Gioacchino Cannizzaro, Pietro Felice, Daniela Rita Ippolito, Matteo Lazzarini, Eugenio Velasco-Ortega, Marco Esposito

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EARLY IMPLANT LOADING IN THE ATROPHIC POSTERIOR MAXILLA: AN 11-YEAR RANDOMISED CONTROLLED TRIAL OF 1-STAGE LATERAL *VERSUS* CRESTAL SINUS LIFT AND 8-MM-LONG HYDROXYAPATITE-COATED IMPLANTS

GIOACCHINO CANNIZZARO, MD, DDS
Adjunct Professor, Department of Dentistry, Vita-Salute University, IRCCS San Raffaele, Milan, and private practice, Pavia, Italy

PIETRO FELICE, MD, DDS, PhD
Associate Professor, Odontostomatologic Surgery, Department of Biomedical and Neuromotor Sciences, University of Bologna, Italy

DANIELA RITA IPPOLITO, DDS
Resident, Department of Orthodontics, University of Bologna, Italy

MATTEO LAZZARINI, DDS
Private practice, Forlí, Italy

EUGENIO VELASCO-ORTEGA, MD, DDS
Professor of General Dentistry and Gerodontology, University of Seville, Italy

MARCO ESPOSITO, DDS, PhD
Freelance Researcher and Associate Professor, Department of Biomaterials, The Sahlgrenska Academy at Göteborg University, Sweden

Correspondence to:
Marco Esposito
Casella Postale 34, 20862 Arcore (MB), Italy
E-mail: espositomarco@hotmail.com

OBJECTIVES. To compare 10- to 16-mm-long implants inserted into maxillary sinuses augmented with a lateral approach *versus* 8-mm-long implants placed in crestally augmented sinuses, both loaded early after 45 days.

MATERIALS AND METHODS. Forty partially or fully edentulous patients having 3 to 6 mm of residual crestal bone height and at least 4 mm thickness below the maxillary sinuses were randomised according to a parallel group design to receive either one to three 10- to 16-mm-long hydroxyapatite- coated implants (20 patients) after lateral sinus lift with 50% anorganic bovine (Bio-Oss) and 50% autogenous bone, or 8-mm-long implants (20 patients) after crestal sinus lift with autogenous bone. All implants were submerged and left to heal for 45 days before being loaded. Within one week after abutment connection, implants were loaded with screw-retained fully acrylic provisional prostheses. Definitive metal-ceramic prostheses were provisionally cemented 45 days after abutment connection. Outcome measures were: prosthesis or implant failure, any complications, and radiographic peri-implant marginal bone level changes. All patients were followed up to 11 years after loading.

RESULTS. One patient per group dropped out. One implant failed in the short implant group *versus* five implants in three patients from the longer implant group, the difference being not statistically significant (difference in proportions: 0.11; P = 0.604; 95% CI = -0.15 to 0.36). Three prostheses in the long implant group could not be fitted or were replaced *versus* one crown on short implants, the difference being not statistically significant (difference in proportions: 0.11; P = 0.604; 95% CI = -0.15 to 0.36). Six complications occurred in six patients from the short implant group *versus* ten complications in seven patients from the long implant group, the difference being not statistically significant different (difference in proportions: 0.053; P = 1.000; 95% CI = -0.265 to 0.357); however, two major postoperative complications occurred in the longer implant group: one abscess and one sinusitis, both of which determined the complete failure of the treatment in two patients (four implants lost). After 11 years, a total of 1.26 mm of peri-implant marginal bone had been lost at long implants and 0.64 mm at short implants, and the difference between the two groups was statistically significant (difference: 0.62 mm, 95% CI = 0.25 to 0.99; P=0.002).

CONCLUSIONS. In atrophic maxillary sinuses with a residual bone height of 3 to 6 mm, 8-mm short implants placed in simultaneously crestally lifted sinus might be a preferable choice than one-stage lateral sinus lift for placing longer implants, since the former appear be associated with lower morbidity. Implants placed with an insertion torque superior to 35 Ncm can be early loaded at 6 weeks.

CONFLICT OF INTEREST STATEMENT. This study was completely self-supported and no financial contribution or free materials were received from any commercial party.

INTRODUCTION

Not all patients have adequate bone volumes for receiving dental implants. This condition is not uncommon, especially in the posterior jaw and especially below the maxillary sinuses. While patients with extremely atrophic bone could be good candidates for bone augmentation procedures, since this is the only reasonable means of providing them with a fixed prosthesis, there is some controversy on how to treat patients with an "intermediate" amount of bone. There are three main problems associated with bone augmentation procedures in general: the cost and duration of treatment, greater patient morbidity, and success rates that are not necessarily ideal[1,2]. Therefore, current clinical research is focussing on evaluating the performance of shorter implants (4 to 8 mm) or tilted implants, in conjunction or not with less invasive bone augmentation procedures.

In the intermediately atrophic posterior maxilla (3 to 6 mm of residual bone height), the use of a crestal lift procedure could be a less invasive alternative to the conventional lateral window sinus lift technique, which is one of the most commonly performed augmentation procedures; considered to be one of the most reliable procedures, particularly when autogenous bone is used[3,4]. The sinus lift technique was originally described in the late seventies[5]; it involved opening a lateral window onto the maxillary sinus, carefully lifting the sinus membrane, and placing autogenous bone (or a bone substitute) into the sinus; the area was then allowed to heal for about 6 months or more before implants were inserted. This technique, with some minor modifications, is still widely used nowadays. Indeed, if there is sufficient bone to stabilise the implants, these can be placed in conjunction with the sinus lift procedure, thus substantially reducing the rehabilitation period. In order to further minimise patient discomfort, it has been suggested that the sinus be lifted crestally, directly from the implant sites. This technique was originally described by Tatum[6] in 1986 and then modified by Summers[7] in 1994. The main difference with the lateral window technique is that the sinus membrane is lifted through the crestal bone using osteotomes, and implants are inserted directly into the sites prepared with the osteotomes[8]. The crestal approach technique was subsequently modified by Cosci[9,10], who introduced a series of drills of various lengths, including a no-trauma lifting drill, to minimise the risk of sinus membrane perforation. A trephine bur can be used to collect bone, to be used as a graft material, directly from the osteotomy site, and while the crestal approach is less invasive, it is associated with several disadvantages. Specifically, the amount of bone which can be obtained using a crestal approach is less than that gained by the lateral window technique, and it has been reported that a minimum of 3 mm of crestal bone height is required to stabilise the implant at placement[9], even though this figure could be called into question. Furthermore, short implants may be required for the crestal sinus lift procedure, and it is commonly believed that implants 8 mm long or shorter have less than optimal long-term prognosis. Indeed, a review on the topic has suggested failures rates of around 10% for 7-mm-long implants[11]. While these figures must be interpreted with caution, since they may reflect a gross underestimation due to the poor quality of the studies assessed by the review, they do seem to suggest that shorter implants may have a poorer prognosis than longer ones. This perception is widespread among dentists, who prefer to place implants at least 10 mm in length.

Although this precaution makes clinical sense when there is sufficient bone for placing longer implants, when bone is insufficient dentists are often faced with a dilemma, i.e. whether to place short, 4- to 8-mm-long implants or whether, instead, to resort to augmentation in order to place longer implants. New and purportedly improved implant surface modifications and designs[12], together with improved surgical techniques may be shifting

the balance in favour of short implants when the alternative is an augmentation procedure[13-20], although reliable evidence is still lacking.

Implants in grafted sinuses are usually left to heal for at least 4 months, or more frequently for longer periods, to allow new bone formation before being functionally loaded. Nevertheless, data suggests that early loading of implants placed in non-grafted bone can be highly successful in experienced hands[21]. It would therefore be interesting to determine whether a less invasive technique for lifting maxillary sinuses with residual bone height of 3 to 6 mm in conjunction with shorter implants could provide as good results or even better than the lateral window technique in conjunction with the placement of longer implants. It would also be interesting to discover whether the unloaded period of the implants could be shortened for the benefit of the patients.

With this in mind, this randomised controlled trial was designed to compare the outcome of fixed prostheses supported by 10- to 16-mm-long implants inserted in maxillary sinuses augmented, according to a lateral approach technique, with 50% particulated autogenous bone harvested from the oral cavity and 50% Bio-Oss, *versus* 8-mm-long implants placed in sinuses crestally augmented with autogenous bone according to the Cosci technique[9,10]. All implants were to be loaded early, at 45 days after placement. This article is reported according the CONSORT statement for improving the quality of reports on parallel-group randomised trials (http://www.consort-statement.org/). One-year[22] and 5-year data[23] have been reported previously.

MATERIALS AND METHODS

Any patient with edentulous posterior maxilla requiring one to three adjacent implants; having a residual bone height under the maxillary sinus of between 3 to 6 mm and a thickness of at least 4 mm, as measured on preoperative computed tomography (CT) scans; and being 18 years or older and able to sign an informed consent form was eligible for inclusion in this trial. Patients were not admitted to the trial if any of the following exclusion criteria applied: 1) general contraindications to implant surgery; 2) irradiation of the head and neck area in the preceding year; 3) previous or ongoing treatment with intravenous aminobisphosphonates; 4) untreated periodontal disease; 5) poor oral hygiene and motivation; 6) uncontrolled diabetes; 7) pregnancy or lactation; 8) substance abusers; 9) psychiatric problems or unrealistic expectations; 10) lack of opposing occluding dentition/prosthesis in the area intended for implant placement; 11) acute infection in the area intended for implant placement; 12) participation in other trials, if precluding proper adherence to the present protocol; or 13) referral for implant placement alone.

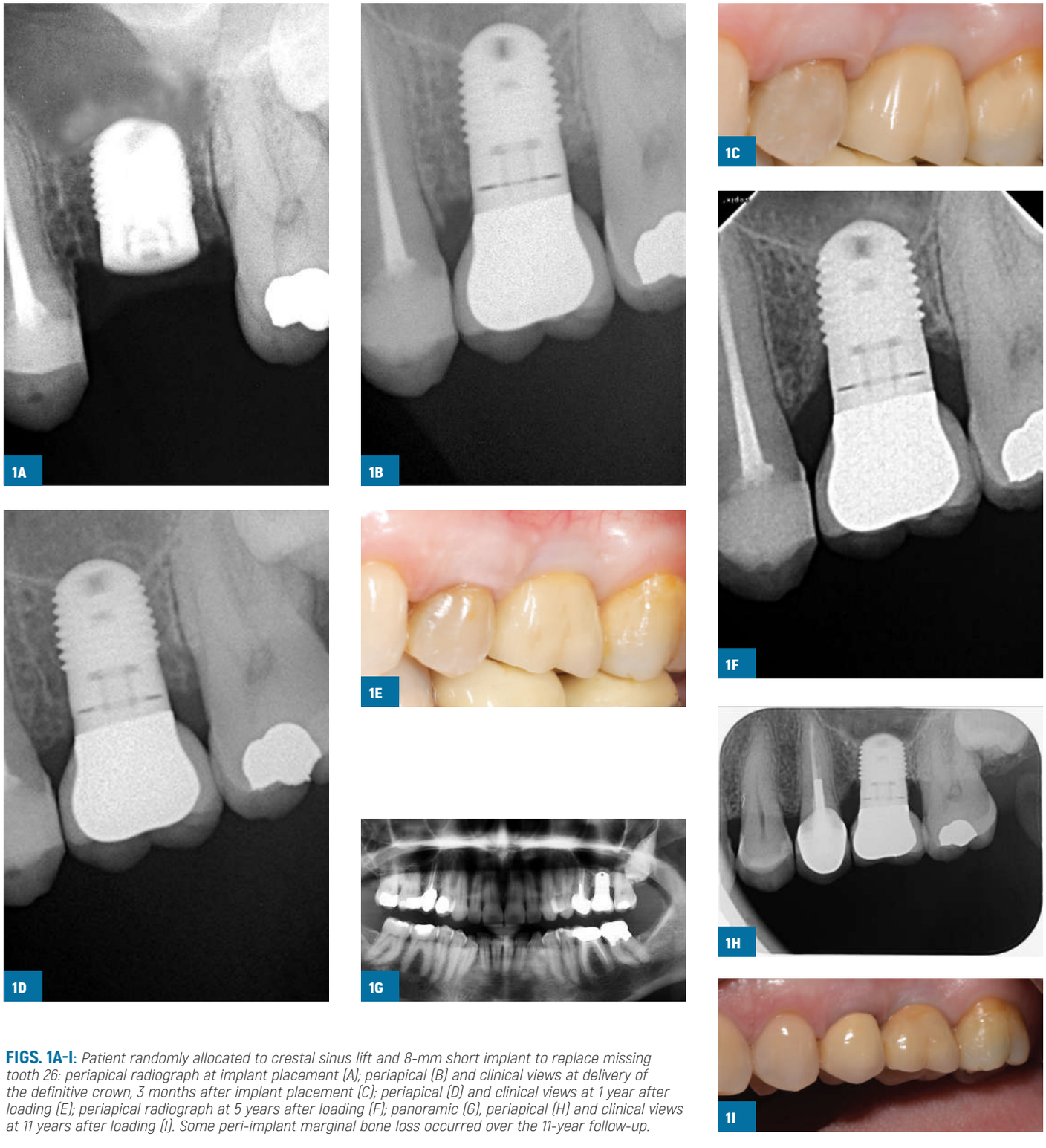
Patients were categorised into three groups according their declaration: non-smokers, moderate smokers (up to 10 cigarettes per day), or heavy smokers (more than 10 cigarettes per day). Patients were recruited and treated in one private practice, and were all treated by the same operator (Dr. Cannizzaro performed all the surgical and prosthetic interventions) using similar procedures.

All patients received a through explanation and signed an informed written consent form before being enrolled in the trial. Within the 10 days prior to bone augmentation and implant placement, all patients underwent at least one session of oral hygiene instruction and professionally delivered debridement when required. Two days prior the intervention, patients were instructed to rinse with 0.2% chlorhexidine mouthwash for 1 minute twice a day. Patients also rinsed for one minute prior to the augmentation procedure. All patients received prophylactic antibiotic therapy: 2 g of amoxicillin (or clarithromycin 500 mg if allergic to penicillin) one hour before the intervention, and continued to take the antibio-

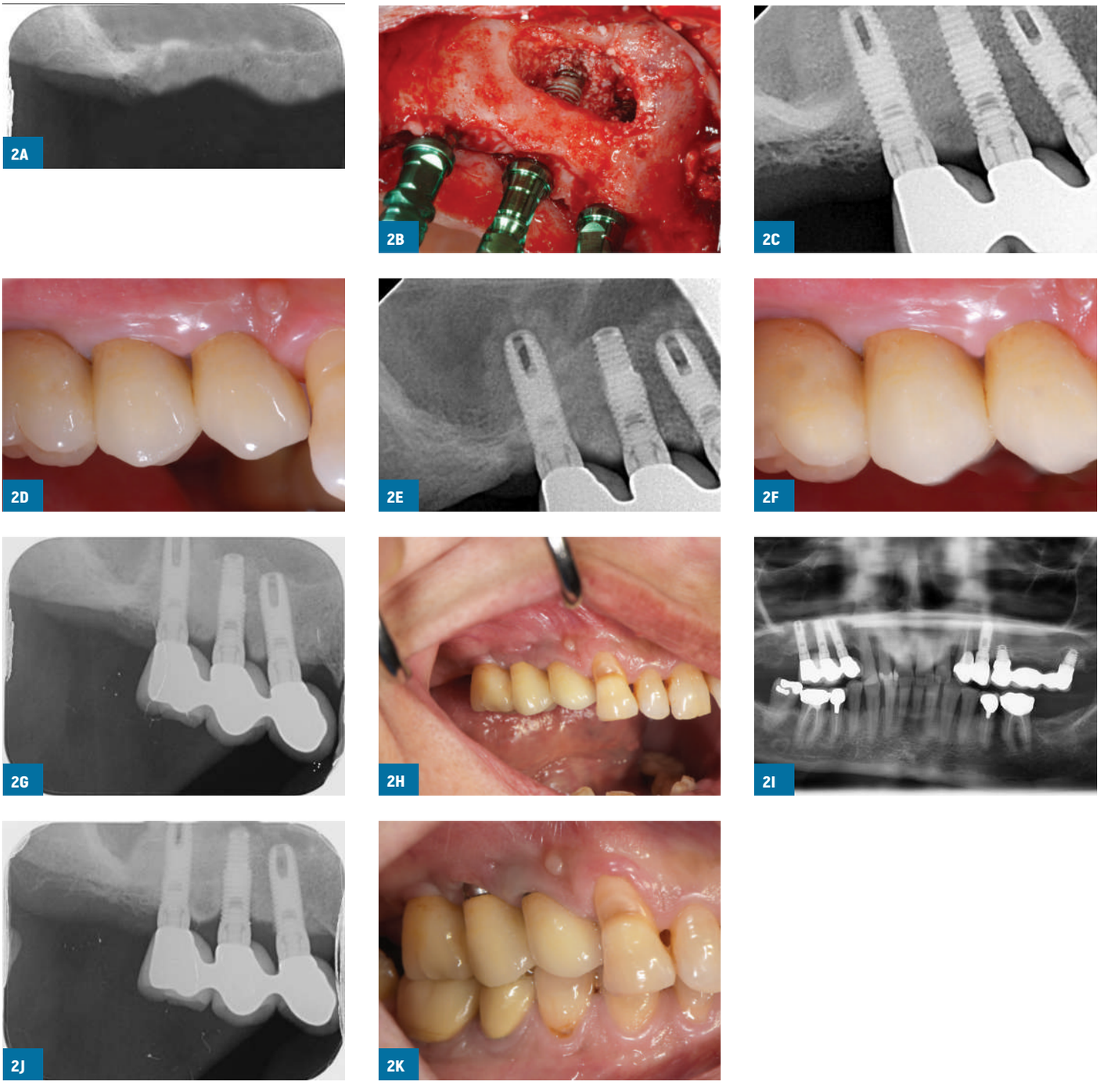
tics postoperatively, 1 g amoxicillin twice a day, for 7 days (or 250 mg clarithromycin twice a day, for 7 days). All patients were treated under local anaesthesia using articaine with epinephrine 1:100,000. Intravenous sedation was used in some patients. After local anaesthesia was given, patients were randomised to receive either 8-mm-long implants after crestal sinus lift following the Cosci technique[9,10] (**FIGS. 1A-I**) or identical 10- to 16-mm-long implants after lateral sinus lift using 50% particulated autogenous bone harvested from the oral cavity and 50% anorganic bovine bone (Bio-Oss, Geistlich Pharma, Wolhusen, Switzerland) (**FIGS. 2A-K**).

In the long implant group, a crestal incision was made through the buccal area to expose the alveolar ridge of the sites. A mucoperiosteal flap was retracted, exposing the lateral wall of the maxillary sinus, and a window was delineated with a bur under abundant saline irrigation. The bone was gently removed, layer by layer, until a bluish line indicating the sinus membrane was visible around the entire outline of the window. The bone window was gently tapped with a blunt instrument until it fractured completely and was then removed. Next, the sinus membrane was gently detached from the sinus bone, starting from the borders of the window and proceeding towards the sinus floor. The sinus membrane was lifted to a degree that would allow the placement of 10- to 16-mm-long implants. In the event of perforation of the sinus membrane, a resorbable collagen barrier (BioMend Extend, Zimmer Dental, Carlsbad, Ca, USA) was used to contain the graft. A mixture of 50% autogenous bone harvested from the tuberosity area and 50% Bio-Oss was inserted into the space between the medial wall of the sinus and the raised sinus membrane. One to three implants sites were prepared with 2.3- and 3.8-mm diameter surgical drills. An additional 5.1-mm drill was used when placing implants with a 6 mm diameter. Once the implant sites were prepared, the height of the sinus floor was measured in mm with a periodontal probe, and only those implant sites measuring 3 to 6 mm were entered into the trial. Tapered Screw-Vent MP-1 HA Dual Transition Selective Surface Implants (Zimmer Dental) of length 10, 13 or 16 mm and diameter 3.7, 4.7 or 6 mm were used. Implants were inserted in the under-prepared osteotomy sites with a torque of at least 35 Newton/cm and, once the motor stopped, manually with a ratchet until seated in the proper position. In the event that the prescribed torque was not achieved, the surgeon could either prepare an alternative implant site or increase the healing period to 3 months. The transition line between the machined collar and the textured surface of the implant was placed on a level with the alveolar bone crest. Additional bone graft was loosely packed to fill the voids and to completely cover the implant surfaces. A collagen barrier (BioMend) was used to seal the sinus window, and flaps were sutured with Vicryl 3-0 (Ethicon, Johnson & Johnson, St. Stevens Woluwe, Belgium) sutures, submerging the implants.

In the short implant group, a paracrestal incision was made on the palatal side, flaps were raised, and one to three implant sites were prepared using the Cosci kit (Zimmer Dental)[9]. The original Cosci technique was modified in the sense that to collect autogenous bone, sites were prepared directly with a 3-mm-diameter trephine drill up to roughly 1 mm from the sinus cortical wall, as visually calculated on radiographs and from tactile clues, and then the 3.1-mm-diameter atraumatic lifting drill was used. The sites were probed to confirm the integrity of the Schneider membrane, and the height of the sinus floor was measured with a periodontal probe; only those implant sites having 3 to 6 mm residual bone height were entered into the trial. In the event of perforation of the sinus membrane, a collagen barrier (BioMend) was placed in the sinus to contain the particulated autogenous bone graft. The particulate autogenous bone grafts were pushed inside the prepared site, and 8-mm-long implants (Tapered Screw-Vent MP-1 HA Dual Transition Selective Surface



FIGS. 1A-I: *Patient randomly allocated to crestal sinus lift and 8-mm short implant to replace missing tooth 26: periapical radiograph at implant placement (A); periapical (B) and clinical views at delivery of the definitive crown, 3 months after implant placement (C); periapical (D) and clinical views at 1 year after loading (E); periapical radiograph at 5 years after loading (F); panoramic (G), periapical (H) and clinical views at 11 years after loading (I). Some peri-implant marginal bone loss occurred over the 11-year follow-up.*



FIGS. 2A-K: *Patient randomly allocated to lateral sinus lift for placing implants longer than 10 mm: preoperative periapical view showing subantral residual bone heights (A); one-stage lateral window sinus lift procedure showing placement of three implants in positions 14, 15 and 16 (B); periapical (C) and clinical views at delivery of the definitive prosthesis, 3 months after implant placement (D); periapical (E) and clinical views at 1 year after loading (F); periapical (G) and clinical views at 5 years after loading (H); and panoramic (I), periapical (J) and clinical views at 11 years after loading (K). Some peri-implant marginal bone loss and recession of soft tissues occurred over the 11-year follow-up.*

Implants; Zimmer Dental) were inserted as previously described. The surgeon had the option of using any of the following implant diameters: 3.7, 4.7 or 6 mm. Implants were submerged under the flaps, sutured with Vicryl 3-0 (Ethicon).

Baseline periapical radiographs of the implants were taken using the paralleling technique. Nimesulide powder (100 mg), to be dissolved in water, was prescribed as an analgesic to be taken 2 to 4 times a day during meals, as long as required. Patients were instructed to use 0.2% chlorhexidine mouthwash for one minute twice a day for 2 weeks, to have a soft diet for one week, to avoid blowing the nose and using drinking straws, to keep the mouth open when sneezing (to reduce intra-sinal pressure), and to avoid brushing and trauma to the surgical sites. Patients were seen after 3 days, and sutures were removed after 10 days.

After 45 days of submerged healing, the implants were exposed; when sufficient keratinised mucosa was present, it was punched away; otherwise a flap was raised. Implants were manually tested for stability, and baseline measurements were made with Osstell (Integration Diagnostics, Göteborg, Sweden) and Periotest (Siemens AG, Benshein, Germany). Impressions were taken with the pick-up impression copings using a polyether material (Impregum 3M, ESPE, Neuss, Germany) and customised resin impression trays. The vertical dimension was registered, and models were cast using class 4 precision plaster and mounted in a standard articulator. Patients were instructed to use 0.2% chlorhexidine mouthwash for one minute twice a day for 2 weeks and nimesulide 100 mg was prescribed to be taken 2 to 4 times a day during meals as long as required. Within one week, provisional screw-retained acrylic restorations rigidly joining the implants were fitted. The flat occlusal surfaces were in slight contact with the opposing dentition, but no lateral contact was ensured. Periapical radiographs were taken of the implants, and, the following week, oral hygiene instructions were given.

One month after delivery of the provisional prostheses, impressions for the permanent prostheses were taken, and within 2 weeks definitive cemented metal-ceramic restorations rigidly joining the implants were provisionally cemented. Implant stability was manually checked, measurements were made with Osstell and Periotest, and periapical radiographs were taken. One week later, the prostheses were checked, and patients were given additional oral hygiene instructions.

Patients were enrolled in an oral hygiene programme with recall visits every 3 months for the first year and every 6 months thereafter. Follow-ups were conducted by an independent blind outcome assessor (Dr. Fontana) together with the operator (Dr. Cannizzaro).

Outcome measures were the following.

- Prosthesis failure: defined as a planned prosthesis which could not be placed due to implant failure(s), loss of the prosthesis secondary to implant failure(s), and replacement of a definitive prosthesis for any reason.
- Implant failure: defined as implant mobility, removal of stable implants dictated by progressive marginal bone loss or infection, and/or implant facture or any other mechanical problem rendering the implant unusable. Stability of individual implants was measured with the prosthesis removed at delivery of the provisional prostheses (about 50 days after implant placement); at delivery of the definitive prosthesis (1 month and a half after delivery of the provisional prosthesis); and at 1, 5 and 11 years after loading using the handles of two metallic instruments. Periotest and Osstell measurements were also made, the former being discontinued after the 5-year follow-up. Periotest measurements were performed by positioning the device perpendicular to the implant abutment on the buccal side. For each implant, four measurements were taken, and readings that occurred at least twice were recorded. In the case of two pairs of iden-

tical values (this never occurred), additional measurements were to be taken until one value was reported in three measurements. Implants showing Periotest values (PTV) of between – 8 and 0 were considered successful, values of between + 1 and + 5 borderline, and values ≥ 6 as failed. Osstell was used for resonance frequency analysis (RFA). Results were expressed in ISQ (implant stability quotient), with values ranging from 1 (minimum stability) to 100 (maximum stability). Implants showing values of up to 40 were considered failures. Periotest and Osstell measurements were averaged for each patient and then for each group.

- Any biological or prosthetic complications.
- Peri-implant marginal bone levels: evaluated on periapical radiographs taken using the paralleling technique at implant placement, delivery of the provisional prosthesis, and at 1 and 5 and 11 years after loading. If bone levels around the study implants were obscured or difficult to be read, the radiographs were taken again. Radiographs were scanned, digitised as JPGs, converted to TIFF format with 600-dpi resolution, and stored on a personal computer. Peri-implant marginal bone levels were measured using Scion Image (Scion Corporation, Frederick, MD, USA) software. The software was calibrated for each single image using the known diameter of the implant at its neck. Measurements of the mesial and distal bone crest levels adjacent to each implant were made to the nearest 0.01 mm. Reference points for the linear measurements were: the coronal margin of the implant collar and the most coronal point of bone-to-implant contact. Measurements of the mesial and distal sides were averaged for individual implants.

Without knowing group allocation, one dentist (Dr. Fontana), not involved in the treatment of the patients, made all the clinical assessments and another dentist (Dr. Torchio) made all the radiographic assessments. Outcome assessors were therefore blind, but sites augmented with Bio-Oss were identifiable on radiographs due to their increased radio-opacity, not to mention the longer length of the implants in this group.

The sample size was calculated for the primary outcome measures (implant failure); a two-group continuity-corrected chi-squared test with a 0.050 two-sided significance level will have 80% power to detect the difference between a proportion of 0.100 and a proportion of 0.300 for patients experiencing at least one implant failure (odds ratio of 3.857) when the sample size in each group is 72. However, it was decided to recruit only 20 patients per group.

A computer-generated restricted randomisation list was created. Only one of the investigators (Dr. Esposito), not involved in the selection and treatment of patients, was aware of the randomisation sequence and could have access to the randomisation list, which was stored on his password-protected portable computer. The randomised codes were enclosed in sequentially numbered, identical, opaque, sealed envelopes, which were opened sequentially after eligible patients were anaesthetised; treatment allocation was therefore concealed to the investigators in charge of enrolling and treating the patients.

All data analysis was carried out according to a pre-established analysis plan. A dentist (Dr. Ippolito) with expertise in medical statistics analysed the data, without knowing the group codes. The patient was the statistical unit of the analyses. Differences in the proportions of patients with prosthesis failures, implant failures, complications (dichotomous outcomes) were compared between groups using Fisher's exact probability test. Differences in patient means for continuous outcomes (Osstell and Periotest implant stability values and peri-implant marginal bone level changes) were compared between groups using t-tests, and within-group changes were assessed using paired t-tests. All statistical comparisons were conducted at the 0.05 level of significance.

RESULTS

Fifty-seven patients were screened for eligibility, but seventeen patients could not be enrolled in the trial for the following reasons: 12 patients were willing to receive short implants but were not willing to undergo a lateral sinus augmentation procedure; three patients were unwilling to be randomised; and two patients had unrealistic expectations and were not treated. Forty patients were considered eligible and were consecutively enrolled in the trial. All patients were treated according to the allocated interventions. Only two drop-outs occurred, one from each group. In particular, one patient from the long implant group died of amyotrophic lateral sclerosis (ALS, also known as motor neurone disease or Lou Gehrig's disease) 3 years after treatment, and the other patient, from the short implant group, moved away after the first year; fortunately, however, the latter patient's dentist was able to assess the 5-year ISQ values using an Osstell device, and kindly sent us his 5- and 9-year periapical radiographs. After this date, the patient elected not to attend regular maintenance and check-up appointments. Data from all patients were evaluated in the statistical analyses. Only one deviation from the protocol occurred; specifically, one patient from the long implant group had their implants loaded 60 days after placement due to the loss of a family member.

Patients were recruited and subjected to the sinus lift procedures from January 2006 to July 2006. The last definitive prosthesis was fitted in September 2006. The follow-up of all patients was up to 11 years after prosthetic loading.

The main baseline patient characteristics are presented in **TABLE 1**. Forty-four implants were placed in the long implant group and 38 in the short implant group. There was a major systematic baseline imbalance between the two groups in terms of the implant diameters, as the longer implants had systematically smaller diameters than shorter implants (**TABLE 1**).

TABLE 1 PATIENT AND INTERVENTION CHARACTERISTICS

	Long implants (n = 20)	Short implants (n = 20)
Females	14 (70%)	7 (35%)
Mean age at implant insertion (range)	53.3 (30-72)	47.5 (21-70)
Smokers	5 (25%) moderate + 2 (10%) heavy	6 (30%) moderate + 5 (25%) heavy
Fully edentulous	3 (15%)	1 (5%)
Natural/fixed opposing dentition	13 (65%)	17 (85%)
Patients treated with intravenous sedation	1 (5%)	2 (10%)
Mean residual bone height	4.35±0.57 mm	4.46±0.80 mm
Total number of inserted implants	44	38
Implants inserted with <35 Ncm torque	0	3 (15%) replaced immediately
Patients receiving 1 implant	2 (10%)	6 (30%)
Patients receiving 2 implants	12 (60%)	10 (50%)
Patients receiving 3 implants	6 (30%)	4 (20%)
Mean length of implants placed	11.35±1.29 mm	8 mm
Total number of 3.7-mm diameter implants	20	0
Total number of 4.7-mm diameter implants	24	15
Total number of 6-mm diameter implants	0	23

Three 4.7-mm-diameter implants in three different patients from the short implant group were unstable at placement and were immediately replaced by 6-mm implants, which were tapped into the sites of the removed implants.

The main results are summarised in **TABLE 2**. Five implants in three patients failed in the long implant group *versus* one implant in the short implant group up to 11 years after loading. The failed implants were not replaced. The differences in proportions of implant failures were not statistically significant at the patient level (0.11; P = 0.604; 95% CI = -0.15 to 0.36). Due to implant failure, two prostheses from the long implant group and one from the short implant group could not be fitted. In addition, in the long implant group, one crown was remade as a screw-retained crown due to multiple debondings. The differences in proportions of prosthesis failures were not statistically significant at patient level (0.11; P = 0.604; 95% CI = -0.15 to 0.36). In the long implant group, four implants in two patients had to be removed because of an abscess 2 weeks after the lateral sinus lift procedure (two implants), and severe acute sinusitis (two implants), respectively. The last implant was found to be mobile at abutment connection. It was the most distal implant, and the patient was happy to have a shorter prosthesis than planned and did not want to have it replaced. At augmentation, the sinus lining was ruptured and a barrier was used to contain the graft. The only failed implant belonging to the short implant group was mobile at abutment connection. A summary of failures is given in **TABLE 2**.

Complications up to 11 years after loading are summarised in **TABLE 2**. In total, ten complications occurred in seven patients from the long implant group *versus* six complications in six patients from the short implant group. The difference in proportions was not statistically significant (difference in proportions: 0.053; P = 1.000; 95% CI = -0.265 to 0.357). At surgery, only two complications occurred in the long implant group, both sinus membrane rupture. One of these patients experienced the loss of an implant at abutment connection. Postoperatively, two severe postoperative complications (one abscess and one sinusitis) occurred in the long implant group (both caused the loss of four implants in two patients) *versus* the bone loss between two implants observed at abutment connection in one patient who received short

TABLE 2 SUMMARY OF THE MAIN RESULTS AT THE PATIENT LEVEL

	Long implants (n = 19)	Short implants (n = 19)	P-value
Augmentation failures	2 out of 20	0 out of 20	0.487
Prosthesis failures	3 (2 not delivered and 1 remade)	1 not delivered	0.604
Implant failures	3 (5 implants)	1	0.604
Complications	10 in 7 patients	6 in 6 patients	1.000
Intrasurgical complications	2 2 ruptures of sinus membrane	0	-
Postoperative complications	2 1 abscess 1 sinusitis	1 1 peri-implant bone loss	-
After loading complications	6 2 repeated crown loosening 2 peri-implantitis 1 food accumulation 1 connecting screw fracture	5 1 ceramic coating fracture 1 abutment screw fracture 1 peri-implantitis 1 internal screw-loosening 1 peri-implant mucositis	-

implants; this bone gap was filled with Bio-Oss directly at abutment connection. After loading, six complications occurred in three patients from the long implant group. In the first case, one crown was remade with a metallic occlusal surface after repeated debonding; eight years after loading the connecting screw loosened twice and was replaced with a new one. Another patient complained about food accumulation between their implants and natural teeth. Re-contouring the contact points solved the problem, but 30 months after loading the same patient experienced peri-implantitis at one of the implants, with a circumferential bone loss of about 3 mm. The site was surgically treated with by grafting the defect with granules of anorganic bovine bone (Bio-Oss) and healed fine. However, the patient, a heavy smoker, never presented regularly for maintenance and never put sufficient effort into oral hygiene; this patient had colon carcinoma and his teeth were not a priority. However, 9 years after loading he presented with pus exuding when the buccal mucosa was pressed (peri-implantitis). He refused surgery and accepted only a deep cleaning of the area. He claims he is now fine. Another patient returned after 3 years with a mobile prosthesis, since one the two implants had a broken connection screw, which was easily replaced.

After loading, five complications occurred in five patients from the short implant group. Specifically, one fracture of the ceramic prosthesis coating was observed a few months after fitting the definitive prosthesis. Two years after loading, one patient experienced loosening of an abutment screw, which was retightened. Another patient, a member of the armed forces, was deployed abroad and could not attend two consecutive maintenance sessions; after 2 years the mucosa was hyperplastic and bleeding (peri-implant mucositis) at the distal of the two implants due to inadequate oral hygiene. After surgical cleaning and repeat oral hygiene motivation, the problem resolved. Six years after loading, another patient, who did not present for maintenance for 2 years, showed up with a swollen and slightly painful buccal mucosa; the interdental spaces were filled with food debris, and the area was non-surgically professionally cleaned, and the crown was removed and replaced by a large healing screw for 3 weeks. In the final case of complications in the short implant group, 7 years after loading a cemented crown loosened, and since it could not be removed with a crown-remover, it was perforated and transformed into a screw-retained crown. All complications were resolved.

Peri-implant marginal bone levels: there were statistically significant differences in bone level between the two groups after 1, 5 and 11 years of loading (**TABLE 3**), with less bone being lost around short implants. Both groups gradually lost marginal peri-implant bone from baseline, and this was statistically significant for all time periods, except from baseline to 45 days in the short implant group (**TABLE 4**). At initial loading, short implants had lost 0.15 mm (SD = 0.31) and long implants had lost 0.26 mm (SD = 0.26) of peri-implant bone; the difference between groups was not statistically significant (P = 0.26; **TABLES 3, 4**). Neither was the difference between groups statistically significant (P = 0.08; **TABLES 3, 4**) one year after loading, at which point short implants had lost 0.27 mm (SD = 0.34) and long implants 0.44 mm (SD = 0.23) of peri-implant bone. However, five years after loading, short implants had lost 0.41 mm (SD = 0.42) and long implants 0.72 mm (SD = 0.41) peri-implant bone, a between-group difference that was statistically significant (P = 0.028; **TABLES 3, 4**). Similarly, eleven years after loading, short implants had lost 0.64 mm (SD = 0.52) and long implants 1.26 mm (SD = 0.57) of peri-implant bone, the difference between groups being statistically significant (P = 0.002; **TABLES 3, 4**).

There were no statistically significant differences between groups at any time interval for Osstell measurements (**TABLE 5**). Up to 5 years, Osstell values increased in both groups and then slightly decreased (**TABLE 6**). Periotest measurements were discontinued after the fifth year of follow-up. The last Periotest data available can be found in the 5-year report[23].

TABLE 3 PERI-IMPLANT MARGINAL BONE LEVELS BY STUDY GROUP AT BASELINE, INITIAL LOADING, AND 1, 5 AND 11 YEARS AFTER LOADING

	Long implants			Short implants			P-value*	95% CI of the difference
	N	Mean	(SD)	N	Mean	(SD)		
Baseline	20	0.03	(0.08)	20	0.00	(0.00)	0.49	
Initial loading	18	0.28	(0.25)	19	0.15	(0.31)	0.15	-0.53 to 0.33
1 year	18	0.47	(0.21)	19	0.27	(0.34)	0.04§	-0.39 to -0.01
5 years	17	0.75	(0.40)	19	0.41	(0.42)	0.015§	-0.62 to -0.07
11 years	17	1.29	(0.56)	19	0.64	(0.52)	0.001§	-1.02 to -0.29
Baseline to initial loading	18	-0.26	(0.26)	19	-0.15	(0.31)	0.26	-0.08 to 0.30
Baseline to year 1	18	-0.44	(0.23)	19	-0.27	(0.34)	0.08	-0.02 to 0.36
Baseline to year 5	17	-0.72	(0.41)	19	-0.41	(0.42)	0.028§	0.04 to 0.60
Baseline to year 11	17	-1.26	(0.57)	19	-0.64	(0.52)	0.002§	0.25 to 0.99

**From chi-squared test for baseline (only two patients had scores greater than 0) and independent sample t-test for other endpoints*

§ Statistically significant difference

TABLE 4 PERI-IMPLANT MARGINAL BONE LEVEL CHANGES BY STUDY GROUP UP TO INITIAL LOADING, AND 1 AND 5 YEARS AFTER LOADING

	Long implants				Short implants			
	N	Mean change	(SD)	P-value paired-sample t-test	95% CI of the difference	N Mean changes	(SD)	P-value paired-sample t-test	95% CI of the difference
Baseline to initial loading	18	-0.26	(0.26)	=0.001*	-0.39 to -0.12	19 -0.15	(0.31)	0.052	-0.30 to 0.001
Baseline to year 1	18	-0.44	(0.23)	<0.001*	-0.56 to -0.33	19 -0.27	(0.34)	0.002*	-0.43 to -0.11
Baseline to year 5	17	-0.72	(0.41)	<0.001*	-0.93 to -0.51	19 -0.41	(0.42)	0.001*	-0.61 to -0.20
Baseline to year 11	17	-1.26	(0.57)	<0.001*	-1.55 to -0.97	19 -0.64	(0.52)	<0.001*	-0.89 to -0.38

**Statistically significant differences*

TABLE 5 BETWEEN-GROUP COMPARISON OF MEAN OSSTELL (SD) VALUES AT BASELINE, DELIVERY OF THE DEFINITIVE PROSTHESES (3 MONTHS AFTER PLACEMENT), AND 1, 5 AND 11 YEARS AFTER LOADING

	Long implants			Short implants			P-value independent sample t-test	95% CI of the difference
	N	Mean	(SD)	N	Mean	(SD)		
Baseline (abutment connection)	18	68.85	(1.09)	19	68.88	(1.52)	0.948	-0.86 to 0.92
3 months after implant placement	18	69.68	(1.30)	19	69.72	(1.59)	0.946	-0.94 to 1.00
Year 1 after loading	18	71.52	(1.11)	19	71.51	(1.44)	0.989	-0.87 to 0.85
Year 5 after loading	17	71.65	(2.57)	19	71.95	(2.25)	0.711	-1.33 to 1.93
Year 11 after loading	17	70.59	(2.58)	18	71.50	(2.28)	0.275	-0.76 to 2.58

TABLE 6 WITHIN-GROUP COMPARISON OF MEAN OSSTELL (SD) CHANGES FROM BASELINE TO DELIVERY OF DEFINITIVE PROSTHESES (3 MONTHS AFTER PLACEMENT), AND 1, 5 AND 11 YEARS AFTER LOADING

	Long implants					Short implants				
	N	Mean changes	(SD)	P-value paired-sample t-test	95% CI of the difference	N	Mean changes	(SD)	P-value paired-sample t-test	95% CI of the difference
Baseline to 3 months	18	-0.83	(1.17)	0.008*	-1.42 to -0.25	19	-0.84	(1.07)	0.003*	-1.35 to -0.32
Baseline to year 1	18	-2.67	(1.41)	<0.001*	-3.37 to -1.97	19	-2.63	(1.53)	<0.001*	-3.37 to -1.90
Baseline to year 5	17	-2.75	(2.07)	<0.001*	-3.81 to -1.68	18	-3.07	(2.76)	<0.001*	-4.40 to -1.74
Baseline to year 11	17	-1.69	(1.80)	0.001*	-2.62 to -0.76	18	-2.46	(2.65)	0.001*	-3.78 to -1.14

**Statistically significant differences.*

DISCUSSION

This trial was designed to indicate which approach would be a more effective implant-supported partial fixed prosthesis treatment in posterior maxillae with 3 to 6 mm of residual alveolar bone height below the maxillary sinus, a classical sinus lift procedure using a lateral approach[6] allowing for placement of 10 to 16 mm long implants; or 8-mm-long implants placed via the less invasive mini-sinus lift directly through the implant site, according to a modified Cosci technique[9]. Both techniques were able to achieve their stated goals, unless a major complication occurred. Apart for peri-implant marginal bone loss, there were no statistically significant differences between the procedures, possibly due to the limited sample size of this study, but some interesting trends were noted. First and foremost, the more invasive procedure there appeared to be associated with a trend of more failures and complications. In particular, there were two postoperative sinus complications (one abscess and one sinusitis) in the long implant group that caused the failure of the augmentation procedure and of all the placed implants, not to mention considerable pain and discomfort, in the affected patients.

It seems reasonable to assume that patients would prefer the least invasive procedure when the final outcome is comparable with the outcome of more invasive procedures. This assumption is supported by the fact that 12 out of 17 of patients who declined to participate in this trial did so because they did not want to risk undergoing a more invasive lateral approach sinus lift and preferred shorter implants placed in crestally lifted sinuses. Curiously, in another trial[24,25] comparing 6.6-mm short implants with longer implants placed in interpositional bone blocks to vertically augment the posterior mandible, the opposite trend was observed.

In fact, four out of the nine patients who refused to join the trial, were not willing to receive short implants. Patients motivated their decision with the belief that short implants have a poorer prognosis than longer implants and therefore preferred the more invasive vertical augmentation procedure with interpositional blocks which allowed the placement of longer implants. These differences probably reflect the "conflicting rumours and opinions" heard by the patients from their dentists regarding the prognosis of short implants and the outcome of augmentation procedures. It would be wiser if the correct evidence-based information, when available, were accepted by dentists and properly delivered to patients.

There are few published RCTs[13-20] comparing short *versus* longer implants in atrophic posterior maxillas. While there are some obvious differences between the present trial and the others since different type of grafts, sinus lifting procedures, implant types, diameters and

lengths of "short" implants have been studied, the results of all these studies suggest that the clinical performance of relatively short implants is as good as that of longer implants placed in augmented sinuses, and short implants may therefore be the preferable solution, being associated with less morbidity.

There are different crestal sinus lift procedures, but only few of them have been compared in RCTs. In one split-mouth RCT[10,26], the Cosci technique was preferred by the patients over the Summers technique, probably because the Summers technique was associated with the unpleased sensation of hammering the osteotomes to break the basal bone of the sinus floor. In another RCT, comparing the traditional Summers technique using a hand mallet *vs.* an electric mallet, 5% of the patients treated with the hand mallet developed a benign paroxysmal positional vertigo *versus* none of those treated with the electric mallet[27]. However, more RCTs are needed to identify the best crestal sinus lift procedures.

The most surprising finding of this study is that it is possible to load implants inserted with a torque of greater than 35 Ncm in about 4 to 4.5 mm of residual bone height below the maxillary sinuses early (at about 7 weeks). No RCT to our knowledge has loaded implants placed in augmented sinuses early[21]. This observation questions whether any of the sinus lift procedures used in this trial actually added any additional benefit to the implant success since grafts cannot be transformed in "supporting functional" bone in less than 2 months. More investigations are needed to understand when sinus lift procedures are actually beneficial[2].

Peri-implant marginal bone level changes showed 0.62 mm more bone loss at 11 years for long implants, a finding in line with those of other similar trials[13,15-20]. It is difficult to find a reliable explanation for this difference, but it may not have clinical significance due to the very small quantity of additional bone loss.

Osstell values increased over time in a statistically significant way in both groups up to 5 years post-loading, and then slightly decreased. There were no differences between groups at any time interval. Interpretation of these results is difficult, and may call into question the clinical utility of such measurements.

The main limitation of the present investigation was the systematic difference in implant diameters. The diameter of the longer implants was smaller than those of the short implants (**TABLE 1**). This was not by chance; in fact the surgeon, who was free to choose the diameters of the implants, systematically compensated for the reduced implant surface of the 8-mm implants by increasing their diameters. Therefore, the results of this study, which was aimed at evaluating the role of implant length on the success rate, might have been confounded by the different implant diameters. This can be considered an error made at the protocol design stage; the original idea was to give the clinician freedom to use the diameter they considered to be the most indicated for the individual situation, and the study designer did not consider the eventuality that the surgeon would compensate for reduced implant length by using larger diameters. While the decision made by the surgeon makes clinical sense, it complicates interpretation of the result of this study, as the role, if any, of implant diameter on establishing and maintaining osseointegration remains unclear. Indeed, there is as yet no data from trials comparing short implants with conventional 4 mm diameters *versus* larger 6 mm diameters. However, data from several RCTs[13,16,18,28] evaluating short implants with 4 to 4.5 mm diameter placed below maxillary sinus is available, and yielded good clinical outcomes, comparable to the results of this study; this suggests that the implant diameter may not play the major role in the clinical success of implant-supported restorations that it is often attributed.

Another limitation of this trial was the small sample size. However, it was decided to enrol a limited number of patients, as this trial was potentially at risk of increased implant failures because of the decision to functionally load the implants so early. Patients were aware of this

potential risk (this could also partly explain why about one in three patients asked to participate in this study refused). Surprisingly the failure rates were lower than expected, and all failures occurred before the implants were actually loaded. The fact that not a single implant was lost after loading rules out the possibility that loading the implants so early was detrimental to the implant success. The calculation of the sample size was performed in order to provide the reader with an idea of the minimal number of patients required to detect a certain difference based on a predicted failure rate. Nonetheless, the actual failure rate up to 11 years has been half of that estimated, and, therefore, a much greater number of patients than that calculated may be required to detect a statistically significant difference between the two procedures.
Both techniques were tested under real clinical conditions, and patient inclusion criteria were broad, meaning that the results of the present trial may be generalisable to a larger population with similar characteristics.

CONCLUSIONS

With the proviso that the following may only apply to patients with similar characteristics treated with similar procedures and materials, both techniques investigated yielded good results. However, there was a tendency towards more complications and failures in the group treated with longer implants after lateral augmentation of the maxillary sinus. Hence, when the residual maxillary sinus bone is between 3 and 6 mm in height, short, 8-mm implants placed after crestal sinus lifting may be the preferable option, since the intervention appears to be associated with less morbidity. This study also suggests that it is possible to load implants placed in lifted sinuses early, at about 7 weeks, with an insertion torque greater than 35 Ncm.

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REFERENCES

1. 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 of Systematic Reviews. Chichester, UK: John Wiley & Sons, Ltd., 2009.
2. Esposito M, Felice P, Worthington HV. Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database of Systematic Reviews. Chichester, UK: John Wiley & Sons, Ltd., 2014.
3. Wallace SS, Froum SJ. Effect of maxillary sinus augmentation on the survival of endosseous dental implants. A systematic review. Annals of Periodontology 2003;8:328-43.
4. Del Fabbro M, Testori T, Francetti L, Weinstein R. Systematic review of survival rates for implants placed in the grafted maxillary sinus.
The International Journal of Periodontics and Restorative Dentistry 2004;24:565-77.
5. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. Journal of Oral Surgery 1980;38:613-6.
6. Tatum HJ. Maxillary and sinus implant reconstructions. Dental Clinics of North America 1986;30:207-29.
7. Summers RB. A new concept in maxillary implant surgery: the osteotome technique. Compendium of Continuing Education in Dentistry 1994;15:152-8.
8. Emmerich D, Att W, Stappert C. Sinus floor elevation using osteotomes: a systematic review and meta-analysis. Journal of Periodontology 2005;76:1237-51.
9. Cosci F, Luccioli M. A new sinus lift technique in conjunction with placement of 265 implants: a 6-year retrospective study. Implant Dentistry 2000;9:363-8.
10. Esposito M, Cannizzaro G, Cosci F, Soardi E, Felice P. Cosci *versus* Summers technique for crestal

sinus lift: 3-year results from a randomised controlled trial. European Journal of Oral Implantology 2014;7(2):129-37.
11. das Neves FD, Fones D, Bernardes SR, do Prado CJ, Neto AJ. Short implants - an analysis of longitudinal studies. The International Journal of Oral and Maxillofacial Implants 2006;21:86-93.
12. Esposito M, Ardebili Y, Worthington HV. Interventions for replacing missing teeth: different types of dental implants. Cochrane Database of Systematic Reviews. Chichester, UK: John Wiley & Sons, Ltd., 2014.
13. Pistilli R, Felice P, Cannizzaro G, Piatelli M, Corvino V, Barausse C et al. Posterior atrophic jaws rehabilitated with prostheses supported by 6 mm long 4 mm wide implants or by longer implants in augmented bone. One-year post-loading results from a pilot randomised controlled trial. European Journal of Oral Implantology 2013;6:359-72.
14. Gulje FL, Raghoebar GM, Vissink A, Meijer HJ. Single crowns in the resorbed posterior maxilla supported by either 6-mm implants or by 11-mm implants combined with sinus floor elevation surgery: a 1-year randomised controlled trial. European Journal of Oral Implantology 2014;7:247-55.
15. Esposito M, Pistilli R, Barausse C, Felice P. Three-year results from a randomised controlled trial comparing prostheses supported by 5-mm long implants or by longer implants in augmented bone in posterior atrophic edentulous jaws. European Journal of Oral Implantology 2014;7:383-95.
16. Thoma DS, Haas R, Tutak M, Garcia A, Schincaglia GP, Hammerle CH. Randomized controlled multicentre study comparing short dental implants (6 mm) *versus* longer dental implants (11-15 mm) in combination with sinus floor elevation procedures. Part 1: Demographics and patient-reported outcomes at 1 year of loading. Journal of Clinical Periodontology 2015;42:72-80.
17. Esposito M, Barausse C, Pistilli R, Sammartino G, Grandi G, Felice P. Short implants *versus* bone augmentation for placing longer implants in atrophic maxillae: one-year post-loading results of a pilot randomised controlled trial. European Journal of Oral Implantology 2015;8:257-68.
18. Bolle C, Felice P, Barausse C, Pistilli R, Trullenque-Eriksson A, Esposito M. Four mm-long *versus* longer implants in augmented bone in posterior atrophic jaws: one year post-loading results from a multicentre randomised controlled trial. European Journal of Oral Implantology 2018;11(1):31-47.
19. Gastaldi G, Felice P, Pistilli R, Barausse C, Trullenque-Eriksson A, Esposito M. Short implants as an alternative to crestal sinus lift: a 3-year multicentre randomised controlled trial. European Journal of Oral Implantology 2017;10(4):391-400.
20. Pistilli R, Felice P, Piattelli M, Gessaroli M, Soardi E, Barausse C et al. Posterior atrophic jaws rehabilitated with prostheses supported by 5 x 5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. One-year results from a randomised controlled trial. European Journal of Oral Implantology 2013;6:343-57.
21. Esposito M, Grusovin MG, Maghaireh H, Worthington H. Interventions for replacing missing teeth: different times for loading dental implants. Cochrane Database of Systematic Reviews Mar 28;2013(3):CD003878.
22. Cannizzaro G, Felice P, Leone M, Viola P, Esposito M. Early loading of implants in the atrophic posterior maxilla: lateral sinus lift with autogenous bone and Bio-Oss *versus* crestal mini sinus lift and 8-mm hydroxyapatite-coated implants. A randomised controlled clinical trial. European Journal of Oral Implantology 2009;2:25-38.
23. Cannizzaro G, Felice P, Minciarelli AF, Leone M, Viola P, Esposito M. Early implant loading in the atrophic posterior maxilla: 1-stage lateral *versus* crestal sinus lift and 8 mm hydroxyapatite-coated implants. A 5-year randomised controlled trial. European Journal of Oral Implantology 2013;6:13-25.
24. Felice P, Cannizzaro G, Checchi V, Marchetti C, Pellegrino G, Censi P et al. Vertical bone augmentation *versus* 7-mm-long implants in posterior atrophic mandibles. Results of a randomized controlled clinical trial of up to 4 months after loading. European Journal of Oral Implantology 2009;2:7-20.
25. Felice P, Cannizzaro G, Barausse C, Pistilli R, Esposito M. Short implants *versus* longer implants in vertically augmented posterior mandibles: a randomised controlled trial with 5-year after loading follow-up. European Journal of Oral Implantology 2014;7:359-69.
26. Checchi L, Felice P, Soardi Antonini E, Cosci F, Pellegrino G, Esposito M. Crestal sinus lift for implant rehabilitation: a randomised clinical trial comparing the Cosci and the Summers techniques. A preliminary report on complications and patient preference. European Journal of Oral Implantology 2010;3:221-32.
27. Crespi R, Caparré P, Gherlone E. Sinus floor elevation by osteotome: hand mallet *versus* electric mallet. A prospective clinical study. International Journal of Oral and Maxillofacial Implants 2012;27:1144-50.
28. Gulje F, Abrahamsson I, Chen S, Stanford C, Zadeh H, Palmer R. Implants of 6 mm *vs.* 11 mm lengths in the posterior maxilla and mandible: a 1-year multicenter randomized controlled trial. Clinical Oral Implants Research 2013;24:1325-31.