Quantification of Bone Resorption in the Interforaminal Region of the Atrophic Mandible

Rudolf M. S. Blahout, DMD[1]/Stefan Hienz, DMD, PhD[1]/Peter Solar, DMD[2]/
Michael H. Matejka, DMD[3]/Christian W. Ulm, DMD[4]

Purpose: *This anatomic study was undertaken to examine the effects of atrophy on bone quantity and quality in the mandibular interforaminal region.* ***Materials and Methods:*** *Three sections were made from each jaw studied, and each section was measured by means of a morphometric software program (Artma-Biomed, Vienna, Austria). The mandibular specimens were grouped according to the classification of Cawood and Howell and also according to that of Lekholm and Zarb.* ***Results:*** *The macromorphometric measurements revealed that mandibular atrophy may cause the loss of up to 60% of the original bone mass. As the maximum width remained relatively consistent in all jaw sections, it can be assumed that the reduction in total area of each jaw section results from a reduction in mandibular height. The compact and cancellous bone portions were equally affected by resorption. The assessment of bone quality showed that most mandibles displayed a thick cortical compartment, especially inferiorly and lingually, with variations in the amount of cancellous bone. There was a clear predominance of bone types 2 and 3.* ***Discussion and Conclusion:*** *The interforaminal region of the mandible appears to be the site of choice for implantation, since it can be expected that the bone structure is well suited to provide the necessary stability even in severely atrophic mandibles. As the degree of alveolar ridge resorption does not depend on the patient's age but on the time elapsing postextraction, implants should be placed as soon as possible after tooth loss in order to avoid excessive resorption.*
INT J ORAL MAXILLOFAC IMPLANTS 2007;22:609–615

Key words: *atrophy, bone density, cancellous bone, compact bone, interforaminal region, mandible, residual ridge resorption*

One of the most frequent problems for the surgeon planning the insertion of an endosseous implant is the reduced quantity of bone available as an implant bed. Alveolar ridge resorption may be influenced by a number of local and systemic factors: biomechanical factors, prosthetic factors, local inflammation, hormones, and systemic diseases.[1–5]

[1]Assistant Professor, Department of Periodontology, Dental School of the Bernhard Gottlieb University of Vienna, Austria.
[2]Associate Professor, Department of Prosthetics, Dental School of the University of Vienna, Austria.
[3]Professor, Department of Prosthetics, Dental School of the University of Vienna, Austria.
[4]Associate Professor, Department of Periodontology, Dental School of the Bernhard Gottlieb University of Vienna, Austria.

Correspondence to: Dr Rudolf Blahout, Department of Periodontology, Dental School of the Bernhard Gottlieb University of Vienna, Waehringerstrasse 25a, A-1090 Vienna, Austria. Fax: +43 1 4277 67 212. E-mail: blahout@aon.at or rudolf.blahout@meduniwien.ac.at

Knowledge of mandibular bone quantity and quality is of vital importance for planning implant placement. It also has an impact on the selection of the implant (eg, type, length) and on long-term survival of the implant. The width and the height of the bone must be considered, since it has been shown that placing longer implants improves the success rate.[6,7]

As has often been described in the literature, the body of the mandible may lose up to 50% of its volume after tooth loss[4,8–10] Atwood[1,11] and Tallgren[12] were the first to classify the various stages of alveolar ridge resorption by means of morphologic criteria. Based on studies by these authors, Cawood and Howell[9,13] later established their classification of the edentulous jaws, which is currently the most widely used classification.

However, height and width of the edentulous alveolar ridge are not the only factors crucial to the success of an implant. The ratio of compact to cancellous bone in the mandible may have an influence on mandibular bone density, which, in turn, is essential

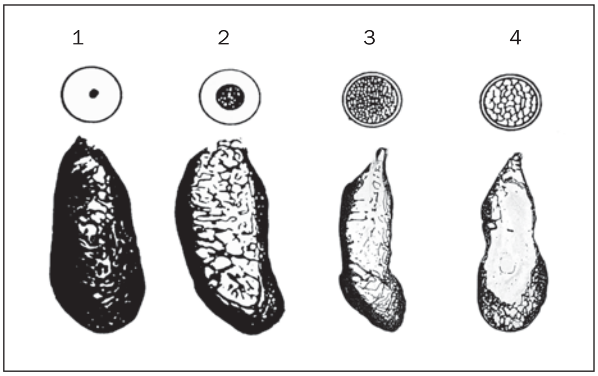


Fig 1 Bone morphology of Lekholm and Zarb. Types 1 through 4 are shown, with appropriate mandible sections below.

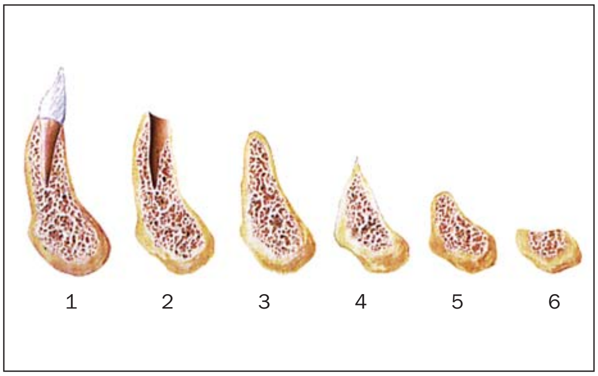


Fig 2 Classification of atrophic mandibles established by Cawood and Howell (residual ridge order, or RRO): 1 = pre-extraction; 2 = postextraction; 3 = high, well-rounded ridge; 4 = knife-edge ridge; 5 = low, well-rounded ridge; and 6 = depressed ridge.

to primary implant stability and thus to the success of endosseous implants.[14] Authors who have investigated the endosseous processes taking place simultaneously with the external visible atrophic changes have reported divergent results.[4,15–18] Apart from age-related osteoporotic symptoms, atrophy-related bone apposition and remodeling and resorptive processes affecting both compact and cancellous bone have been described. These appear to be related to biomechanical causes.

Lekholm and Zarb[19] distinguished the following 4 types of bone morphology in edentulous jaws, taking into account both cortical and cancellous bone: type 1, homogenous cortical bone, no cancellous bone; type 2, bone with a thick cortical compartment and a variably sized cancellous portion; type 3, bone with a thin cortical compartment and a dense cancellous portion; and type 4, bone with an extremely thin compact layer, consisting mainly of cancellous bone of reduced density. While types 1 and 2 are typical of the mandible, types 3 and 4 have been observed mainly in the maxillary alveolar process (Fig 1).

This anatomic study was undertaken to examine the effects of atrophy on bone quantity and quality in the mandibular interforaminal region, which is frequently used for the placement of endosseous implants.

MATERIALS AND METHODS

Forty-one edentulous, bony, left mandibular halves (26 female, 15 male) were taken from formalin/phenol-fixed corpses supplied by the Institute of Anatomy of the University of Vienna. The deceased had bequeathed their bodies to the institute for medical-scientific research and training purposes, and the institute agreed to the removal of the mandibles for use in the specified study protocol. The mean age of the specimens was 82.4 years (range, 61 to 93 years).

The mandibular specimens were grouped according to Cawood and Howell's classification[9,13] of residual ridge orders (Fig 2). Borderline cases were assigned to the residual ridge order (RRO) that predominated in the respective mandible. Ten mandibles were classified as RRO 3 (high, well-rounded ridge), 7 were classified as RRO 4 (knife-edge ridge), 11 were classified as RRO 5 (low, well-rounded ridge), and 13 were classified as RRO 6 (depressed ridge). RRO 1 (pre-extraction) and 2 (immediately postextraction) were not considered in this study, as they are not affected by atrophy-related resorptive processes and were not encountered in the anatomic specimens examined because of the age of the deceased.

The following 3 sections were carried out in the mandibular interforaminal region using a diamond-coated precision saw (Exact Apparatebau, Norderstedt, Germany):

S 1: Midsagittal section between the central incisors
S 2: Section between the lateral incisor and the canine
S 3: Section between the 2 premolars

The sectional planes formed a right angle with both the basal tangent and the horizontal axis of the jaw section, which ran parallel to the mandibular base (Fig 3). The most caudal and buccal points of each section were marked to register the spatial orientation of the sections. The 3 sections of each mandible were photographed together with a ruler, and the 41 highly enlarged photographs were scanned into a computer. The following data were stored for each section: the size of the section, the border between compact and cancellous bone, the aforementioned marked basal and buccal points, and the ruler. Any bony parts of the sections which did not belong to the compact portion of the bone and contained medullary and hollow spaces or cancellous trabeculae were classified as cancellous bone. This cancellous portion was distinguished from the compact external cortical layer. Since it proved difficult to assess the bone structure of some of the sections, undecalcified ground sections were produced and stained by means of von Kossa's staining to facilitate accurate classification.

The following components of each jaw section were measured by means of a morphometric software program (Artma-Biomed, Vienna, Austria; Fig 3):

- The maximum height of the jaw section between the most cranial and most caudal bony point (measured at right angles to the mandibular base, mm)
- The maximum width of the jaw section between the most buccal and most lingual bony point (measured at right angles to its height, parallel to the basal plane, mm)
- The total area of the jaw section (compact and cancellous bone, mm^2)
- The compact portion of the jaw sections (total area minus cancellous portion, mm^2)
- The cancellous portion of the jaw sections (total area minus compact portion, mm^2)

In addition to being assigned to RROs, the sections were also grouped according to their bone quality using the classification system of Lekholm and Zarb.[19]

Statistical Analysis

The mean values, standard deviations, and analysis of variances (ANOVA) of the data were determined using Statgraphics (Centurion 15, StatPoint, Herndon, VA). Comparisons of the RROs and osseous dimensions of each section were performed. Furthermore, Tukey's honestly significant difference (HSD) procedure was used to do a pairwise comparison of all pairs of means.[20] $P < .05$ was considered the threshold for statistical significance.

RESULTS

The results of this study are listed in Tables 1 to 5. The differences between the results for female and male corpses were not significant; for this reason, female and male data have been combined for each RRO.

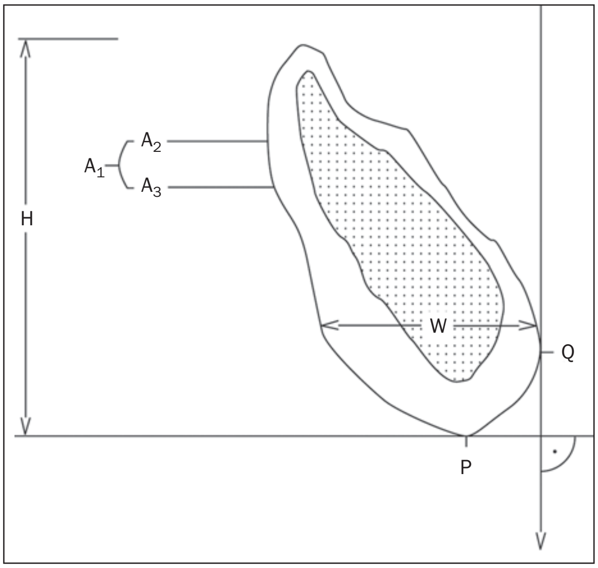


Fig 3 Measurements of the jaw sections. H = height of the jaw section; W = maximum width of the jaw section (parallel to the horizontal plane); A1 = total area of the jaw section; A2 = area of the compact portion of the jaw section; A3 = area of the cancellous portion of the jaw section; P = most caudal point of the jaw section; Q = most lateral/buccal point of the jaw section.

DISCUSSION

Bone Quantity

The most striking changes caused by atrophy were found in mandibular height (Table 1). The mandibles examined showed a highly significant height reduction (46% to 57%, more than 60% in extreme cases), with the greatest loss of vertical dimension occurring in the atrophic episode between RROs 3 and 4 (Figs 4 and 5). The data obtained in this cross-sectional study reveal that approximately one third of the original bone height is lost at a relatively early stage of the resorptive process. The mandible loses only one fifth of its original bone substance in all subsequent stages of resorption. The atrophic episode between RROs 3 and 4 takes place within 6 to 24 months after tooth loss.[1] No more than 2 years after tooth loss, the ratio of RRO 3 to RRO 4 is 1:14.[1] The degree of alveolar ridge resorption does not depend on the patient's age but on the amount of time elapsed postextraction.[21]

The maximum width of the anterior region of the mandible was minimally reduced during all remodeling and resorptive processes (Table 2). The statistical data analysis showed that there was only a 2-mm difference in width between the anterior region (S1) of mildly atrophic mandibles (RRO 3, Fig 6) and that of severely atrophic mandibles (RRO 6, Fig 7). However, the width of the alveolar ridge, which is affected by

Table 1 Vertical Height of the Jaw Section

	RRO 3		RRO 4		RRO 5		RRO 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S 1	27.4	4.0	21.8	4.3	18.8	4.1	14.9	4.2
S 2	27.7	4.3	20.3	3.2	18.9	3.3	13.7	3.7
S 3	28.5	2.9	20.8	6.0	19.1	3.9	12.2	2.9

Maximum height (mm) of the jaw section between the most cranial and the most caudal bony points, measured at a right angle to the mandibular base. RRO = residual ridge order; S = section.
HSDs (P = .01) were found between the mean values for RROs 3 and 5; RRO 3 and 6 also showed HSDs, as did RROs 4 and 6 and RROs 3 and 4. HSDs were also found between RROs 5 and 6 in sections 2 and 3.

Table 2 Width of the Jaw Section

	RRO 3		RRO 4		RRO 5		RRO 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S 1	14.3	1.1	12.5	1.2	13.3	1.7	12.0	1.6
S 2	11.7	0.8	10.1	0.8	11.5	2.0	10.9	1.6
S 3	10.5	1.3	9.7	1.1	11.4	1.5	10.6	1.5

Maximum width (mm) of the jaw section between the most buccal and the most lingual bony points (measured at right angles to mandibular height, parallel to the basal plane). Only 1 HSD (P = .01) was found between the mean values for RRO 3 and 6 in section 1.

Table 3 Total Area of the Jaw Section

	RRO 3		RRO 4		RRO 5		RRO 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S 1	261.3	32.7	190.2	36.0	187.9	44.6	140.7	27.7
S 2	252.2	42.3	169.4	47.1	172.7	41.5	117.5	28.5
S 3	231.4	43.8	155.9	52.4	172.0	46.1	97.2	28.4

Compact and cancellous bone in the bone section (mm^2). HSDs (P = .01) were found between the mean values for RROs 3 and 4 as well as between RROs 3 and 6 in all 3 sections, between RROs 3 and 5 in sections 1 and 2, and between RROs 5 and 6 in sections 2 and 3. Significant differences (P = .05) were found between the mean values of RROs 4 and 6 in all 3 sections, between RROs 5 and 6 in section 1, and between RROs 3 and 5 in section 3.

Table 4 Compact Portion of the Jaw Section

	RRO 3		RRO 4		RRO 5		RRO 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S 1	132.9	17.9	100.1	19.0	107.8	32.0	67.3	19.8
S 2	110.7	25.3	80.9	14.6	77.5	20.6	52.4	8.9
S 3	108.9	24.3	73.7	21.4	90.4	21.3	55.9	9.7

Total area of the bone section minus the cancellous portion (mm^2). HSDs (P = .01) were found between the mean values for RROs 3 and 6, between the means for RROs 5 and 6 in all 3 sections, between the means for RROs 3 and 4 in sections 2 and 3, between the means for RROs 4 and 6, and between the means for RROs 3 and 5 in section 2. A significant difference (P = .05) was found between RROs 3 and 6 in section 1.

Table 5 Cancellous Portion of the Jaw Section

	RRO 3		RRO 4		RRO 5		RRO 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
S 1	128.4	22.1	90.1	29.3	80.2	24.3	73.4	15.4
S 2	141.5	23.9	88.4	40.1	95.2	25.5	65.1	24.5
S 3	122.4	26.9	82.2	42.8	81.6	30.9	41.3	25.5

Total area minus the compact portion (mm^2). HSDs (P = .01) were found between the mean values of RRO 3 and 6 in all 3 sections and between RRO 3 and 4 as well as RRO 3 and 5 in sections 1 and 2. Significant differences (P = .05) were found between the mean values of RRO 5 and 6 in sections 2 and 3, and between RRO 4 and 6 in section 3.

intense remodeling and resorptive processes which sometimes result in complete loss of the ridge,[1] was not considered in these measurements.

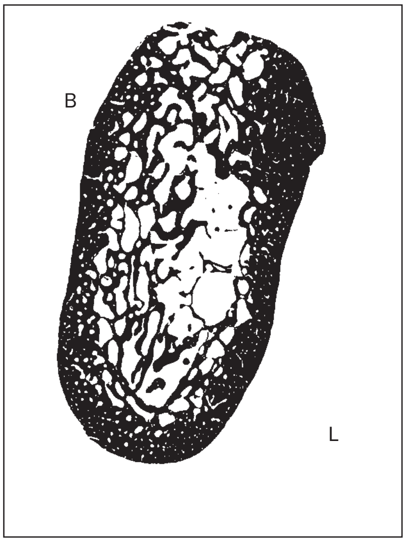
Since the maximum width remained relatively unchanged in all jaw sections, it may be assumed that the reduction in total area (Table 3) of each jaw section was due to a reduction in mandibular height. A comparison of the degree of height reduction with the total reduction of the jaw section showed that the values, expressed in percentages, corresponded very well. Height loss was 46% in section 1, 51% in section 2, and 57% in section 3; this loss corresponded to total reduction in area of 46% for section 1, 53% in section 2, and 58% in RRO 3 to 6.

It was not possible to obtain strictly matching values, since the material used in this study did not consist of geometric bodies. It may thus be stated that reduction in the body of the mandible as a result of atrophy was due to a loss of height only (Figs 6 and 7).

The reduction in the compact and cancellous portions of the bone (Table 4 and 5) mainly corresponded to the reduction in total area and height of the jaw section. Furthermore, the ratio of compact to cancellous bone was approximately 1:1 in all jaw sections. This value did not depend on the degree of atrophy. Deviations generally tended to favor the cancellous portion of the bone. Only in severely atrophic mandibles was a "reverse trend" observed in the premolar region, in which the compact bone portion was larger. This means that the remodeling and resorptive processes affecting the atrophic mandible did not influence the ratio of compact to cancellous bone; both bone substances were reduced to approximately the same extent.

Bone Density

Several authors have described distinct individual variations in mandibular trabecular bone.[2,16,18,22–25] For example, Ulm et al[25] found differences in trabecular bone volume of up to 65% in the premolar region of edentulous mandibles.



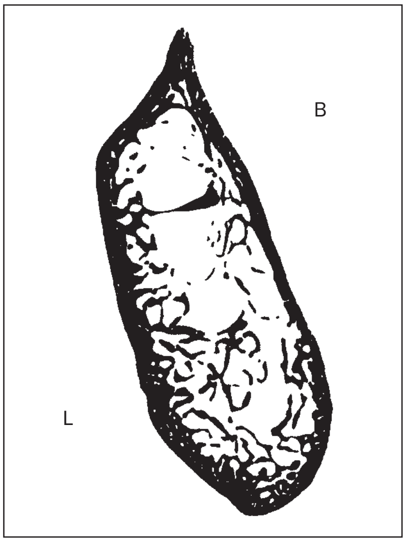
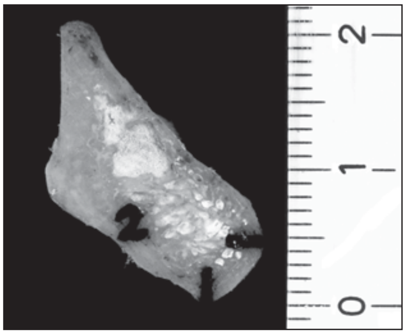


Fig 4 *(left)* Undecalcified ground section in the area between first and second premolar (high, well-rounded ridge = RRO 3). Cancellous bone appears dense and trabeculae show a high degree of connectivity. Cancellous bone is enclosed by a thick portion of cortical bone (type 2 bone; von Kossa's staining). B = buccal; L = lingual.

Fig 5 *(right)* Undecalcified ground sections in the area between the first and second premolar (knife-edge ridge; RRO 4). Cortical bone was not as thick as in the specimen in Fig 4. The density of the cancellous portion was relatively low and varied considerably within the section (type 3 bone; von Kossa's staining). B = buccal; L = lingual.



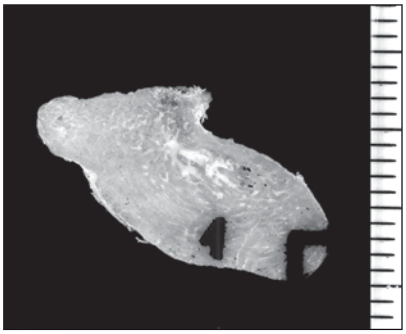


Fig 6 *(left)* Jaw section in the area between the mandibular lateral incisor and the canine (high, well-rounded ridge = RRO 3). The height is 21.5 mm. The cancellous portion consisted of a fine mesh structure and could be clearly distinguished from the cortical bone. The cortical bone was considerably thicker basally and lingually than buccally and crestally.

Fig 7 *(right)* Midsagittal section classified as RRO 6 (depressed ridge). The height was 12.5 mm. The alveolar process was completely resorbed, and the basal arch had undergone atrophy from the cranial side. The maximum diameter was not reduced, in spite of the extreme extent of vertical bone resorption.

A clear predominance of type 2 bone (Lekholm and Zarb[19]; Fig 4) as opposed to type 3 bone was observed in all sections. Type 1 was observed in some cases, especially in the anterior region (Fig 8). Type 4 was not encountered (Table 6). Another striking finding was the relatively inhomogeneous cancellous structure and the variable expansion of the compact bone. It was often difficult to assign the sections to a bone density class, as there was no clear-cut delineation (Fig 9). However, compact bone was markedly wider basally and lingually than buccally and crestally in all cases. In some cases the compact bone portion was lacking in some alveolar ridge regions, and cancellous bone thus formed part of the residual ridge.

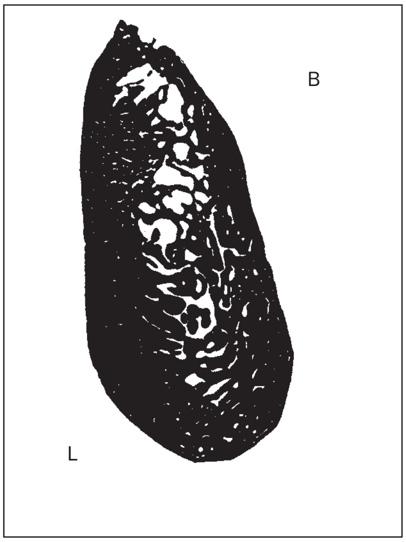
Table 6 Classification of Bone Density According to Lekholm and Zarb (n = 41)

	Type 1	Type 2	Type 3	Type 4
S 1	6	26	9	–
S 2	3	25	13	–
S 3	2	24	15	–

Type 1: homogeneous cortical bone, no cancellous bone
Type 2: thick cortical compartment, variably sized cancellous portion
Type 3: thin cortical compartment, dense cancellous portion
Type 4: extremely thin compact layer, cancellous bone of reduced density
S = jaw section.

Clinical Implications

As the degree of alveolar ridge resorption does not depend on the patient's age but on the amount of time elapsed postextraction,[21] implants should be placed as soon as possible after tooth loss to avoid excessive resorption. RRO 4 (a knife-edge alveolar ridge) presents a particular problem for implant stability. In such cases, additive surgical augmentation such as bone splitting, guided bone regeneration, distraction osteogenesis, or onlay grafts before



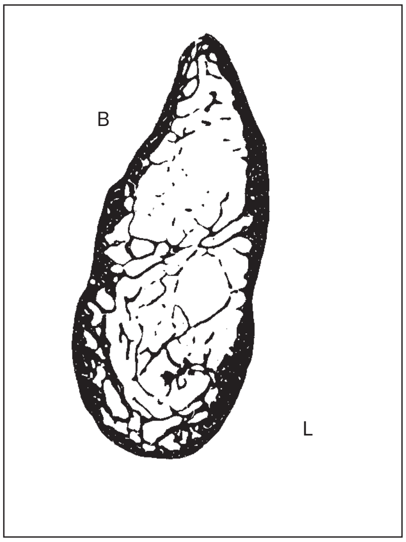


Fig 8 *(left)* Undecalcified ground sections from the incisal region. The ridge configuration was high and well-rounded (RRO 3). Cancellous bone showed an extremely dense, almost cortical structure and was enclosed by an unusually thick layer of cortical bone. (von Kossa's staining; type 1 bone). The height was 21 mm. B = buccal; L = lingual.

Fig 9 *(right)* Undecalcified ground sections from the canine region. The height was 26 mm. The ridge configuration of this specimen was high and well-rounded (RRO 3). The structure of the cancellous bone appeared very loose and wide-meshed, and trabecular connectivity was low. The cortical sheet was very thin (type 3 bone; von Kossa's staining). B = buccal; L = lingual.

implantation may be employed. The results suggest that implants may be indicated even with RRO 5 and RRO 6 since the remaining bone mass, particularly the compact basal bone, remains very strong.

Currently computerized tomography provides the most accurate presurgical diagnostic evaluation of both the available bone quantity and, to a more limited degree, bone density. This method allows 3-dimensional assessment of all bone structures and an evaluation of the trabecular bone density and extension.[2,6,7,15,25–28]

Because of the great local variations in bone within the mandible, the use of bone biopsies to determine the bone density seems inappropriate as a method of preimplantation evaluation. This method does not allow any conclusions to be drawn about the bone density in neighboring regions. Moreover, it results in deterioration of the local bone condition at the donor site. Overall, a significantly higher implant failure rate can generally be expected when implants are placed in alveolar bone with reduced density and stability.[14]

Based on the results obtained, the interforaminal region of the mandible appears to be the site of choice for implantation, since it can be expected that the bone structure is well suited to provide the necessary stability. However, it should be noted that, throughout the interforaminal region, particularly midsagitally, the cortical sheath is thickest lingually and caudally. This can result in cooling problems during drilling. Furthermore, results confirm the authors' clinical findings that, on account of its extension and bone quality, the mental protuberance is an ideal donor site for autologous bone.

ACKNOWLEDGMENT

The authors wish to acknowledge Prof Dr H. Gruber (Institute of Anatomy of the University of Vienna) for his kind contributions to this article.

REFERENCES

1. Atwood DA, Coy WA. Clinical, cephalometric, and densitometric study of reduction of residual ridges. J Prosthet Dent 1971; 26:280–286.
2. Choel L, Duboeuf F, Bourgeois D, Briguet A, Lissac M. Trabecular alveolar bone in the human mandible: A dual- energy x-ray absorptiometry study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;95:364–370.
3. Devlin H, Ferguson MW. Alveolar ridge resorption and mandibular atrophy. A review of the role of local and systemic factors. Brit Dent J 1991;170:101–104.
4. Gruber H, Solar P, Ulm C. Maxillomandibular anatomy and patterns of resorption during atrophy. In: Watzek G (eds). Endosseous Implants: Scientific and Clinical Aspects. Chicago: Quintessence, 1996;29–62.
5. Klemetti E. A review of residual ridge resorption and bone density. J Prosthet Dent 1996;75:512–514.
6. Chuang SK, Wei LJ, Douglas CW, Dodson TB. Risk factors for dental implant failure: A strategy for the analysis of clustered failure-time observations. J Dent Res 2002;81:572–577.
7. Hermann I, Lekholm U, Holm S, Kultje C. Evaluation of patient and implant characteristics as potential prognostic factors for oral implant failures. Int J Oral Maxillofac Implants 2005;20: 220–230.
8. Mercier P. Ridge form in preprosthetic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1985;60:235–243.
9. Cawood JI, Howell RA. A classification of the edentulous jaws. Int J Oral Maxillofac Surg 1988;17:232–236.
10. Ulm C, Solar P, Blahout RM, Matejka M, Gruber H. Reduction of the compact and cancellous bone substances of the edentulous mandible caused by resorption. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1992;74:131–136.

11. Atwood DA. Postextraction changes in the adult mandible as illustrated by microradiography of midsagittal sections and serial cephalometric roentgenograms. J Prosthet Dent 1963; 13:810–824.
12. 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;27:120–128.
13. Cawood JI, Howell RA. Reconstructive preprosthetic surgery. 1. Anatomical considerations. Int J Oral Maxillofac Surg 1991;20: 75–79.
14. Jaffin RA, Berman CL. The excessive loss of Brånemark fixtures in type 4 bone: A 5-year analysis. J Periodontol 1991;62:2–4.
15. Neufeld JO. Changes in the trabecular pattern of the mandible following the loss of teeth. J Prosthet Dent 1958;8:685–697.
16. Von Wowern N, Stoltze K. Sex and age differences in bone morphology of mandibles. Scan J Dent Res 1978;86:478–485.
17. Tillmann B, Härle F, Schleicher A. Biomechanics of the mandible [in German]. Dtsch Z Zeitschrift 1983;38:285–293.
18. Klemetti E, Vainio P, Lassila V, Alhava E. Trabecular bone mineral density and alveolar height in postmenopausal women. Scand J Dent Res 1993;101:166–170.
19. Lekholm U, Zarb GA. Patient selection. In: Brånemark PI, Zarb GA, Albrektsson T (eds). Tissue-integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985: 199–209.
20. Saunders BD, Trapp RG. Basic & Clinical Biostatistics, ed 2. Norwalk, CT: Appleton & Lange, 2002.
21. Atwood DA. Bone loss of edentulous alveolar ridges. J Periodontol 1979;50:11–21.
22. Atkinson PJ, Woodhead, C. Changes in human mandibular structure with age. Arch Oral Biol 1968;13:1453–1463.
23. Solar P, Ulm C, Thornton B, Matejka M. Sex-related differences in the bone mineral density of atrophic mandibles. J Prosthet Dent 1994;71:345–349.
24. Soikkonen K, Ainamo A, Xie Q. Height of the residual ridge and radiographic appearance of bony structure in the jaws of clinically edentulous elderly people. J Oral Rehab 1996;23: 470–475.
25. Ulm C, Kneissel M, Hahn M, Solar P, Matejka M, Donath K. Characteristics of the cancellous bone of edentulous mandibles. Clin Oral Implants Res 1997;8:125–130.
26. Quirynen M, Lamoral Y, Dekeyser C. The CT scan standard reconstruction technique for reliable jaw bone volume determination. Int J Oral Maxillofac Implants 1990;5:384–389.
27. Quirynen M, Mraiwa N, van Steenberghe D, Jacobs R. Morphology and dimensions of the mandibular jaw bone in the interforaminal region in patients requiring implants in the distal areas. Clin Oral Implants Res 2003;14:280–285.
28. Rothman SL. Dental applications of computerized tomography. Chicago: Quintessence, 1998:39–64.