Luigi Canullo, Angelo Sisti

Early implant loading after vertical ridge augmentation (VRA) using e-PTFE titanium-reinforced membrane and nano-structured hydroxyapatite: 2-year prospective study

Luigi Canullo, DDS
Department of Orthodontics and Prosthetics, University of Bonn, Germany

Angelo Sisti, DDS
Private practice, Piacenza, Italy

Correspondence to:
Luigi Canullo
Via Nizza, 46
00198 Roma, Italy
e-mail: luigicanullo@yahoo.com

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Aims: This 2-year prospective multi-centre study aimed to evaluate the survival of implants loaded 14 weeks after vertical ridge augmentation (VRA).

Materials and methods: Twenty consecutive patients scheduled for VRA around implants were selected for this study in three private centres. Nano-structured Mg-enriched hydroxyapatite (Mg-e HAP) was used as the only augmentation filler material. It was covered with a titanium reinforced extended polytetrafluoroethylene (e-PTFE) membrane (Gore-Tex). A total of 42 rough-surface implants were inserted in the same surgical session. Healing abutments 2 mm long were used instead of cover screws to optimise aesthetics. All patients underwent a second surgery after 3 months. Thereafter, definitive restorations were seated within 2 weeks using a platform-switching concept. Outcome measures were amount of vertical bone gain, prosthesis and implant success, complications and radiographic marginal bone level changes assessed at 12 and 24 months of prosthetic loading. Frequency resonance analysis expressed using ISQ (implant stability quotient) values was performed at implant insertion (T0), when definitive restoration was seated (T1) and after 24 months of prosthetic loading (T2).

Results: At the end of the study, no patient dropped out, all implants were clinically stable and no prosthesis failed. Initial clinical evaluations showed an average defect height of 4.1 mm. Only one late membrane exposure was registered. Complete bone filling of the regeneration volume was obtained in 19 out of 20 cases. The mean bone height gain was 5.6 mm. Radiographic assessments of inter-implant regenerated bone levels after 24 months of loading presented a mean value of 1.0 mm (SD 0.48 mm), stable compared to the same analysis at the 12-month follow-up. A statistically significant loss of peri-implant bone level occurred over time. Mean peri-implant bone levels were 0.3 mm at the time of prosthetic loading, 0.90 mm after 1 year and 0.98 after 2 years. ISQ values statistically significantly increased over time. At implant placement the mean ISQ value was 49.3, at delivery of the final restoration it was 63.9 and after 2 years of loading it was 73.6.

Conclusion: This clinical study suggests that VRA around rough-surface implants using e-PTFE membrane and nano-structured Mg-e HAP can be successful even in cases with early loading.

Introduction

Local conditions of the edentulous alveolar ridges may be unfavourable for implant placement in accordance with Albreksson's principles[1]. In particular, a relevant vertical defect of the alveolar ridge may render the use of dental implants difficult or impossible due to an insufficient bone volume to insert dental implants of adequate dimensions.

In the past decade, guided bone regeneration (GBR) provided a tool for the dental surgeon to augment atrophic edentulous ridges in order to place implants in the preferred place[2]. GBR is based on an occlusive membrane that spans the space to be augmented, preventing soft tissue penetration from above and providing a space for the osteogenic cells to migrate into from the residual bone. The sequence of new bone formation has been shown histologically[3]. Hämmerle[4] demonstrated that at least 4 months were needed to give evidence of significant bone regeneration with mineral tissues.

Titanium re-enforced barrier membranes (extended polytetrafluoroethylene, ePTFE) allow for space maintenance by the membrane and the undisturbed formation of new bone tissue underneath. In fact, Simion[5] suggested that the outcome of the GBR procedure is more predictable when grafting materials are used. These findings were supported and summarised in a long-term retrospective multicentre study with 5 years of follow-up. In this study, 123 implants were inserted using a vertical ridge augmentation (VRA) procedure. Although controversial[6] and not supported by higher quality studies, the results demonstrated that VRA has a positive long-term effect and can be successful when a non-resorbable titanium-reinforced membrane is used, at least if a 6-month healing period is granted and an adequate filler material is chosen[6].

The chosen filler material may influence the outcome of the augmentation procedure. For a long time, autogenous bone was considered the gold standard, but it involves a second surgery to harvest the bone and therefore extra morbidity for the patient. The use of deproteinised bovine bone as the filler material, either in combination with autogenous bone or by itself, has shown good and reproducible results after 6 to 9 months of healing in VRA procedures[7-9].

Clinical investigations have shown that the new generation of hydroxyapatites (so called 'nano-structured' due to the size of their interconnected porous structure) have osteoconductive and biomimetic properties and could be integrated into the host's physiological bone turnover even at a very early stage[10,11]. In particular, magnesium-enriched hydroxyapatites (1.23% in Mg) showed an increased solubility compared to traditional hydroxyapatites and histological and histomorphometric results comparable to autologous bone in regenerative procedures[12-15].

This 2-year preliminary prospective multi-centre study aimed to evaluate bone regeneration around rough-surface implants loaded 14 weeks after VRA using nano-structured Mg-enriched hydroxyapatite (Mg-e HAP) covered by an e-PTFE membrane. It also evaluated radiographically and clinically the longitudinal stability of the implants and grafted bone after 24 months of prosthetic loading. This study followed the guidelines for observational studies (STROBE: http://www.strobe-statement.org/).

Materials and method

Patient enrolment

In three private centres (Rome 1, Rome 2 and Piacenza, Italy), three skilled surgeons recruited 20 consecutive patients with vertical bone deficiency in need of a fixed implant-supported prosthesis for the present study. All patients were in good general health and underwent comprehensive dental care and were instructed to maintain a high level of oral hygiene. Inclusion criteria were:

- need for fixed implant-supported prosthesis in maxilla and mandible with vertical bone defects
- age > 18 years
- no relevant medical conditions
- non-smoking or smoking ≤ 10 cigarettes/day (pipe or cigar smokers were excluded)
- Full Mouth Plaque Score and Full Mouth Bleeding Score ≤ 25 % (measured at 4 sites per tooth)
- presence of native bone height of at least 3 mm to achieve primary stability
- never treated with bisphosphonates

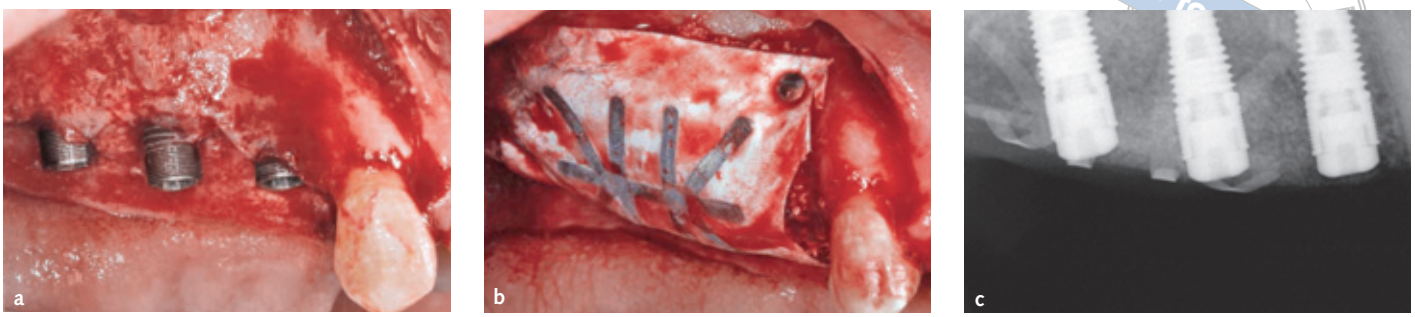


Fig 1 The pictures of a single patient are used to represent the surgical procedure: a) implants placed into severely atrophic maxillae (buccal view), b) membrane completely covering the defect and c) post-surgical radiograph showing the 2 mm cover screw and the defect completely filled by the graft material.

Surgical protocol

First stage surgery

The patients received antibiotic prophylaxis (amoxicillin and clavulanic acid 1 g, every 12 h, starting 1 day preoperatively) in association with 0.2% chlorhexidine gluconate mouth rinse (every 12 h, starting 1 day preoperatively) for 7 days.

The surgery was carried out after administering local anaesthesia (Ultracain DS Forte, Hoechst), which was combined with a sedative pre-medication (Delorazepan, 5 mg orally 30 minutes before surgery). The surgical procedure was carried out as described in the literature[10]. A full-thickness incision was made within the keratinised gingiva from the distal aspect of the first mesial tooth to the distal end of the edentulous ridge. The incision was extended intrasulcularly and anteriorly to the mesial aspect of the second last residual tooth. Vertical releasing incisions were made at the mesiobuccal angle and at the distal aspect of the crestal incision. The buccal and the lingual flaps were reflected with a periosteal elevator, avoiding damage to the anatomical structures. Once exposed, the cortical bone was curetted with a back-action chisel in order to remove all residual connective tissue and the periosteum. Immediately after curettage, releasing incisions were made at the base of the periosteum of the buccal flap to enhance the elasticity of the flap for achieving a tension-free adaptation of the soft tissue at closure.

Using a surgical stent, one to three implants (Global Implant System, Sweden & Martina, Padua, Italy) with a diameter of 4.3 mm were placed. The root-shape implant used in the present study presented a complete length sand-blasted and acid-etched surface. In the coronal zone, mini-threads were present (Fig 1a).

To obtain better primary stability, an undercontoured osteotomy was carried out (last drilling bur: 3.4 mm). In cases where the implant could not be properly seated, it was removed and the site re-prepared with a 3.8 mm bur.

Implant platforms were positioned in a vertical position located at the marginal buccal bone level of the mesial tooth (Fig 1a). The distance observed between implants and teeth was at least 2 mm, and the distance between implant and implant was at least 2.5 mm.

The bone defect was measured using a modified periodontal probe measuring the buccal distance between bone crest and the implant platform.

Healing abutments 2 mm long and 3.8 mm in diameter were used instead of the traditional 0.5-mm-long cover screw to vertically implement the tent effect. It theoretically would lead to increased bone regeneration, recreating an interproximal bone peak in cases of multi-implant rehabilitation.

A titanium-reinforced GTAM Gore-Tex® membrane (W. L. Gore & Associates, Flagstaff, AZ, USA) was shaped in order to adapt to the vertical defect and to not touch the distal margin of the mesial teeth. Two mini-nails were used to lingually fix the membrane in order to achieve optimal stabilisation. The augmentation material (Sintlife 600 to 900 µm, Finceramica, Faenza, Italy) was mixed with an antibiotic solution (Lincocin 600 mg, Pharmacia Italia, Italy) and plugged under the membrane. The defect was completely filled, buccally overcontoured and covered by the membrane. Finally, the membrane was buccally fixed (Fig 1b).

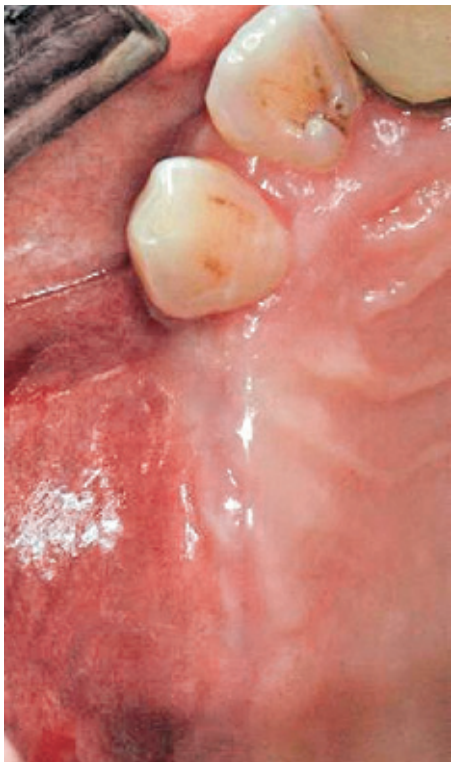


Fig 2 Soft tissue healing just before the second surgery.

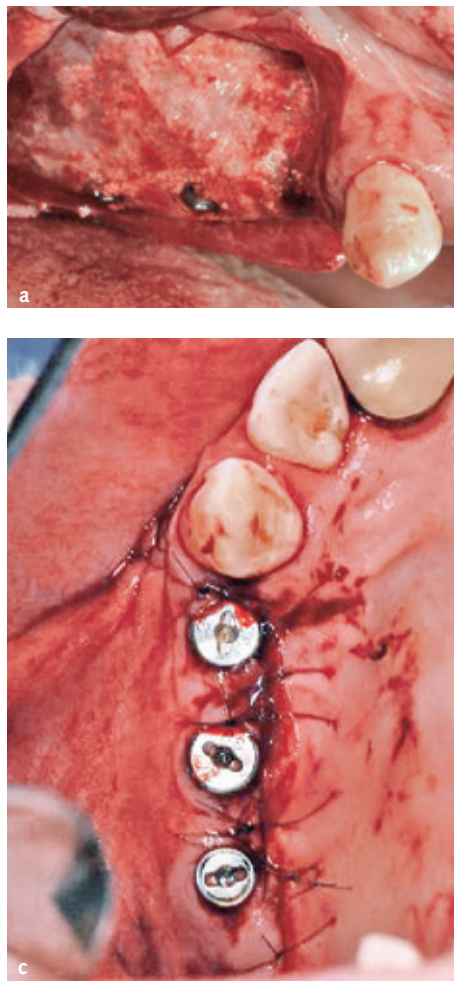


Fig 3 Second surgery 3 months after implant insertion: a) regenerated hard tissues, buccal view, 2 mm cover screws are completely covered, grafted material granules are still visible in the periphery of the regenerated bone; b) regenerated bone, occlusal view; c) soft tissue adaptation and healing abutment insertion; and d) periapical radiograph showing the inter-implant vertical regeneration over the implant platform.

The flap was closed by horizontal mattress sutures (Gore-Tex 5.0, W. L. Gore & Associates) with alternating interrupted sutures (Polinyl 6.0, Sweden & Martina) and a periapical radiograph was taken (Fig 1c).

In order to decrease swelling and pain, the patient received corticosteroid therapy (Bentelan 1 mg, Sigma Tau, Italy) for 3 days and non-steroidal anti-inflammatory drugs for 4 days.

The sutures were removed after 14 days, following application of 0.2% chlorexidine gel for 2 minutes to reduce bacterial contamination of the wound. After suture removal, patients were checked once a week for the first month and then once a month until stage 2 surgery.

Second stage surgery

After 3 months of submerged healing, re-entry surgery was performed (Figs 2 and 3a). After membrane removal, the thickness of the soft tissue layer was measured. Vertical bone regeneration was assessed with a periodontal probe measuring the vertical distance between the implant platform and the regenerated bone crest rounded to the nearest half mm (Fig 3b and c). Healing abutments were screwed onto the implants and flaps were sutured using a soft tissue enhancement technique[16] to minimise interproximal bone remodelling (Fig 3b) and periapical radiographs were taken (Fig 3c and d).

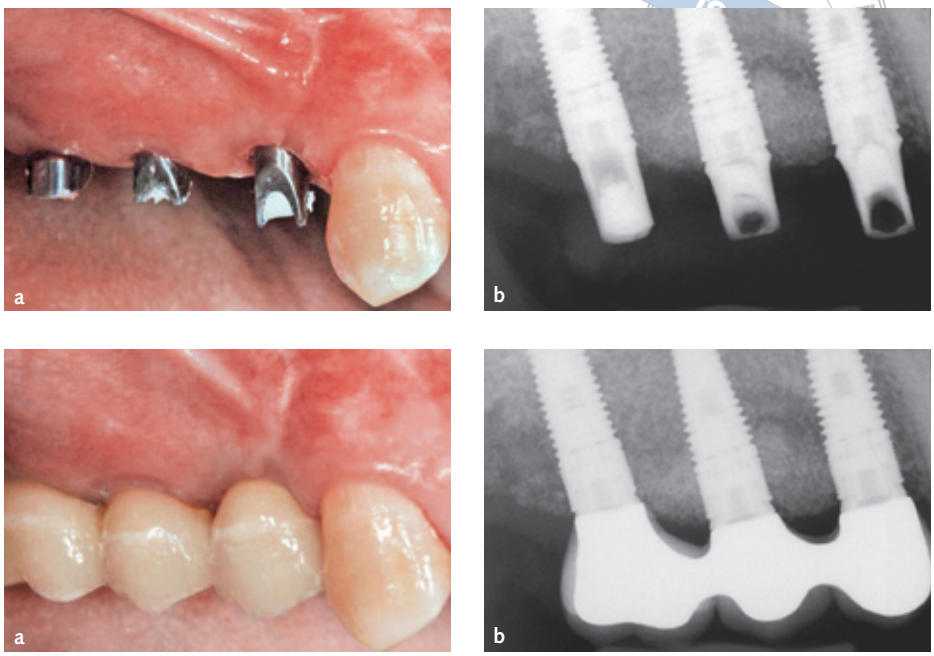


Fig 4 Provisional restoration: a) definitive abutments screwed at 20 Ncm, 2 weeks after second surgery and b) radiograph showing the inter-implant vertical regeneration over the implant platform before definitive restoration.

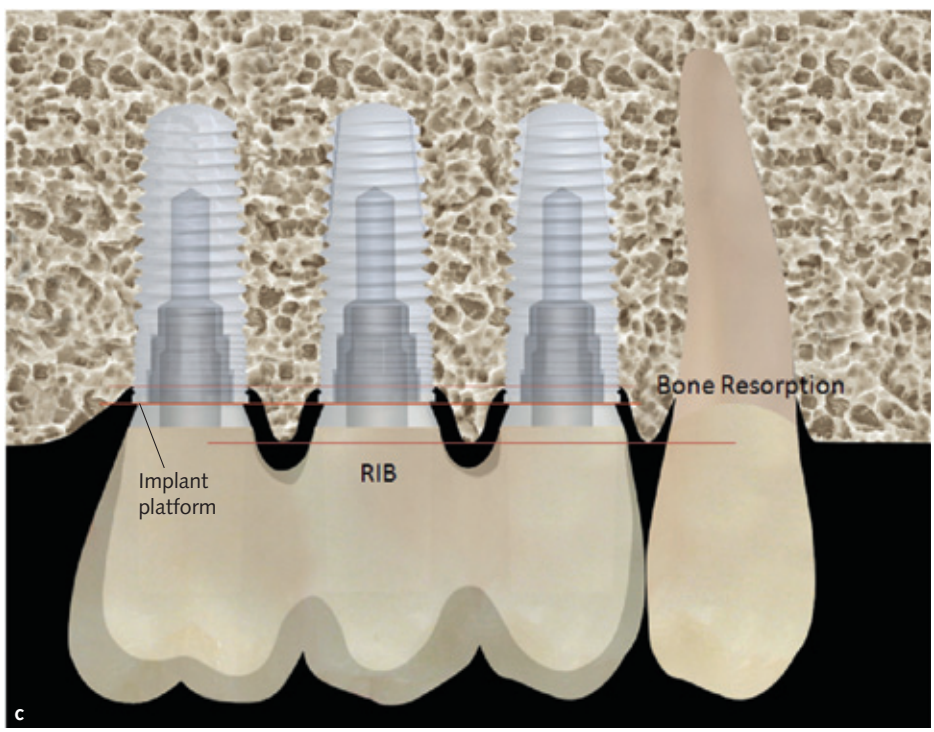
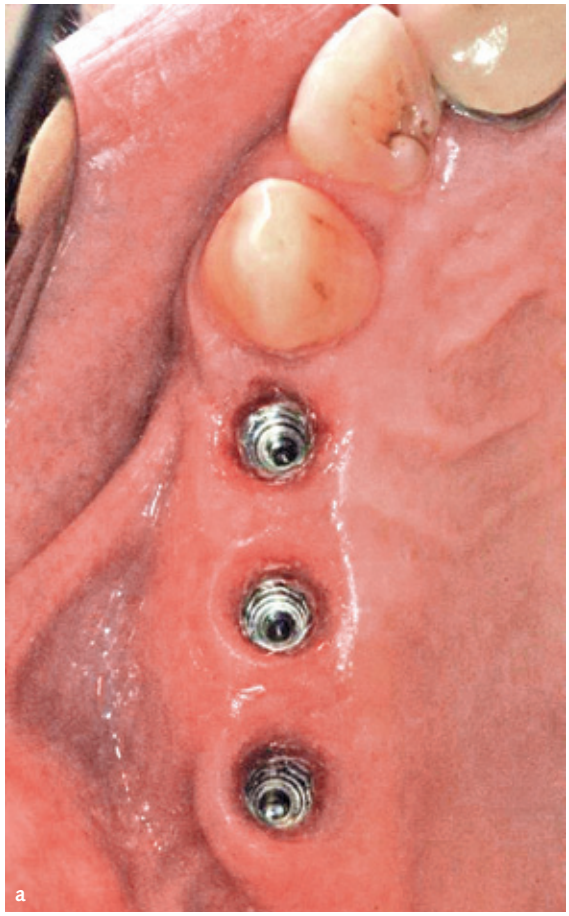


Fig 5 Definitive restoration after 24 months of prosthetic loading: a) definitive restoration, b) peri-apical radiograph after 24 months of prosthetic loading demonstrates well-integrated implants and successful vertical bone augmentation (shrinkage of the inter-implant regenerated bone [RIB] can be noted compared to second surgery radiograph and minimal peri-implant bone loss can be detected) and c) illustration of the radiographic measurements performed at the annual follow-up and compared to baseline. The implant platform was used as reference in RIB assessments.

One to 2 weeks later, definitive restorations were seated (Fig 4a and b) on abutments of 3.8 mm diameter, according to the platform-switching concept. Every 6 months, patients were recalled for professional oral hygiene.

Annual implant evaluations

All patients underwent a follow-up recall after 12 and 24 months of prosthetic loading. At each visit, clinical evaluation (prosthetic and implant failures, complications) and periapical radiographs (taken with a radiographic stent) were made (Fig 5a and b).



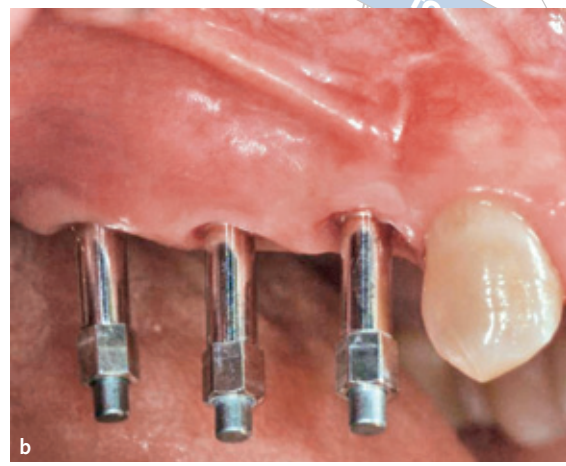


Fig 6 Resonance frequency analysis (RFA): a) healthy appearance of soft tissues after 24 months of prosthetic loading and presence of inter-implant papillae can be demonstrated and b) smart pegs used for RFA.

Radiographic analysis

A radiographic analysis was performed to evaluate the peri-implant regenerated bone. Using software (Autocad 2006, version Z 54.10, Autodesk, USA) able to compensate for film distortions, baseline and 12- and 24-month follow-up radiographic inter-implant regenerated bone levels (RIB) were assessed[17]. The distance was measured, using as a reference an imaginary line connecting the implant platforms, and measured to the nearest 0.05 mm as described in Fig 5c.

Peri-implant bone levels at prosthetic loading and 1 and 2 years after loading were measured as the distance from the mesial and distal margin of the implant neck to the most coronal point where the bone appeared to be in contact with the implant, as described in Fig 5c. For each implant, mean values of mesial and distal records were calculated and then averaged at implant and patient level. All measurements were made in duplicate by two independent calibrated examiners. Calibration of blind examiners was performed on triplicate measurements before the beginning of the study. For each sample, mean values of first and second examiner records were used.

Implant stability measurements

Immediately after implant insertion (T0), resonance frequency analysis (RFA) (Osstell Mentor, Goteborg, Sweden) was carried out for each implant and the values were used as baseline. The transducer (type 48) was hand-screwed into the implant body as recommended by manufacturer. The RFA value is represented by a quantitative parameter called the implant stability quotient (ISQ). The ISQ ranges between 1 and 100. The measurements were repeated for each implant 13 weeks (T1) and 24 months after prosthetic loading (T2) (Fig 6a and b). Each measurement was taken twice and the mean value was used.

Statistical analysis

Descriptive statistics including mean values and standard deviations were used to describe changes in implant stability over time. Data was subjected to ANOVA, followed by Scheffe test. The level of statistical significance was set at $P < 0.05$.

Results

A total of 20 patients were recruited (9 men and 11 women) aged between 30 and 72 years (mean age of 59 years, SD 12).

Forty-two implants were inserted. In three patients only a single implant was placed. The first clinical centre (Rome 1, LC) treated a total of 10 patients with 20 implants. The second clinical centre (Piacenza, AS) treated five patients with 13 implants. The third centre (Rome 2, Francesca Tirocchi) treated five patients with nine implants. All patients were followed up for 24 months after prosthetic loading. No patient dropped out of the study.

Clinical results

Before the regeneration procedure, the bone defect, measured as the distance between the implant head and the native bone crest, was 2 to 7 mm (average 4.1 mm, SD 1.3).

In the first post-operative days, all patients showed moderate swelling. After 1 week, no inflammation symptoms or hematomas were detectable. After 14 days, sutures were removed. Healing was uneventful in all patients.

Only one late membrane exposure (8 weeks after first surgery) occurred in a patient provisionally restored using a resin-bonded prosthesis. Soft tissues presented moderate signs of inflammation and plaque was found over the exposed surface of the membrane. The membrane was immediately removed, in anticipation of the second surgery. Non-calcified tissue measuring 1.5 to 2 mm in thickness was found in the late exposure case (patient #5).

The ePTFE membranes were removed after a 12-week period and the results are listed in Table 1. At that time, the membranes appeared to be integrated with the surrounding tissues. Slightly bleeding thin soft tissue with integrated hydroxyapatite particles was present under 19 membranes (out of 20). In one case (patient #5), the soft tissue width under the barrier was up to 2 mm thick.

The adjacent tooth bone peak was maintained and, at the time of the second surgery, a connective-like soft tissue encapsulating granules of graft material was detected in 16 cases.

The average distance between the implant head and the new bone crest above the implant platforms after the regeneration procedure was -1.5 mm (SD 0.78 mm). This represented a mean bone height gain of 5.6 mm (SD 1.4 mm, range 3 to 9 mm).

In the 17 multiple implant cases, an interproximal hard tissue peak supracrestally to the implant platform presented a mean value of 1.7 mm (SD 0.65 mm, range 1 to 2 mm), with the exception of patient #5.

Radiographic results

At the time of the re-opening procedure, radiographic inter-implant bone level (RIB_0) presented a mean value of 1.7 mm (SD 0.65 mm) supracrestally. As shown in Table 1 at the last follow-up, 24 months after prosthetic loading, the radiographic inter-implant bone level (RIB_2) demonstrated 1.0 mm (SD 0.48 mm) of supracrestal regenerated bone, which was stable compared to the 12-month follow-up (RIB_1). In fact, no appreciable differences were noted when comparing 12- and 24-month follow-up radiographs.

From a statistical point of view, radiographic inter-implant bone level at RIB_2 was significantly lower compared to RIB_0 ($P < 0.05$). No statistically significant differences were found between RIB_2 and RIB_1. The radiographic analysis of the marginal bone level showed a cone of bone resorption all around the implant neck: at the time of prosthetic loading, peri-implant bone levels were 0.3 mm (SD 0.1 mm). After the 1- and 2-year follow-up, bone loss measured a mean value of 0.90 mm (SD 0.60 mm) and 0.98 mm (SD 0.42 mm), respectively (Fig 4b and 5b). Statistically significant marginal bone loss was found between baseline and the 1-year follow-up ($P < 0.05$). No statistically significant differences were found between the 1- and 2-year follow-ups.

Table 1 Results of vertical ridge augmentation.

Patient	Sex	Age	Implant position	Adjacent tooth	Bone defect	Buccal bone	Gain	RIB_0	RIB_2	ISQ T0	ISQ T1	ISQ T2
1	f	71	26	mesial	4	2	6			48	67	72
			27		4	1	5	2	1.3	40	61	72
2	m	46	26	mesial	6	2	8			66	68	75
			27		3	2	5	2	1.25	50	64	73
3	m	68	43	distal	2	2	4			48	62	75
			41		5	1	6	2	1.2	45	65	73
			32	distal	6	1	7	2	1.3	49	59	73
4	f	44	15	mesial	3	2	5			52	61	76
			16		4	2	6	2	1.25	47	58	74
			17		5	1	6	2	1.4	35	63	76
5	f	62	42	mesial	4	-1	3			50	63	70
			43	distal	4	-1	3	-1	-1	52	66	71
7	f	30	11	mesial/distal	6	2	8			57	69	75
8	f	67	12	distal	4	2	6			46	67	72
			22	distal	2	2	4	2	0.8	49	67	74
9	m	72	46	mesial	5	1	6			59	69	74
			47		5	1	6	1.5	0.9	55	63	71
10	f	65	15	mesial	3	2	5			58	67	78
			16		5	2	7	2	1.2	45	61	76
			17		5	1	6	2	1.1	40	62	75
11	f	65	25	mesial	4	2	6			50	60	72
			26		4	2	6	1.5	0.95	48	63	74
			27		4	1	5	1.5	1.1	46	60	71
12	m	65	33	distal	2	1	3			56	67	75
			31		4	1	5	1	0.75	58	67	77
			42	distal	2	0	2	2	1.05	63	65	77
13	f	47	12	distal	2	2	4			46	60	72
			11	mesial	3	2	5	2	1.4	48	61	70
14	f	72	24	mesial	4	2	6			48	66	77
			25		5	2	7	1.5	0.9	50	66	75
			26		5	1	6	1.5	0.9	48	64	71
15	m	56	21	mesial/distal	6	2	8			60	63	74
16	m	68	26	mesial	3	2	5			41	66	74
			27		3	2	5	2	1.3	43	61	73
17	f	49	15	mesial	6	1	7			47	63	77
			16		6	1	7	1.5	0.8	41	67	74
18	m	46	11	mesial/distal	7	2	9			32	55	74
19	m	52	15	mesial	4	2	6			49	66	71
			16		4	1	5	2	1.3	52	61	72
20	f	68	13	mesial	3	2	5			56	69	72
			14	distal	4	2	6	2	1	50	66	70
mean values		59			4.1	1.5	5.6	1.7	1.0	49.3	63.9	73.6
SD		12			1.28	0.78	1.4	0.65	0.48	6.94	3.27	2.14

bone defect: buccal bone deficiency at implant insertion using implant shoulder as reference (mm)

buccal bone: buccal bone at the time of membrane removal using implant shoulder as reference (mm)

gain: buccally regenerated bone (mm)

RIB_0: inter-implant bone height over the implant shoulder (mm)

RIB_2: radiographic inter-implant bone height over the implant shoulder after 24 months of prosthetic loading (mm)

ISQ T0: resonance frequency value at implant insertion

ISQ T1: resonance frequency value at membrane removal

ISQ T2: resonance frequency value after 2 years of prosthetic loading

ISQ results

As shown in Table 1, the ISQ mean value at baseline (T0) was 49.3 (SD 6.94). The ISQ T1 mean value was 63.9 (SD 3.27) and the ISQ T2 mean value was 73.6 (SD 2.14) (Fig 6a and 6b). From a statistical point of view, T0 was significantly lower compared to T1 ($P < 0.05$), and T1 was significantly lower compared to T2.

Discussion

The aim of this prospective clinical study was to evaluate the possibility of promoting vertical ridge augmentation in atrophic partially edentulous ridges by using a titanium reinforced ePTFE membrane (Gore-Tex) in combination with new generation hydroxyapatite, even in cases with early loading (14 weeks after implant insertion) with a follow-up of 24 months after loading.

It has been previously shown that it is possible to generate new bone vertically when autogenous bone chips with or without bone substitute materials are used in association with an e-PTFE membrane[6-8]. Similar results were obtained using deproteinized bovine bone as the only bone filler under titanium-reinforced Gore-Tex membranes[9,10]. By using a bone substitute, bone harvesting from a donor site can be avoided, thus reducing the invasiveness of the procedure and the patient discomfort in the post-operative period.

Nano-structured hydroxyapatite bone has been shown to be highly biocompatible and osteoconductive[10-15]. This new generation of hydroxyapatite, so-called biomimetic scaffold, simulates bone structure not only from a chemical point of view but also microscopically, reproducing micropores and their interconnections. In fact, their osteoconductivity has been widely demonstrated in the literature[12,14]. Within this category of graft material, hydroxyapatite partially substituted with Mg presents a non-stoichiometric structure and, being more similar to the bone mineral matrix, shows a nearly complete resorption in 6 to 12 months[18].

The use of non-resorbable membranes, due to their occlusive properties, seem to positively affect the bone regeneration pattern of the graft material. This combination, furthermore, seems to be stable. Minimal remodeling of inter-implant regenerated bone was observed after 2 years of prosthetic loading (1.7 mm at membrane exposure compared to 1.0 mm at the second radiographic follow-up). The exception is the physiological cone of resorption after abutment connection, lower than usual (1 mm) due to the prosthetic concept adopted for the rehabilitation, as shown in Fig 5b.

Clinical and radiographic findings have demonstrated new bone formation interproximally up to the implant shoulder level in cases of multiple implants. The use of a 2-mm-long cover screw instead of a traditional 0.5 mm cover screw increased the tent effect, thus allowing for the regeneration of the interproximal bone peak. The use of a cover screw longer than 2 mm could theoretically help in achieving a higher interproximal bone peak, but, on the other hand, could lead to an increased risk of membrane exposure. An individually customised cover screw with a different height might be suggested according to the patient bone defect, implant position and aesthetic demand.

According to the literature[5-9], although controversial[19,] during membrane removal, a soft tissue layer (ranging between 1 and 2 mm in thickness) has been observed between the membrane and the regenerated bone, indicating a periosteal-like soft tissue. The presence of this connective tissue layer might be correlated to incomplete bone regeneration in the most coronal part of the grafted area. However, in the present study, a soft tissue layer that was thinner than in previous studies (when present, approximately 0.5 mm) was only sometimes observed under the membrane.

No implant failed, and this success may be due to the implant design. Implant topography is relevant in cases of poor bone quantity at implant insertion sites. Moreover, a microscopically rough surface increases bone apposition.

In fact, surface characteristics of implants have been shown to influence their bone integration after simultaneous placement of implant and GBR membrane[20,21], enhancing cell adhesion. A platform-switching concept[17,22] was adopted in the present study, which may have had a role in the maintenance of the regenerated bone. It has been shown in the literature[17,22] that implants restored according

to platform switching may present lower marginal bone loss in both the vertical and horizontal component[23] compared to traditionally restored implants. In fact, despite 0.98 mm of peri-implant bone remodeling in the present study, and given a minimal inter-implant distance of 2.5 mm, a supracrestal regenerated bone peak of 1.0 mm was still present after 24 months of prosthetic loading.

Additionally, a microrough and nanorough titanium surface extending to the implant shoulder in conjunction with the platform-switching concept may provide osseous integration along the entire length of the implant. A fine thread may optimally distribute the occlusal load in the region of the implant neck, minimising further bone loss in this region[24].

Regarding resonance frequency analysis, the baseline ISQ mean value indicated a poor primary stability. However, even though the mean value at T0 was very low, the data reported at T1 are in line with previously reported studies. In fact, Lai et al[25] reported, for rough-surface implants installed after minor sinus floor elevation, ISQ values ranging between 66.8 and 69.2 at 12 to 16 weeks after surgery.

The statistically significant increase in ISQ values between T0 and T1 could indicate fast maturation of the graft after just 3 months, and seems to guarantee an adequate implant stability against occlusal loading. Additional increases between T1 and T2 could highlight, after 24 months of prosthetic loading, a further maturation of the osseointegration, probably also correlated to the occlusal loading.

Rigorous surgical technique and strict periodontal care at the follow-up appointments could be the most important factors associated with the high success rate observed in the present study. However, the lack of a control group and the small sample size limit the validity of the study.

Conclusions

Radiographic and clinical results showed that vertical ridge augmentation using a Gore-Tex titanium-reinforced membrane in combination with nanostructured Mg-e HAP can be a successful procedure for rebuilding a resorbed ridge in the early stage of healing.

Two years after loading, radiographic measurements showed a smaller bone resorption cone around the implant/abutment connection. ISQ analysis confirmed longitudinally an increase in implant stability.

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References

1. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11-25.
2. Buser D, Bragger U, Lang NP, Nyman S. Regeneration and enlargement of jaw bone using guided tissue regeneration. Clin Oral Implants Res 1990;1:22-32.
3. Schenk RK, Buser D, Hardwick WR, Dahlin C. Healing pattern of bone regeneration in membrane-protected defects: a histologic study in the canine mandible. Int J Oral Maxillofac Implants 1994;9:13-29.
4. Hämmerle CH, Schmid J, Olah AJ, Lang NP. A novel model system for the study of experimental guided bone formation in humans. Clin Oral Implants Res 1996;7:38-47.
5. Simion M, Jovanovic SA, Tinti C,Benfenati SP. Long-term evaluation of osseointegrated implants inserted at the time or after vertical ridge augmentation. A retrospective study on 123 implants with 1-5 year follow-up. Clin Oral Implants Res 2001;12:35-45.
6. Esposito M, Grusovin MG, Felice P, Karatzopoulos G, Worthington HV, Coulthard P. Interventions for replacing missing teeth: horizontal and vertical bone augmentation techniques for dental implant treatment. Cochrane Database Syst Rev 2009;4:CD003607.
7. Canullo L, Trisi P, Simion M.Vertical ridge augmentation around implants using e-PTFE titanium-reinforced membrane and deproteinized bovine bone mineral (bio-oss): A case report. Int J Periodontics Restorative Dent 2006;26:355-361.
8. Canullo L, Malagnino VA. Vertical ridge augmentation around implants by e-PTFE titanium-reinforced membrane and bovine bone matrix: a 24- to 54-month study of 10 consecutive cases. Int J Oral Maxillofac Implants 2008;23:858-866.
9. Rocchietta I, Fontana F, Simion M. Clinical outcomes of vertical bone augmentation to enable dental implant placement: a systematic review. J Clin Periodontol 2008;35(8 Suppl):203-215.
10. Götz W, Gerber T, Michel B, Lossdörfer S, Henkel KO, Heinemann F. Immunohistochemical characterization of nanocrystalline hydroxyapatite silica gel (NanoBone(r)) osteogenesis: a study on biopsies from human jaws. Clin Oral Implants Res 2008;19:1016-1026.
11. Canullo L, Dellavia C. Sinus lift using a nanocrystalline hydroxyapatite silica gel in severely resorbed maxillae: histological preliminary study. Clin Implant Dent Relat Res 2009;13 [Epub ahead of print].

12. Ducheyne P, Qiu Q. Bioactive ceramics: the effect of surface reactivity on bone formation and bone cell function. Biomaterials 1999;20:2287-2303.
13. Crespi R, Marani E, Benasciutti E, Capparè P, Cenci S, Gherlone E. Magnesium-enriched hydroxyapatite versus autologous bone in maxillary sinus grafting: combining histomorphometry with osteoblast gene expression profiles *in vivo*. J Periodontol 2009;80:586-593.
14. Ripamonti U. Soluble, insoluble and geometric signals sculpt the architecture of mineralized tissues. J Cell Mol Med 2004;8:169-80.
15. Trombelli L, Farina R. Clinical outcomes with bioactive agents alone or in combination with grafting or guided tissue regeneration. J Clin Periodontol 2008;35(suppl 8):117-135.
16. Palacci P, Nowzari H. Soft tissue enhancement around dental implants. Periodontol 2000 2008;47:113-32.
17. Canullo L, Rossi-Fedele G, Iannello G, Jepsen S. Platform switching and marginal bone level alteration: results of a randomized controlled trial. Clin Oral Implants Res 2010;21:115-121.
18. Mangano C, Scarano A, Iezzi G, Orsini G, Perrotti V, Mangano F et al. Maxillary sinus augmentation using an engineered porous hydroxyapatite: a clinical, histological, and transmission electron microscopy study in man. J Oral Implantol 2006;32:122-131.
19. Merli M, Migani M, Bernardelli F, Esposito M. Vertical bone augmentation with dental implant placement: efficacy and complications associated with 2 different techniques. A retrospective cohort study. Int J Oral Maxillofac Implants 2006;21:600-606.
20. Lima LA, Fuchs-Wehrle AM, Lang NP, Hammerle CH, Liberti E, Pompeu E, Todescan JH. Surface characteristics of implants influence their bone integration after simultaneous placement of implant and GBR membrane. Clin Oral Implants Res 2003;14:669-679.
21. Conner K-A, Sabatini R, Mealey B-L, Takacs V-J, Mills M-P, Cochran D-L. Guided bone regeneration around titanium plasma-sprayed, acid-etched, and hydroxyapatite-coated implants in the canine model. J Periodontol 2003; 74:658-668.
22. Prosper L, Redaelli S, Pasi M, Zarone F, Radaelli G, Gherlone EF. A randomized prospective multicenter trial evaluating the platform-switching technique for the prevention of post-restorative crestal bone loss. Int J Oral Maxillofac Implants 2009;24:299-308.
23. Rodríguez-Ciurana X, Vela-Nebot X, Segalà-Torres M, Calvo-Guirado L, Cambra J, Méndez-Blanco V, Tarnow DP. The effect of interimplant distance on the height of the interimplant bone crest when using platform-switched implants. Int J Periodontics Restorative Dent 2009;29:141–151.
24. Hermann F, Lerner H, Palti A. Factors influencing the preservation of the periimplant marginal bone. Implant Dent 2007;16:165-175.
25. Lai H, Zhang ZY, Wang F, Zhuang LF, Liu X. Resonance frequency analysis of stability on ITI implants with osteotome sinus floor elevation technique without grafting: a 5-month prospective study. Clin Oral Implants Res 2008;19:469-475.