Inlay versus Onlay Iliac Bone Grafting in Atrophic Posterior Mandible: A Prospective Controlled Clinical Trial for the Comparison of Two Techniques

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ABSTRACT

Purpose: To compare the efficacy of inlay and onlay bone grafting techniques in terms of vertical bone formation and implant outcomes for correcting atrophic posterior mandibles.

Materials and Methods: Twenty surgical sites were assigned to two treatment groups, inlay and onlay, with iliac crest as donor site. After 3 to 4 months, 43 implants were placed and loaded 4 months later. The median follow up after loading was 18 months.

Results: For the inlay versus onlay group, median bone gain was 4.9 versus 6.5 mm ($p = .019$), median bone resorption was 0.5 versus 2.75 mm ($p < .001$), and median final vertical augmentation was 4.1 versus 4 mm ($p = .190$). The implant survival rate was 100% in both groups, while the implant success rate was 90% versus 86.9% ($p = .190$, not significant). A minor and major complication rate of 20% and 10%, respectively, for both groups was encountered.

Conclusions: Inlay results in less bone resorption and more predictable outcomes, but requires an experienced surgeon. In contrast, onlay results in greater bone resorption and requires a bone block graft oversized in height, but involves a shorter learning curve. Once implant placement has been carried out, the outcomes are similar for both procedures.

KEY WORDS: implant-borne prosthesis, inlay versus onlay bone grafting, posterior mandibular atrophy

INTRODUCTION

Insufficient bone height in the posterior mandible, as a result of early teeth extractions, periodontal disease, tumor resection, trauma, or congenital diseases, complicates implant-supported prosthetic rehabilitation due to the reduction of the bone gap between the residual alveolar ridge and the mandibular canal.[1–3] Many surgical procedures have been proposed to allow dental implant placement in either a simultaneous or staged approach. Transpositioning of the mandibular nerve is technically demanding and may affect nerve bundle integrity;[4] the placement of short implants, especially when the available bone above the inferior canal is ≤7 mm, is an unpredictable procedure.[5,6] Furthermore, because both of these techniques result in an excessive crown length with an unfavourable crown/implant ratio and poor aesthetic outcomes, the ideal approach should be to augment bone vertically.

A lack of comparative studies has made it difficult to choose the most reliable and predictable augmentation technique. A recent review on this topic stated that although vertical bone augmentation is possible, the

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associated number of complications and failures with the various described techniques remains unacceptably high (>20%).[6] In particular, insufficient data are available regarding vertical bone gain and stability over time in atrophic posterior mandibles.

The inlay technique shows great potential for bone graft incorporation, with a low resorption level and high implant survival and success rates,[7–9] and recent studies into this technique have reported good outcomes in atrophic posterior mandibles.[1,10–13] However, this technique is not simple to perform and requires at least 4 to 6 mm of residual bone above the mandibular canal.[11,12] Onlay grafting has been used successfully in the correction of vertically deficient edentulous ridges,[2,14] although the reported two-stage approach results in considerable resorption of the bone graft before implant insertion.[2,14,15]

The major difficulty in vertical reconstruction of the posterior mandible is the management of soft tissues, which have a high risk of dehiscence and subsequent infection and necrosis of the graft.

The use of an autogenous bone block harvested from extra-oral donor sites has been reported to be effective,[16–18] and iliac bone grafts in particular have been used successfully with inlay procedures in the posterior mandible.[1,12,13,19]

The aim of this study was to compare the effectiveness of the inlay and onlay techniques in terms of bone gain, bone resorption, final vertical augmentation, periimplant bone resorption, implant survival, implant success, and complication rate in implant-borne prosthetic rehabilitation of atrophic posterior mandibles.

PATIENTS AND METHODS

A total of 20 systemically healthy patients (six males and 14 females) between 30 and 75 years of age (mean, 53.9 years) with resorbed partially edentulous posterior mandibles were recruited between 2003 and 2006. These patients required correction of a vertical bone deficit to provide adequate bone support for implant-borne prosthetic rehabilitation. The median value for preoperative bone height over the mandibular canal was 7.5 mm (range, 4.8–10.7 mm). All of the surgical sites were affected by early tooth loss atrophy.

The inclusion criteria were: (1) age from 20 to 80 years; (2) desire for implant-borne fixed prosthesis rehabilitation; and (3) a minimum native bone height above the mandibular canal of 4 to 5 mm (as determined via computed tomography [CT]). The exclusion criteria were: (1) reduced thickness (≤5 mm) of the edentulous ridge; (2) any general contraindication to implant surgery; (3) chemotherapy, irradiation, immunosuppressive therapy, or aminobisphosphonate treatment in the previous 5 years; (4) pregnancy or lactation; (5) uncontrolled diabetes; (6) previously subjected to reconstructive procedures of the posterior mandible; (7) active periodontal disease involving the residual dentition; (8) mucosal disease such as lichen planus in the areas to be treated; (9) poor oral hygiene; and (10) noncompliance.

These 20 patients were randomly assigned to two different groups: 10 patients (four males and six females) with 10 monolateral surgical sites underwent an interpositional bone graft procedure (the inlay group), and the remaining 10 patients (two males and eight females) with 10 monolateral surgical sites underwent an appositional bone graft procedure (the onlay group) for a total of 20 surgical sites. The surgeons were blind to the group assignment until the surgical procedure. The mean age of the patients in the inlay group was 55.2 years (range, 30–75 years), whereas the mean age of the onlay group was 52.6 years (range, 39–63 years).

Clinical records, casts, and radiographic evaluations (periapical X-ray, orthopantomograms [OPT], and CT) of the patients were assessed. Two experienced surgeons performed all reconstructive and implant placement procedures. Each patient provided written informed consent for the treatment.

Operative Procedure for the Inlay Group

The mandible was augmented under general anesthesia by interposing a monocortical iliac crest bone graft harvested from the medial surface of the anterior ilium. All patients received prophylactic antibiotic therapy. Ceftriaxone (Ceftriaxon, Tyrol Pharma, Bordon, UK) was administered intravenously upon anesthetic induction at a loading dose of 2 g, and local anesthesia was induced with articain 4% and adrenaline 1:100,000.

After making a full-thickness vestibular incision in the lower vestibule while avoiding the emergence of the mental nerve, the subperiosteal tissue was carefully dissected to obtain adequate visibility of the underlying bone, with no tension on the ipsilateral mental nerve. Mucoperiosteal dissection was not performed toward the alveolar crest or on the lingual side to preserve an

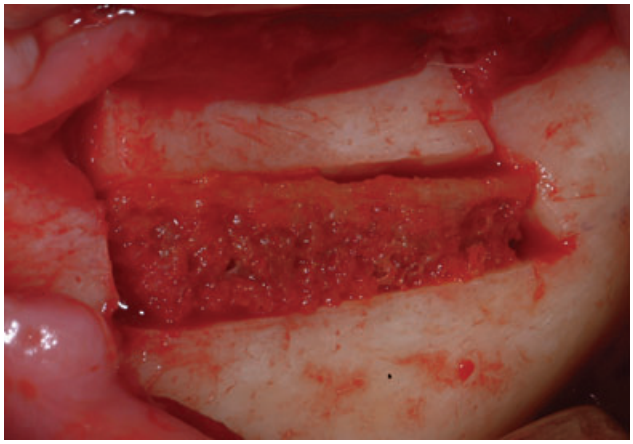

Figure 1 Inlay procedure: after vestibular periosteum elevation and exposure of the buccal surface of the mandibular bone, the iliac block is interposed between the raised fragment and the mandibular basal bone.

adequate blood supply to the bone segment to be osteotomized. Horizontal osteotomy and two oblique cuts were made using a reciprocal saw and by piezosurgery (Mectron Piezosurgery Device™; Mectron, Carasco, Italy) to obtain a cleaner osteotomy line, with minor risk of transport segment fracture. The horizontal osteotomy was 2 to 4 mm above the mandibular canal; the mesial oblique cut was 2 mm distal to the last tooth in the arch, and the distal oblique cut was relative to the implant–graft treatment plane. The height of the transport segment was at least 3 mm to allow for the insertion of the stabilizing screws without fracturing. The osteotomized segment was then raised in the coronal direction, sparing the lingual periosteum.

At this point, the autogenous bone block was harvested from the iliac crest in a conventional manner.[20] The iliac block was modeled to be properly fitted in the recipient site, interposed between the raised fragment and the mandibular basal bone (Figure 1), and fixed with titanium miniplates and miniscrews (Gebrüder Martin and Co., Tuttlingen, Germany) to both the basal bone and the transport fragment (Figure 2). Gaps between the graft and the recipient site were filled with particulated iliac bone. The grafted areas were covered with a resorbable barrier (Bio-Guide®; Geistlich Pharma, Wolhusen, Switzerland). After releasing the vestibular periosteum, the flap was closed with 4.0 vicryl sutures (Ethicon FS-2, St-Stevens-Woluwe, Belgium).

The postsurgical therapy protocol consisted of Ceftriaxone at a dose of 2 g/day, for 10 days after surgery, together with a nonsteroidal analgesic drug (ketoprofen, Orudis; Aventis Pharma, Bridgewater, UK) at a dose of 200 mg twice daily for 3 days and thereafter as required. Cortisone (betametason; 4 mg) was administered twice daily for 2 days and once a day on day 3. A soft diet and appropriate oral hygiene were prescribed for 2 weeks, including twice daily rinsing with 0.2% chlorhexidine mouthwash and the application of 1% chlorhexidine gel (Corsodyl gel; GlaxoSmithKline, Middlesex, UK). Patients were instructed not to wear removable prostheses for 30 days postsurgery, and to avoid brushing or otherwise traumatizing the surgical site.

Sutures in the oral cavity were removed 10 days after the procedure, whereas the iliac crest sutures were removed after 7 days. Additional postoperative checkups were carried out at 3 and 6 weeks and 3 months after surgery.

After a 3- to 4-month waiting period, the augmented site was exposed after elevation of a mucoperiosteal flap. The miniplates were removed (Figure 3), and two endosseous implants were inserted under local anesthesia in each treated site. The implant features (type, diameter, and length) were decided according to the anatomical situation. Twenty titanium screw-shaped endosseous implants were positioned in the crestal augmented region; nine patients received 18 Biomet 3i implants (Palm Beach, FL, USA) and one patient received two XiVe implants (Friadent-Dentsply, Mannheim, Germany; Figure 4). The fixtures were allowed to heal for 4 months for osseointegration before prosthetic

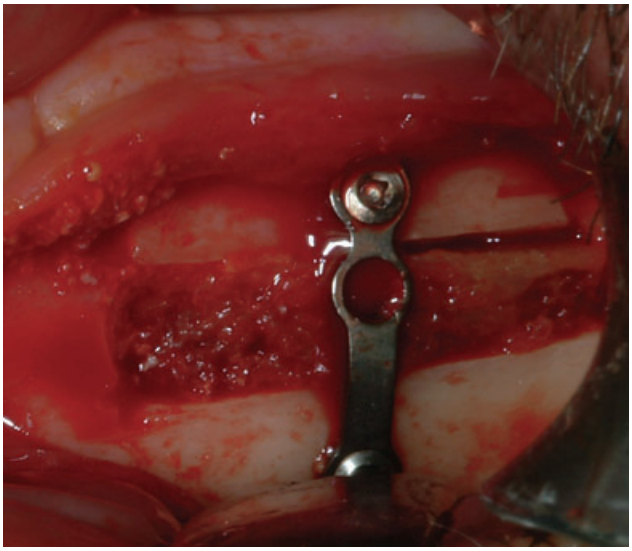

Figure 2 Inlay procedure: the iliac block is fixed with titanium miniplates and miniscrews to both the basal bone and the transport fragment.

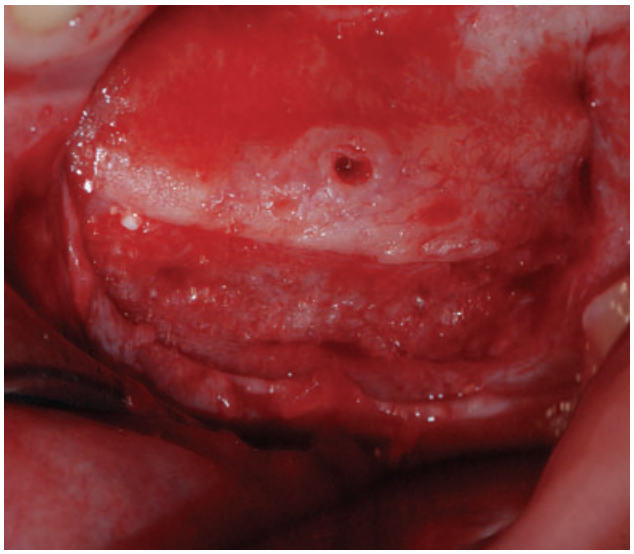

Figure 3 Inlay procedure: surgical site during reentry for implant placement, after the elevation of overlying soft tissues and the removal of miniplates and miniscrews.

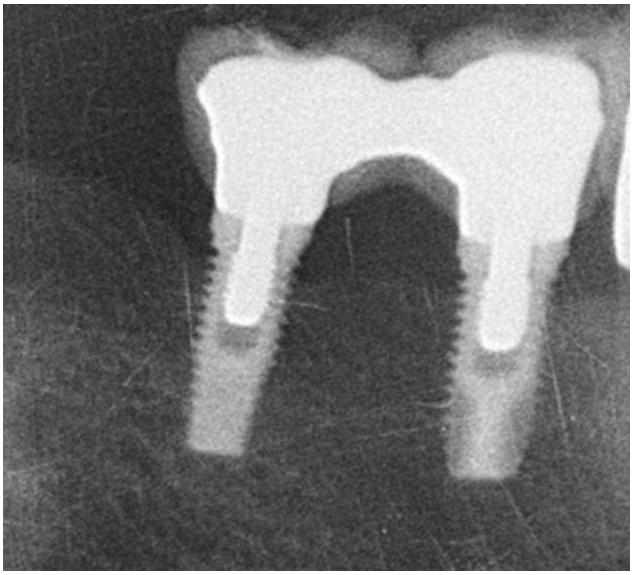

Figure 5 Inlay group: periapical X-ray at the end of the follow-up period.

rehabilitation was initiated. Two grams of amoxicillin were administered preoperatively and then 1 g twice a day for 5 days. Ibuprofen 600 mg was prescribed to be taken as required. The implants were uncovered 4 months later; abutments were placed, and a screw-retained, acrylic-resin, temporary fixed prosthesis was affixed for 4 to 5 months until the insertion of a screw-retained definitive prosthesis. Patients were enrolled in an oral hygiene program with evaluations every 3 to 4 months until the end of the follow-up period (Figure 5).

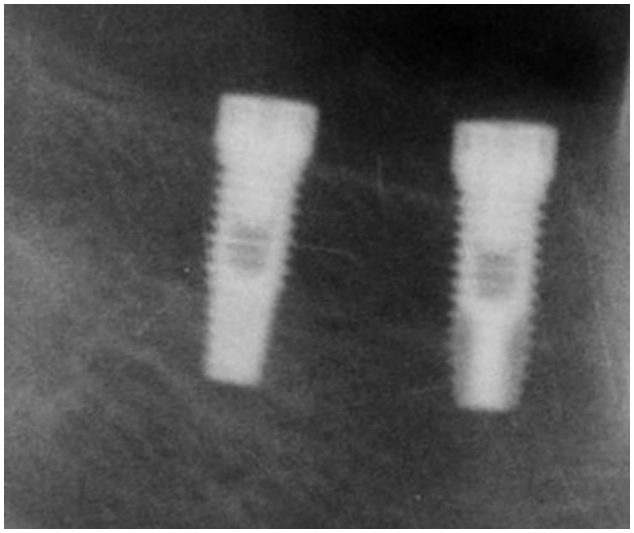

Figure 4 Inlay group: periapical X-ray immediately after implant insertion.

Table 1 reports in details the radiographic, clinical, and treatment data for the inlay group.

Operative Procedure for the Onlay Group Patients

The mandible was augmented under general anesthesia by placing a monocortical iliac crest bone graft, which was harvested from the medial surface of the anterior ilium, on the ridge. The onlay group was administered the same prophylactic antibiotic therapy as the inlay group, and local anesthesia was induced with articain 4% and adrenaline 1:100,000.

After making a full-thickness crestal incision continuing into the adherent gingiva of the mesial teeth without involving their periodontal attachment, the subperiosteal tissue was carefully dissected to obtain adequate visibility of the underlying bone without applying tension to the ipsilateral mental nerve. Releasing incisions were performed when required to improve the mobility of the buccal flap. The bone recipient site was flattened slightly to eliminate asperities and perforated with a 1-mm round bur under copious saline irrigation to increase the blood supply from endosseous vessels. The autogenous bone block was harvested from the iliac crest in a conventional manner.[15] The iliac block was modeled to be properly fitted in the recipient site and rigidly fixed upon the mandibular ridge with 1.5-mm-diameter titanium miniscrews (Gebrüder Martin and Co.; Figure 6). Gaps between the graft and

TABLE 1 Inlay Group: Radiographic, Clinical, and Treatment Data

Patient no.	Sex	Age (years)	Starting bone height above mandibular canal (mm)	Treated site	Implant no.	Implant location and dimension (mm)	Follow-up after loading (months)
#1	F	67	5.7	left	2	36 = 4 × 10 37 = 4 × 10	18
#2	F	46	4.8	left	2	35 = 3.8 × 8.75 37 = 3.8 × 9.5	18
#3	F	50	8.6	right	2	46 = 4 × 10 47 = 4 × 11.5	17
#4	F	30	6.2	right	2	45 = 4 × 10 46 = 4 × 11.5	20
#5	M	69	7.6	left	2	35 = 4 × 10 36 = 4 × 10	22
#6	F	59	5.6	right	2	46 = 4 × 10 47 = 4 × 10	18
#7	M	61	8.5	left	2	36 = 4 × 10 37 = 4 × 11.5	17
#8	F	75	8.2	right	2	45 = 4 × 10 47 = 4 × 10	19
#9	M	43	8.5	right	2	46 = 4 × 11.5 47 = 4 × 11.5	19
#10	M	52	6.3	left	2	36 = 4 × 10 37 = 4 × 10	17

the recipient site were filled with particulated iliac bone. The grafted areas were covered with a resorbable barrier (Bio-Guide®; Geistlich Pharma). After releasing the vestibular periosteum, the flap was closed with 4.0 vicryl sutures (Ethicon FS-2).

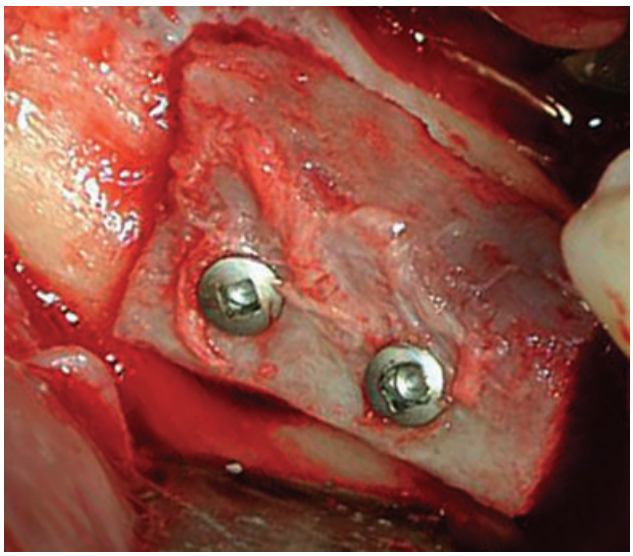

Figure 6 Onlay procedure: the iliac block superimposed on the residual ridge and fixed with titanium miniscrews.

The postsurgical therapy protocol and postoperative care instructions was identical as for the inlay group such as the sutures removal and the postoperative check-ups timing.

After a 3- to 4-month waiting period, the augmented site was exposed after the elevation of a muco-periosteal flap (Figures 7 and 8). The miniscrews were removed, and two or three endosseous implants were inserted under local anesthesia in each treated site. The implant features (type, diameter, and length) were decided according to the anatomical situation. Twenty-three titanium screw-shaped endosseous implants were positioned in the crestal augmented region (Figure 9). Seven patients received 17 Astra implants (Astra Tech AB, Mölndal, Sweden), two patients received four Biolok implants (Biolok, Deerfield, FL, USA), and one patient received two Alpha Bio implants (Alpha-Bio Tec Ltd., Petak-Tikva, Israel). The same antibiotic and analgesic as the inlay group was prescribed. Four months later, the implants were uncovered. Abutments were placed, and a screw-retained, acrylic-resin, temporary fixed prosthesis was placed for 4 to 5 months until the insertion of a screw-retained definitive prosthesis. The patients were

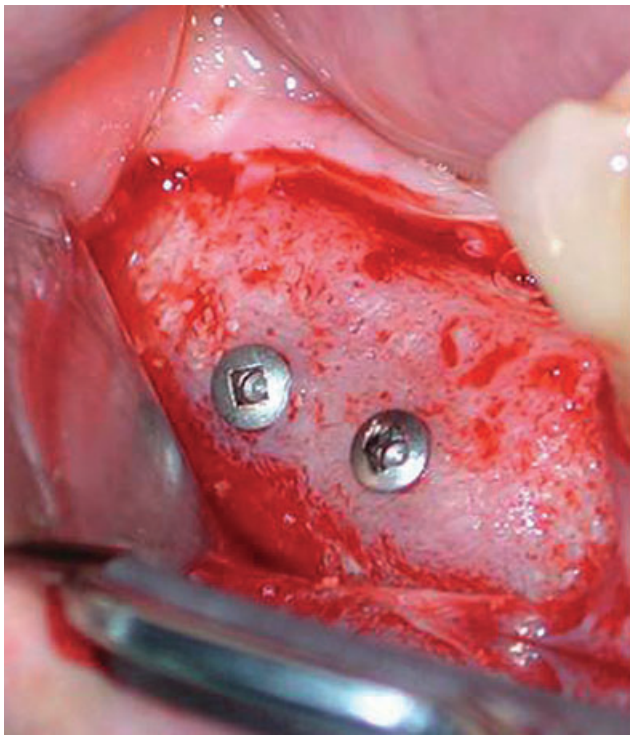

Figure 7 Onlay procedure: surgical site during reentry for implant placement, after elevation of overlying soft tissues.

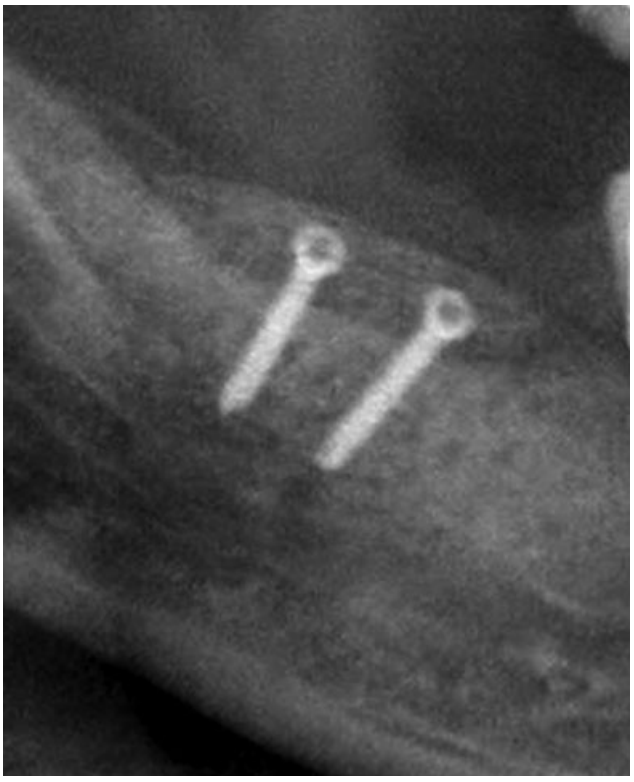

Figure 8 Onlay procedure: representative orthopantomogram during surgical reentry just before miniscrew removal and implant insertion.

enrolled in an oral hygiene program with evaluations every 3 to 4 months until the end of the follow-up period (Figure 10). Table 2 reports in details the radiographic, clinical, and treatment data for the onlay group.

Assessment Timing

Every patient underwent a clinical examination 1 week after surgery, twice in the first month, and monthly in the subsequent months before implantation. The patients were then evaluated in the first week and twice monthly for the subsequent 4 months after implant placement, and monthly after prosthetic loading until the end of the follow-up period.

A subjective evaluation of neurosensory function was carried out at each clinical check-up by asking the patient if there were any areas of hypoesthesia, numbness, tingling, or pain in the lip or chin region. The time required to recover full lip and chin region sensitivity after the augmentation procedures was recorded.

The following assessment surveys (clinical and X-ray evaluations) were carried out for both groups:

- T0 = Preoperative phase: clinical records, casts, OPT, and CT.
- T1 = Postoperative phase: OPT and CT.
    - T1a = Immediately after surgery.
    - T1b = Surgical reentry (3–4 months postoperatively), just before miniplate removal and implant insertion.
- T2 = Immediately after implant insertion: periapical X-rays.

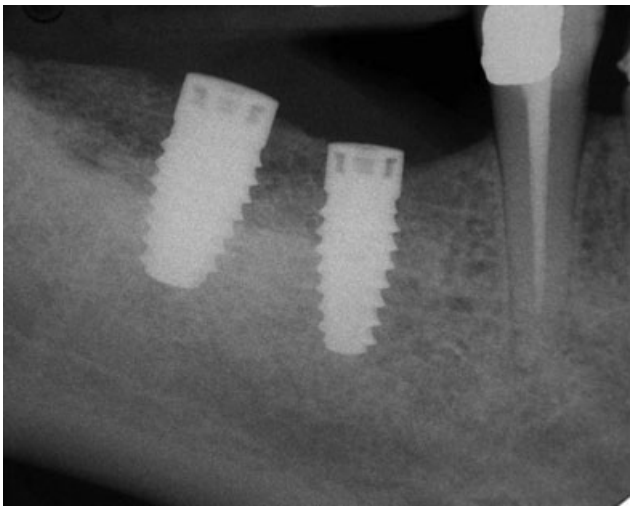

Figure 9 Onlay group: periapical X-ray immediately after implant insertion.

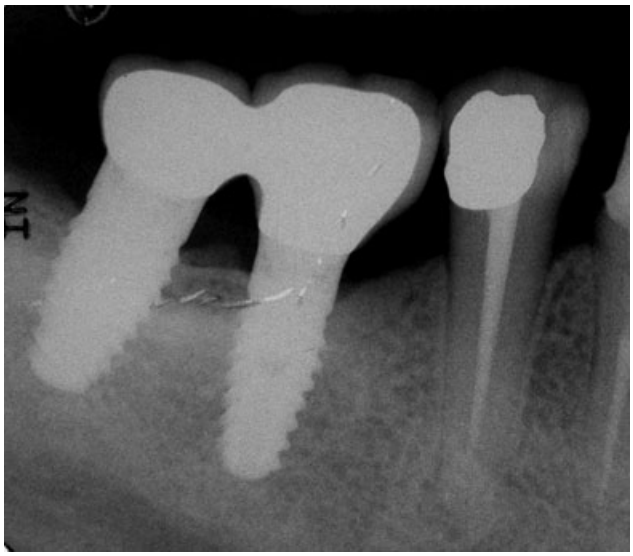

Figure 10 Onlay group: periapical X-ray at the end of the follow-up period.

- T3 = Prosthetic loading.
- T4 = End of the follow-up time (median, 18 months; range, 13–22 months).

Radiographic Parameters Evaluated

A qualified examiner performed all radiographic assessments. The paraxial 1-mm-thick CT slices obtained at 6, 12, and 18 mm posterior to the mental foramina were assessed for pre-implant placement phase investigation; for all parameters taken into consideration, except *vertical resorption of the inlay graft*, the distance from the most coronal point of the mandibular canal to the intermediate point of the crestal ridge was measured using Autocad-Autodesk® Software (San Rafael, CA, USA) and a mean value was considered. First, *starting bone height* above the mandibular canal was assessed at T0 via CT in both groups. *Vertical bone gain* was assessed by comparing T0 and the immediate postoperative time (T1a) via CT in both groups. *Vertical bone resorption* of the augmented ridge was assessed by comparing T1a and

TABLE 2 Onlay Group: Radiographic, Clinical, and Treatment Data

Patient no.	Sex	Age (years)	Starting bone height above mandibular canal (mm)	Treated site	Implant no.	Implant location and dimension (mm)	Follow-up after loading (months)
#1	F	63	10.7	left	3	35 = 4.5 × 13 36 = 4.5 × 13 37 = 4.5 × 13	22
#2	F	55	9.1	right	2	46 = 4 × 10 47 = 5 × 10	18
#3	F	55	6.8	left	3	34 = 4 × 9 35 = 4 × 8 36 = 4 × 8	17
#4	F	58	7.8	right	2	46 = 4 × 10 47 = 4 × 10	20
#5	M	39	8.1	right	2	46 = 4 × 11 47 = 5 × 11	14
#6	F	40	8.1	left	2	36 = 4 × 8 37 = 4 × 9	14
#7	F	54	4.9	right	2	44 = 3.75 × 10 47 = 5 × 8	15
#8	F	54	5.6	left	3	34 = 3.5 × 9 35 = 3.5 × 10 37 = 4 × 9	13
#9	F	57	7.5	left	2	34 = 4 × 9 35 = 4 × 13	22
#10	M	52	5.4	left	2	36 = 4 × 10 37 = 4 × 9	20

T1b CT evaluations for both groups. This measurement assessed the resorption of the osteotomized fragment in the inlay group and the resorption of the graft in the onlay group.

Final vertical augmentation was assessed by subtracting bone resorption of augmented ridge values from vertical bone gain values for each group; this comparison was required to evaluate the real effectiveness of the two techniques in augmenting bone. *Vertical resorption* of the graft interposed between the transport segment and the basal bone in the inlay group was assessed by comparing T1a and T1b CT evaluations. This parameter was investigated, measuring the distance from the intermediate point of the upper border to the intermediate point of the lower border of the graft.

Peri-implant bone resorption was assessed according to the criteria of Albrektsson and colleagues[21] by comparing periapical radiographs made perpendicular to the long-axis of the implants, using conventional film holders. Radiographs were taken at T2, T3, and T4; the change in bone level was evaluated mesial and distal to each implant using a transparent ruler to measure the distance in millimeters between the top of the implant head shoulder and the most coronal point of the direct bone-to-implant contact. The bone level measured periapically immediately after implant placement was considered the baseline for further measurements. The measurements were recorded to the nearest 0.5 mm.

Implant Success and Survival Rates

We evaluated implant survival and success according to the criteria of Albrektsson and colleagues.[21]

Complication Assessment and Sensitivity Alteration

Complications were assessed and classified as "minor" or "major," based on the criteria established by Enislidis and colleagues[22] and considering the treatment phase in which they occurred.

Changes in the sensitivity of the area innervated by the inferior alveolar nerve were considered separately. A subjective evaluation was carried out by asking the patient if there were any areas of hypoesthesia, numbness, tingling, or pain in the lip or chin region.

Statistical Analysis

Data were analyzed using non-parametric statistical methods. The two-tailed Mann–Whitney *U*-test and chi-square test were used to detect significant differences between groups (inlay vs onlay). Friedman's test (non-parametric analysis of variance) was used to detect differences throughout the three time intervals within the two groups (inlay and onlay).

RESULTS

Inlay Group Patients

The median value for starting bone height above the mandibular canal were 6.9 mm (range, 4.8–8.6 mm), with a residual ridge shape of IV/V according to the Cawood/Howell classification.[23] The median vertical bone gain from T0 to T1a was 4.9 mm (range, 4–7 mm), with a median bone resorption value of 0.5 mm (range, 0.10–2.9 mm) at T1b corresponding to a median bone gain of 10.2% (range, 2.2–51.8%). The median final vertical augmentation was 4.1 mm (range, 2.7–6.3 mm). Vertical bone resorption of the graft was insignificant, ranging from 0 to 0.1 mm.

Recovery of the surgical site was uneventful in all but three patients. Two weeks after surgery, patients 4 and 8 developed buccal dehiscence at the treated site; dehiscence was <1 cm in diameter and resulted in partial exposure of the titanium miniplate and screw and signs of inflammation. These complications were addressed by local debridement and increased use of clorhexidine for the entire healing period; the soft tissues closed progressively until the implant placement phase. Dehiscence was considered to be a minor complication, yielding a 20% minor complication rate. However, patient 2 developed a buccal dehiscence that was >2 cm in the augmented site in the first postsurgical week, resulting in greater exposure of the titanium miniplate, inflammation, and resorption of the cranial segment; this situation required surgical reentry 10 days after the initial surgery to remove inflammatory tissues and mobilize a new mucoperiosteal flap to obtain complete closure of the bone graft. Considerable bone loss of the cranial segment (51.8% at the time of implant placement) necessitated the use of shorter implants to complete the treatment. This problem was considered to be a major complication because it resulted in the modification of the original treatment plan; therefore, a 10% major complication rate was obtained.

Six patients did not report any subjective sign of impaired lip or chin sensation after the augmentation procedure. Four patients reported hypoesthesia

immediately after the augmentation procedure in their ipsilateral inferior lip and chin region, and two of these patients had progressively increasing numbness and tingling. Altered sensitivity persisted for 2 weeks in three of the four patients and 3 weeks in the remaining patient.

Recovery of the graft donor sites was uneventful in all cases, with no complications. At the end of the follow-up period, the cumulative implant survival rate was 100%. Two of the 20 implants exhibited peri-implant bone resorption >1.5 mm in the first year after prosthetic loading, yielding a cumulative implant success rate of 90%. Complications between implant placement and implant loading occurred in only one patient (patient 1, implant #36), in whom peri-implantitis was observed and resolved with local debridement before loading.

The median cumulative peri-implant bone resorption was 0.9 mm (range, 0.3–1.8 mm). The median follow-up periods from the start of prosthetic loading were 18 months (range, 17–22 months). All patients showed acceptable function of the implant-borne prosthesis, and no complication occurred during implant loading to the end of the follow-up period. Table 3 reports in details the clinical and radiographic outcomes of the inlay group.

Onlay Group Patients

The median value for starting bone height above the mandibular canal was 7.6 mm (range, 4.9–10.7 mm), with a residual ridge shape of IV/V according to the Cawood/Howell classification.[23]

The median value for vertical bone gain from T0 to T1a was 6.5 mm (range, 4.7–8 mm), with a median vertical bone resorption value of 2.7 mm (range, 1.3–4.7 mm), at 4 months postoperatively (i.e., immediately before implant placement). This corresponded to a median value of 40.4% bone gain (range, 22.8–68.7%). The median final vertical augmentation was 4 mm (range, 2–4.9 mm).

Recovery of the surgical site was uneventful except in three patients. Patients 1 and 2 developed a dehiscence, resulting in partial exposure of the graft at 13 and 21 days, respectively, after the reconstruction. In patient 2, this problem required surgical reentry to remove inflammatory tissue, mobilize a new mucoperiosteal flap, and completely cover the bone graft. In patient 1, the exposed bone was ground with a round diamond bur, and the site healed completely after 20 days of increased use of chlorhexidine. These complications were considered minor, yielding a 20% minor complication rate. Patient 6 reported an inflammatory acute process involving the distal fixation screw in the second week after augmentation. This patient was reoperated with local anesthesia for the removal of screw and inflammatory tissues. Considerable loss of the grafted bone (68.7% at the time of implant placement) necessitated the use of shorter implants to complete the treatment. This was considered to be a major complication because it modified the original treatment plan, producing a 10% major complication rate.

Eight patients did not report subjective signs of impaired lip or chin sensation after the augmentation procedure; however, patients 8 and 9 reported hypoesthesia immediately after the augmentation procedure in the ipsilateral lip and chin region that was characterized by progressively increasing numbness and tingling. These sensitivity alterations persisted for 6 months after the augmentation procedure in patient 8 and lasted until the end of the follow-up period in patient 9.

The recovery of the graft donor sites was uneventful in all cases and, at the end of the follow-up period, the cumulative implant survival rate was 100%. Three of the twenty-three implants exhibited peri-implant bone resorption >1.5 mm in the first year after prosthetic loading; therefore, the cumulative implant success rate was 86.9%. Only patient 8 (implant #37) showed complications between implant placement and implant loading. In this patient, peri-implantitis was observed and resolved with local debridement before loading.

The median cumulative peri-implant bone resorption was 0.85 mm (range, 0.2–2.8 mm), and the median follow-up periods from the start of prosthetic loading was 17.5 months (range, 13–22 months). All patients showed acceptable function of the implant-borne prosthesis, and no complication occurred during the period between implant loading and the end of follow up. Table 4 reports in details the clinical and radiographic outcomes of the onlay group.

The overall median follow-up period from the start of prosthetic loading was 18 months (range, 13–22 months). No significant difference in the starting bone height was observed between groups ($p = .910$); however, the onlay group showed greater vertical bone gain ($p = .019$) and greater vertical bone resorption ($p < .001$). In terms of final vertical augmentation (subtracting bone resorption from bone gain values for each

TABLE 3 Inlay Group: Outcomes with Regard to Clinical and X-Ray Parameters and Complications

Patient no.	Vertical bone gain (mm)	Vertical bone resorption (mm)	Vertical bone resorption %	Vertical graft resorption	Final vertical augmentation	Implant survival %	Implant success %	Complication before implantology
#1	5.3	0.4	7.5	0.0	4.9	100%	50%	none
#2	5.6	2.9	51.8	0.0	2.7	100%	100%	dehiscence
#3	6.7	0.9	10.4	0.0	5.8	100%	100%	none
#4	7	0.7	10	0.0	6.3	100%	100%	dehiscence
#5	4.2	0.7	21.4	0.1	3.5	100%	100%	none
#6	4	0.2	5	0.0	3.8	100%	100%	none
#7	6.3	0.3	4.8	0.0	6	100%	100%	none
#8	4.4	0.5	11.4	0.1	3.9	100%	100%	dehiscence
#9	4.5	0.1	2.2	0.0	4.4	100%	100%	none
#10	4.4	0.5	11.4	0.0	3.9	100%	50%	none

TABLE 4 Onlay Group: Outcomes with Regard to Clinical and X-Ray Parameters and Complications

Patient no.	Vertical bone gain (mm)	Vertical bone resorption (mm)	Vertical bone resorption %	Final vertical augmentation	Implant survival %	Implant success %	Complication before implantology
#1	7.9	3.6	45.5	4.3	100%	100%	dehiscence
#2	6.4	4.4	68.7	2	100%	100%	dehiscence
#3	5.1	2.6	59	2.5	100%	100%	none
#4	6.4	2.7	42.1	3.7	100%	100%	none
#5	8	3.1	38.7	4.9	100%	50%	none
#6	7	4.7	67.1	2.3	100%	100%	infection
#7	6.7	2.2	32.8	4.5	100%	0%	none
#8	5.7	1.3	22.8	4.4	100%	100%	none
#9	4.7	1.4	29.7	3.3	100%	100%	none
#10	7.3	2.8	38.3	4.5	100%	50%	none

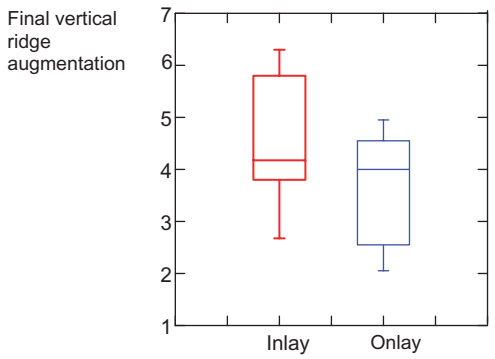

Figure 11 Box and whisker plots showing final vertical ridge augmentation in the inlay versus onlay group upon implant insertion. Each plot shows the median, interquartile range, and outliers.

group), the two techniques produced comparable results ($p = .190$) (Figure 11).

With regard to intergroup observations across the three follow-up examinations for both the inlay and onlay groups, a statistical difference ($p < .001$) was found (Friedman's test); therefore, both of the methods are effective. The distribution of bone height in the inlay versus onlay group at various stages is presented in Figure 12.

Peri-implant bone resorption at the end of the follow-up period was similar between groups ($p = .971$), as was the implant success rate ($p = .190$). In addition, both groups showed similar complication rates before implant placement and implant survival rates.

DISCUSSION

Inlay technique provides superior bone graft incorporation than the onlay method by assuring blood supply by the cranially displaced segment and protecting the graft from direct functional loading.[8,11,22,24–28] However, successful correction of vertically deficient atrophic ridges has also been reported with the onlay technique,[2,3,14,29] which offers greater flexibility in approaching defects with complex morphologies.[3] Recently, inlay bone grafting produced good results in atrophic posterior mandibles,[1,10–13,19,30] whereas only two studies reported treating these surgical sites with the onlay technique.[2,3]

The decision to use extra-oral harvesting from the iliac crest was related to the severity of the defects to be treated, and is supported by good histological outcomes reported in the mandible using both the onlay[15] and inlay[1,19] techniques.

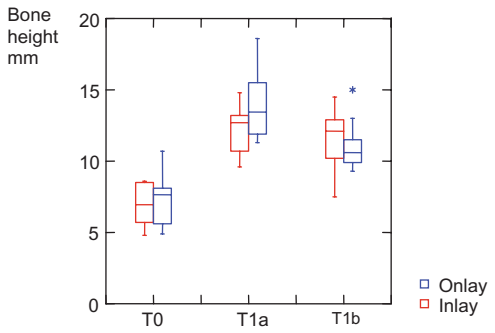

Figure 12 Box and whisker plots showing the distribution of bone height in the inlay versus onlay group at various stages (T0 = pretreatment; T1a = immediately after surgery; T1b = 3–4 months postoperatively, immediately before implant placement). Each plot shows the median, interquartile range, and outliers.

Minimum Native Bone Height above the Alveolar Nerve

To perform the inlay technique, the minimum bone height above the mandibular canal is 4 mm.[11] Based on our results and those of previous studies,[1,12,13] a minimum bone height of 5 to 6 mm above the mandibular canal is required to avoid complications such as resorption or fracture of the transport segment[31] or inferior alveolar nerve damage.[32] A minimum bone height has not been reported for the onlay technique in posterior mandible.

Bone Gain

The inlay technique has recently shown good outcomes in the augmentation of posterior atrophic mandibles, with postoperative vertical bone gain values of 4 to 8 mm.[1,10–13,19,30,33] This study corroborates these results. In various regions of the jaw, the onlay technique provided a mean bone gain of 4.22 mm (range, 0–15 mm),[11] with extra-oral harvesting, and from 3.4 ± 0.66 mm at 1 month postsurgery[2] to 6.12 or 5.12 mm at 4 to 6 months postsurgery with bone blocks taken from the symphysis or ramus regions, of the mandible, respectively.[34] In the posterior mandible, increases from a mean of 2.4 mm (range, 2–3 mm)[2] to a mean of 4.6 mm (range, 3–6 mm)[3] have been obtained with intra-oral bone harvesting. Our results, higher than those reported in literature, may be related to the greatest amount of bone harvested from the iliac crest.

The increase in bone gain in the onlay compared with the inlay group may reflect the fact that the onlay procedure allows clinicians to apply a higher bone block, while taking care not to cause excessive soft tissue strain. In the inlay technique, the presence of the upper

transport segment and the necessity of maintaining the integrity of the lingual periosteum may limit vertical augmentation.

Bone Resorption

In the posterior mandible, Bianchi and colleagues[13] reported a median crestal bone resorption of 0.9 mm (range, 0.5–1.2 mm) at 3 to 4 months postoperatively when using the inlay technique; this accounted for 14.2% of the obtained bone gain. A split-mouth study recently reported a mean resorption of 1.1 mm with an iliac bone graft and 0.6 mm with bovine anorganic bone 4 months after grafting. The bone resorption of the augmented ridge encountered in this study, 10.2% of obtained bone gain, was almost completely attributable to the transport segment, based on data showing that interposed graft resorption was almost 0 for all treated sites.

In cases treated using iliac grafts at various jaw sites, resorption values for the inlay technique ranged from 12 to 60% at 1 to 5 years after loading.[35] In the posterior mandible, the onlay technique with intra-oral graft harvesting resulted in resorption from 0.6 mm (13% of bone gain)[3] to 1 mm (43.5% of bone gain)[2] before implant placement.

Notably, we observed significantly greater bone resorption in the onlay group (40.4% of the obtained bone gain) than in the inlay group. Considering the lack of vertical reduction in the interposed graft, the minimal bone height reduction observed in the inlay group may be attributable to resorption of the transport segment or to its arrangement during the healing period. These results confirm the results of previous studies.[8,11,12,25–29,36,37] On one hand, the interposed graft is well incorporated in the recipient site, it is not subjected to functional loading, and shows minimal resorption; on the other hand, a coronally displaced native bone fragment attached to its own soft tissues is less prone to resorption than a superimposed free non-vascularized bone graft. Of note, however, was the observation that the two techniques were comparable in terms of final vertical augmentation.

Peri-Implant Bone Resorption, Implant Survival, and Success Rate

For the inlay technique, the overall implant survival rate in atrophic mandibles ranges from 90 to 95%.[35] In the posterior mandible, implant survival and success rates of 90% at 1 to 4 years post-implant placement[11] and survival and success rates of 100 and 95.2%, respectively, after a median postloading period of 22.5 months[13] have been reported.

Regarding the onlay technique, cumulative implant survival rates of 60, 76, and 100% have been reported,[35,38] whereas success rates ranging from 83 to 100% have been obtained, independent of the jaw treatment site, duration of follow up, and bone graft harvesting.[34] The overall survival rate of implants placed in reconstructed mandibles is 94.5% (range, 88.2–100%).[35] According to a literature review,[39] 88% of 753 implants placed on iliac crest bone grafts survived when using the onlay technique. In the posterior mandible, the onlay technique with intra-oral graft harvesting resulted in cumulative survival and success rates of 100% and 89.5 to 100%, respectively, after mean follow-up periods of 38 and 12 months postloading.[2,3] Our results are in line with correspondent ones above mentioned both for inlay and onlay techniques in the posterior mandible.

The median value for cumulative peri-implant bone resorption from implant placement to the end of the follow-up period, 0.85 mm (range, 0.2–1.4 mm), is comparable to those reported by Chiapasco and colleagues[3] (0.9 and 1.2 mm at 1 and 2 years postloading, respectively), but results are higher than those reported by Levin and colleagues[40] (mean, 0.22 mm). Additionally, the survival and success rates of implants placed in the treated areas were comparable between groups and with those obtained in native bone.

Complication Rate before Implant Placement

Only a case of major complication has been reported for the inlay technique applied to the posterior mandible: a transport segment fracture with complete failure of the augmentation procedure.[1] Regarding minor complications, the occurrence of a single spot of buccal dehiscence with plate exposure has been reported in 10, 7, and 6 surgical sites,[11–13] and dehiscence on the buccal and lingual sides have been reported at 20 treated sites.[1]

Of the three cases of postsurgical dehiscence in the inlay group recorded in this study, one case, involving a significant bone resorption, represented a major complication.

Regarding neurological complications, two previous studies on six patients did not report any sign of impaired sensitivity with iliac crest inlay grafting in the posterior mandible.[12,13] In contrast, Jensen[11] and Felice and colleagues[1] reported transient postsurgical

paresthesia in all of their patients; impaired sensitivity lasted up to 6 weeks[11] and 13 days,[1] respectively. Our neurological impairments, limited to four patients, did not persist longer than 3 weeks.

Generally, uneventful healing/consolidation has been reported for the majority of patients (90–100%) treated via the onlay technique, with dehiscence and partial/total loss of the graft reported in only 3.3 and 1.4% of patients, respectively.[35] Other authors have reported a 38.5% complication rate in vertical bone augmentation using an onlay bone graft.[14] In the posterior mandible, one case of eight reported showed graft exposure and partial loss of the graft 2 months after reconstruction, and implant placement was subsequently performed using shorter implants.[3] In contrast, other authors did not report complications at this site.[2]

Paresthesia in the area innervated by the inferior alveolar nerve was previously observed in three of eight patients and persisted until the end of the follow-up period in one case (3 years after surgery), but this complication was attributed to the harvesting procedure from the chin.[3] In our study, two patients complained of sensitivity impairment, lasting in one case till the end of follow-up. The rate of complication in our study, the same for inlay and onlay, may be considered low for both groups.

CONCLUSIONS

This comparative study suggests that the inlay and onlay techniques provide adequate correction of vertical deficits in atrophic posterior mandibles, with acceptable complication rate and implant results similar to those in native bone.

The inlay technique is associated with lower bone resorption values and produces more predictable outcomes, but requires an experienced surgeon. The onlay technique results in higher bone resorption values before implant placement and requires a bone block graft that is oversized in height, with respect to the desired final vertical augmentation; however, it has a shorter learning curve. Once implant placement has been carried out, the outcomes are similar for both graft procedures; this demonstrates that the type of augmentation technique performed has no effect on the maintenance of vertical bone after implant-loading. Considering the lack of published data, we believe that the personal experience of the surgeon should dictate which technique is to be used in the posterior mandible.

CONFLICTS OF INTEREST STATEMENT

The authors have declared no conflicts of interest. [Correction added after online publication 23 October 2009: Conflicts of Interest Statement added.]

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