Bone Structure Changes in Iliac Crest Grafts Combined with Implants

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ABSTRACT

Background: Remodeling of onlay grafts combined with implants to the mandible results in predictable changes in the graft's radiographic density. We studied the relationship between changes in radiographic density and trabecular structure during the first year after onlay grafting with simultaneous implant placement to the mandible.

Purpose: The aim of this study was to evaluate changes in bone structure after onlay grafting.

Materials and Methods: Standardized extraoral radiographs were taken regularly of 16 mandibular sides. Bone structure was measured using the Carl Zeiss Vision KS 400 3.0 imaging system. The parameters studied were trabecular area and perimeter, cavity area and perimeter, end points, branching points, skeleton length, branch angle and direction, and texture.

Results: No differences were found between measurements ventrally versus dorsally of the implant, nor close to versus away from the implant. Early cortical changes suggest partial resorption and formation of a more complex structure. In the fourth quarter after surgery, progressive resorption is seen in the graft's upper cortex. In the graft's upper spongiosa, most parameters indicate bone formation during the first postoperative year. Loading-induced structure changes could not yet be found.

Conclusion: The technique can be used to study changes in the architecture of bone grafts. Changes found in the graft's architecture are in accordance with changes in bone density.

KEY WORDS: bone graft, bone structure, implant, mandible, radiology

One of the treatment modalities in extreme mandibular atrophy is the placement of implants combined with onlay or interpositional bone grafting of the anterior mandible.[1–10] Various techniques have been described, and the results with respect to morbidity and resorption of the graft vary considerably, depending on the author and the method of treatment.

Remodeling of the graft follows a predictable pattern. The first half year is dominated by bone resorption, mainly confined to the graft's cortex, whereas the second half year is characterized by an increase in bone density in the cortex, as well as the lower spongiosa of the graft.[11] The observed changes in radiographic density of the graft can result from changes in the trabecular structure of the bone, which can be in direction, number, thickness, length, and branching of bone trabecles.

Functional loading is an important factor in the maintenance of bone.[12,13] There is also an intimate relationship between forces acting on bone and its

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structure.[14] Depending on the dominating loading pattern, trabecular bone lamellae are aligned along principal stress trajectories. According to Wolff's law,[15] a changed loading pattern, for instance through implants, should result in restructuring of bone and grafts. Most bones of the body are composed of cortical and spongeous bone, but the anterior part of an atrophic mandible consists almost completely of cortical bone. The two principal stress trajectories run from the mandibular body and mandibular angle to the condylar head.[16] However, in case of augmentation with a graft, the aforementioned principles are no longer necessarily valid, because iliac crest grafts consist of a relatively thin layer of cortical bone and a wider layer of spongeous bone with a more or less random orientation of the trabecular architecture. One could expect a change in the graft's architecture upon loading.

We studied the radiographic change in bone architecture of an iliac crest bone graft and the original mandible after onlay augmentation combined with implant placement in the edentulous anterior mandible, during the first postoperative year.

MATERIALS AND METHODS

Patients and Method of Treatment

A total of eight right and six left mandibular sides from eight patients with severe mandibular atrophy and complete radiographic records were studied. All patients were edentulous in both jaws and lacked adequate retention of their lower denture. The group consisted of one male and seven female patients, with a mean age of 59.1 years (SD = 9.3; range: 50–78). A corticocancellous iliac crest graft was placed on top of the anterior mandible, using an intraoral approach. Two titanium implants fixed the graft to the mandible. After 45 months, second-stage surgery was performed and healing abutments were placed. Loading of the 16 implants and bone by means of a bar-retained overdenture commenced 293 days after implant surgery (SD = 87; range: 185–484).[11,17]

Radiographic Technique

Standardized extraoral oblique lateral cephalometric radiographs were taken at regular intervals after augmentation and loading of the superstructure. This technique has been extensively described.[8,18,19] Usually, 5 to 12 weeks (= quarter 0) postoperative the first (= baseline reference) radiographs were obtained.

Image Correction and Analysis

For image analysis, all radiographs were positioned on a homogeneous light source. Images were recorded with a Panasonic B/W CCD camera (type WC-CD50; Panasonic The Netherlands, Haagtechno, Den Bosch, The Netherlands) and digitized (frame size 640 × 512 pixels and 256 gray levels, which is sufficient for the required resolution in the studied parameters). An image of the light source without radiograph was used for shading correction. Image processing and bone structure measurements were performed with a customized application written for the Carl Zeiss Vision KS 400 3.0 image analysis system (Carl Zeiss, Munich, Germany).

Bone Structure Measurements

For the bone structure measurements, a series of 48 measurement fields was defined, three columns of six fields ventrally and five columns of six fields dorsally of and parallel to the imaged implant (Figure 1).

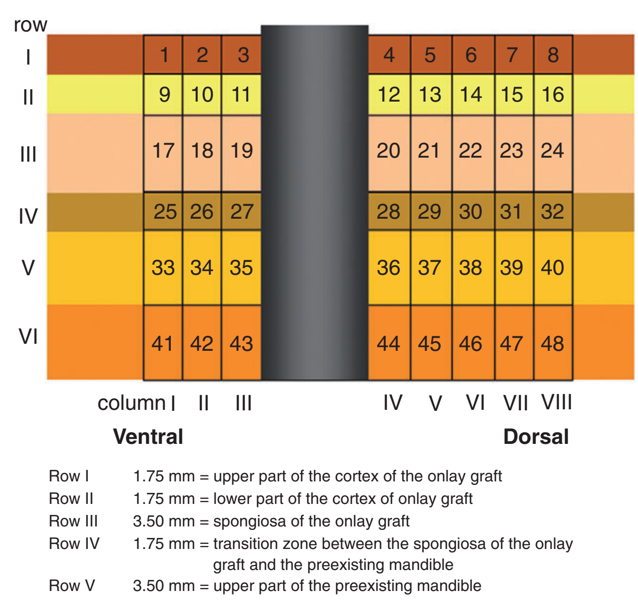

Figure 1 Schematic drawing of oblique lateral cephalometric radiograph with implant and 48 measurement fields used for analysis of bone structure. Columns I–III are located ventrally of the implant; columns IV–VIII are located dorsally of the implant. Row I = cortex of the onlay graft; row II = upper spongiosa of the onlay graft; row III = lower spongiosa of the onlay graft; row IV = transition zone between the spongiosa of the onlay graft and the original mandible; row V = upper part of the original mandible, and row VI = lower part of the original mandible.

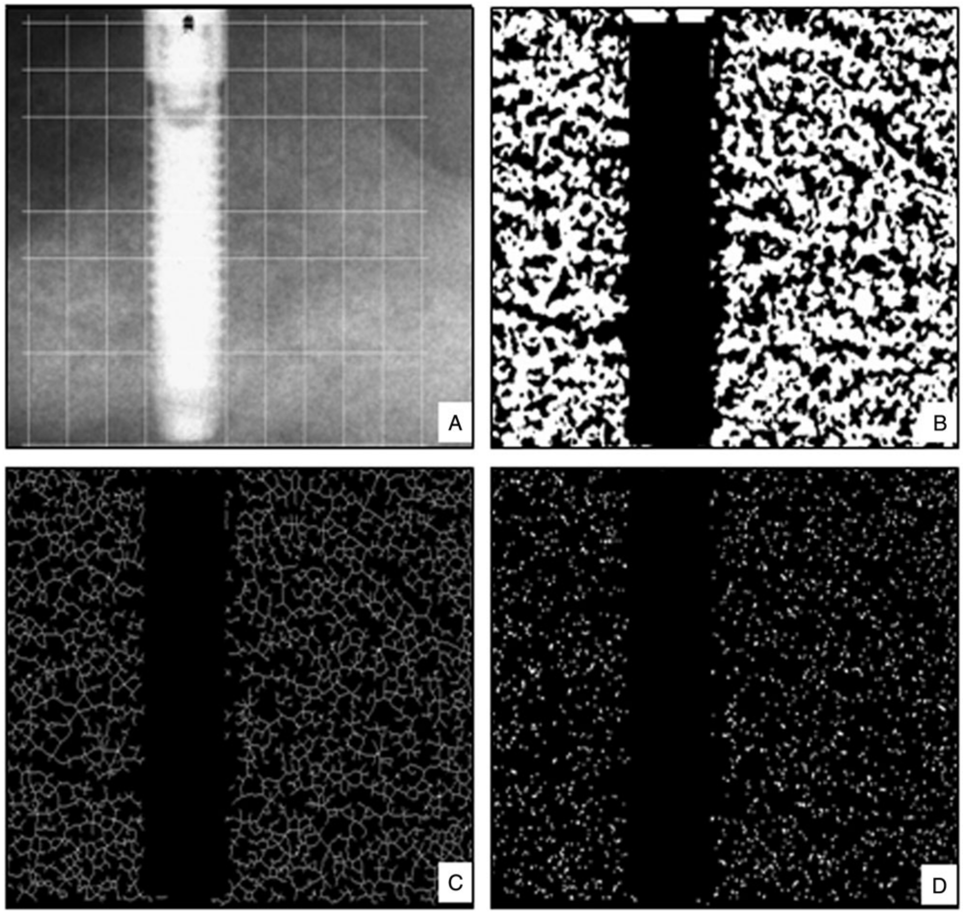

Figure 2 (A) Oblique lateral cephalometric radiograph (OLCR) with implant and fields of measurement. (B) Digitized OLCR with implant (black column), trabecular (white), and cavity area (black). (C) Digitized OLCR of implant and skeletonized trabecles. (D) Digitized OLCR with implant and (dilated) branching points in trabecular area.

Measurement fields in the transitional zone (area between graft and preexisting mandible; row IV) and in the lower part of the original mandible (row VI) were excluded from analysis. Because several of the latter measurement fields were partially located below the inferior border of the mandible, their inclusion would lead to unreliable measurements.

For analysis, we used an approach derived from the custom trabecular bone morphology measurement method developed by White and Rudolph,[20] which they used for bone structure analysis of osteoporotic jaws. The following bone structure parameters were measured for all measurement fields:

- Trabecular area: total area of all bone trabecles in the radiograph; for each radiograph, two observers visually determined the gray level value to be used to distinguish between bone trabecles and cavities (= bone marrow) (Figure 2);
- Trabecular perimeter: total perimeter of trabecular area;
- Cavity area: total area of all cavities (= bone marrow);
- Cavity perimeter: total perimeter of cavity area;
- Skeleton length: total length of skeletonized trabecles (see Figure 2);
- End points: number of end points of trabecular network after skeletonization;
- Branching points: number of branching points in trabecular network (see Figure 2);
- Mean branch length: length of trabecular branches;
- Distribution of branches by length;
- Mean branch angle: 0 degrees = horizontal branches in a dorsal direction perpendicularly to length axis of implant; 90 degrees = branches upward and parallel to the length axis of implant; 180 degrees = horizontal branches in a ventral direction perpendicularly to length axis of implant;

- Distribution of branch angles;
- Mean branch direction: calculated from branch angle measurements: 0 degrees = horizontal branches toward length axis of implant; 90 degrees = branches upward and parallel to length axis of implant; 180 degrees = horizontal branches pointing away from length axis of implant;
- Distribution of branch directions; and
- Texture: we used the Haralick parameter 1.[21,22] A texture parameter value of 0 is indicative for bone with few structural elements, and a value of 1 is indicative for bone with many structural elements.

Removal of Between-Patient Variation and Normalization

Quarterly periods were calculated dividing the number of days after operation by 91: quarter 0, wherein the first postoperative radiographs were obtained, being the first 3 months after surgery. Inter-patient variation in each of the parameters was removed by calculating a correction factor for each patient, based on all patients and all observations, grouped per quarter. In short, this correction procedure calculates a correction factor from a matrix of between-patient ratios, based on the assumption that the variation between patients is the result of a multiplicative variation between patients.[23] Only this systematic bias between patients is thus removed from the data set, the intra-patient changes in time, and the statistical error in the measurements is not affected. For easy comparison between quarters, after the removal of the between-patient variation, all parameters were standardized by setting the mean value of quarter 0 to 100, and all measurements were adjusted accordingly. The difference in size of the measurement fields was accounted for in all calculations.

Statistical Analysis

A first comparison was made between the measurement fields ventrally and dorsally of the implant (columns I–III and columns IV–VIII, respectively). Subsequently, a comparison was made between the measurement fields close to and away from the implant (columns III, IV, and all other columns, respectively). Both tests were performed as three-way analysis of variance (ANOVA) with location of the measurement fields, rows, and position of columns, and quarter as factors. Neither test showed a significant effect of column location, but row and quarter had significant and interacting effects on the observed values. Therefore, in the final analysis, for each parameter a one-way ANOVA was performed in which the measurement fields per row were pooled per patient and compared between quarters. The Student-Newman-Keuls test was used to determine differences between quarters. Data are presented as mean (± SEM) per quarter, with the mean of quarter 0 set to 100.

RESULTS

No statistically significant differences in any of the parameters were found between observations ventrally compared to those dorsally of the implant, nor for observations close to and away from the implant. This allowed the pooling of the data of all eight fields in each row for further analysis between quarters.

The statistical analysis demonstrated that changes in architecture are predominantly seen in the cortex and upper spongiosa of the graft (rows I and II, respectively). Detailed results for the parameters with statistically significant changes between quarters in these areas are displayed in Figure 3. These results will be discussed in detail. A general interpretation of the structural changes is given in Table 1. Apart from the decrease in texture in row III, the bone structure of the lower spongiosa of the graft (row III) and of the original mandible (row V) showed no statistical differences between quarters for any of the parameters, and can thus be concluded to remain mostly stable in time.

DISCUSSION

The change in bone architecture after augmentation of the mandible and subsequent loading by implants is the result of bone healing and adaptation of bone to loading. The current data set presents a unique opportunity to study such adaptations. This process is characterized by bone resorption, bone formation, and remodeling, and results in changes in parameters describing bone architecture. The measurement technique presented here can be used for the study of changes in the architecture of bone grafts.

The results show an initial increase in cavity parameters which indicates that cavities are formed in the amorphous regions of the graft cortex. This is probably the result of partial resorption of the amorphous cortical bone mass. The concomittant increase in the number of end points, branching points, skeleton length, and trabecular perimeter shows that the bone structure

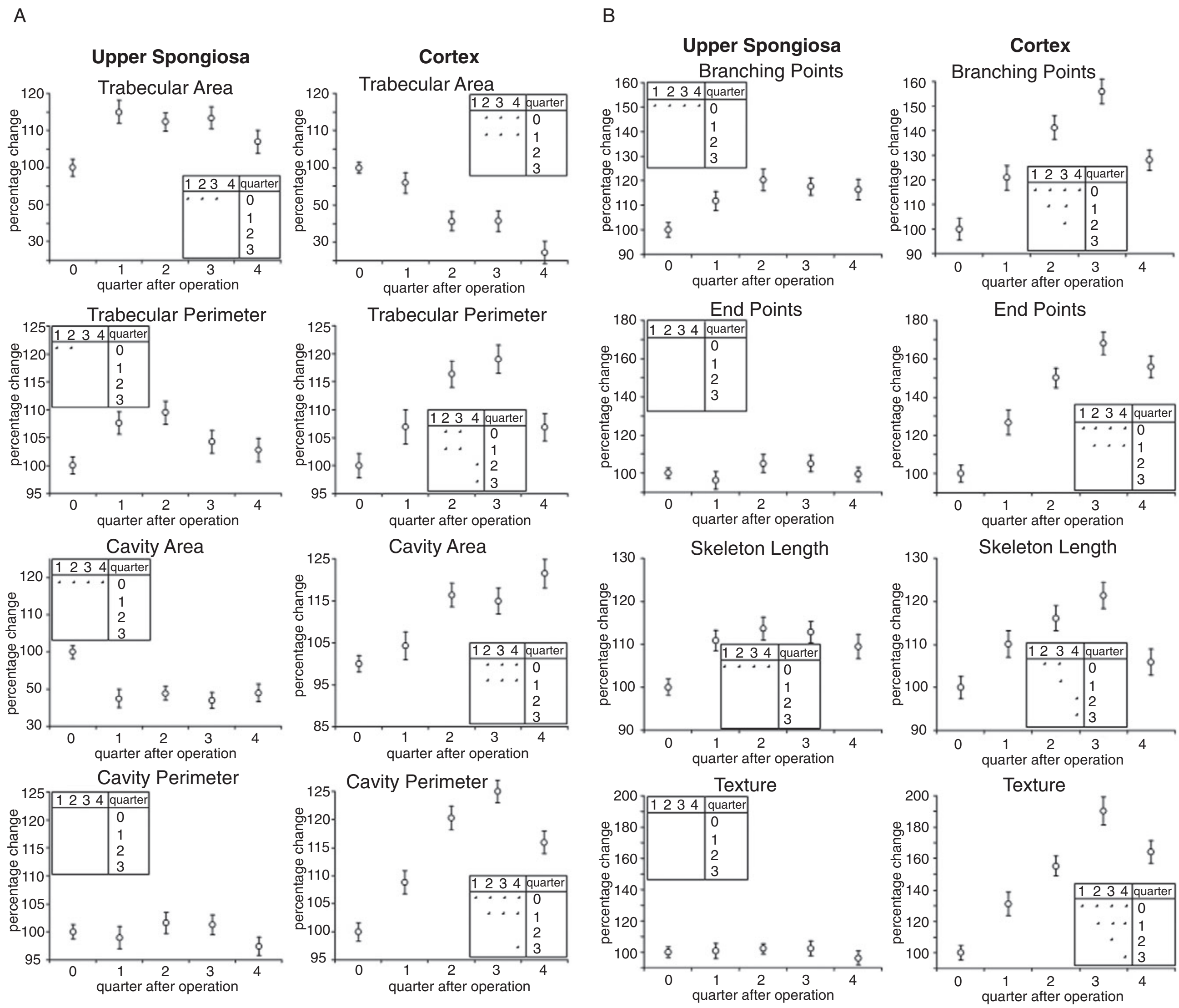

Figure 3 (A) Error bar plots of the measured parameters: trabecular area and perimeter, and cavity area and perimeter (mean SEM per quarter after operation) with the mean of quarter 0 set to 100, for upper spongiosa and cortex of the onlay graft. The inset in each graph gives the result of the Student-Newman-Keuls multiple comparison of groups; the asterisks indicate which quarters differ significantly ($p < .05$) from each other. For each parameter, the scaling of the y-axis was set to allow the observations in both the cortical and the upper spongiosa layer to be plotted on the same axis. (B) Error bar plots of the parameters: number of branching and end points, skeleton length and texture.

becomes more complex. This overall picture of resorption corresponds to the results of our previous study on bone density changes in the same population.[11] In the fourth quarter after surgery, however, texture, number of branching points, skeleton length, and trabecular perimeter decrease, which is suggestive for progressive resorption of the cortex.

In the graft's upper spongiosa, most parameters indicate bone formation in quarters 1–4. The number of branching points, skeleton length, trabecular area, and perimeter increase and inversely, cavity area and perimeter decrease. In our earlier densitometric study, we found no significant changes in the radiographic density of this bone. It is not always clear which bony structures give rise to the trabecular pattern seen on the radiographs of the jaws.[20] As a consequence, a strict correlation between an increase in structural complexity and density need not be present.

The structure parameters for the graft's lower spongiosa and for the original mandible were observed to be mostly stable in time (see Table 1). Only the texture parameter in the graft's lower spongiosa decreases statistically significant. Changes in the dense structure of the original mandible after augmentation were not to be

TABLE 1 Changes in Studied Parameters (See Left-Hand Column) for Different Parts of Graft and Original Mandible (See Top Row) During the First Postoperative Year

	Graft: Cortex (Row I)	Graft: Upper Spongiosa (Row II)	Graft: Lower Spongiosa (Row III)	Original Mandible (Row V)	From Osteoporosis Literature (White and Rudolph)[20]
Trabecular area	↓	↑	–	–	↓
Trabecular perimeter	↑;↓	↑	–	–	↓
Cavity area	↑	↓	–	–	↑
Cavity perimeter	↑;↓	–	–	–	↑
End points	↑	–	–	–	↓ (= fine structure)
Branching points	↑;↓	↑	–	–	– (= core trabecular structure)
Skeleton length	↑;↓	↑	–	–	– (= core trabecular structure)
Mean branch length	↓	–	–	–	
Distribution of branch lengths	–	–	–	–	
Mean branch direction	–	–	–	–	
Mean branch angle	–	–	–	–	
Distribution of branch angles	–	–	–	–	
Texture	↑;↓	–	↓–	–	↓

– = no statistically significant change; ↑ = statistically significant increase; ↓ = statistically significant decrease.

expected. We found no statistically significant changes in angle or direction of the trabecles. This may be the consequence of the relatively short period of loading. The loading by the bar-retained overdenture commenced on average at 293 days after surgery. Changes in the bone structure can therefore not yet be expected in quarter 4. It will be interesting to see if loading the bone by means of the implants will have a more profound effect on bone structure in the long run. The latter is subject of a future study.

All patients were treated with simultaneous placement of implants and graft. The possibility of considerable graft resorption was described, and the procedure is recommended only on stringent indications.[7,8] The presented measurement technique can be used for all standardized radiographs – including intraoral radiographs and computed tomography (CT) scans – of both jaws. The applied image processing algorithms can easily be implemented in other image analysis systems. The results of this study are important for a better understanding of changes occurring in grafts used in combination with implants.

A clear distinction must be made between the trabecular pattern on a radiograph and the histologic appearance of bone.[13,24] The usual two-dimensional radiography does not record the exact architecture of bone, but rather the overlapping X-ray shadows produced by calcified tissues at different distances to the X-ray source. CT scans, cone beam CT scans, and MRI scans give a three-dimensional image of the internal structure of bone in vivo.[25,26] It is expected that they will replace the inexpensive, widely available plain radiograph technique for obtaining information about bone structure in vivo in the (near) future. However, studies to compare the reliability and usefulness of the different radiographic techniques need to be performed.

Other methods using radiographs for bone structure analysis are described in the literature. Fractal analysis was used studying mandibular bone with implants.[27] This technique describes complex shapes and structural patterns, and is relatively insensitive to variations in film exposure or alignment.[28] Radiographic changes in the mandibular bone structure could be diagnosed in vitro by fractal analysis or, as in the present study, by counting trabecular parameters (number of segments, terminal and branching points).[29]

CONCLUSIONS

Early changes in the cortical region are suggestive for partial resorption and the formation of a more complex structure. This observation is in accordance with those from an earlier study on bone density in the same population.[11] In the fourth quarter after surgery, indications for progressive resorption are seen in the upper cortex of the graft. In the graft's upper spongiosa area, most parameters indicate bone formation during the whole first postoperative year. Loading-induced bone structure changes could not yet be found, possibly because of the short post-loading observation period.

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