taiwan) at 8-bit, 600 DPI and stored in a personal computer. For the measurement of grey levels, the ISSA 3.0 program (VAMS, Zagreb, Croatia) was used. ISSA is software originally developed for the Ministry of Health for digitisation of X-rays, electron exchange between hospitals and linear and surface measurements including measurements of mean grey scale values in the regions of interest. Before the measurement of mean grey levels, black and white colours of the images were inverted. The mean grey levels were measured on each of the steps on the copper stepwedge using a probe of 16 × 16 pixels. The mean grey level of the third cervical vertebra was measured with the probe of 50 × 50 pixels. The optical densities for each of the measurement points (regions of interest) were calculated as follows: OD = −log I/255 (OD = optical density and I = mean measured intensity of GL). The optical density values obtained from each step of the stepwedge were plotted against the related actual thickness of the corresponding step of the stepwedge to express all optical density values in the equivalents of the actual stepwedge thickness, using the third-degree polynomial[35,36]. In that way, by referencing pixel intensities, mean cervical spine regions of interest, grey-level intensity was expressed as an equivalent of the copper stepwedge thickness. During the cervical spine BMD measurement, 12 lateral radiographs were excluded owing to the overlapping of the parts of the stepwedge with the soft or the hard tissues. Finally, the cervical BMD was calculated for only 50 patients.

Statistical analysis

Statistical analysis was performed using the SPSS statistical software, version 17.0, for Windows (SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was used to check the normality of the distribution. The descriptive statistics were calculated. Student's paired tests were performed to compare the alveolar height between the two observation stages. New variables were computed: the mean frontal (or lateral) mandibular (L-frontal, L-lateral) RRR and the mean frontal (and lateral) maxillary ridge (U-frontal, U-lateral) reduction by adding the amount of reduction in the first three measurement points, by dividing the sum by two (frontal RRR), or by adding up the amount of the RRR obtained at the last two points of measurement and dividing the sum by two (lateral RRR). The correlation analysis included the calculation of the Pearson's linear correlation coefficient and the point-biserial coefficient of correlation. Univariate multifactorial analysis was also performed. The type III sum of squares was used to evaluate the hypotheses. The hierarchical regression analysis of factors contributing to RRR was performed. p-Value ≤0.05 was considered statistically significant.

Results

As all the heights of the residual ridges, as well as the amounts of RRR showed normal distribution (one-way Kolmogorov–Smirnov test, $p > 0.05$), further analysis such as parametric tests have been used. The amount of the residual ridge reduction (RRR) in each of the measurement points (U 1-5 = upper five points of measurement; L 1-5 = lower five points of measurement), together with the significance of the differences between the mean values of the two observation stages, is presented in Table 1. The height of the residual ridges was significantly reduced ($p < 0.001$) at all measurement points. However, the amount of the RRR was higher in frontal regions of the both jaws and gradually decreased towards the posterior sections of the residual alveolar ridges. The highest amount of RRR was observed in the most anterior region of the mandible (L1). The new variable, anterior RRR, was computed for the mandibular jaw: (L1 + L2 + L3)/3, as well as for the maxilla: (U1 + U2 + U3)/3. In the same way, the new variable, posterior RRR, was computed for the mandible, (L4 + L5)/2, and for the maxilla, (U4 + U5)/2.

Table 1 The difference [residual ridge resorption (RRR)] (in mm) and the significance of the difference in the residual alveolar bone height between the measurement at the delivery of the dentures and after the period of 5 years of denture wearing for all measurement points (five in the maxilla: upper-U 1-5; 5 in the mandible: lower-L1-5).

Variable	$\bar{x}$ *(diff.)*	*SD (diff.)*	*t*	*p*
U1: U1 5-year	1.18	0.70	13.32	<0.001
U2: U2 5-year	0.97	0.68	11.26	<0.001
U3: U3 5-year	0.73	0.79	7.26	<0.001
U4: U4 5-year	0.76	0.88	6.81	<0.001
U5: U5 5-year	0.28	0.36	6.08	<0.001
L1: L1 5-year	2.40	1.21	15.63	<0.001
L2: L2 5-year	1.87	1.17	12.56	<0.001
L3: L3 5-year	1.45	1.29	8.87	<0.001
L4: L4 5-year	0.61	0.85	5.70	<0.001
L5: L5 5-year	0.32	0.58	4.38	<0.001

Table 2 The difference (residual ridge resorption, RRR) (in mm) and the significance of the difference in the residual alveolar bone height through the period of 5 years of denture wearing for the frontal and lateral parts of the maxillary (upper-U) and the mandibular (lower-L) residual ridges.

Variable	*x (dif.)*	*SD (dif.)*	*t*	*p*
U-frontal: U-frontal 5-year	0.96	0.62	12.18	<0.001
U-lateral: U-lateral 5-year	0.53	0.56	7.39	<0.001
L-frontal: L-frontal 5-year	1.91	1.11	13.54	<0.001
L-lateral: L-lateral 5-year	0.47	0.63	5.88	<0.001

The mean amount of the anterior and lateral RRR of the maxillary and the mandibular jaw through the 5-year period, together with the significance of the difference between the two observation stages, is presented in Table 2. The height of the RRR was significantly reduced ($p < 0.001$), but the amount was higher in the frontal regions of the both jaws. The cervical spine BMD was also calculated, and the mean value($\bar{x}$ ± SD) was 0.59 ± 0.10 mm (expressed in the equivalents of actual stepwedge thickness).

Table 3 presents mean values ($\bar{x}$) and standard deviations (SD) of the RRR in the maxilla (upper-U) and the mandible (lower-L) in frontal and lateral regions of the residual ridges (in mm), together with the cervical BMD (expressed in mm of the stepwedge thickness) in patients of different gender, BMI, age group and DE.

Table 4 presents univariate analysis of the dependent variable: cervical spine BMD by factors gender, BMI and age group. The model showed statistical significance; each factor had a significant effect (age, BMI and gender) on the dependent variable (cervical spine BMD). With the increase in age, the cervical spine BMD decreased significantly; in women, cervical spine BMD was significantly lower than in men, and in patients with higher BMI, the cervical spine BMD was also significantly higher (Tables 3 and 4).

The coefficients of correlation between the cervical spine BMD and the continuous variables such as the amount of the RRR in the maxilla (U) and the mandible (L) in the frontal and lateral residual areas, the age and the BMI are presented in Table 5. There was a significant negative correlation between the cervical spine BMD and the amount of RRR in anterior and posterior edentulous regions of the both jaws. Pearson's coefficient

Table 3 Mean values ($\bar{x}$) and standard deviations (SD) of amounts of the residual ridge resorption (RRR) in the maxilla (upper-U) and the mandible (lower-L) in the frontal and lateral regions of the residual ridges (in millimetre) together with the cervical bone density (in millimetre of the stepwedge thickness) dependent on gender, body mass index (BMI), age group and the duration of edentulousness (DE).

Variable (mm)	*DE*	*N*	$\bar{x}$	*SD*
Difference U-frontal	<1 years	14	1.26	0.43
	1–10 years	14	1.45	0.74
	>10 years	34	0.63	0.40
Difference U-lateral	<1 years	14	0.75	0.34
	1–10 years	14	0.93	0.88
	>10 years	32	0.27	0.23
Difference L-frontal	<1 years	14	2.02	0.48
	1–10 years	14	3.38	1.15
	>10 years	34	1.25	0.55
Difference L-lateral	<1 years	14	0.68	0.62
	1–10 years	14	0.93	0.86
	>10 years	34	0.19	0.31
Cervical bone density	<1 years	14	0.55	0.04
	1–10 years	14	0.53	0.06
	>10 years	34	0.60	0.14
	Age at the denture delivery			
Difference U-frontal	<65 years	24	1.06	0.78
	65–75 years	28	0.93	0.51
	>75 years	10	0.80	0.46
Difference U-lateral	<65 years	22	0.77	0.79
	65–75 years	28	0.39	0.34
	>75 years	10	0.40	0.13
Difference L-frontal	<65 years	24	2.33	1.48
	65–75 years	28	1.70	0.78
	>75 years	10	1.47	0.26
Difference L-lateral	<65 years	24	0.71	0.88
	65–75 years	28	0.34	0.34
	>75 years	10	0.25	0.24
Cervical bone density	<65 years	20	0.63	0.12
	65–75 years	20	0.59	0.05
	>75 years	10	0.51	0.11
	Gender			
Difference U-frontal	Female	32	1.19	0.60
	Male	30	0.71	0.55
Difference U-lateral	Female	32	0.73	0.67
	Male	28	0.30	0.24
Difference L-frontal	Female	32	2.13	0.97
	Male	30	1.68	1.22
Difference L-lateral	Female	32	0.75	0.75
	Male	30	0.17	0.20
Cervical bone density	Female	24	0.56	0.06
	Male	26	0.61	0.13

Table 3 (Continued.).

Variable (mm)	*DE*	*N*	$\bar{x}$	*SD*
	BMI			
Difference U-frontal	<24	26	0.74	0.59
	>24	36	1.11	0.60
Difference U-lateral	<24	24	0.27	0.22
	>24	36	0.71	0.65
Difference L-frontal	<24	26	1.54	0.83
	>24	36	2.18	1.22
Difference L-lateral	<24	26	0.12	0.19
	>24	36	0.72	0.71
Cervical bone density	<24	22	0.58	0.13
	>24	28	0.59	0.08

of significant correlations varied between $r = -0.33$ and $r = -0.46$. There was also a significant negative correlation between the cervical spine BMD ($r = -0.42$) and the age of the patient, while there was no significant correlation observed between the cervical spine BMD and the BMI, although a negative trend existed. According to Cohen[37], a coefficient of correlation from 0.24 to 0.36 reflects medium effect size, and a coefficient of correlation >0.37 large effect size.

The coefficients of correlation between the RRR in the maxilla (U) and the mandible (L) in frontal and lateral residual ridge areas and variables such as age, BMI, DE, gender and night-time denture wearing are presented in Table 6. A negative but insignificant correlation between age and the amount of RRR existed in all observed edentulous regions. However, for the frontal mandibular region, the relation was almost significant ($p = 0.051$) with the medium effect size at the lowest level ($r = 0.24$). The correlation between the BMI and RRR was also insignificant, as well as between the amount of RRR and the night-time of denture wearing. The DE showed a strong negative and significant correlation with the amount of the RRR in all observed regions (r varied from −0.51 to 0.65, reflecting large effect size according to Cohen[37]). Gender also showed a significant negative correlation (−0.25 to −0.47) with the amount of RRR.

The linear hierarchical regression analysis was conducted for dependent variables: RRR U-Frontal, RRR U-Lateral, RRR L-Frontal and RRR L-Lateral, respectively. The only significant correlation with the above-mentioned dependent variables had the following variables: the DE, the cervical spine BMD

Table 4 ANOVA analysis for the dependent variable: Cervical spine bone density.

Source	*Type III sum of squares*	*df*	*Mean square*	*F*	*p*
Corrected model	0.307(a)	9	0.034	6.666	<0.001
Intercept	9.227	1	9.227	1804.048	<0.001
Age group	0.079	2	0.039	7.677	0.002
BMI group	0.053	1	0.053	10.351	0.003
Gender	0.034	1	0.034	6.664	0.014
Age × BMI	0.063	2	0.031	6.149	0.005
Age × gender	0.003	2	0.002	0.297	0.745 NS
BMI × gender	0.009	1	0.009	1.845	0.182 NS
Age × BMI × gender	0.000	0			
Error	0.205	40	0.005		
Total	17.752	50			
Corrected total	0.511	49			

BMI, body mass index; NS, not significant.
(a) R squared = 0.658; (R squared adjusted = 0.593).

Table 5 Coefficients of correlation (Pearson's) between the cervical spine bone density and the amount of residual ridge resorption (RRR) in upper (U) and lower (L) frontal and lateral edentulous ridges, between the cervical spine bone density and age and between cervical spine bone density and body mass index (BMI); $^{**}p < 0.01$; $^{*}p < 0.05$.

Cervical spine bone density	*RRR U-frontal*	*RRR U-lateral*	*RRR L-frontal*	*RRR L-lateral*	*Age*	*BMI*
r	−0.433	−0.409	−0.456	−0.335	−0.422	−0.135
p (two-tailed)	0.002	0.004	0.001	0.017	0.002	0.349
N	50	48	50	50	50	50

Table 6 Pearson's coefficients of correlation between the amount of residual ridge resorption (RRR) in upper (U) and lower (L) frontal and lateral edentulous residual ridge area and age, between RRR and body mass index (BMI) and between RRR and the DE; Point-biserial coefficients of correlation between the amount of RRR in upper (U) and lower (L) frontal and lateral edentulous residual ridge area and gender, between the RRR and the night-time of denture wearing.

Amount of RRR	*Age*	*BMI*	*Duration of edentulousness (DE)*	*Gender (1 = Female, 2 = Male)*	*Night-time of denture wearing (1 = no, 2 = yes)*
RRR U-frontal					
r	−0.064	0.159	−0.647	−0.388	−0.187
p (two-tailed)	0.619	0.216	<0.001	0.002	0.144
N	62	62	62	62	62
RRR U-lateral					
r	−0.238	0.172	−0.557	−0.388	0.008
p (two-tailed)	0.067	0.185	<0.001	0.002	0.955
N	60	60	60	60	60
RRR L-frontal					
r	−0.245	0.161	−0.596	−0.254	0.089
p (two-tailed)	0.051	0.212	<0.001	0.049	0.056
N	62	62	62	62	62
RRR L-lateral					
r	−0.228	0.185	−0.511	−0.469	0.091
p (two-tailed)	0.074	0.187	<0.001	<0.001	0.481
N	62	62	62	62	62

and gender. Therefore, only DE, cervical spine BMD and gender were introduced in a hierarchical regression model in a way such that the variable with the highest strength of relationship was introduced first and the variable with the lowest strength (lowest coefficient of correlation) last. The results of the linear regression analysis together

Table 7 Linear hierarchical regression analysis of factors influencing the amount of residual ridge reduction in complete denture wearers.

Dependent variable	*Model*	*R*	R^2 [a]	*Adjusted* R^2	*SE of the estimate*	*Change statistics*				
						R^2 *Change*	*F Change*	*df 1*	*df 2*	*p*
U-frontal RRR	1	0.69[b]	0.48	0.47	0.48	0.484	440.94	1	48	<0.001
	2	0.74[c]	0.55	0.53	0.45	0.061	60.32	1	47	0.015
	3	0.74[d]	0.55	0.52	0.46	0.001	0.08	1	46	0.777 NS
U-lateral RRR	1	0.58[b]	0.34	0.33	0.51	0.339	230.63	1	46	<0.001
	2	0.64[c]	0.41	0.38	0.49	0.070	50.32	1	45	0.026
	3	0.66[d]	0.43	0.39	0.48	0.022	10.67	1	44	0.203 NS
L-frontal RRR	1	0.63[b]	0.40	0.39	0.84	0.400	320.00	1	48	<0.001
	2	0.69[c]	0.48	0.46	0.79	0.084	70.60	1	47	0.008
	3	0.70[d]	0.49	0.45	0.79	0.004	0.32	1	46	0.573 NS
L-lateral RRR	1	0.56[b]	0.32	0.30	0.56	0.315	220.08	1	48	<0.001
	2	0.59[c]	0.35	0.32	0.56	0.034	20.45	1	47	0.124 NS
	3	0.65[d]	0.43	0.39	0.53	0.077	60.21	1	46	0.016

[a] R^2 Change multiplied by 100 explains the percentage of the change of the dependent variable (RRR) by introducing each independent variable into the regression model.
[b] Predictors: (Constant), duration of edentulousness.
[c] Predictors: (Constant), duration of edentulousness, cervical spine BMD.
[d] Predictors: (Constant), duration of edentulousness, cervical spine BMD, gender.
RRR, amount of residual ridge resorption; U-frontal, upper frontal area; U-lateral, upper lateral area; L-frontal, Lower frontal area; L-lateral, lower lateral area; NS, not significant.

Table 8 B and β coefficients obtained by hierarchical regression analysis of the dependent variable: the amount of residual ridge resorption (RRR) in upper frontal area (U-frontal), upper lateral area (U-lateral), lower frontal (L-frontal) area and lower lateral (L-lateral area) by introducing independent variables: DE (duration of edentulousness), cervical spine bone mineral density and gender.

		Unstandardised coefficients	*Standardised coefficients*			
Model	*U-frontal RRR*	*B*	*SE*	*Beta*	*t*	*p*
1	(Constant)	1.423	0.103		13.804	0.000
	DE	−0.039	0.006	−0.695	−6.703	0.000
2	(Constant)	2.341	0.378		6.191	0.000
	DE	−0.035	0.006	−0.623	−6.070	0.000
	CSBD	−1.657	0.659	−0.258	−2.514	0.015
3	(Constant)	2.389	0.417		5.731	0.000
	DE	−0.034	0.007	−0.602	−4.728	0.000
	CSBD	−1.645	0.667	−0.256	−2.467	0.017
	Gender	−0.046	0.163	−0.036	−.285	0.777
	U-lateral RRR					
	(Constant)	0.951	0.110		8.640	0.000
	DE	−0.030	0.006	−0.583	−4.861	0.000
2	(Constant)	2.040	0.484		4.216	0.000
	DE	−0.027	0.006	−0.510	−4.294	0.000
	CSBD	−1.980	0.858	−0.274	−2.307	0.026
3	(Constant)	2.323	0.528		4.402	0.000
	DE	−0.021	0.008	−0.399	−2.733	0.009
	CSBD	−2.016	0.852	−0.279	−2.365	0.023
	Gender	−0.225	0.174	−0.184	−1.294	0.203
	L-frontal RRR					
1	(Constant)	2.586	0.182		14.200	0.000
	DE	−0.058	0.010	−0.632	−5.657	0.000
2	(Constant)	4.344	0.660		6.580	0.000
	DE	−0.050	0.010	−0.548	−5.012	0.000
	CSBD	−3.173	1.151	−0.301	−2.757	0.008
3	(Constant)	4.179	0.726		5.756	0.000
	DE	−0.054	0.012	−0.592	−4.381	0.000
	CSBD	−3.214	1.162	−0.305	−2.767	0.008
	Gender	0.161	0.283	0.076	.568	0.573
	L-lateral RRR					
1	(Constant)	0.933	0.122		7.659	0.000
	DE	−0.032	0.007	−0.561	−4.699	0.000
2	(Constant)	1.635	0.464		3.523	0.001
	DE	−0.029	0.007	−0.507	−4.135	0.000
	CSBD	−1.267	0.809	−0.192	−1.566	0.124
3	(Constant)	2.115	0.481		4.401	0.000
	DE	−0.017	0.008	−0.300	−2.101	0.041
	CSBD	−1.146	0.769	−0.174	−1.490	0.143
	Gender	−0.468	0.188	−0.350	−2.492	0.016

with the R^2 change are presented in Table 7 and B and β coefficients in Table 8.

Discussion

Our study showed a statistically significant decrease in the vertical height of residual alveolar ridges (RRR) at all measurement points of the maxilla and the mandible (U1-5, L1-5) through a 5-year period. The amount of RRR was the highest in frontal points of measurement of both jaws and decreased gradually towards the lateral regions. The anterior region of the mandible showed the highest degree of RRR (L1, L-frontal, Tables 1 and 2). The amounts of the RRR obtained in this study were consistent with similar studies[3,38–41]. The smaller amount of RRR in the lateral region rather than in the frontal residual ridge region was attributed to the fact that lateral teeth had probably been the first extracted teeth, and the highest amount of bone resorption had already occurred much earlier than the manufacture of the existing CDs, so at CD delivery, the highest amount of bone reduction had already taken place in the posterior sites. Moreover, in the mandible, the insertion of the pterygomandibular fold is actually at the posterior end of the retromolar pad, and the extension of the temporal muscle tendon almost encircles the retromolar pad. Therefore, owing to temporal muscle activity and mouth opening, the lateral region of the mandible is submitted to the tensile forces, which is supposed to prevent extensive bone reduction[40–43]. However, the results of this study also confirmed that the RRR was more pronounced in those patients who had been edentulous for <10 years than in patients who had been edentulous for more than 10 years, both in frontal and in lateral alveolar ridge regions. Obviously, in patients who had been edentulous for a long period, the highest amount of RRR had already occurred.

Some studies showed a relationship between the severity of the RRR and osteoporosis and/or BMD[44,45], while others suggested that bone resorption was dependent more on local factors than on general factors such as osteoporosis and low BMD[46,47]. To assess mineral BMD in the skeleton, we measured the cervical spine BMD because the cervical spine can be clearly observed on the lateral cephalographs. Moreover, it was suggested that a link between substantial bone loss in the jaw and moderate-to-severe bone loss in the vertebrae may exist[44]. For the purpose of a cervical vertebrae BMD measurement, at the 5-year observation stage, a copper stepwedge had been attached to the film cassette. This was done as jaw bone densitometry is far more accurate when including a reference wedge[48]. The BMD of the maxilla and the mandible were not assessed in this study owing to overlapping of the left and the right sides on the lateral cephalograms.

The results showed that age, gender and BMI had a statistically significant influence on the density of the third cervical spine (cervical spine BMD), as well as the combination age × BMI ($p < 0.05$); older patients had lower cervical spine BMD, patients with lower BMI had lower cervical spine BMD, and women had lower cervical spine BMD than men.

It is well known from the literature that skinfold thickness is correlated with BMD in all parts of body, and coefficients of correlation vary from 0.15 to 0.32[49]. Although this is only a small-to-medium size effect, it would mean that low skin thickness would contribute a little to the smaller BMD of the cervical spine in the present study. However, Kann *et al.*[50] found only insignificant correlation (r = 0.13) for sonographically determined skin thickness and bone mineral density. According to Richards[51], the lip alone recorded one-tenth the density of the lip and the mandible together. However, skinfold thickness of the neck is smaller than that of the lip, and all participants in this study were within normal body mass limits. Those who were overweight had probably more fatty tissue in other parts of the body than in the neck soft tissue.

The results of this study also showed that there was negative correlation between the cervical spine BMD and the amount of the RRR in the both jaws (about 16%), meaning that less RRR would occur in patients with higher cervical spine BMD. The low BMD in the skeleton is accepted as a predisposing factor for a rapid RRR. The results of this study confirm the negative relationship between the cervical spine BMD and the amount of RRR, which is consistent with the results of Kribbs *et al.*[46], who suggested that the height of the edentulous alveolar ridge is correlated with the total amount of calcium in the body and that the bone mass of the jaws depends more on the status of the bony tissues in the whole skeleton. Von Wowern[20,47] found a relationship between low bone mineral density status in the jaws and a degree of RRR after wearing conventional CDs, so low BMD may produce only a risk factor for more severe resorption of the residual ridges. Goldberg *et al.*[52] found out that there was no significant relationship between BMD of the lumbar spine and the residual ridge height on panoramic radiographs. Klemetti and Vainio[53] reported that the remaining height of the edentulous mandibles was more dependent on the BMD values of the femoral neck than on the BMD of the spine. Severe RRR was also observed in individuals with good mineral status of their skeleton[53,54], and it was concluded that this played a minor role in alveolar atrophy when compared with local factors. Nackaerts *et al.*[55] found out that the bone quality index did not show a statistically significant relation to alveolar bone level on panoramic radiographs and that radiographic mandibular BMD showed a weak but significant relation to alveolar bone level, with more periodontal breakdown for less dense alveolar bone.

The individual BMI may have an influence on the RRR[47,54]. Decreased physical activity, lowered secretion of oestrogen, diet, race and heredity may all play a role in bone loss. The results of this study showed no statistically significant correlation between BMI and the amount of RRR in the both jaws or between the BMI and the cervical spine BMD. This can be explained by the fact that all individuals had BMI within normal limits. There were no patients with low BMI, who are supposed to be predisposed to bone loss.

Ulm *et al.*[56] reported a significant difference in bone mineral content between the sexes with higher BMD in older men. Von Wowern[57] found that the bone mineral loss in the mandible seemed to be higher in older women than in older men. The results of the present study show lower values of cervical spine BMD in women than in men. The density of the jaw bone was not measured in this study owing to superimposition of the left and the right sides.

The extent of the RRR in frontal and lateral regions of the maxilla shows slightly higher values in women than in men. In the mandible, the extent of the RRR is slightly higher in men in the frontal region, while it is higher in women in the lateral region. Karkazis *et al.*[58] reported more rapid bone loss in female CD wearers than in men in the frontal region of the mandible through a 7-year observation period.

The correlation analysis revealed that the strongest association existed between the amount of RRR and the DE, while age, BMI and night-time denture wearing showed no significant association. The cervical spine BMD was affected by a patient's age, BMI and gender, while RRR was not affected by a patient's age and BMI, only by gender and the DE. Therefore, we hypothesised that the cervical spine BMD depends more on systemic factors and that the RRR depends more on local factors. As numerous factors have frequently been mentioned as causative factors contributing to the RRR, it is difficult to specify the most important factor(s) affecting individual variations in RRR[58–60]. In many previous studies there was no precise data about the exact duration of the edentulousness, or about the precise extent of the RRR at different sites of the maxilla and the mandible. This study monitored patients throughout a period of 5 years and the abovementioned data had been accurately provided. We tried to find out how different variables and factors affect the variability of the dependent variable: the extent of the RRR. The amount of the RRR in frontal and lateral regions of the maxilla and the mandible showed a significant correlation only with the DE, the cervical spine BMD and gender. Therefore, only DE, cervical spine BMD and gender were introduced in a hierarchical order into the linear regression model using the method Enter, firstly introducing the variable with the strongest relation and lastly introducing the variable with the weakest relation. In that way, we found out that the frontal-U RRR could be explained up to 48.4% by the variable DE and only 6.1% by the cervical spine BMD, while gender had almost no influence and was not significant in the regression model (1%). Altogether, the DE and the cervical spine BMD explained 55% of the frontal-U RRR. Similar results were obtained for the lateral-U RRR (33.9%; 7%; 2%, altogether 43%), frontal-L RRR (40%; 8.4%; 0.4%), while for the lateral-L, the DE explained 31.5% of the variability, cervical spine BMD 3.4% and gender 7.7%. Standardised β coefficients also confirmed the strength and the weight of the relation between the RRR and other variables. Therefore, we can conclude that cervical spine BMD is not the only causative factor affecting the RRR, its contribution being quite small (up to 8%). The DE was the factor contributing most to the RRR, up to 48.4%.

Some limitations of this study must be taken into account in the interpretation of the study results. The starting sites of the measurement had probably been changed over 5 years, but this is the same for all similar studies[1–4,6–8,21,29,30,38,39,58–61]. The residual alveolar ridge reduces in size not only downwards but also backwards. Residual ridge atrophy is a 3D process, and in this study, only vertical reduction was assessed and monitored over 5 years. Skinfold thickness of the skin overlying cervical vertebra was also of same volume in all individuals, and therefore, thinner skin in patients with lower BMI could, although only to a small extent, contribute to the lower BMD values.

This study gave valuable information about age, gender, DE, denture wearing, BMI, but no information about the strength and the direction of muscle contractions, the amount of alveolar ridge loading, chewing habits, consistency of the food, possible parafunctions or some other behavioural or medical data. Previous studies did not perform multivariate and/or regression analysis to determine the influence of each particular factor on the amount of the RRR. A problem was the relatively small number of patients remaining at follow-up recalls and a high number of factors potentially affecting the RRR. For such analysis, a larger sample of patients would be desirable. Our study group was also not numerous, but we excluded some factors in a correlation analysis, as they had not been significantly correlated with the amount of RRR. The excluded factors were BMI, night-time of denture wearing and age. Of the remaining factors, the highest influence was the DE [the variable including both the local (chewing habits, denture-bearing area loading, extent and duration of such forces, hygiene, etc.) and systemic factors], and a moderate influence was the cervical spine BMD (the factor influencing mostly systemic factors). The results of the present study do not reveal the exact influence of particular systemic and local factors but, within the abovementioned limitations, suggest the most important factors responsible for the RRR and show their approximate amount of influence. The cervical spine BMD is associated with approximately 8% of the amount of RRR, so low skeletal bone density is only weakly related to RRR.

Acknowledgement

The authors acknowledge the Ministry of Science, Education and Sport of Croatia, for funding the project No. 065-0650446-0420.

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