RESEARCH ARTICLE

The evaluation of MCI, MI, PMI and GT on both genders with different age and dental status

G Bozdag and S Sener

Department of Oral Radiology, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey

Objectives: The aim of this study was to measure the mandibular cortical index (MCI), mental index (MI), panoramic mandibular index (PMI) and cortical bone thickness in the zone of the gonial angle (GT) in panoramic radiographies from a large sample of males and females and to determine how they relate to patients' age, gender and dental status.

Methods: 910 panoramic radiographs were obtained and grouped into age, dental status and gender. The MCI, MI, PMI and GT were analysed.

Results: Remarkable differences were observed for MCI and GT regarding gender, age groups and dental status on both sides ($p < 0.05$). While age and dental status had an effect on the MI and PMI in females, dental status had an effect on the MI and PMI in males ($p < 0.05$). Also, gender had an effect on the MI and PMI ($p < 0.05$).

Conclusions: The effects of age and tooth loss are different in females and males. In females, the harmful effects of tooth loss and age are more prominent according to the PMI and MI measurements. The effects of age and tooth loss in the GT and MCI measurements are similar, and these indices can be accepted as more reliable in studies including both genders. *Dentomaxillofacial Radiology* (2015) **44**, 20140435. doi: [10.1259/dmfr.20140435](https://doi.org/10.1259/dmfr.20140435)

Cite this article as: Bozdag G, Sener S. The evaluation of MCI, MI, PMI and GT on both genders with different age and dental status. *Dentomaxillofac Radiol* 2015; **44**: 20140435.

Keywords: bone; remodelling; radiomorphometric indices

Introduction

Bone tissue undergoes constant change owing to the simultaneous processes of resorption and regeneration, generally termed as bone remodelling.^{1,2} This turnover ensures the continuous replacement of old bone tissue which, in turn, affects bone adaptation to various mechanical forces exerted on the skeleton.³ In the course of life, the mandible undergoes substantial, morphological and dimensional changes.¹

Mandibular stimuli are present from the development stage to adulthood and can change the growth of the mandible, along with its bone remodelling. According to Ghosh et al,⁴ the mandible is subject to remodelling and morphological changes in several of its regions and parts, such as the gonial, antegonial, condylar and ramus regions. The shape of the mandible correlates with the occlusal condition and functions of the masticatory muscles. Thus,

in adults, the mandible undergoes various morphological changes that are influenced by the occlusal status and age of the subjects. Various studies have shown that the remodelling of the mandible occurs with age and loss of dentition.^{2,3,5-8} Owing to progressive loss of teeth, the functional and structural relationships of the mandible change, including altered occlusal relationships, rotations of the entire mandible, realignment of the mandibular corpus, redesign of the morphology of the corpus, altered muscle-to-bone alignments, changes in locations of muscle attachments, and changes in regional form and size of the mandible in response to some or all of these altered functional relationships.² Gender is also proposed as the affective factor, relating differences in the remodelling process.³

Morphological changes of the mandible have been investigated mainly by analysis of radiomorphometric measurements.⁹⁻¹¹ Although a large number of methods have been proposed, mandibular cortical index (MCI), mental index (MI), panoramic mandibular index (PMI)

Correspondence to: Assistant Professor Dr Guldane Bozdag. E-mail: gul_dent@hotmail.com

Received 24 December 2014; revised 23 June 2015; accepted 30 June 2015

and cortical thickness in the zone of the gonial angle (GT) have been used to evaluate mandibular morphological changes. When the morphological changes have been evaluated by radiomorphometric indices, it is necessary to know their normal values and ranges in the population studied and their relationship with age, gender and dental status.¹²

Our aim in this study was to measure the MCI, MI, PMI and GT in panoramic radiographs from a large sample of males and females and to determine how they relate to patients' age, gender and dental status.

Methods and materials

910 panoramic radiographs taken for routine dental examination of patients over the age of 18 years who attended the Oral and Maxillofacial Radiology Department of Dentistry Faculty were evaluated between 2012 and 2013 (Table 1). All panoramic images were taken using the same panoramic machine (Eastman Kodak® 8000; Rochester, NY) by the same technician, according to the manufacturer's reference guide. All images were recorded as JPEG files.

Criteria for the selection of the radiographs were as follows: mental foramen, tympanic plate, condyle, and the lower border of the mandible and the posterior border of the ramus had to be readable on the radiograph to measure the structures on both sides. Only clear radiographs with high quality and with no gross distortion were selected. Panoramic radiographs of patients with orthognathic surgery, facial asymmetry or fractures were excluded from the study.

The measurements were made by one observer for two times. The observer had professional experience of 3 years in the oral radiology department. To assess the intra-observer reliability, 50 samples were randomly selected, MCI classifications were reassessed and the measurements were repeated at an interval of 1 month.

All panoramic radiographic measurements were performed on both sides of the mandible by a single

trained observer, using ImageJ v. 1.48 (www.rsby.info.nih.gov/ij/) and Adobe® Photoshop® CS4 (www.adobe.com), after correction for a 30% magnification, to better simulate the clinical situation. The linear measurements were made by the ruler function of Adobe Photoshop CS4. Angular measurements were obtained by the angular function of ImageJ v. 1.48 (Figures 1–3).

The MCI was categorized into three classes (C1–C3) according to a minor modification of Klemetti's classification¹³ as follows:

- C1: normal cortex—the endosteal margin of the cortex was even and sharp on both sides.
- C2: mild to moderately eroded cortex—the endosteal margin showed semi-lunar defects (lacunar resorption) or it appeared to form endosteal cortical residues.
- C3: severely eroded cortex—the cortical layer formed heavy endosteal cortical residues and was clearly porous (Figure 4).

The MI was determined according to Ledgerton et al.¹² A line was traced which passed perpendicular to the tangent to the lower border of the mandible and through the centre of the mental foramen (Figure 1). The cortical width was measured at this point.

The PMI is the ratio between cortical thickness at the base of the mandible and the distance from the centre of the mental foramen to the lower border of the base of the mandible, according to Benson et al.¹⁴ (Figure 2).

The GT was measured according to the method of Xie et al.¹⁵ (Figure 3).

The dental status was assessed using the following classification (third molars were not included):

- (1) 18–40 years old, dentate
- (2) above 40 years old, dentate
- (3) above 40 years old, partially dentate (maximum 15 teeth)
- (4) above 40 years old, maxillary edentulous
- (5) above 40 years old, mandibular edentulous
- (6) above 40 years old, totally edentulous.

The age was categorized into four age groups as 18–40, 41–55, 56–69 and 70 years or above.

Statistical analysis of the data was performed using the software packages SPSS® 21.0 (IBM Corp., Armonk, NY; formerly SPSS Inc., Chicago, IL). Descriptive statistics for each variable were calculated. The kappa value was calculated for MCI classification, and the intraclass correlation coefficient was calculated for GT, MI and PMI. The Kolmogorov–Smirnov test was used to determine the homogeneity of distribution. The Wilcoxon test was used to determine the differences of the mean values between the right and left parameters. The Mann–Whitney *U* test was used to test the difference in measurements between genders. The Kruskal–Wallis test was used to analyse the difference in measurements among age and tooth groups. Categorical parameters were evaluated using the χ^2 test. The level of significance was set at 5%.

Table 1 The distribution of sample is presented as number (*n*) and percentage (%) by gender, age group and dental status

Characteristics	n	%
Gender		
Male	445	48.9
Female	465	51.1
Age (years)		
18–40	154	16.9
41–55	104	11.4
56–69	449	49.3
70 and above	203	22.3
Dental status		
18–40 years old, dentate	150	16.5
Above 40 years old, dentate	154	16.9
Above 40 years old, partially dentate	150	16.5
Above 40 years old, maxillary edentulous	150	16.5
Above 40 years old, mandibular edentulous	156	17.1
Above 40 years old, totally edentulous	150	16.5

Figure 1 MCI classification.¹³

Results

All observations were readable and were included in the present study. For right and left reassessments of MCI, kappa values were 0.934 and 0.964 (almost perfect), respectively. Intraclass correlation coefficient values were 0.887, 0.812 and 0.934, and 0.964, 0.943 and 0.923 (nearly perfect) for right and left measurements of GT, MI and PMI, respectively.

The mean values of right and left measurements of lengths and angles are presented in Table 2 for both genders. There was a statistical difference between right

and left sides ($p < 0.05$) in the values of GT measurements. The mean value of the left side was significantly greater than that of the right side.

The mean and standard error values according to gender, age groups and dental status are presented in Tables 2, 3 and 4, respectively.

The distributions of MCI categories according to gender, age groups and dental status are presented in Tables 5, 6 and 7, respectively. Of the three cortical appearance categories, C2 (59.6% for the right and 55.8% for the left) was the most common category in all age groups and both sexes in general. Remarkable

Figure 2 Mental index.

Figure 3 Panoramic mandibular index.

differences were observed for MCI regarding gender, age groups and dental status on both sides ($p < 0.01$). The most common category was C1 in females in the 18–40 years group. When the age increased, C2 was the most visible category in females. In males, C2 was the most common category in all age groups. The increase of the C3 category was observed with age in both sexes. The C1 category was less common in 70 years and above in both sexes. The C1 category was less common as the number of teeth decreased in both sexes. The C2 and C3 categories increased as the number of teeth decreased in both sexes. Females had more C3 categories than did males.

In females, there were significant changes in the values of MI according to age groups ($p < 0.01$) (Table 8). When the age increased, MI values decreased in females. No statistically significant differences were seen between age groups in males for MI ($p > 0.05$) (Table 8). There were significant variations found for MI in both sexes according to dental status ($p < 0.05$) (Table 8). MI values declined when the number of teeth

decreased in females. Males above 40 years of age who were mandibular edentulous had smaller MI than the other dental groups. There was a significant difference in MI between males and females ($p < 0.05$) (Table 8). Males had greater MI than females.

In females, there were significant changes in the values of PMI according to age groups ($p < 0.01$) (Table 8). When the age increased, PMI values decreased in females. No statistically significant differences were seen between age groups in males for PMI. There were significant variations found for PMI as to dental status in both sexes ($p < 0.05$) (Table 8). There were declining PMI values when the number of teeth decreased in females. In males, there was remarkable difference between only the above 40-year totally edentulous patients and above 40-year mandibular edentulous patients. Above 40-year mandibular edentulous patients had smaller PMI than the other group. There was a significant difference in PMI between males and females ($p < 0.05$) (Table 8). Males had greater PMI than females.

Significant differences were observed in GT regarding gender, age and dental status on both sides ($p < 0.01$) (Table 8). There was a decrease in GT values with increasing age and decreasing number of teeth in both sexes. Males had significantly thicker GT than females ($p < 0.01$) (Table 8).

Discussion

The study group of patients was not selected on the basis of any radiographic or medical criteria and was not chosen from any particular dental speciality. All the measurements were assessed on panoramic radiographs taken for routine dental examination of patients. To ensure reliability and consistency, one dentomaxillofacial radiologist evaluated each image to select only those radiographs of the highest quality. The intraclass correlation coefficient and kappa values were perfect. This indicates that the method of indices for assessment is very reliable.

In this study, the measurements and classifications were made on panoramic radiography. Panoramic radiography

Figure 4 Gonial thickness.¹⁵

Table 2 Mean measurement values in millimetres by gender, quadrant and panoramic measurement [cortical thickness in the zone of gonial angle (GT), mental index (MI)] and panoramic mandibular index (PMI). Standard error (SE) values for each measure are also included

Measurement	Females		Males		Total	
	Mean (mm)	SE	Mean (mm)	SE	Mean (mm)	SE
Right GT	0.77	0.38	0.89	0.41	0.83	0.40
Left GT	0.80	0.36	0.93	0.40	0.87	0.39
Right MI	4.21	1.40	4.94	1.37	4.57	1.44
Left MI	4.26	1.48	4.96	1.44	4.61	1.50
Right PMI	0.35	0.12	0.39	0.12	0.37	0.12
Left PMI	0.35	0.13	0.39	0.13	0.37	0.13

is preferred in the assessment of mandibular morphology, such as vertical and angular measurements.^{16–27} There is acceptable reproducibility for the vertical angular variables for group comparisons, provided the head positioning is standardized and remains constant.¹⁶ Catić et al¹⁷ reported that linear measurements which cover the left and right side and do not pass the middle line are very close to the actual values in panoramic radiographs. Another study¹⁸ compared the mandibular angular measurements in panoramic radiographs, lateral cephalometric views and direct skull measurements. Their results revealed a high degree of accuracy in both imaging modalities, especially in the orthopantomograms.

The studies stated that panoramic machine magnification was about 15–30%.^{7,28–33} In the present study, all measurements were reduced to the original size of the mandibular features, according to the magnification of the panoramic machine used (27%, according to the manufacturer). The magnification value of the panoramic machine used in this study is in accordance with the literature.^{28–33} Nevertheless, it has to be pointed out in this context that the theoretically well-understood^{28–33} complexity regarding magnification and distortion in panoramic radiography is not well reflected by applying a crude global magnification factor. However, using indices largely compensates for the unknown local magnification in the image.

MCI was initially mentioned by Klemetti et al,¹³ and Knezović-Ziatarić and Celebić³⁴ reported that age-related increase in the number of individuals with C3 cortices was common in older age groups. In our study, age had

a statistically significant influence on the MCI on both sides in both genders. As age increased, the likelihood of the C2 and C3 categories increased and the likelihood of the C1 category decreased as well. It was stated that gender had no statistically significant influence on the MCI on both sides.^{26,34–36} However, Uysal et al³⁷ said that gender had a significant effect on the MCI. The result of the present study is in accordance with the findings of Uysal et al.³⁷ Hastar et al³⁸ reported that the C1 category was more frequently seen in males, the C2 category was more frequently in females and the C3 category was observed only in females. Nakajima and Osato³⁹ found that the C3 category appeared more frequently in females than in males, and the C2 category was predominant in males. In the present study, MCI values were significantly affected by gender on both sides. The C2 category was more common in males than in females. Also, the C3 category was more frequent in females than in males. The difference between the findings of the different studies can be attributed to the difference in gender distribution study samples. It was shown that the dental status was one of the important parameters affecting MCI,²⁶ but it was also indicated that dental status had no statistically significant influence on the MCI.^{12,37,38} Imirzalioglu et al³⁵ found that the C3 category increased as the number of teeth decreased. Tozdoğan and Cakur³⁶ reported that there were more C2 and C3 categories than C1 categories in edentulous patients. In the present study, dental status had a statistically significant influence on the MCI on both sides in both genders. As the number of teeth decreased, the likelihood of the C2 and C3 categories increased and the likelihood of the C1 category decreased as well. These findings are consistent with other studies.^{26,35,36}

In panoramic radiographs, MI measurement is a recommended method for determining the lowest bone density.⁴⁰ It was stated that there was an age-related decrease for MI values in both genders.^{12,14,25–27,41–43} The present study revealed that the mean MI values did not change as age increased in males and the mean MI values decreased significantly with age in females. This finding is similar to the findings of the study by Yüzügüllü et al.²⁷ It was also observed that dental status was a prominent factor on the MI in males. In our study, gender had a statistically significant influence on the MI on both sides of both genders. This result is consistent with the results of the various studies.^{25,27,38,41,42} However, the

Table 3 Mean measurement values in millimetres by age groups, quadrant and panoramic measurement [cortical thickness in the zone of gonial angle (GT), mental index (MI)] and panoramic mandibular index (PMI). Standard error (SE) values for each measure are also included

Measurement	18–40 years old				41–55 years old				56–69 years				70 years and above			
	Female		Male		Female		Male		Female		Male		Female		Male	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Right GT	0.98	0.41	1.15	0.42	0.73	0.36	0.94	0.42	0.74	0.36	0.80	0.38	0.68	0.37	0.85	0.40
Left GT	1.01	0.42	1.16	0.33	0.68	0.33	0.96	0.30	0.77	0.32	0.88	0.41	0.76	0.37	0.86	0.39
Right MI	5.23	0.93	5.05	1.09	4.39	1.33	5.18	1.11	4.06	1.31	4.91	1.42	3.65	1.55	4.81	1.56
Left MI	5.42	1.01	5.36	1.20	4.53	1.51	5.14	1.31	4.09	1.35	4.96	1.47	3.64	1.56	4.61	1.54
Right PMI	0.42	0.09	0.38	0.09	0.37	0.13	0.43	0.12	0.34	0.12	0.39	0.13	0.30	0.13	0.38	0.12
Left PMI	0.42	0.09	0.39	0.10	0.38	0.14	0.41	0.10	0.34	0.12	0.39	0.14	0.30	0.12	0.36	0.13

Table 4 Mean measurement values in millimetres by dental status, quadrant and panoramic measurement [cortical thickness in the zone of gonial angle (GT), mental index (MI)] and panoramic mandibular index (PMI). Standard error (SE) values for each measure are also included

Measurement	18–40 years old, dentate				Above 40 years old, dentate				Above 40 years old, partially dentate				Above 40 years old, mandibular edentulous				Above 40 years old, maxillary edentulous				Above 40 years old, totally edentulous			
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Female		Male	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Right GT	1.00	0.40	1.15	0.40	0.74	0.39	0.85	0.41	0.79	0.41	1.03	0.41	0.79	0.41	0.77	0.34	0.66	0.29	0.75	0.30	0.68	0.38	0.75	0.48
Left GT	1.02	0.42	1.16	0.32	0.77	0.31	0.93	0.42	0.86	0.39	1.08	0.35	0.86	0.39	0.81	0.32	0.57	0.25	0.75	0.31	0.76	0.33	0.84	0.45
Right MI	5.24	0.92	5.05	1.09	4.63	1.25	5.33	1.21	4.25	1.39	5.27	1.58	4.25	1.39	4.30	1.46	3.89	1.37	4.73	1.40	3.96	1.32	4.89	1.23
Left MI	5.43	1.02	5.36	1.20	4.46	1.36	5.29	1.32	4.40	1.60	5.24	1.62	4.40	1.60	4.37	1.51	3.98	1.33	4.64	1.34	3.95	1.31	4.81	1.38
Right PMI	0.41	0.08	0.37	0.09	0.35	0.10	0.39	0.11	0.34	0.12	0.39	0.11	0.34	0.12	0.34	0.11	0.33	0.12	0.41	0.16	0.35	0.13	0.40	0.09
Left PMI	0.42	0.09	0.39	0.09	0.34	0.11	0.37	0.09	0.35	0.13	0.38	0.11	0.35	0.13	0.34	0.13	0.34	0.12	0.41	0.16	0.34	0.12	0.40	0.12

Table 5 The distribution of mandibular cortical index (MCI) classification is presented as number (*n*) by gender and quadrant

Measurement	MCI			Total
	1.00	2.00	3.00	
Right				
Female	144	237	84	465
Male	110	305	30	445
Total	254	542	114	910
Left				
Female	152	219	94	465
Male	112	289	44	445
Total	264	508	138	910

result of the present study is not similar to the findings of the study by Imirzalioglu et al.³⁵ This may be due to the non-homogeneous distribution of females and males in their study. The investigations of Dutra et al.²⁵ and Imirzalioglu et al.³⁵ showed no significant differences between dental status and MI. However, it was also stated that dental status had a statistically significant influence on the MI.^{12,26,44} In our study, the MI value was found to decline as the number of teeth decreased in both genders. This finding is in accordance with the literature.^{12,26,44} According to the present investigation, loss of any kind of teeth in females and loss of all of the teeth of the lower jaw in males affect the value of MI. These results may indicate that masticatory muscle atrophy may be related to change in the quality of the mandibular bone.²⁶ In the complete dentition, all masticatory muscles take part in mastication. The function of the temporal and masseter muscle is reduced in partial or complete loss of teeth. A long duration of edentulousness and possibly low masticatory force may be related to the change in the MI and PMI. The reduction of cortical bone thickness had an association with metabolic bone loss.^{45–47} The lower value of cortical bone thickness in older females was considered to be the result of accelerated bone loss after menopause.⁴⁶ Elderly edentulous subjects with a long history of edentulousness may have very low masticatory force. Males have greater masticatory force than females.⁴⁸ Because of gender hormonal differences affecting bone metabolism with age, more serious care must be taken to avoid teeth extraction to protect the bone structure and mandibular morphology in females. The teeth must be kept in the mouth by endodontic and restorative treatments.

Wical and Swoope⁴⁹ stated that the anatomical reference points were the mental foramen and upper and lower borders of the mandible in all patients' panoramic radiography for radiomorphometric analyses, as sometimes the upper borders of the mental foramen may not be seen.^{27,38} For this reason, the lower borders of the mental foramen were evaluated in this study. One advantage in the use of PMI over MI is that its method of calculation considers differences in magnification associated with different panoramic machines. Thus, unlike other linear indices, it is possible to make a direct comparison of absolute figures with other studies.¹² In accordance with the results of studies, bilateral PMI value declined as age increased.^{12,26,38,42,50} One article³⁵

Table 6 The distribution of mandibular cortical index (MCI) classification is presented as number (*n*) by age groups and quadrants

	<i>MCI</i>			
<i>Measurement</i>	<i>1.00</i>	<i>2.00</i>	<i>3.00</i>	<i>Total</i>
Right (years)				
18–40	100	54	0	154
41–55	36	62	6	104
56–69	91	301	57	449
70 and above	27	125	51	203
Total	254	542	114	910
Left (years)				
18–40	104	50	0	154
41–55	33	61	10	104
56–69	100	272	77	449
70 and above	27	125	51	203
Total	264	508	138	910

is not in agreement with the results of this study. This may be due to the non-homogeneous distribution of age groups in their study. Recent studies on PMI values have been performed primarily on females^{12,13,40,41,51,52} and demonstrate PMI values between 0.31 and 0.38, which are consistent with the mean value of 0.34–0.38 found in the present study. In our study, there was a significant difference between genders for PMI values. This is not consistent with the finding of Yüzügüllü et al.²⁷ The difference may be related to the sample size in their study. Dental status had a strong effect on PMI.^{12,53} However, Imirzalioglu et al.³⁵ said that PMI showed no changes according to dental status. In our study, the PMI value was found to decline as the number of teeth decreases on both sides and genders. According to the present investigation, loss of any kind of the number of teeth in females and only all of the teeth in the lower jaw in males affect the value of PMI. The difference may be due to the

Table 7 The distribution of mandibular cortical index (MCI) classification is presented as number (*n*) by dental status and quadrant

	<i>MCI</i>			
<i>Measurement</i>	<i>1.00</i>	<i>2.00</i>	<i>3.00</i>	<i>Total</i>
Right				
18-40 years old, dentate	97	53	0	150
Above 40 years old, dentate	51	94	9	154
Above 40 years old, partially dentate	53	82	15	150
Above 40 years old, maxillary edentulous	13	90	47	150
Above 40 years old, mandibular edentulous	27	104	25	156
Above 40 years old, totally edentulous	13	119	18	150
Total	254	542	114	910
Left				
18-40 years old, dentate	102	48	0	150
Above 40 years old, dentate	55	84	15	154
Above 40 years old, partially dentate	53	78	19	150
Above 40 years old, maxillary edentulous	16	84	50	150
Above 40 years old, mandibular edentulous	27	101	28	156
Above 40 years old, totally edentulous	11	113	26	150
Total	264	508	138	910

insufficient sample size of the edentulous dental group in the study of Imirzalioglu et al.³⁵

GT was used as radiographic evidence of metabolic bone loss.^{15,41,46,54,55} In this study, there was a statistical difference between the left and right GT measurements. These differences may derive from the shape of the mandibular base, especially the gonial region, and correlate with the function and shape of the muscles of mastications.⁵⁶ If this hypothesis is correct, it can be concluded that the function of the muscles of mastication especially affect the region of GT. Also, the difference could be due to the increased function of a preferred chewing side. The effect of the unilateral chewing on GT measurement should be evaluated in the studies with other related parameters fixed. Cortical thinning and erosion of the mandible may be regarded as indicators of alterations of the mandible at the gonial region in the present study. These changes reflect the increase in widened Haversian canals with resorption surfaces in the cortex.²⁹ According to the findings of the present study, gender, age and dental status had a statistically significant influence on the GT on both sides and sexes. GT is decreased with increasing age and reduction of the number of teeth. This finding is consistent with the results of the other studies.^{15,41,46,47,54,55}

In morphological assessment by GT measurement, it should be kept in mind that GT is a highly variable morphological structure according to gender, age and dental status. Therefore, if GT is used to determine the morphological changes, age, gender and number of teeth should be maintained as stable in investigations.

These results may indicate that local factors, such as age, gender and dental status, affect mandibular bone quality. Masticatory muscle atrophy owing to tooth loss may be considered as one of the factors resulting in a change in the quality of mandibular bone. However, in individuals with a short-term edentulous experience, morphological changes may not have been perceptible. The difference between the genders can be caused by factors that affect bone metabolism, such as hormonal condition; therefore, as age, gender and dental status hold steady, other factors may be investigated more reliably. Future studies that evaluate different clinical parameters, such as the duration of usage of prosthesis, type of

Table 8 The differences between age groups, gender and dental status

Measurement	Age group		Dental status		Gender
	Female	Male	Female	Male	
Right GT	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a
Left GT	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a
Right MI	0.000 ^a	0.219	0.000 ^a	0.000 ^a	0.000 ^a
Left MI	0.000 ^a	0.572	0.000 ^a	0.000 ^a	0.000 ^a
Right PMI	0.000 ^a	0.068	0.000 ^a	0.023 ^a	0.000 ^a
Left PMI	0.000 ^a	0.214	0.000 ^a	0.010 ^a	0.000 ^a
Right MCI	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a
Left MCI	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a	0.000 ^a

GT, cortical thickness in the zone of gonial angle; MCI, mandibular cortical index; MI, mental index; PMI, panoramic mandibular index. ^a*p* < 0.05.

prosthesis, occlusion type, habit of chewing and parafunctions such as bruxism, together with radiological findings, may give more obvious information about the mandibular bone morphology's remodelling in both genders.

The methods used in the present study have been used in other studies for many years with most studies arriving at similar conclusions. A large number of images have been used in the present study, and appropriate exclusion criteria were used in order to provide meaningful results. In addition, multiple indices of mandibular morphological change were used with the aim of determining change in relation to gender, age and dental status (tooth loss).

According to the findings of the study, the measurements of GT and MCI are affected by gender, age and dental status. Age and dental status have similar effects on both genders for these measurements. There was a difference between the genders in indices of PMI and MI. The effects of age and tooth loss are different for females and males. In females, the harmful effects of tooth loss and age are more prominent according to the PMI and MI measurements. As females are more vulnerable to reduced bone quality owing to hormonal

conditions and/or age, natural dentition should be strictly preserved. The tooth loss should be avoided by restorative or endodontic treatments if possible. Since in the assessment of mandibular morphology, the effect of age and tooth loss in GT and MCI measurements is similar for both genders, and these indices can be accepted as more reliable in studies including both genders.

In the limitations of this study, all indices show differences by tooth loss and gender. PMI, MI and GT are quantitative indices, which correlated with skeletal bone loss. Although the measurements of PMI and MI do not vary with age, GT decreases with the increase of age in males. The difference between the genders relating to age may result from hormonal conditions. It has also been found that males have stronger masticatory activity than females. It can therefore be concluded that the activity of masticatory muscles can be more effective on the gonial region and correlated with the decrease of GT in males.

Acknowledgments

This investigation is a part of Guldane Magat's doctoral thesis.

References

- Parfitt AM. The coupling of bone formation to bone resorption: a critical analysis of the concept and of its relevance to the pathogenesis of osteoporosis. *Metab Bone Dis Relat Res* 1982; **4**: 1–6. doi: [10.1016/0221-8747\(82\)90002-9](https://doi.org/10.1016/0221-8747(82)90002-9)
- Enlow DH, Bianco HJ, Eklund S. The remodelling of the edentulous mandible. *J Prosthet Dent* 1976; **36**: 685–93. doi: [10.1016/0022-3913\(76\)90035-4](https://doi.org/10.1016/0022-3913(76)90035-4)
- Huomonen S, Sipilä K, Haikola B, Tapio M, Söderholm AL, Remes-Lyly T, et al. Influence of edentulousness on gonial angle, ramus and condylar height. *J Oral Rehabil* 2010; **37**: 34–8. doi: [10.1111/j.1365-2842.2009.02022.x](https://doi.org/10.1111/j.1365-2842.2009.02022.x)
- Ghosh S, Vengal M, Pai KM, Abhishek K. Remodeling of the antegonial angle region in the human mandible: a panoramic radiographic cross-sectional study. *Med Oral Patol Oral Cir Bucal* 2010; **15**: e802–7. doi: [10.4317/medoral.15.e802](https://doi.org/10.4317/medoral.15.e802)
- Raustia AM, Pirttiniemi P, Salonen MA, Pyhtinen J. Effect of edentulousness on mandibular size and condyle-fossa position. *J Oral Rehabil* 1998; **25**: 174–9. doi: [10.1046/j.1365-2842.1998.00222.x](https://doi.org/10.1046/j.1365-2842.1998.00222.x)
- 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. doi: [10.1016/0022-3913\(72\)90188-6](https://doi.org/10.1016/0022-3913(72)90188-6)
- Dutra V, Yang J, Devlin H, Susin C. Mandibular bone remodelling in adults: evaluation of panoramic radiographs. *Dentomaxillofac Radiol* 2004; **33**: 323–8. doi: [10.1259/dmfr/17685970](https://doi.org/10.1259/dmfr/17685970)
- Xie QF, Ainamo A. Correlation of gonial angle size with cortical thickness, height of the mandibular residual body, and duration of edentulism. *J Prosthet Dent* 2004; **91**: 477–82. doi: [10.1016/S0022391304001118](https://doi.org/10.1016/S0022391304001118)
- Chen LL, Xu TM, Jiang JH, Zhang XZ, Lin JX. Longitudinal changes in mandibular arch posterior space in adolescents with normal occlusion. *Am J Orthod Dentofacial Orthop* 2010; **137**: 187–93. doi: [10.1016/j.ajodo.2008.03.021](https://doi.org/10.1016/j.ajodo.2008.03.021)
- Krupar S, Darvann TA, Larsen P, Marsh JL, Kreiborg S. Three-dimensional analysis of mandibular growth and tooth eruption. *J Anat* 2005; **207**: 669–82. doi: [10.1111/j.1469-7580.2005.00479.x](https://doi.org/10.1111/j.1469-7580.2005.00479.x)
- Tsai HH. A study of growth changes in the mandible from deciduous to permanent dentition. *J Clin Pediatr Dent* 2003; **27**: 137–42. doi: [10.17796/jcpd.27.2.p77tn2515w157661](https://doi.org/10.17796/jcpd.27.2.p77tn2515w157661)
- Ledgerton D, Horner K, Devlin H, Worthington H. Radiomorphometric indices of the mandible in a British female population. *Dentomaxillofac Radiol* 1999; **28**: 173–81. doi: [10.1038/sj/dmfr/4600435](https://doi.org/10.1038/sj/dmfr/4600435)
- Klemetti E, Kolmakov S, Heiskanen P, Vainio P, Lassila V. Panoramic mandibular index and bone mineral densities in post-menopausal women. *Oral Surg Oral Med Oral Pathol* 1993; **75**: 774–9. doi: [10.1016/0030-4220\(93\)90438-A](https://doi.org/10.1016/0030-4220(93)90438-A)
- Benson BW, Prihoda TJ, Glass BJ. Variations in adult cortical bone mass as measured by a panoramic mandibular index. *Oral Surg Oral Med Oral Pathol* 1991; **71**: 349–56. doi: [10.1016/0030-4220\(91\)90314-3](https://doi.org/10.1016/0030-4220(91)90314-3)
- Xie Q, Wolf J, Ainamo A. Quantitative assessment of vertical heights of maxillary and mandibular bones in panoramic radiographs of elderly dentate and edentulous subjects. *Acta Odontol Scand* 1997; **55**: 155–61. doi: [10.3109/00016359709115409](https://doi.org/10.3109/00016359709115409)
- Larheim TA, Svanaes DB. Reproducibility of rotational panoramic radiography: mandibular linear dimensions and angles. *Am J Orthod Dentofacial Orthop* 1986; **90**: 45–51. doi: [10.1016/0889-5406\(86\)90026-0](https://doi.org/10.1016/0889-5406(86)90026-0)
- Čatić A, Celebić A, Valentić-Peruzović M, Catović A, Jerolimov V, Muretić I. Evaluation of the precision of dimensional measurements of the mandible on panoramic radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998; **86**: 242–8.
- Mattila K, Altonen M, Haavikko K. Determination of the gonial angle from the orthopantomogram. *Angle Orthod* 1977; **47**: 107–10. doi: [10.1043/0003-3219\(1977\)047<0107:DOTGAF>2.0.CO;2](https://doi.org/10.1043/0003-3219(1977)047<0107:DOTGAF>2.0.CO;2)
- Yanikoğlu N, Yılmaz B. Radiological evaluation of changes in the gonial angle after teeth extraction and wearing of dentures: a 3-year longitudinal study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; **105**: e55–60. doi: [10.1016/j.tripleo.2008.02.014](https://doi.org/10.1016/j.tripleo.2008.02.014)
- Ceylan G, Yanikoglu N, Yılmaz AB, Ceylan Y. Changes in the mandibular angle in the dentulous and edentulous states. *J Prosthet Dent* 1998; **80**: 680–4. doi: [10.1016/S0022-3913\(98\)70055-1](https://doi.org/10.1016/S0022-3913(98)70055-1)
- Stramotas S, Geenty JP, Petocz P, Darendeliler MA. Accuracy of linear and angular measurements on panoramic radiographs taken at various positions *in vitro*. *Eur J Orthod* 2002; **24**: 43–52. doi: [10.1093/ejo/24.1.43](https://doi.org/10.1093/ejo/24.1.43)

22. McKee IW, Glover KE, Williamson PC, Lam EW, Heo G, Major PW. The effect of vertical and horizontal head positioning in panoramic radiography on mesiodistal tooth angulations. *Angle Orthod* 2001; **71**: 442–51. doi: [10.1043/0003-3219\(2001\)071<0442:TEOVAH>2.0.CO;2](https://doi.org/10.1043/0003-3219(2001)071<0442:TEOVAH>2.0.CO;2)
23. Hardy TC, Suri L, Stark P. Influence of patient head positioning on measured axial tooth inclination in panoramic radiography. *J Orthod* 2009; **36**: 103–10. doi: [10.1179/14653120723013](https://doi.org/10.1179/14653120723013)
24. Joo JK, Lim YJ, Kwon HB, Ahn SJ. Panoramic radiographic evaluation of the mandibular morphological changes in elderly dentate and edentulous subjects. *Acta Odontol Scand* 2013; **71**: 357–62. doi: [10.3109/00016357.2012.690446](https://doi.org/10.3109/00016357.2012.690446)
25. Dutra V, Yang J, Devlin H, Susin C. Radiomorphometric indices and their relation to gender, age, and dental status. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005; **99**: 479–84. doi: [10.1016/j.tripleo.2004.09.013](https://doi.org/10.1016/j.tripleo.2004.09.013)
26. Gulsahi A, Yüzügüllü B, Imirzalioglu P, Genç Y. Assessment of panoramic radiomorphometric indices in Turkish patients of different age groups, gender and dental status. *Dentomaxillofac Radiol* 2008; **37**: 288–92. doi: [10.1259/dmfr/19491030](https://doi.org/10.1259/dmfr/19491030)
27. Yüzügüllü B, Gulsahi A, Imirzalioglu P. Radiomorphometric indices and their relation to alveolar bone loss in completely edentulous Turkish patients: a retrospective study. *J Prosthet Dent* 2009; **101**: 160–5. doi: [10.1016/S0022-3913\(09\)60021-4](https://doi.org/10.1016/S0022-3913(09)60021-4)
28. McDavid WD, Tronje G, Welander U, Morris CR. Dimensional reproduction in rotational panoramic radiography. *Oral Surg Oral Med Oral Pathol* 1986; **62**: 96–101. doi: [10.1016/0030-4220\(86\)90079-4](https://doi.org/10.1016/0030-4220(86)90079-4)
29. Tronje G, Welander U, McDavid WD, Morris CR. Image distortion in rotational panoramic radiography. VI. Distortion effects in sliding systems. *Acta Radiol Diagn* 1982; **23**: 153–60.
30. McDavid WD, Welander U, Brent Dove S, Tronje G. Digital imaging in rotational panoramic radiography. *Dentomaxillofac Radiol* 1995; **24**: 68–75. doi: [10.1259/dmfr.24.2.9527513](https://doi.org/10.1259/dmfr.24.2.9527513)
31. Tronje G, Welander U, McDavid WD, Morris CR. Image distortion in rotational panoramic radiography. I. General considerations. *Acta Radiol Diagn* 1981; **22**: 295–9.
32. Tronje G, Eliasson S, Julin P, Welander U. Image distortion in rotational panoramic radiography. II. Vertical distances. *Acta Radiol Diagn* 1981; **22**: 449–55.
33. Devlin H, Yuan J. Object position and image magnification in dental panoramic radiography: a theoretical analysis. *Dentomaxillofac Radiol* 2013; **42**: 29951683. doi: [10.1259/dmfr/29951683](https://doi.org/10.1259/dmfr/29951683)
34. Knezović-Ziatareć D, Celebić A. Mandibular bone mineral density changes in complete and removable partial denture wearers: a 6-month follow-up study. *Int J Prosthodont* 2003; **16**: 661–5.
35. Imirzalioglu P, Yüzügüllü B, Gulsahi A. Türk toplumunda panoramik radyomorfometrik indekslerin demografik faktörlere göre belirlenmesi. *SU Diş Hek Fak Derg* 2009; **18**: 143–7.
36. Tozoğlu U, Cakur B. Evaluation of the morphological changes in the mandible for dentate and totally edentate elderly population using cone-beam computed tomography. *Surg Radiol Anat* 2014; **36**: 643–9. doi: [10.1007/s00276-013-1241-y](https://doi.org/10.1007/s00276-013-1241-y)
37. Uysal S, Cagrankaya BL, Hatipoglu MG. Do gender and torus mandibularis affect mandibular cortical index? A cross-sectional study. *Head Face Med* 2007; **3**: 37. doi: [10.1186/1746-160X-3-37](https://doi.org/10.1186/1746-160X-3-37)
38. Hastar E, Yilmaz HH, Orhan H. Evaluation of mental index, mandibular cortical index and panoramic mandibular index on dental panoramic radiographs in the elderly. *Eur J Dent* 2011; **5**: 60–7.
39. Nakajima S, Osato S. Association of gonial angle with morphology and bone mineral content of the body of the adult human mandible with complete permanent dentition. *Ann Anat* 2013; **195**: 533–8. doi: [10.1016/j.aanat.2013.06.006](https://doi.org/10.1016/j.aanat.2013.06.006)
40. Dutra V, Devlin H, Susin C, Yang J, Horner K, Fernandes AR. Mandibular morphological changes in low bone mass edentulous females: evaluation of panoramic radiographs. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; **102**: 663–8. doi: [10.1016/j.tripleo.2006.02.023](https://doi.org/10.1016/j.tripleo.2006.02.023)
41. Kribbs PJ. Comparison of mandibular bone in normal and osteoporotic women. *J Prosthet Dent* 1990; **63**: 218–22. doi: [10.1016/0022-3913\(90\)90108-O](https://doi.org/10.1016/0022-3913(90)90108-O)
42. Zlatarić DK, Celebić A. Clinical bone densitometric evaluation of the mandible in removable denture wearers dependent on the morphology of the mandibular cortex. *J Prosthet Dent* 2003; **90**: 86–91.
43. Lee BD, White SC. Age and trabecular features of alveolar bone associated with osteoporosis. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005; **100**: 92–8. doi: [10.1016/j.tripleo.2004.11.020](https://doi.org/10.1016/j.tripleo.2004.11.020)
44. Taguchi A, Tanimoto K, Suei Y, Wada T. Tooth loss and mandibular osteopenia. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1995; **79**: 127–32.
45. Habets LL, Bras J, Borgmeyer-Hoelen AM. Mandibular atrophy and metabolic bone loss. Endocrinology, radiology and histomorphometry. *Int J Oral Maxillofac Surg* 1988; **17**: 208–11. doi: [10.1016/S0901-5027\(88\)80035-3](https://doi.org/10.1016/S0901-5027(88)80035-3)
46. Bras J, van Ooij CP, Abraham-Inpijn L, Kusen GJ, Wilmink JM. Radiographic interpretation of the mandibular angular cortex: a diagnostic tool in metabolic bone loss. Part I. Normal state. *Oral Surg Oral Med Oral Pathol* 1982; **53**: 541–5. doi: [10.1016/0030-4220\(82\)90473-X](https://doi.org/10.1016/0030-4220(82)90473-X)
47. Bras J. Mandibular atrophy and metabolic bone loss. *Int Dent J* 1990; **40**: 298–302.
48. Bakke M, Holm B, Jensen BL, Michler L, Möller E. Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. *Scand J Dent Res* 1990; **98**: 149–58.
49. 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. doi: [10.1016/0022-3913\(74\)90093-6](https://doi.org/10.1016/0022-3913(74)90093-6)
50. Dagistan S, Bilge OM. Comparison of antegonial index, mental index, panoramic mandibular index and mandibular cortical index values in the panoramic radiographs of normal males and male patients with osteoporosis. *Dentomaxillofac Radiol* 2010; **39**: 290–4. doi: [10.1259/dmfr/46589325](https://doi.org/10.1259/dmfr/46589325)
51. Taguchi A, Suei Y, Sanada M, Ohtsuka M, Nakamoto T, Sumida H, et al. Validation of dental panoramic radiography measures for identifying postmenopausal women with spinal osteoporosis. *AJR Am J Roentgenol* 2004; **183**: 1755–60. doi: [10.2214/ajr.183.6.01831755](https://doi.org/10.2214/ajr.183.6.01831755)
52. Taguchi A, Suei Y, Ohtsuka M, Otani K, Tanimoto K, Ohtaki M. Usefulness of panoramic radiography in the diagnosis of postmenopausal osteoporosis in women. Width and morphology of inferior cortex of the mandible. *Dentomaxillofac Radiol* 1996; **25**: 263–7.
53. Von Wowern N. Microradiographic and histomorphometric indices of mandibles for diagnosis of osteopenia. *Scand J Dent Res* 1982; **90**: 47–63.
54. Bras J, van Ooij CP, Abraham-Inpijn L, Wilmink JM, Kusen GJ. Radiographic interpretation of the mandibular angular cortex: a diagnostic tool in metabolic bone loss. Part II. Renal osteodystrophy. *Oral Surg Oral Med Oral Pathol* 1982; **53**: 647–50. doi: [10.1016/0030-4220\(82\)90356-5](https://doi.org/10.1016/0030-4220(82)90356-5)
55. Bollen AM, Taguchi A, Hujoel PP, Hollender LG. Number of teeth and residual alveolar ridge height in subjects with a history of self-reported osteoporotic fractures. *Osteoporos Int* 2004; **15**: 970–4. doi: [10.1007/s00198-004-1695-1](https://doi.org/10.1007/s00198-004-1695-1)
56. Rönning O, Barnes SA, Pearson MH, Pledger DM. Juvenile chronic arthritis: a cephalometric analysis of the facial skeleton. *Eur J Orthod* 1994; **16**: 53–62. doi: [10.1093/ejo/16.1.53](https://doi.org/10.1093/ejo/16.1.53)