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Volume changes of autogenous bone grafts after alveolar ridge augmentation of atrophic maxillae and mandibles

L. Sbordone[1], P. Toti[1], G. B. Menchini-Fabris[1], C. Sbordone[2], P. Piombino[2], F. Guidetti[3]

[1]Department of Surgery, University of Pisa, Italy. Advanced Implantology, Azienda Ospedaliero-Universitaria Pisana (A.O.U.P.), Via Roma 67, 56126 Pisa, Italy; [2]Department of Maxillo-Facial Surgery, School of Medicine, University of Naples "Federico II", Via S. Pansini 5, 80100 Napoli, Italy; [3]Azienda Ospedaliero-Universitaria Pisana (A.O.U.P.), Maxillo-Facial Surgery, Complex Operating Unit (U.O.C.), Via Paradisa 2, 56100 Pisa, Italy

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Abstract. The aim of the present retrospective chart review was to determine the relationship between nonvascularized osseous graft remodeling and the three-dimensional (3D) features of grafts and recipient sites, the anatomical recipient regions and different graft sources. 32 iliac crest or chin grafts were onlay-positioned in the mandible or maxilla of 14 patients. CT scans, taken before implant positioning and after 1 year, revealed a mean volume resorption of 35–51%. For iliac crest grafts, the average resorption was 42% when the onlay was positioned in the anterior maxilla and 59% when it was positioned in the posterior mandible. Spearman correlation and 3D interpolation analysis revealed, for both iliac crest groups, a moderate or advanced remodeling pattern depending on 3D features, namely graft thickness and shape, basal bone volume of recipient site, and the basal bone/graft volume ratio of the recipient site. No statistically significant differences were found between the recipient and donor site groups. Retrospective analysis of the data indicates that iliac crest grafts, onlay-positioned on adequate basal bone volume, may register a reduced volume remodeling when shaped thick in the anterior maxilla or rounded and convex, on the external surface, in the posterior mandible.

Keywords: bone graft; bone resorption; interpolation analysis; iliac crest graft; chin graft.

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Functional implant-supported oral rehabilitation is increasingly being used as a restoration strategy for fully and partially edentulous patients, whenever sufficient bone volume is available. Implant-supported restoration is possible even in severely resorbed jaws using a reconstruction technique with bone augmentation that includes vascularized[14] or nonvascularized bone grafting[14] and tissue regeneration techniques[14].

Standard donor sites for free autogenous bone-graft techniques are: the chin or ramus mandible[2,15], the iliac crest[7], the tibia and the calvaria[21]. Advantages of intraoral mandibular sources include easy access, low morbidity, short healing periods, minimal graft resorption, and maintenance of high bone density; side effects include possible postoperative sensory disturbances and discomfort[15]. Calvaria and iliac crest donor areas are most commonly used in cases of extensive alveolar ridge augmentation[3,9]. The iliac crest generally supplies large quantities of corticocancellous bone. Complications that have been reported following the harvesting procedure include arterial injury, ureteral injury, herniation, chronic pain, nerve injury, infection, fracture, pelvic instability, cosmetic defects and hematoma[18]. Calvaria graft harvesting requires properly trained surgeons, but the procedure is associated with an extremely low incidence of serious complications[12].

Variable and unpredictable osseous graft remodeling after nonvascularized procedures may result in insufficient bone quality and quantity for dental implant positioning. Two-dimensional radiographic studies have shown bone resorption of approximately 25% of the height of the graft[24]. Further studies measured the volume of bone graft remodeling on CT scans, showing different percentages of resorption, depending on the different graft sources[9,21]. Remodeling of iliac crest grafts seems to be greater than that of calvaria grafts[9,21].

The difference in the behavior of grafts harvested from different sources has been ascribed either to embryologic origin (endochondral or intramembranous) or to micro-architecture (cortical or cancellous). Intramembranous bone grafts are reported to retain volume better than endochondral grafts[17]; several authors consider the micro-architecture is the key factor in remodeling.

Hardesty and Marsh[8] hypothesize that the volume-retaining differences between a densely cortical calvarial graft and an endochondral graft with a thinner cortex may be related to the three-dimensional (3D) osseous architecture rather than to the embryologic origin. Other authors showed that onlay bone graft survival is determined primarily by its relative cortical and cancellous composition rather than by its embryologic origin, and that the micro-architecture of a graft is the basis for volume maintenance[4]. There is a lack of data correlating volume graft remodeling with its spatial rearrangement and the volume of the recipient site.

The purpose of this retrospective chart review was to determine changes in the volume of bone grafts that were onlay-positioned in severely atrophic jaws for implant-supported restoration, and to identify factors associated with remodeling of the bone grafts.

The hypothesis is that, in addition to embryologic origin and micro-architecture composition[4,8], bone graft remodeling depends, in ways that are different in the maxilla and in the mandible, on some of the 3D features of the bone graft (thickness, external surface, shape) and the recipient site (volume), and on the relationship between the two (a contact surface and a volume ratio). Bone remodeling probably depends on the anatomical region of the recipient site and on the graft sources.

The primary aim was to find possible correlations between bone remodeling and the 3D features of the grafted bone and the recipient site. A secondary aim was to test the relationship between bone resorption and the anatomical region of the recipient site and the different graft sources. A third aim was to analyze the survival of restored implants positioned in reconstructed bone.

Materials and methods

A retrospective chart review was conducted on patients subjected to onlay graft procedures for implant positioning from January 2000 to December 2002. Consecutive patients affected by severe jaw atrophy and requesting fixed prosthesis rehabilitation by means of implants were considered. Patients with a complete set of CT scan data (before bone grafting, just before implant insertion and 12 months after implant insertion) were included in the study. Written informed consent was obtained from all subjects included, and approval for this study was obtained from the Ethical Committee of the University of Pisa, Pisa, Italy.

Variables

The bone graft volume and area were measured for each patient just before implant insertion and 12 months after implant insertion. To analyze the correlation between bone remodeling and the 3D features of the grafted bone and the recipient site, six variables were introduced.

Graft variables

The first graft variable is external surface of the graft at time T_1 (ES_{T_1}, surface with no direct contact with the recipient site). The second is height index ($indexH_{T_1}$ Eq. (1)): the ratio between the volume of the grafted bone at T_1 (V_{T_1}) and the contact surface area between the graft and the recipient site at T_1 (CS_{T_1}), this index indicates the thickness of the graft:

$$indexH_{T_1} = \frac{V_{T_1}}{CS_{T_1}} \tag{1}$$

To analyze the correlation between bone remodeling and the shape of the graft, a second index was devised, shape index ($indexS_{T_1}$ Eq. (2)) is the ratio between the volume of the graft at T_1 (V_{T_1}) and the external surface of the graft (ES_{T_1}).

$$indexS_{T_1} = \frac{V_{T_1}}{ES_{T_1}} \tag{2}$$

Recipient site variables

The recipient site variable is the volume of the recipient site below the graft or basal bone at time T_1 (BB_{T_1}).

Variables in relationship between the graft and the recipient site

The first of these variables is contact surface area at time T_1 (CS_{T_1}, boundary surface between bone graft and the recipient site). A correlation was sought between bone remodeling and the volume of the graft and the bone supporting the graft by using a volume index ($indexV_{T_1}$ Eq. (3)): the ratio between the volume of the recipient site (basal bone BB_{T_1}) and the volume of the graft at T_1 (V_{T_1}):

$$indexV_{T_1} = \frac{BB_{T_1}}{V_{T_1}} \tag{3}$$

The change in graft volume was expressed as the percentage of residual bone graft (R%), obtained as the ratio between the volume at time T_2 (V_{T_2}) and the volume at time T_1 (V_{T_1}).

All variables were grouped, according to different donor sites (iliac crest or chin) and maxillary and mandibular recipient sites (anterior or posterior). Implant survival was recorded 1 year after implant placement.

Data collection methods and summary of operative methods

As part of the standard treatment protocol, all patients had CT scans (High Speed double detector CT scanner, General Electric Medical System, Milwaukee, WI, USA) taken immediately before bone grafting (T_0), 3–5 months after the graft[19], just before implant insertion (T_1), and 12 months after implant insertion (T_2). Measurements were taken in axial CT slices with a thickness of 1 mm.

The area and volume of the bone grafts were measured with SimPlant Pro 11.04, (Materialise Dental Italia. Via L. Fincati 13/f, 00154 Roma, Italy), according to Smolka et al.[21], by two of the authors, and a consensus was reached.

All patients were examined clinically in the postoperative maintenance program, 1 year after implant positioning, and the dental implants checked individually. A surviving implant was defined as being non-mobile, free from peri-implant radiolucency, infection or neurological disorder[1], and without associated pain, either spontaneous or on application of a torque of 10–20 Ncm[20]. The implant also had to allow for placement of a functional fixed prosthesis.

Jaw bone resorption in the edentulous regions was classified according to Cawood and Howell[5] for diagnosis and treatment planning.

Preoperative CT scan analysis of the residual crests was used to assess the need for onlay bone graft for implant placement, and to guide the choice of harvesting procedure. Horizontal bone augmentation was deemed necessary in cases of a residual crest width of < 6 mm[10], but with an adequate bone height. Vertical augmentation was adopted in cases of available residual crest height <7 mm[3]. Onlay grafts were carried out, where needed, via either vertical or horizontal autogenous bone block grafting, following procedures described by TRIPLETT and SCHOW[23].

Two donor sites were utilized for the grafting procedure: the mandibular parasymphysis and the iliac crest area. One or two blocks, depending on need, were harvested from the parasymphyseal area, following the procedure described by BALAJI[2], but using a horizontal mucosal incision 5 mm apical to the muco-gingival junction. No material was used to fill the residual defect in the donor area. The iliac crest graft was obtained following the technique described by GRILLON et al.[7], using a cutaneous approach via elective lines of incision. The recipient site was approached as described by TRIPLETT and SCHOW[23]: horizontal or vertical bone block grafting if the residual alveolar crest deficiencies were in width or height, respectively. Autogeneous bone chips were used to fill gaps between the grafts and the recipient area. A ‘lag screw’ technique was used to secure the bone blocks to the residual bone[11].

All surgery was performed under general anesthesia, with local administration of 2% mepivacain with epinephrine (20 mg/ml + 12.5 μg/ml) to reduce bleeding. All patients underwent antibiotic prophylaxis and analgesic anti-inflammatory therapy.

Bone grafts were left to heal for 3–5 months before implants were placed[19]. 3–5 months after the reconstructive stage, titanium dental implants, root-form, external-hex, rough surface screws, were inserted into the reconstructed bone areas. This is usually planned in such a way as to reduce possible unpredictable remodeling[25], and because the delayed approach has resulted in better implant integration[22]. The implants were allowed at least 6 months to osseointegrate before prosthetic loading.

Data analysis

A correlation between R% and all of the variables representing the 3D features of both the grafted bone and of the recipient site was sought. Spearman’s correlation coefficient (ρ) and p-value were used in correlation analysis between the percentage of residual bone graft (R%) and all of the 3D features obtained[13].

3D features of graft and recipient site that had a correlation with R% (ρ c. coefficient < -40 and ρ c. coefficient > +40) were used in scatter plot fitting. A 3D interpolation procedure was implemented for the 3D scatter data and was shown as an image, in which R% values were represented as colors (red indicates minimum resorption; blue indicates maximum resorption).

All correlation analysis, data fitting and interpolation were implemented with MatLab 7.0.1 (The MathWorks, Inc. Massachusetts, USA).

Nonparametric methods were used to evaluate the significance of the differences between T_1 and T_2 times for different grafted areas (anterior and posterior of either maxilla or mandible) and different sources of graft (iliac crest or chin). Owing to the nature of the data, which are discrete and asymmetric in distribution, Wilcoxon signed-rank test (statistically significant at a level of $\alpha = 0.05$) was adopted to evaluate the significance of the differences in bone remodeling between coupled classes of grafted sites.

Statistical analyses of data were implemented with MatLab 7.0.1 (Statistics Toolbox, MatLab 7.0.1, The MathWorks, Inc. Massachusetts, USA).

Results

14 patients affected by severe jaw atrophy were treated (8 females; 6 males), ranging in age from 37.5 to 62.9 years (mean 51.9 ± 8.3 years). Three patients (2 males and 1 female) were edentulous, while the remaining patients were partially edentulous. Of these latter, 1 female was partially edentulous in only the upper arch, and completely edentulous in the lower arch. 11 of the 14 were non-smokers. Atrophy of the jaw bone was the result of one of the following: a long-standing edentulous condition treated by removable prosthesis; alveolar bone loss due to a periodontal disease; a major trauma. No patient had undergone bone resection as part of oncologic treatment.

32 onlay graft procedures were performed via either vertical or horizontal autogenous bone grafting; 18 grafts were positioned in mandibular areas and 14 in maxillary areas. Of the 18 mandibular grafts, 5 were anterior and 13 were posterior, while of the 14 maxillary grafts, 8 were anterior and 6 were posterior. Horizontal versus vertical alveolar ridge reconstruction ratio was 9:2 in the maxilla and 2:7 in the mandible. Data regarding bone source and graft position are summarized in Table 1. All grafts healed without complications, and neither total nor partial graft exposure occurred during follow-up. 84 dental implants were inserted into the graft areas, and of these 28 were in the posterior mandible and 30 were in the anterior maxilla. All patients received fixed prosthetic restoration with metal ceramic crowns and bridges, either cemented over a custom metal abutment or via a UCLA-type abutment.

Postoperatively, the clinical course of all harvesting sites was uneventful, and no patient exhibited clinical signs of nerve damage[16]. No implant failure was recorded. The mean volumes (at T_1 and T_2) and the mean percentage of residual

Table 1. Number of grafting procedures, orientation, and graft source in maxilla and mandible, and respective mean value of the overall 3D features at T_1 [volume (in $mm^3 \pm$ SD), contact surface (CS_{T_1}) ($mm^2 \pm$ SD), basal bone volume (BB_{T_1}) ($mm^3 \pm$ SD) and external surface (ES_{T_1}) ($mm^2 \pm$ SD)] and of the volume (in $mm^3 \pm$ SD) at time T_2. Percentage of residual bone graft (R%) and Wilcoxon signed-rank test significance (p_{Wilcoxon}) in volume comparison between T_1 and T_2. for the overall groups presented.

	Source	Position	no.	V_{T_1} (mm^3)	CS_{T_1} (mm^2)	BB_{T_1} (mm^3)	ES_{T_1} (mm^2)	V_{T_2} (mm^3)	R%	p_{Wilcoxon} V_{T_1} vs V_{T_2}
Maxilla	Iliac crest	ANTERIOR	8	2049 (±1836)	464 (±322)	3586 (±2728)	664 (±523)	1372 (±1879)	57.9	0.235
		POSTERIOR	3	659 (±356)	284 (±196)	2834 (±453)	280 (±192)	606 (±418)	84.5	0.7
		TOTAL ARCH	11	1670 (±1675)	415 (±296)	3381 (±2318)	559 (±481)	1163 (±1623)	65.2	0.237
	Chin	POSTERIOR	3	733 (±500)	257 (±142)	2649 (±1439)	475 (±313)	406 (±308)	55.5	1
Mandible	Iliac crest	ANTERIOR	5	2518 (±1600)	533 (±288)	9013 (±5187)	1003 (±558)	1551 (±989)	68.6	0.31
		POSTERIOR	13	1741 (±1244)	391 (±153)	5662 (±1453)	660 (±390)	850 (±1077)	41.2	0.027
		TOTAL ARCH	18	1957 (±1350)	430 (±201)	6593 (±3194)	752 (±447)	1045 (±1074)	48.8	**0.0279**

Statistically significant values are in **bold**.

Table 2. Spearman's ρ correlation coefficients between R% values and all 3D features of graft and recipient site (CS_{T_1}, ES_{T_1}, BB_{T_1}, $indexV_{T_1}$, $indexH_{T_1}$ and $indexS_{T_1}$). Statistical significance set at 0.05 level (two-tailed) for both the horizontal procedure in the anterior maxilla and the vertical procedure in the posterior mandible.

	R% *vs*	CS_{T_1}	ES_{T_1}	BB_{T_1}	$indexV_{T_1}$	$indexH_{T_1}$	$indexS_{T_1}$
Horizontal procedure in the anterior maxilla	ρ c. coefficient	−0.1786	0.3214	−0.3214	−0.4643	0.5714	−0.1429
	Sig. (two-tailed)	0.7131	0.4976	0.4976	0.3024	0.2000	0.7825
	no.	7	7	7	7	7	7
Vertical procedure in the posterior mandible	ρ c. coefficient	0.3364	0.2818	0.4182	0.0909	-0.0818	-0.5273
	Sig. (two-tailed)	0.3130	0.4021	0.2031	0.7966	0.8177	0.1001
	no.	11	11	11	11	11	11

bone graft (R%) together with the mean contact surface, the mean basal bone and the mean external surface of the different grafts related to their position and source (chin grafts positioned in posterior maxilla, iliac crest grafts positioned in anterior and posterior maxilla, and iliac crest grafts positioned in anterior and posterior mandible) are reported in Table 1.

The mean volume of chin grafts positioned in the maxilla, iliac crest grafts positioned in the maxilla, and iliac crest grafts positioned in the mandible were, respectively, 733(±500) mm^3, 1670(±1675) mm^3 and 1957(±1350) mm^3 (Table 1).

After 1 year the volumes had been reduced to 406(±308) mm^3 for chin grafts positioned in the maxilla, with a mean resorption of 45%, to 1163(±1623) mm^3 for iliac crest grafts positioned in the maxilla, with a mean resorption of 35%, and to 1045 (±1074) mm^3 for iliac crest grafts positioned in the mandible, with a mean resorption of 51% (Table 1). Comparisons between T_1 and T_2 showed that statistically significant differences were registered in the group of the iliac crest grafts positioned in the posterior mandible (Table 1).

A relationship between bone remodeling and the 3D features of the bone graft after implant insertion was sought. Correlation analysis revealed that in horizontal grafts in the premaxilla there was a correlation between R% and both $indexV_{T_1}$ (ρ c. coefficient = −0.4643 with Sig. [two-tailed] = 0.302) and $indexH_{T_1}$ (ρ c. coefficient = 0.5714 with Sig. [two-tailed] = 0.2) (Table 2). In vertical grafts in the posterior region of the mandible, correlations were found between R% and both BB_{T_1} (ρ c. coefficient = 0.418 with Sig. [two-tailed] = 0.203) and $indexS_{T_1}$ (ρ c. coefficient = −0.527 with Sig. [two-tailed] = 0.1) (Table 2).

Scatter plot, linear fitting and 3D interpolation analysis were presented for data regarding the premaxillary horizontal graft group and the posterior mandibular vertical graft group. Correlation analysis revealed that bone remodeling of maxillary horizontal iliac crest graft depended only on the thickness of the graft ($indexH_{T_1}$) and on the volume ratio between the recipient site and the graft ($indexV_{T_1}$). None of the other 3D features were involved (Table 2).

Correlation analysis showed that bone remodeling of mandibular iliac crest graft was affected by the shape of the graft ($indexS_{T_1}$) and the basal bone volume (BB_{T_1}). None of the other 3D features were involved (Table 2).

Linear fittings showed that not all data fit the straight line, as suggested by the values of R^2 (Figs. 1 and 2). 3D interpola-

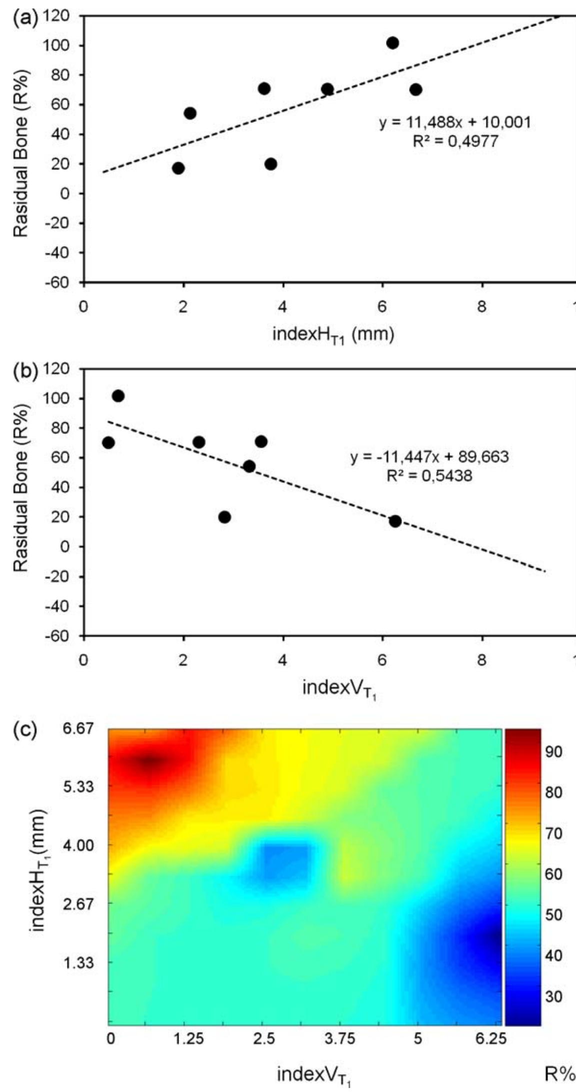

Fig. 1. Scatter plots (a and b) and the 3D interpolation (c) showing the percentage of the residual graft (R%) in the anterior maxilla horizontally augmented with iliac crest in function of: (a) the height index or mean thickness of the graft ($indexH_{T_1}$); (b) the volume index or volume ratio between the recipient site and the graft ($indexV_{T_1}$); (c) the two indices, $indexH_{T_1}$ and $indexV_{T_1}$. Color bar shows the R% from maximum (red) to minimum (blue).

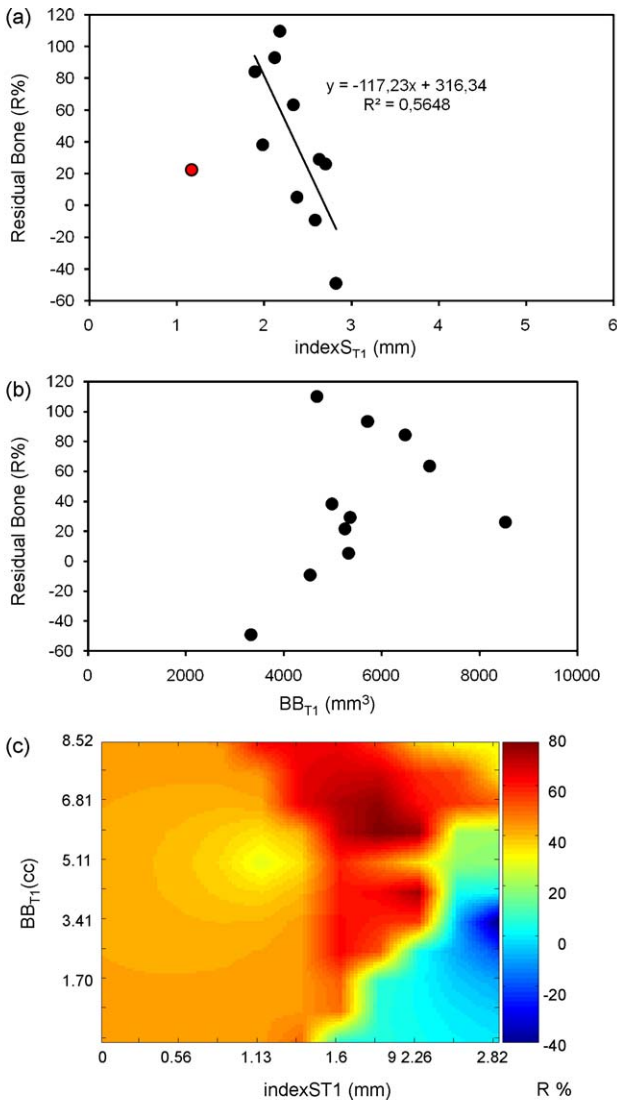

Fig. 2. Scatter plots (a and b) and 3D interpolation (c) showing the percentage of the residual graft (R%) in the posterior mandible vertically augmented with iliac crest in function of: (a) the shape index or the ratio between the volume of the graft and its surface not in contact with recipient site (indexS$_{T_1}$), the red point was excluded from the linear fitting; (b) the basal bone or the volume of the recipient site below the graft (BB$_{T_1}$); (c) the two independent variables, indexS$_{T_1}$ and BB$_{T_1}$. Color bar shows the R% from maximum (red) to minimum (blue).

tions of R% in the function of the couples indexH$_{T_1}$ - indexV$_{T_1}$ and BB$_{T_1}$ - indexS$_{T_1}$ were made (Figs. 1c and 2c), and showed that the area of minimal resorption (R% > 70) was delimited for the horizontal premaxillary dataset by indexH$_{T_1}$, ranging from 5 to 6.7 mm, and indexV$_{T_1}$, ranging from 0 to 1.5, and for the vertical posterior mandibular dataset by BB$_{T_1}$, ranging from 5.5 to 7.7 cc, and indexS$_{T_1}$ ranging from 1.5 to 2.3 mm. No statistically significant differences were recorded between recipient and donor site groups (Table 3).

Table 3. Wilcoxon signed-rank test significance in volume comparison at T$_1$ and T$_2$ between anatomical regions of the recipient site and different graft sources.

		Compared groups	V$_{T_1}$	V$_{T_2}$	R%
Maxilla	Iliac crest	ANTERIOR *VS* POSTERIOR	0.194	0.776	0.291
Maxilla	POSTERIOR	Iliac crest *vs* Chin	1	0.400	0.700
Mandible	Iliac crest	ANTERIOR *VS* POSTERIOR	0.443	0.208	0.246

Discussion

The purpose of this retrospective chart review was to analyze bone remodeling and the associated factors of onlay-positioned grafts, in severely atrophic jaws for implant-supported restoration. The hypothesis is that some of the 3D features of the bone graft and the recipient site, and their interrelation, greatly affect bone graft remodeling. The aims were to discover a possible correlation between bone remodeling and the 3D features of the grafts and the recipient site, and to test the relationship between the remodeling and either the anatomical region of the recipient site or of the different graft sources.

Autogenous free bone grafts have been extensively employed to reconstruct defective alveolar ridges. One of the major pitfalls of the technique, even when judged successful, is graft remodeling over time. 5-year, two-dimensional radiographic studies on autogenous onlay grafts in the human mandible reported resorption of grafted iliac bone ranging from 44 to 50%[25]. Johansson et al.[9], evaluating the changes in volume of autogenous iliac crest grafted as onlay or inlay in the maxilla, recorded, at the 6 month post-operative control (just before dental implant insertion), an average volume reduction of 47% for inlays and of 50% for onlays. Smolka et al., evaluating autogenous calvaria grafts of membranous embryologic origin and rich in cortical bone, found that the mean volume reduction was 11% at 6 months and 19% at the 1 year follow-up, suggesting a pattern of resorption, linear in time for this type of graft, apparently unaffected by intercurrent dental implant placement[21].

The present survey showed the following respective mean percentages of resorption: 42% for grafts harvested from the iliac crest that were onlay-positioned in the anterior maxilla, and 46% for chin grafts onlay-positioned in the posterior maxilla.

Grafts harvested from the iliac crest showed resorption percentages of 31% and 59%, respectively, when onlay-positioned in the anterior or posterior mandible. Only the iliac crest grafts onlay-positioned in the posterior maxilla showed a smaller percentage of resorption (16%), with no apparent explanation. Comparisons between volumes at T$_1$ and at T$_2$ showed a reduction at T$_2$, suggesting a resorption phenomenon, even if a statistically significant difference ($p = 0.027$) was found only in the posterior mandibular group.

Data for osseous remodeling for the horizontal iliac crest grafts in the anterior maxilla and the vertical iliac crest grafts in the posterior mandible were numerically adequate and uniformly distributed, allowing a linear correlation analysis and a successive linear fitting, suggesting that an eventual bias introduced by the retrospective nature of the data did not affect the validity of the study. The results indicated that only one couple out of the fifteen possible couples of the six variables, describing the 3D features of the graft, of the recipient site and of their relationship, was involved in the remodeling process, and that the couple for the maxillary variables was different from that of the mandibular variables.

Data from these groups failed to fit a straight line, but 3D interpolation analysis showed that, despite an average resorption of 42% in the maxillary horizontal iliac crest graft group and of 59% in the mandibular vertical iliac crest graft group, two distinct types of behavior within each group could be identified. Both groups showed values of minimal resorption ($R\% > 70$) that were limited to a single, small region of the interpolation plane, and were quite well-defined and separate from the single, small region of values of maximal resorption. Two different remodeling patterns might be identified in both these regions (Figs. 1c and 2c). An example might be represented by a thick iliac crest graft, positioned in an atrophic premaxilla, that resorbed, after implant insertion to a lesser extent than a thinner graft in the same region, due to the contemporary presence of a high value of indexH_{T_1} and a reduction in the value of indexV_{T_1}. Data gathered from the iliac crest graft in the posterior mandible suggest that the shorter the mean distance between the center of gravity of the graft and its external surface is (low indexS_{T_1} value), and the larger the basal bone volume is (high BB_{T_1} value), the more limited is the remodeling. Retrospectively, rounded iliac grafts with a convex external surface positioned in the posterior mandible with an adequate basal bone volume experienced the least resorption.

No statistically significant differences were recorded for V_{T_1}, V_{T_2} and R% between recipient or donor site groups (Table 3). This lack of statistical significance was probably due to the small usable sample for a signed-rank test.

The implant survival rate of 100% in maxilla and mandible was in line with the current literature for short-term studies[6].

The result of the present interpolation analysis is the description of a remodeling pattern of an onlay graft only after implant insertion. Such a pattern does not necessarily reflect remodeling before implant insertion.

Apart from the 3D features, other properties of the bone graft, such as density or the cortical/cancellous ratio, may interfere with graft remodeling. A further multidimensional analysis of bone structure might provide a more accurate prediction of possible resorption. More studies are needed to confirm the current data.

Competing interests

None declared.

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Ethical approval

The study was approved by the Scientific Ethics Committee of the University of Pisa.

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Address:
Ludovico Sbordone,
Department of Surgery,
University of Pisa,
Via Roma 67,
56126 Pisa,
Italy
Tel:/Fax: +39 050 995555.
E-mail: lsbordon@med.unipi.it