Long-Term Results of Intraforaminal Immediately Loaded Implants and Posterior Mandibular Regrowth Evaluation in Severely Atrophic Mandibles

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Purpose: The aim of this clinical study was to verify the predictability of the rehabilitation of extremely atrophic jaws with immediately loaded short implants and evaluate posterior mandibular regrowth. **Materials and Methods:** A cohort of consecutive fully edentulous patients wearing complete dentures in both arches was enrolled. Periodically, implant survival and prosthetic success were assessed. After informed consent, a subsample of 10 patients who had preoperative CBCT underwent a postoperative CBCT 1 year after immediate implant loading, and 3D superimpositions of pre- and postoperative images were performed. Linear measurements of bone height were performed at two sites in each hemimandible and, on the same sections, bone density according to the qualitative gray values (GVs) was analyzed in an area of 3 mm^2 including the cortical mandibular bone. **Results:** Fifty-nine fully edentulous patients (31 females, 28 males) with Class VI atrophic mandibles according to Cawood and Howell were rehabilitated with the insertion of four to five short implants (4-mm diameter, 7- or 8.5-mm long). Overall, 251 implants were immediately loaded with a fixed hybrid prosthesis. Four patients did not show up for recall visits, bringing the final number down to 55 patients (31 females, 24 males) and 231 implants. In up to 14 years of follow-up, a total of 4 implant failures were recorded (cumulative survival rate, 98.4%). The biologic complications included 9 mucositis (3.9%) and 3 peri-implantitis (1.3%) at implant-level analysis. Mechanical complications involved 9 chippings of the prosthetic restorations (17.0%). In the 10-patient subsample, the analysis showed bone growth (average of 1.2 ± 0.7 mm) in the posterior areas of the mandible. In addition, bone density was found to increase 17% to 27% with reference to the preoperative CBCT. **Conclusion:** The immediate loading of short implants may represent a feasible therapeutic option for the treatment of fully edentulous patients with severely atrophic mandibles. Bone regrowth in the posterior areas and an increase in bone density of the mandible may occur. *Int J Oral Maxillofac Implants 2022;37:199–207. doi: 10.11607/jomi.9077*

Keywords: atrophic mandibles, immediate implant loading, implant survival

The use of a removable prosthesis to compensate tooth loss can determine the acceleration of residual alveolar bone resorption, especially in the mandible.[1] A recent study showed that the bone resorption continues in the posterior areas when overdentures retained by two intraforaminal implants are placed.[2] This process can gradually lead to severe mandibular atrophy that may require additional corrective surgeries.[3,4] However, these interventions can be invasive and contraindicated in medically compromised or elderly patients.[5]

Bone density of the jaws was first classified by Lekholm and Zarb[6] in 1985 on the basis of the ratio between cortical and cancellous bone. In was later classified by Misch[7] in 1990 on the basis of the clinical hardness of the bone; in 1999, Trisi and Rao[8] showed that the Misch classification is correlated with bone density. After the diffusion of CBCT in implant dentistry, a reliable bone density estimation was possible preoperatively.[9]

Full-arch fixed hybrid prostheses supported by either four or six implants without bone grafts could be a predictable therapeutic option.[10] In cases of extreme atrophy, the use of short implants (≤ 8.5 mm) can avoid the necessity for advanced bone regeneration with lower biologic complications and economic costs, and less discomfort.[11,12]

The aim of this clinical study was to verify the predictability of the rehabilitation of extremely atrophic mandibles with immediately loaded short implants (7 or 8.5 mm) and to evaluate posterior mandibular bone regrowth as described in the literature.[9]

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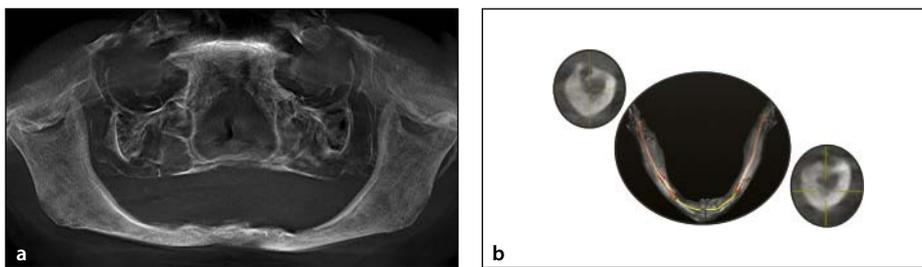
Fig 1 CBCT for anatomical structure identification and presurgical treatment planning. *(a)* CBCT reconstruction of the panoramic radiograph. *(b)* 3D reconstruction highlights the inferior alveolar nerve and the incisive nerve on both sides. The thickness of the cortical bone is seen at the cross sections.

MATERIALS AND METHODS

The sample consisted of a prospective single cohort of consecutive patients meeting the inclusion/exclusion criteria and treated between March 9, 2006 and June 16, 2018 at the Department of Implantology and Oral Rehabilitation, IRCCS Istituto Ortopedico Galeazzi (Milan, Italy). The study protocol was approved by the Review Board of the same institute (approval N. L2058).

Patients who met the following inclusion criteria were entered in the study:

- At least 18 years of age, of any ethnic origin
- Able to understand and sign an informed consent to allow the use of their clinical data in a scientific publication
- Physically and psychologically able to undergo implant surgery (ASA-1 or ASA-2 according to the classification of the American Society of Anesthesiologists)
- Totally edentulous mandibles, Class VI according to Cawood and Howell[13]
- Alveolar ridge in the intraforaminal area 7 to 9 mm high and at least 6 mm wide, in order to allow the placement of 4-mm-diameter implants

Patients presenting the following exclusion criteria were not included:

- Signs of infection at the sites selected for implant placement
- Uncontrolled systemic pathologies (eg, uncontrolled diabetes [HbA1c ≥8])
- Head and neck radiotherapy in the 12 months prior to surgery
- Drug abuse

The following variables were assessed:

- *Implant survival:* Implant in function, absence of mobility, pain, neuropathy, paresthesia, and peri-implantitis.
- *Prosthetic success:* Prosthesis in function and full satisfaction reported by the patients regarding the masticatory and phonation functions, evaluated through a questionnaire at 1- and 5-year follow-ups. Mandibular density and size were measured on CBCT before surgery and 1 year after prosthetic loading.
- *Bone density and bone growth:* On a subset of 10 patients, using the "best-fit" method.

Surgical/Prosthetic Phase

Implant placement in atrophic mandibles requires precaution, especially during surgery[13] because of the dense bone with a pronounced cortical component and poor medullary component[14,15] (Fig 1). The preparation of the implant osteotomy site is performed without perforating the lower border of the mandible to obtain bicortical anchorage, and a distance of at least 5 mm between implants is planned to avoid compromising the vascularity in the dense basal bone. Cylindrical implants with external hex (Osseotite Biomet 3i, Zimmer Biomet) were used in order to develop lower torque during insertion compared to tapered implants.

After local anesthesia with 4% articaine and a vasoconstrictor (adrenaline 1:100,000), a full-thickness flap was elevated. The incision was performed taking care to avoid damage to the mental nerve, which may be present on top of the ridge in patients with Cawood and Howell Class VI atrophy. The study of the anatomy by CBCT was therefore of paramount importance in planning the intervention. If the commonly accepted biologic inter-implant distance[16] could be respected, five implants were planned; otherwise, four implants were positioned. The implant sites were prepared with special attention: The burs were new with perfect cutting efficiency and the preparation was completed using bone taps at low speed (20 rpm) under abundant irrigation with sterile saline to reduce stress at the bone interface.

The implant sites were never underprepared in order to avoid mandibular fracturing during implant placement, and the insertion torque never exceeded 20 Ncm. If this value was reached before the implant was completely seated, the implant was removed and the site was reprepared. Implants were positioned in a straight fashion. Intermediate abutments were inserted, the healing caps were placed, and the flap was completely closed around the healing caps using an interrupted suturing technique.

At this point, the prosthetic phase began and immediate denture conversion was carried out: The engagement surface of the immediate denture was covered using bite-registration material, and the denture was placed over the ridge and pressed down to register the healing caps. After the material had set, the denture was removed and a fissure bur was employed to cut pilot holes in the indentations created in the bite-registration material. Keeping the bite-registration material in place, using a pear-shaped carbide bur, each of the holes was widened and the fit was checked until there was 2 to 3 mm of clearance completely around each healing cap. There should be adequate space between the denture and the healing caps. The bite-registration material was removed when this step was completed. Titanium cylinders were placed after the removal of the healing caps, and the denture was seated and a 2- to 3-mm clearance around each cylinder was verified. The height of each titanium cylinder was reduced, if necessary, using a titanium cutting disk or bur, to be at least 1 mm below the denture.

The sutures were protected from acrylic by placing around each cylinder a square-shaped piece of rubber dam material with a small hole punched in the center. A rolled polytetrafluoroethylene (PTFE) membrane material (Teflon tape) was placed in each titanium cylinder and was covered with a small piece of wax to prevent acrylic from infiltrating the abutment screw. The denture was seated back in the patient's mouth and then, using a small-tipped syringe, acrylic resin was flowed around each of the titanium cylinders to capture and pick them up in the denture. Excess material was wiped away from the occlusal surfaces and the top of the titanium cylinders.

The patient was then immediately guided into centric relation (CR) and held in the CR position until the acrylic material set. Once the acrylic material had set, the wax, Teflon tape, and cylinder screws were removed. The denture was removed from the patient's mouth with the titanium cylinders picked up. Any voids around the cylinders were filled, flanges and distal cantilevers were removed using a carbide bur, and all rough edges were smoothened and polished. Finally, the provisional prosthesis in the patient's mouth was seated and the screws hand-tightened. The patient's occlusion was checked, and any necessary adjustments were made (Fig 2a).

There are limitations in the present prosthetic procedure because it used the patients' previous denture, but due to the fact that the patients were wearing a full maxillary denture and all the patients had worn teeth, the conversion of the full denture into a fixed hybrid prosthesis resembles a sort of flat bite appliance. The goal of this phase was to provide immediate relief for the patients' main complaint: full paresthesia of the lower lip upon chewing with the removable prosthesis. In the study, the Balshi and Wolfinger (1996) protocol that originally was used at second-stage surgery was applied.[12] The final correct jaw position and the reestablishment of all the correct functional/esthetic prosthetic parameters were achieved later upon osseointegration of the implants, manufactudring a hybrid prosthesis with two teeth (a premolar and a small molar) cantilevered that accounted for a total cantilever length of approximately 15 mm.

During the postoperative period, the patient was instructed to assume a soft and fresh diet and avoid traumas at the operated area. The final prosthetic phase was carried out 1 year postoperatively; a hybrid prosthesis with titanium bar was constructed with one distal cantilever tooth (Figs 2b to 2d).

3D Assessment

A 1-year follow-up CBCT was proposed to all the patients via an informed-consent form. A subsample of 10 patients who had preoperative CBCT accepted to undergo a postoperative CBCT 1 year after immediate implant loading. 3D superimpositions of preoperative and postoperative images were performed as described by Capelli and collaborators.[17] All 10 patients used the same CBCT device for both analyses. The pre-/postsurgery analysis involved the use of the "best-fit" algorithm to superimpose and evaluate the bone surfaces; in order to do accurate measurements, CBCT exams were carried out using the same pre- and postoperative parameters. In this way, the bone segmentation, executed by setting the same gray-level threshold values for the two exams, grants a coherent result in the surface extraction, as well as volume calculation. After segmenting the bone parts, the result was exported in STL format and processed through a reverse engineering software (Geomagic Studio 12, Geomagic, PartnerAdvantage) by superimposing the files according to the bone regions not modified by the surgery. After selecting the common bone regions, the files were superimposed through a best-fit method that iteratively minimizes the distances between the respective common areas, giving the best possible result for the surface analysis. After the superimposition, the surface difference along the normal was calculated on all the regions, and the results were exported both as numerical values and as color maps for a more intuitive interpretation. Linear measurements of bone height were performed at two sites in each hemimandible by the same observer and, on the same sections, bone density according to the qualitative gray values (GVs) was analyzed in an area of 3 mm^2 including the cortical mandibular bone. Densitometry was evaluated at a specific region of interest (ROI) distant from any metallic artifacts.

Fig 2 Case illustration. *(a)* Immediate load prosthesis with no cantilever. *(b)* Definitive prosthesis at delivery (1 year after implant placement). *(c)* Orthopantomography with definitive prosthesis. *(d)* Extraoral photograph.

Follow-up

A follow-up visit was scheduled weekly for 1 month, then at 3, 6, 9, and 12 months after surgery. An implant-supportive therapy was scheduled every 3 months in the first year. If the patient was very compliant, this was scheduled every 4 months starting at the second year.[18] Outcome variables were recorded at each follow-up, including peri-mucositis (defined as bleeding on gentle probing, without bone loss)[19] and peri-implantitis (defined according to Weinstein et al, 2020).[20]

Data Analysis

Quantitative data were expressed as mean values ± 1 standard deviation, or as absolute and percentage values. Comparisons were made using parametric and nonparametric tests (Pearson chi-square) where appropriate. A Kaplan-Meier life table analysis was performed to estimate the cumulative implant survival rate. A P value of .05 was considered significant. Cumulative implant survival was estimated through a life table analysis. Post-hoc power analysis for a single sample was performed for bone height change to detect adequacy of the sample size (https://www.gigacalculator.com/calculators/power-sample-size-calculator.php).

RESULTS

Of the 59 patients included (31 females, 28 males), 8 patients were affected by diabetes and 12 patients by hypertension (with both conditions under control), and 1 patient had systemic lupus erythematosus. Six patients smoked up to 10 cigarettes per day, while 7 smoked more than 10 cigarettes. Mean patient age at surgery was 67.5 years (females) and 65.8 years (males); the difference was not significant ($P = .12$). All the enrolled patients were rehabilitated with a fixed hybrid prosthesis (CAD/CAM titanium framework and resin teeth) supported by four (44 patients) or five (15 patients) implants 7 to 8.5 mm in length.

A total of 251 hybrid cylindrical implants were placed (Osseotite Biomet 3i, Zimmer Biomet); all of them had a diameter of 4 mm; 162 were 7 mm and 89 were 8.5 mm in length. The implant distribution is shown in Table 1. The number of rehabilitated mandibles per year is reported in Table 2.

During the study period, 4 patients (4 males with 5 implants each) did not show up at the periodic follow-up visits, bringing the final number to 55 patients (31 females, 24 males) and 231 implants inserted. Out of these 4 patients, 1 died in 2012 after implants were

placed in 2006 (6-year dropout), 2 who underwent surgery in 2012 did not show up at controls after 2015 (3-year dropout), and 1 who had implants placed in 2009 did not show up at controls after 2015 (6-year dropout).

Implant Failures and Biologic and Mechanical Complications

Four implant failures occurred during the first year in patients where five implants were placed (Table 3). Three of the failures were at an intermediate site; the implants were removed and the prosthesis was repositioned on four implants. In one case, the failure was on a distal implant; the implant was replaced and a new prosthesis was manufactured. The failures could have been caused by premature loading, occlusal loading, or unknown reasons. The cumulative implant survival rate was 98.41%, as shown in the life table analysis (Table 4). The prosthesis survival rate was 98.18%. The biologic complications were nine mucositis (3.89% of inserted implants) and three peri-implantitis (1.3%), which were managed with nonsurgical treatment. No neurologic complications were reported in the dataset. The prosthetic complications were nine chipping of resin teeth (16.98%), which were repaired by sending the prostheses back to the lab. The large majority of patients (96.4% at 1 year and 98.2% at 5 years) expressed full satisfaction with phonation and function.

3D Assessment

Linear measurements performed in the cross sections of the pre- and postoperative CBCT exams showed a varying bone shape, with a mean of 1.2 ± 0.7 mm (Fig 3). Post-hoc power analysis showed a 98.4% power, suggesting that a sample size of 10 was adequate to detect the observed difference. The bone density was evaluated as a gray scale in two different areas of interest of 3 mm² in each mandible; an increase in bone density from 17% to 27% was observed (Fig 4).

DISCUSSION

In 1995, Keller published the results of a retrospective study that confirmed the validity of fixed or partially removable prosthetic rehabilitations supported by four or five implants, even in the long-term.[21] Moreover, in several studies the Stellingsma group has investigated the rehabilitation of atrophic jaws with different techniques,[12] concluding that the most predictable results are reached when implants are used without bone augmentation procedures in order to support an overdenture or fixed prosthesis.[5,13,22]

Furthermore, short implants (6 mm and 7 mm) exhibited higher survival rates than long implants placed

Table 1 Distribution of Implant-Supported Prostheses

Patients	7-mm-long implants	8.5-mm-long implants
35	4	–
9	–	4
8	–	5
2	2	3
2	3	2
3	4	1
Total 59	162	89

Table 2 Distribution of Implants and Prostheses Over the Years

Year	Rehabilitated mandibles	Positioned implants	
		Per year	Cumulative
2006	7	30	30
2007	4	16	46
2008	6	24	70
2009	9	38	108
2010	4	19	127
2011	5	21	148
2012	6	26	174
2013	2	9	183
2014	3	13	196
2015	2	9	205
2016	4	16	221
2017	5	22	243
2018	2	8	251
Total	**59**		

in autologous bone grafts. The use of short implants was introduced and discussed at the first Consensus Conference of the European Association for Osteointegration,[23] concluding that short implants can be used even in unfavorable sites associated with bone resorption or previous trauma. Although the number of failures seems higher in these situations, the results must be compared with those associated with regenerative surgical therapies. In the present study, the 7-year implant failure rate was 1.59%, in accordance with the literature data.[24]

The cutoff value for defining an implant as "short" is controversial and it has been decreasing over time from 10 to 7 mm.[23,25,26] In the present study, 8.5 mm was chosen as the cutoff because a 10-mm implant length was

Table 3 Characteristics of Failed Implants

Sex	Age at time of surgery (y)	Months in function	Implant site	Diameter (mm)	Length (mm)	No. of implants placed	Smoker	Cause of failure
M	68	4.7	Intercalated	4	8.5	5	Yes (> 10/day)	Unknown, premature loading or occlusal overload
F	73	4.9	Intercalated	4	7	5	Yes (> 10/day)	Unknown, premature loading or occlusal overload
F	65	9.6	Distal	4	7	5	Yes (> 10/day)	Unknown, premature loading or occlusal overload
F	57	8.1	Intercalated	4	7	5	No	Unknown, premature loading or occlusal overload

Table 4 Life Table Analysis

| Interval	No. of implants	No. of patients	No. of failures	No. of implants not observed at each follow-up	Interval survival rate (%)	Cumulative survival rate (%)
0–1 y	251	59	4	0	98.41	98.41
1–2 y	247	59	0	8	100.0	98.41
2–3 y	239	57	0	22	100.0	98.41
3–4 y	217	52	0	16	100.0	98.41
4–5 y	201	48	0	9	100.0	98.41
5–6 y	192	46	0	13	100.0	98.41
6–7 y	179	43	0	9	100.0	98.41
7–8 y	170	41	0	26	100.0	98.41
8–9 y	144	35	0	21	100.0	98.41
9–10 y	123	30	0	19	100.0	98.41
10–11 y	104	26	0	38	100.0	98.41
11–12 y	66	17	0	24	100.0	98.41
12–13 y	42	11	0	16	100.0	98.41
13–14 y	26	7	0	26	100.0	98.41
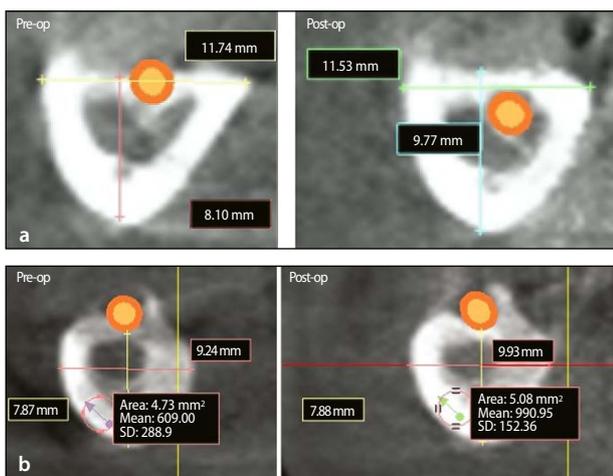
Fig 3 Calibrating the mandibular bone volume and bone density changes pre- and posttreatment. *(a) (left)* Pre- and *(right)* postoperative linear measurements showing mandibular bone volume increase. *(b) (left)* Pre- and *(right)* postoperative (1 year after loading) superimpositions of the 3D rendering obtained from CBCT.
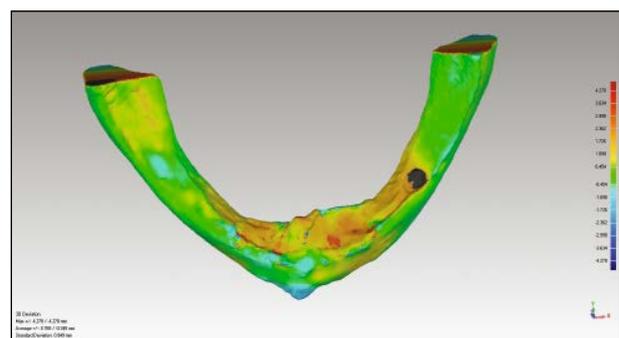

Fig 4 Qualitative gray values (GVs) were used to evaluate bone density in the same area before loading and 1 year after loading. The warm colors represent bony apposition areas, while the cold colors represent bone resorption.

commonly considered to be short at the time the study began.[27]

In some selected clinical cases, placement of tilted implants in atrophic mandibles allows a better implant distribution with a more favorable anteroposterior spread. As reported in literature, tilted implants have a survival rate similar to axial implants, avoiding anatomical structures such as the mandibular nerve.[28,29] In the present study of extremely resorbed mandibles, the implants were placed straight.

The most severe complication that may occur after surgery is mandibular fracture, which is more common in the elderly due to weakening and atrophy of the bone associated with reduced vascularization and, therefore, reduced blood flow.[30] However, its occurrence is very rare.[31,32] In the present dataset in which no fractures were registered, the implants were inserted with a low insertion torque. In dense bone, it is important to control the micromotion between the implant and the bony interface. Since in the present study clinically positive outcomes were achieved with a low insertion torque (in the range of 20 Ncm), it could be postulated that in dense bone, micromotion could be within a tolerated range that allows osseointegration even if values ranging from 30 to 50 Ncm[33] are not reached. The splinting effect also could have played a role in the positive outcome.[34]

The load of the distal flange of a mandibular implant overdenture increases bone resorption as a local factor, whereas implants may help to prevent resorption in the neighboring bone. The absence of load of the distal flanges is a positive factor for increasing bone density favoring bone regrowth.

Individual differences in the extent of resorption have been reported between different individuals and in the same patient at different times.[35,36] Several studies tried to identify factors related to excessive bone loss in edentulous patients.[37] Anatomical aspects,[38] age and gender,[39,40] or habits concerning denture wearing[41] were investigated. Intensive denture wearing and inappropriate loading due to ill-fitting dentures[35,41] were associated with increased bone resorption.

Advanced bone loss can lead to difficulties in restoring patients with dentures. Also, the adaption of a full denture and chewing ability can be affected, especially when the level of the mouth base is higher than the alveolar ridge, as in atrophic mandibles.

The adaptability of bone under impressed mechanical forces has been known since the time of Wolff.[42] A possible control mechanism for the process became apparent with the discovery of the piezoelectric effect in bone[43]: The stress generated by the implants acting on the bone attracts osteoblasts because of the formation of electrical dipoles. The piezoelectric action can alter the chemistry of the collagen molecules, or

influence cell activity providing feedback to the control mechanism that is responsible for the direction of bone growth.

The osteotomy site is critical and can undergo fracture even after mild stress.[44] However, patients with Cawood and Howell Class VI should be warned of the possible risk.[32] In addition, three out of four failures in the present study occurred in patients who smoked. This is in line with the fact that smoking is an important risk factor for implant failure.[45]

Another advantage of implant rehabilitation in the mandible is the reversal of the resorption process with an increase in bone volume, as reported in various studies.[46,47] In particular, Reddy et al in 2002 observed significant bone growth during the first year after prosthetic loading, followed by 3 years of stability in 60 patients rehabilitated with fixed prostheses supported by five or six implants with cantilever.[42] Wolff's law, often stated as "form follows function," indicates that the growth in the mandible is a result of increased work after prosthetic restoration with the fixed cantilever. Classically, Wolff's law is used to describe the physiologic response of bone and muscle to exercise; the observed growth in the posterior mandible could be consistent with this physiologic phenomenon.

Wolff's law states that bone tends to develop the structure best suited to resist the prevailing forces acting upon it,[48] a phenomenon known as functional adaptation. Bone subjected to a given level of stress attains a physiologically determined size and shape but does not hold under all conditions; extreme loads and trauma cause resorption rather than growth. The data of the present study, with the limitations related to the sample analyzed, seem to confirm this trend.

The 3D analysis was performed on a limited number of patients. Despite providing a limited dose in patients having a low risk of effects because of advanced bone age,[49] the 1-year follow-up CBCT could only be performed on patients who agreed to undergo voluntarily an exam indicated only for scientific purposes.[50,51]

All the patients were included in a program of supportive therapy that consisted of professional maintenance visits according to Del Fabbro et al,[18] in which the timing of recall visits is individually determined upon the patient's compliance. The visit consists of the routine professional oral hygiene procedures, a clinical examination, and periapical radiographs at least every 2 years. In specific cases due to anatomical limitations (the floor of the mouth is higher than the bone), a panoramic radiograph was taken instead of the periapical radiographs.

Placement of short implants in the intraforaminal area represents an alternative to bone reconstruction techniques that is less invasive and associated with less morbidity. The type of rehabilitation carried out in this

study involved a low incidence of complications before implant loading, mild or no postoperative pain, and obviously no complications due to graft failure.[52] A recent meta-analysis showed that, in general, fewer complications are observed when short implants are used in comparison to bone augmentation procedures with longer implants in the posterior mandible.[19]

CONCLUSIONS

Immediately loaded fixed hybrid prostheses supported by short (7 to 8.5 mm) implants are a viable option for the treatment of Class VI Cawood and Howell atrophic mandibles in completely edentulous patients. The restoration of the masticatory function can induce bone regrowth at the mandibular level and an increase in density related to a better bone trophism. Even with the limitations related to the size of the analyzed sample, consisting of a subset of only 10 patients, the data collected indicate that fixed implant-supported rehabilitations could stop the process of bone atrophy and promote regrowth of the mandibular bone.

ACKNOWLEDGMENTS

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