Combined Osteotome-Induced Ridge Expansion and Guided Bone Regeneration Simultaneous with Implant Placement: A Biometric Study

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ABSTRACT

Purpose: To evaluate the long-term outcome of a single-step ridge expansion osteotome procedure and implant placement combined with guided bone regeneration in patients presenting narrow maxillary alveolar ridges.

Materials and Methods: During the period 1999 to 2010, 41 patients aged 19 to 77 years (18 males; 23 females) suffering from partial or full edentulism associated with horizontal resorption of the maxillary ridges (2.5–5 mm) were treated using the combined ridge expansion and guided bone-regeneration techniques to obtain an improved bony base for implant placement. Implant survival, bone width measurements, clinical and radiologic implant success, and clinical complications were recorded and analyzed.

Results: Achievement of primary stability of the implant was impossible at six sites; these were recorded as failures. In the remaining 35 patients, one hundred sixteen endosseous titanium implants were simultaneously placed. Follow-up time varied between 6 and 144 months (mean 52.4); of these, 36% were followed up for periods of time longer than 60 months. Implant diameter and lengths varied between 3.3 to 4.8 and 12 to 16 mm, respectively. In the 35 successful procedures (one hundred sixteen implants), the overall implant survival rate was 100%. An average gain in ridge width was 3.5 ± 0.93 ($p < .0001$) and an average enlargement of the buccal bone was 1.91 ± 0.6 ($p < .0001$). The mean vertical mesial bone loss was 1.81 mm ± 1.07 (ranging from 0.3 to 4.2 mm), and the mean vertical distal bone loss was 1.74 mm ± 1.12 (ranging from 0.4 to 4.5 mm). In eight patients (32%), at least one implant presented bone loss of ≥3 mm.

Conclusions: Within the limitations of this study, we suggest that the combined osteotome-induced ridge expansion and guided bone regeneration simultaneous with implant placement is a reliable procedure with reduced morbidity and may offer an alternative in suitable situations.

KEY WORDS: allograft, bone expansion, guided bone regeneration, implant, marginal bone loss

INTRODUCTION

Alveolar ridge resorption following tooth loss is an inevitable and irreversible process, often occurring as early as 6 months after extraction or tooth loss.[1,2] Bone resorption associated with loss of teeth is evident mainly at the expense of the buccal aspect of the jaw, leading to the development of severe ridge deformities.[2,3] Edentulous alveolar ridge resorption, also referred to as "disuse atrophy," often results in reduced ridge width, which may preclude placement of endosseous dental implants unless properly prepared.[3]

Among the methods for alveolar ridge augmentation, guided bone regeneration (GBR) has been the focus of significant clinical research.[4–7] Favorable data have been accumulated using tissue barriers, particularly resorbable collagen membranes, and different augmentation biomaterials such as allografts,[8] alloplasts,[9] and xenogrfts.[10] Another commonly used technique that can expand the narrow ridge is the ridge expansion osteotomy (REO)[11]; this procedure has the advantage of enabling simultaneous ridge expansion and placement

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of implants in a previously relatively narrow ridge. The REO results in mechanical progressive ridge expansion using a series of osteotomes, until the desired dimensions, are achieved.[12] The REO also enables implant placement without ostectomy, thus saving bone otherwise drilled out via the osteotomy preparation. Although the advantage of the REO technique has previously been described in different clinical studies and case reports,[12–16] there is still lack of data regarding the long-term results of the procedure.

Endosseous dental implants should be installed within the bony envelop.[17] The achievement of successful aesthetic results however requires an ideal three-dimensional implant position within optimal bone configuration and dimensions,[18,19] particularly that of the buccal and interproximal bone associated with the implant surface.[18,19] Implant positioning in relation to the bucco-oral and mesio-distal dimensions of the alveolar ridge is a factor thought to influence the degree of bone remodeling.[20] Such remodeling may negatively influence the soft-tissue topography and aesthetic outcome of implant therapy.[21] It has also been claimed that the plate of bone buccal to the implant surface should measure at least 2 mm.[22] These biological concepts have led to several clinical guidelines regarding the correct implant positioning in relation to bucco-oral and mesio-distal bone dimensions.[18,19] This study was undertaken to retrospectively evaluate the long-term outcome of a single-step technique including (1) implant placement following osteotomy preparation using a series of osteotomes with progressive diameters and (2) GBR procedure aiming to increase the width of the buccal plate of bone to at least 2 mm.[18,19,22] The study was based on data collected from 35 individuals who were followed up over a 6- to 144-month period of time.

To our knowledge, a combined REO and GBR technique, aiming to augment the maxillary atrophic ridge and to achieve a critical bone width with concomitant placement of implants, has previously never been described.

MATERIALS AND METHODS

Case Selection

The files of patients who underwent the combined REO-GBR procedure during the period 1999 to 2010 were screened. All patients were operated by the senior author (R.K.). Cases that met the following inclusion criteria were selected:

1 Patients presented with partial or full edentulism in the upper jaw.
2 The width of the alveolar ridge varied between 2.5 and 5.0 mm, i.e., less than the optimal diameter of the chosen implant (3.3–5.0 mm) plus 2 mm.
3 The alveolar process contours presented a topography that would have led to bone fenestration or dehiscence associated with the implant surface, unless enlarged.
4 In the aesthetic zone, an increase of the vestibular–palatal dimensions was indicated.

Exclusion criteria were the following:

1 Severely atrophic ridges (alveolar ridge width less than 2.5 mm).
2 Coexisting vertical defect that required additional corrective intervention.
3 Heavy use of tobacco (more than 20 cigarettes per day).
4 A history of radiotherapy to the head and neck, treatment with bisphosphonates, uncontrolled diabetes, and continuous endocrine therapy.

The surgical procedure and its advantages and limitations, as well as a thorough explanation about the combined technique and the alternative treatment plans, were explained to the patients; each patient signed an informed consent as part of an agreement to perform the treatment. Patients that smoked less than 20 cigarettes per day committed to a smoking cessation protocol starting at least 1 week before surgery and ending not earlier than 1 month after surgery.[23]

All patients signed an informed consent and agreed that the data from their medical file be used for this research project.

A thorough presurgical evaluation including full mouth periodontal chart, occlusal analysis, study of the mounted casts, and diagnostic wax-up was made. Initial periodontal therapy including oral hygiene instructions and training, scaling, and root planning wherever indicated were carried out, followed by additional periodontal therapy aimed to reduce periodontal probing depth (PD) and bleeding on probing until a plaque index (PI)[24] of less than 10% was achieved. Surgical templates were used at the time of implant placement. Panoramic radiographs or periapical radiographs were obtained

before and immediately after implant placement, as well as 6 months later.

Preoperatively, computed tomogram was obtained to evaluate the three-dimensional morphology of the alveolar process and ridge, the presence of cancellous bone between the buccal and palatal plates, and the existence of bony undercuts and horizontal defects.

From a total of five hundred thirty-five files, 41 cases (18 males; 23 females) aged 19 to 77 years old were found suitable (Table 1). In these, one hundred twenty-two combined REO-GBR procedures were performed. The distribution of the implant sites is presented in Table 2. Ridge width was measured using a caliper (Iwanson spring caliper, Hu-Friedy, Chicago, IL, USA). Measurements were taken at the midimplant/osteotomy line, 2 mm apical to the crestal margin. Measurements were identically repeated at implant exposure, 6 months later. All measurements were recorded in the patients' files. The change in width was calculated by subtracting the values for the initial ridge width measurement from the corresponding values. The width of the buccal plate of bone was measured using a 1-mm calibrated periodontal probe (Hu-Friedy).[25] Buccal bone plate measurements were taken immediately after ridge expansion, after implant placement, and 6 month later at the time of implant exposure.[25,26]

At the time of screening the files, whenever possible, bone level mesial and distal to the implants was radiographically measured using computerized dental radiography based on parallel periapical x-rays. The mesial and distal alveolar bone crest to implant shoulder distance was digitally (Schick Technologies, Long Island, NY, USA) measured using computerized dental radiography based on parallel periapical x-rays. Radiographic distortion was calculated by dividing the radiographic implant length by the actual one.

Surgical Technique

Before surgery, the patients were premedicated with 8 mg of dexamethasone (Rekah Pharmaceutical Products Ltd., Holon, Israel)[27] and 875 mg of amoxicillin and clavulanate potassium (Augmentin, Glaxo Smith Klein, Brentford, UK). Penicillin-sensitive patients were premedicated with clindamycin hydrochloride (Dalacin-C, Pfizer NV/SA, Puurs, Belgium) 150 mg bid starting 1 hour before surgery. Patients rinsed their mouths with chlorhexidine 0.2% (Tarodent mouthwash, Taro Pharmaceutical Industries Ltd., Haifa, Israel) solution for 1 minute before the procedure was initiated.

The surgical technique followed the method described by Hahn.[13] The procedure started with preparing the implant bed by drilling a narrow osteotomy, followed by increasing its diameter using osteotomes, progressively increasing in size, until the desired expansion was achieved. The procedure was made under local anesthesia, full thickness flap elevation through a midcrestal incision, and mesial and distal releasing incisions were indicated (Figure 1A). After ridge measurements, osteotomy preparation started using a pilot drill 2.0 mm in diameter (MIS, Shlomi, Israel). Drilling was followed by the insertion of a percussion of an expansion osteotome 2 mm in diameter (Steri-Oss, Yorba Linda, CA, USA) (Figure 1B). A larger osteotome measuring 2.7 mm in diameter was then applied (Figure 1C), followed by a successively larger instrument measuring 3.25 and 3.7 whenever applicable. The expansion osteotomes were inserted manually, and pressed and rotated at the same time; once the desired depth had been reached, a 30-second break was taken to allow bone adaptation to the tension produced and to let bony microfractures to form and dilate and compact the adjacent bone.[13]

Implants were placed immediately after expansion and completion of osteotomy preparation, preventing osteotomy collapse. Implant shoulders were placed flush with the bone (Figure 1D). After implant placement, the buccal cortical plate was perforated using a 1 mm in diameter round bar (Strauss Co., Raanana, Israel) (Figure 1E); this was followed by grafting the buccal aspect of the buccal plate using mineralized ground cortical bone allograft (Oragraft, Life Net, Virginia Beach, VA, USA) stabilized with a collagen membrane (Bio-Gide, Geistlisch Pharma AG, Wolhusen, Switzerland) (Figure 1, F and G) freely adapted to or peripherally fixated with the implant cover screws (Figure 1G). The wound was closed with interrupted 4-0 silk sutures (Figure 1H); before closure, releasing periosteal incisions where made wherever needed.

If primary implant stability could not be achieved by the end of the procedure, cases were recorded as a failure (for the study purposes), and implant placement was postponed for 4 to 6 months, but the augmentation procedure was completed as described. Sutures were removed 7 to 10 days postoperatively.

TABLE 1 Characteristics of Patients (Successful Implants)

	Smoking	Periodontal Status α	Age	Sex	Follow-Up (months)	Implant Site	Length	Width
1	No	Severe	53	F	12	*12,22	13	3.3
2	Yes	Severe	44	F	12	*12,22	16	3.3
3	No	Severe	57	F	18	*24	16	3.75
4	No	Moderate	65	F	30	‡24	15	4
5	No	Gingivitis	19	M	6	*11	16	3.75
6	Yes	Severe	57	M	12	*24,26,27	12.5	3.75
7	No	Moderate	61	M	42	*13,14	13	3.3
8	No	Mild	58	F	120	*23,24,25	16	3.9
9	No	Gingivitis	32	F	54	‡11,22	15	3.75
10	No	Gingivitis	68	F	144	*14,15,16	12.6	4.3
11	No	Severe	56	M	131	*13,14,15,16	16	3.9
12	No	Severe	71	F	120	*11,21,22	13.3	4.1
13	No	Severe	61	F	72	*15,12,11,21,22,25	13.5	3.9
14	No	Severe	56	F	96	§24,25,26	15	4
15	No	Severe	63	M	108	‡15,14,13,11,21,23,24,25	13.8	3.5
16	Yes	Severe	58	F	108	‡17,16,15,14,24,25,26,27	14.6	3.9
17	No	Severe	71	M	102	‡13,12,21,23,24	13.2	3.5
18	Yes	Severe	60	M	66	‡22,23,25,26	15	4
19	No	Severe	67	M	60	*16,14,13,12,22,23,24,26	14.8	3.95
20	No	Gingivitis	30	M	120	‡11	15	4
21	No	Severe	71	M	12	†22,24,25	14	3.7
22	No	Severe	61	F	12	†15,14,12,22,24,25	13.6	3.7
23	No	Moderate	56	M	6	*14	13	3.3
24	No	Severe	68	M	6	*25	13	3.75
25	No	Severe	58	M	24	†15,16,17	13	4.3
26	Yes	Severe	60	F	12	†14,13,12,22,23,24,25	15.1	3.9
27	No	Severe	69	F	12	†22,23	16	3.7
28	No	Mild	39	F	72	‡12,22	15	3.5
29	No	Severe	50	M	72	‡11,12,21,22	15	3.5
30	Yes	Severe	77	F	48	*12,22,23	16	3.9
31	No	Gingivitis	29	F	48	*21	16	3.75
32	No	Mild	46	F	6	†11,22	16	3.7
33	No	Severe	52	F	60	‡12,11,21,22	15	3.5
34	No	Severe	49	F	6	*15,14,24,25	13.3	3.6
35	No	Severe	54	M	6	*23,24,25	15	3.75
Mean			55.6		52.4		14.5	3.8
SD			13.2		44.5		1.2	0.3
Min			19		6		12.5	3.3
Max			77		144		16	4.3
% male				43%				

*Sandblasted acid-etched internal hex (Seven\BioCom\Lans), MIS, Shlomi, Israel.
†Soluble blast media internal hex (Legacy), Implant Direct Malibu Hills Road, Calabasas Hills, CA, USA.
‡Resorbable blast texture (Maesto\Prodigy), Bio-Horizons, South Birmingham, AL, USA.
§Screw-Vent noncoated microtextured surface, Zimmer Dental Inc, Carlsbad, CA, USA.
α Lindhe J, Lang NP, Karring T. Clinical periodontology and implant dentistry. Fifth edition, p. 423.
F = female; M = male; SD = standard deviation.

TABLE 2 Treatment Effect

Patient	Buccal Preop	Buccal Postop	Buccal Increase	Ridge Preop	Ridge Postop	Ridge Increase	Follow-Up (months)	Mesial Bone Loss	Distal Bone Loss
1	0.5	2	1.5	3.25	6.3	3.05	12	1.00	0.70
2	0.5	2	1.5	4.05	6.3	2.25	12	3.25	3.35
3	1	2	1	4.1	6.2	2.1	18	3.50	3.70
4	1	2	1	3.5	6	2.5	30		
5	1	3	2	2.5	6.1	3.6	6		
6	1	3	2	2.9	8.1	5.2	12	0.33	0.47
7	0.5	2	1.5	3.15	6.3	3.15	42		
8	1	3	2	3.63	7.7	4.07	120	2.33	2.23
9	1	2	1	4.2	6.1	1.9	54	2.35	1.35
10	1	3	2	3.97	8.1	4.13	144	1.33	1.40
11	1	3	2	4	7.7	3.7	131	0.35	0.43
12	1	4	3	3.17	8.5	5.33	120	0.70	0.70
13	1	4	3	4.83	8.4	3.57	72		
14	1	3	2	4	7.5	3.5	96	2.43	2.37
15	0.75	2	1.25	3.6	6.5	2.9	108		
16	0.75	2	1.25	3.5	6.4	2.9	108	2.19	2.03
17	0.5	3	2.5	2.86	6.1	3.24	102	1.96	1.78
18	1	3	2	3.3	7.8	4.5	66	1.60	1.85
19	0.81	3	2.19	4.49	7.95	3.46	60	2.21	3.04
20	1	3	2	4.8	7.8	3	120		
21	1	3	2	3.37	7.6	4.23	12	1.83	1.57
22	1	3	2	3.53	7.5	3.97	12		
23	1	3	2	2.5	7.4	4.9	6	0.60	0.50
24	0.5	3	2.5	3	7.2	4.2	6	1.50	1.30
25	1	4	3	4.17	8.5	4.33	24	0.67	0.83
26	0.79	2.21	1.43	3.2	7.11	3.91	12	3.41	3.03
27	1	3	2	3.4	6.8	3.4	12	1.85	2.15
28	1	4	3	5	8.5	3.5	72	0.55	0.55
29	1	2	1	5.03	6.5	1.48	72		
30	0.5	2.67	2.17	3.97	7.57	3.6	48	4.23	4.53
31	1	3	2	3.2	7.7	4.5	48	1.00	0.40
32	1	3	2	4.05	7.25	3.2	6	2.80	1.90
33	1	2	1	4.6	6.5	1.9	60	1.28	1.33
34	0.5	2	1.5	4.23	6.6	2.38	6		
35	0.5	3	2.5	3.6	7.2	3.6	6		
Mean	0.86	2.80	1.91	3.73	7.19	3.50	52.43	1.81	1.74
SD	0.21	0.64	0.59	0.67	0.80	0.93	44.48	1.07	1.12
Range	0.5–1.0	2.0–4.0	1.0–3.0	2.5–5.0	6.0–8.5	1.5–5.3	6.0–144.0	0.3–4.2	0.4–4.5

SD = standard deviation.

Healing of the surgical sites was uneventful (Figure 1I). At 6 months, implants were exposed using a midcrestal incision or a paracrestal (palatal) incision, intending to maintain at least 3 mm of keratinized masticatory mucosa. At this stage, crestal width was remeasured using a caliper 2 mm apical to the exposed implant shoulders, and marginal width of the buccal plate of bone was remeasured using a calibrated periodontal probe (Figure 1J). The bone measurements (periodontal probe and caliper) were thus directly made at the time of implant placement, immediately after ridge expansion, but before graft placement, and were repeated 6 month later at the time of implant exposure.

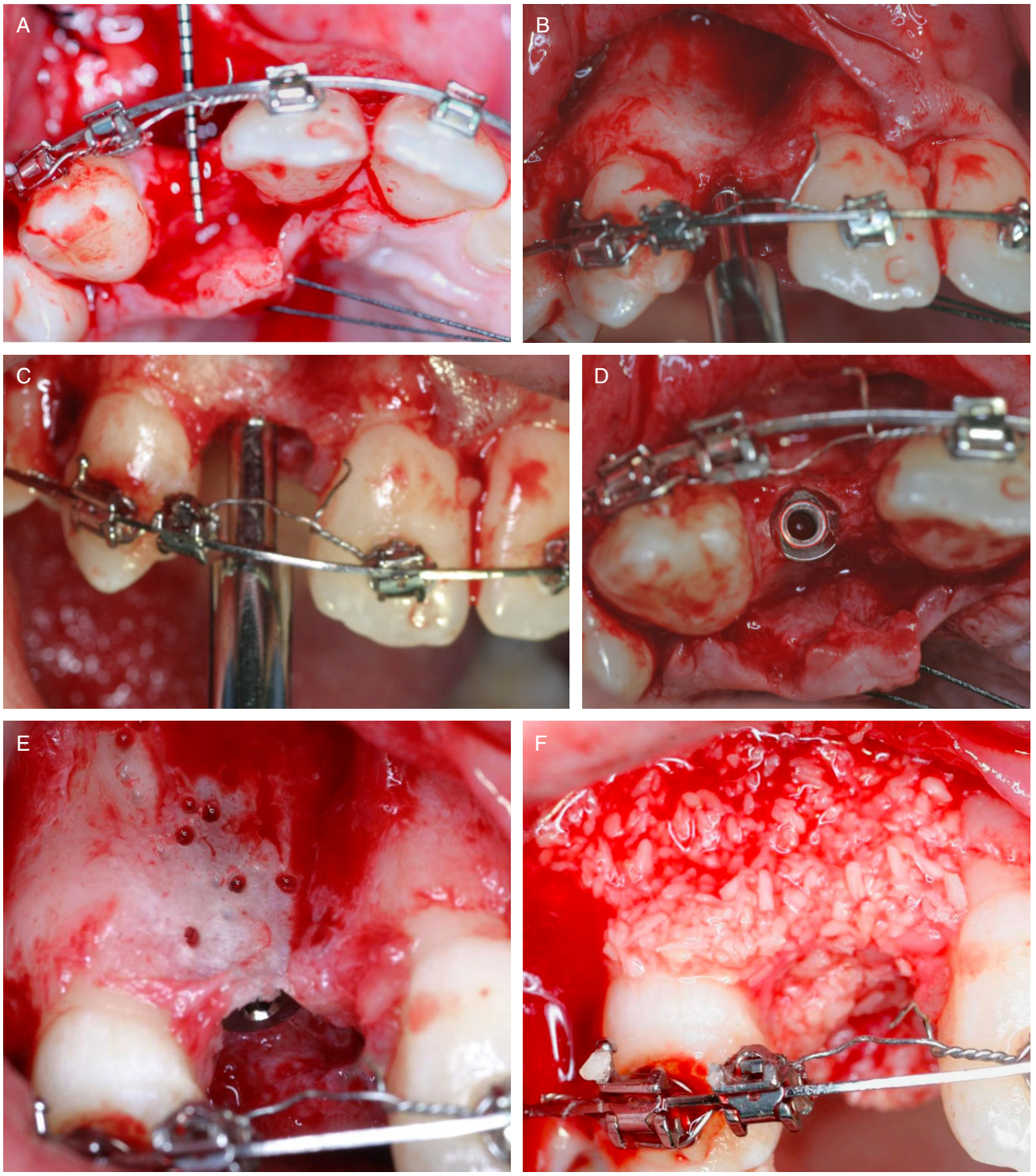

Figure 1 *A*, The alveolar process at an implant site is exposed showing a narrow crestal ridge measuring 3 mm in width. *B*, Osteotomy preparation started using a pilot drill 2.0 mm in diameter followed by no. 1 osteotome (2.0 mm) inserted to the full depth of the initial osteotomy. *C*, Applying a 2.7 mm in diameter osteotome to further enlarge the osteotomy; the crestal ridge shows signs of expansion, with no fractures observed. *D*, A 3.75 mm–diameter implant placed immediately after ridge expansion and osteotomy preparation was completed, preventing osteotomy collapse. The implant is placed within the bony envelop with the implant shoulders flush with the surrounding bone. *E*, Perforation of the buccal plate of bone using a 1 mm in diameter round bar increases bleeding and exposes the bone marrow to the healing site. *F*, Grafting the buccal aspect of the buccal plate using bone allograft is performed to further increase the width of the alveolar bone process and ridge.

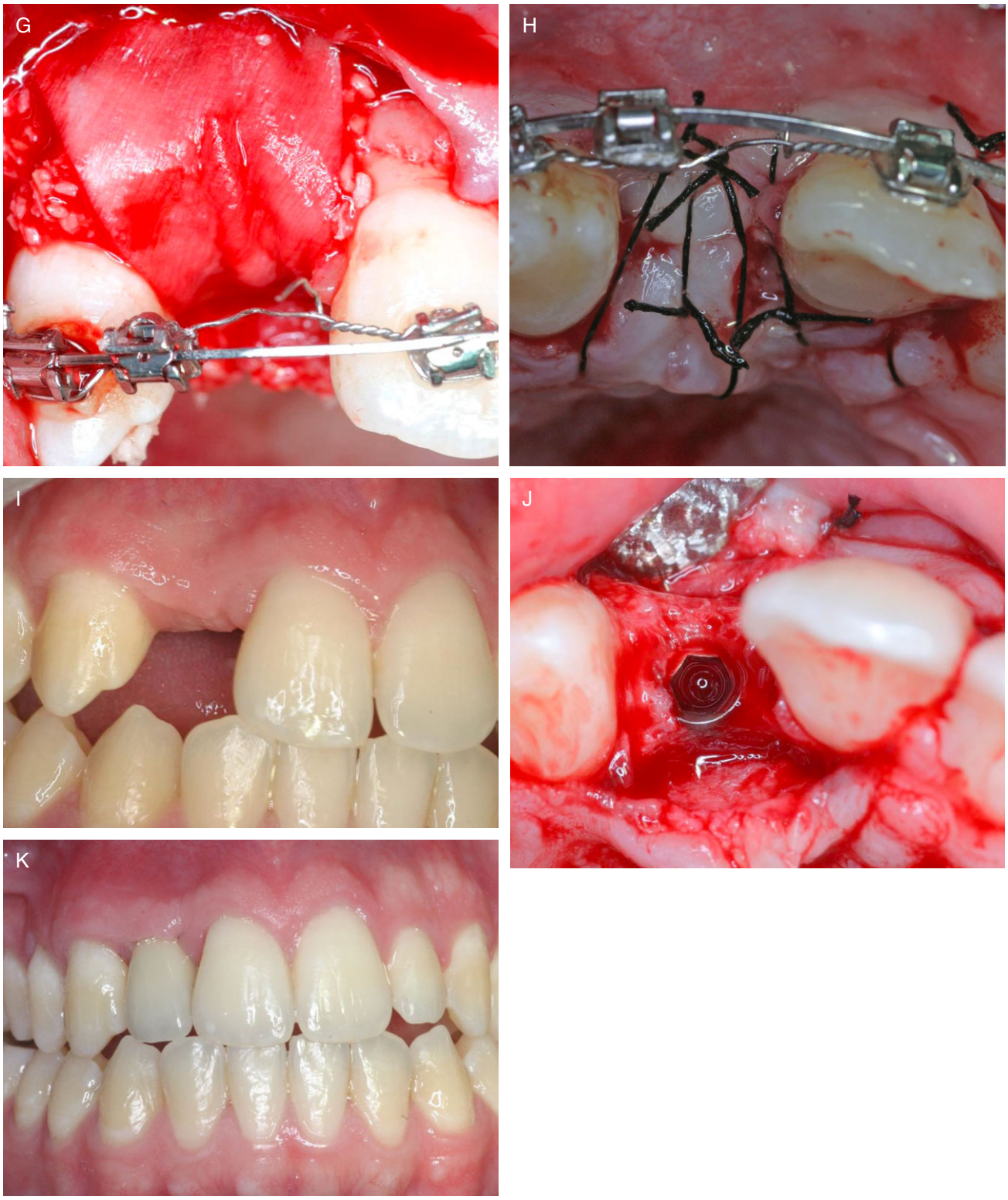

Figure 1 (*continued*) *G*, A resorbable collagen membrane is freely adapted to or peripherally, stabilizing the grafted material and separating it from soft tissues. *H*, Wound closure with interrupted silk 4-0 sutures concluded the procedure. Efforts were made to achieve primary wound closure wherever possible. *I*, Clinical view at 6 months. Healing of the surgical sites was uneventful. *J*, Clinical view of the buccal plate of bone at the time of implant exposure. A calibrated periodontal probe indicated 3 mm width of the buccal plate crestal edge. *K*, Clinical view of the final restoration at 18 months.

Postoperative Management

Following surgery, patients were administered with 875 mg of amoxicillin with clavulanate potassium (Augmentin, Glaxo Smith Klein) bid. Penicillin-sensitive patients were administered with clindamycin HCL (Dalacin-C, Pfizer NV/SA) 150 mg qid. Antibiotic therapy was continued during the first week postoperatively. Dexamethasone, 4 mg/day, was prescribed for the first, second, and third days postsurgery. Whenever needed, analgetic/anti-inflammatory drug (naproxen sodium 275 mg) was given twice a day. Chlorhexidine 0.2% mouth rinse was prescribed twice daily for 1 minute over a 3-week period of time. Patients were instructed to avoid the use of a removable prosthetic devises until after the sutures were removed, i.e., 10 to 14 days postoperatively. In full mouth cases or in cases where removable prosthesis use was unavoidable, complete release of the buccal flange was performed.

Healing Time

Six months after placement, implants were exposed and restored with implant-supported fixed crowns or dentures (Figure 1K). Implants were considered successful if they fulfilled the criteria set up by Albrektsson and colleagues.[28]

Statistical Analysis

A paired sample Student's *t*-test was used to evaluate the significance of changes in ridge and buccal plate width. An independent sample *t*-test was used to test for differences in the outcome measures between male and female patients. The Pearson's correlation coefficient was used to test for correlation between age and outcome measures. All tests were two sided. *p*-value <.05 was considered significant.

Follow-Up and Criteria for Success

Patients were clinically followed up by the same investigator (R.K.) at 3, 6, and 12 months postoperatively and then annually. Patients were instructed individually regarding personal hygiene programs depending on their periodontal status and were seen and/or treated every 3 to 6 months.

Periodical maintenance visits performed by a dental hygienist supervised by R.K. included PI and PD measurements and recording. At the annual evaluation of the peri-implant soft-tissue condition, the assessment of PI and PD was made using the following indices: PI was determined using the O'leary Index.[24] PD was measured to the nearest millimeter using a periodontal probe (Hu-Friedy) at the same surfaces.[29]

RESULTS

The files of 41 patients (23 woman; 18 men) met the inclusion criteria. In these, one hundred twenty-two sites were prepared for implant placement. Age range was 19 to 77 years (mean 54.0 ± 13.8). Follow-up from time from the day of implantation varied between 6 and 144 months (mean 52.4), with 36% of the patients being followed up for periods of time longer than 60 months.

The relevant details of the study group including periodontal diagnosis, smoking status, follow-up period, site, and type of each implant are shown in Table 1. Implants' diameter varied between 3.3 and 4.8 mm (average 3.80), and implants length between 12 and 16 mm (average 14.50).

At six sites(4.9%), it was impossible to establish primary stability of the implant due to fractures of the buccal plates; these were recorded as failures, omitted from the statistical analysis, and were augmented by the same GBR technique, but implant placement was delayed for by 4 to 6 months. In the one hundred sixteen successful surgical sites, the initial width of the alveolar ridge ranged from 2.5 to 5.0 mm (mean = 3.7 ± 0.67) (Table 2). The final width in the successful sites ranged from 6 to 8.5 mm (mean = 7.2 ± 0.8). The difference in ridge width averaged 3.5 ± 0.93 ($p < .0001$) (Table 2). The initial buccal bonny plate after implant installation varied between 0.5 and 1 mm (mean = 0.86 ± 0.21). At 6 months, the width of the buccal plates ranged between 2 and 4 mm (average 2.80 ± 0.64). The average difference in width was 1.90 ± 0.59 ($p < .0001$) (Table 2).

Table 3 presents a comparison between male and female patients in ridge and buccal plate increase, and mesial and distal bone loss. No significant differences were found between male and female patients in any of these outcome measures. Table 4 presents the Pearson's correlations between age and the outcome measures. No significant positive correlations were found between age and distal or mesial bone loss.

Healing was uneventful with no infection noted during the postoperative phase. At 6 months, all implants were successfully osseointegrated and loaded. Follow-up period from the day of implant placement ranged from 6 to 144 months (average 52.4 ± 44.5).

TABLE 3 Differences between Male and Female Patients (Mean ± SD) in Outcome Measures

	Male	Female	*p*-Value
Mesial bone loss (9 M, 16 F)	1.23 ± 0.74	2.12 ± 1.10	.038
Distal bone loss (9 M, 16 F)	1.31 ± 0.86	1.98 ± 1.20	NS
Ridge increase (15 M, 20 F)	3.70 ± 0.92	3.28 ± 0.92	NS
Buccal increase (15 M, 20 F)	2.03 ± 0.51	1.82 ± 0.65	NS

F = female; NS = not significant; M = male; SD = standard deviation.

At the time of implant exposure, all one hundred sixteen implants fulfilled our clinical and radiographic success criteria.[28] Patients were successfully restored with implant-supported fixed ceramic crowns or bridges (Figure 1J).

Clinical Observations

At the time of implant exposure, no remnants of the collagen membranes were observed. In 40 implants (34%), the cover screws were covered by bone to a certain expense, demanding bone removal before healing abutment could be properly placed (Figure 1J).

Complications

Fractures of the buccal plate (green stick) or dehiscence's occurred in 21 (17.2%) implant sites (Figure 2, A–E). In six sites (4.9%), these were associated with failure to achieve primary stability, postponing implant placement by 4 to 6 month; these were recorded as failures. In the remaining 15 (12.3%) sites, primary stability was achieved, enabling successful completion of the combined procedure. Spontaneous exposure occurred in 18 (15.5%) implants (Figure 2F). Spontaneous exposures were treated by replacement of the cover screw with healing abutments. In cases where there was insufficient buccal band of keratinized gingiva, masticatory mucosa pedicle flap was displaced from the palate adjacent to the implant (Figure 2, H and I).

TABLE 4 Pearson Correlations between Age and Outcome Measures

	Age	*p*-Value
Mesial bone loss ($n = 25$)	0.242	NS
Distal bone loss ($n = 25$)	0.326	NS
Ridge increase ($n = 35$)	0.267	NS
Buccal increase ($n = 35$)	0.170	NS

NS = not significant.

Membrane Exposure

Membrane exposure occurred at five sites in five different patients (14%). No exposure demanded premature removal of the membrane because the exposed portions of the membrane absorbed shortly after. When a membrane became exposed, the subject was instructed to topically apply 0.12% chlorhexidine Gel (Corsodyl Dental Gel, Glaxo Smith Klein) twice a day.

PD

Eighty implants in 25 patients (71.4%) were available for the final follow-up.

PD ranged from 1 to 8 mm, with two hundred forty-five (76.6%) sites measuring ≤4 mm. Mean PD per implant was 3.44 mm (standard deviation [SD] ± 1.5). Bleeding on probing was recoreded in 49% of the examined sites.

PI

At the time of data collection, PI[24] ranged between 5 and 40% with a mean of 15%.

Radiographic bone level analysis (Table 2) (Figure 2I) provided mean mesial bone loss of 1.81 ± 1.07 mm (range 0.3–4.2 mm), and mean distal bone loss was 1.74 ± 1.12 mm (range 0.4–4.5 mm). At implant level, the mean peri-implant bone loss was 1.9 mm (median 1.8 mm; SD 1.1 mm; range 0.2–5.6 mm). The most pronounced bone loss at an implant was 5.6 mm.

Subject-Level Analyses

Smokers (six patients) presented a significantly higher bone loss at implants' distal aspects compared with nonsmokers ($m = 2.54 \pm 1.4$ and 1.5 ± 0.92, respectively, $p = .041$) with but only marginally significant higher mesial bone loss ($m = 2.5 \pm 1.41$ and 1.6 ± 0.87, respectively, $p = .068$).

DISCUSSION

A single-step technique for bone expansion using cylindroconical osteotomes with gradually escalating diameters and immediate placement of implants has

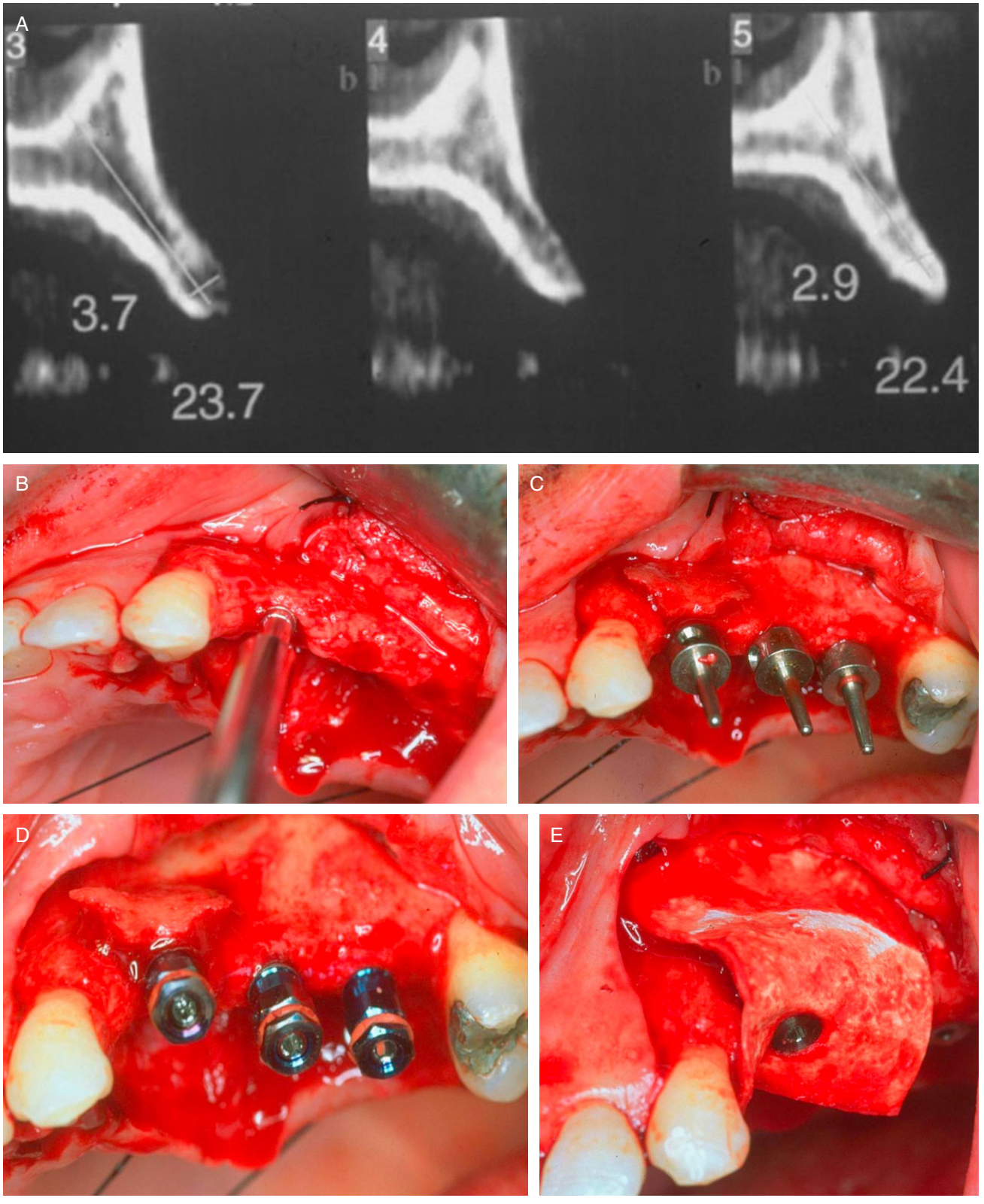

Figure 2 *A*, Radiographic (computerized tomography) presentation of a narrow edentulous alveolar ridge at the upper left premolar region. *B*, A 2-mm-wide osteotome is inserted into a 2-mm-wide initial osteotomy. *C*, Green stick fracture of the buccal plate at the first premolar region following insertion of a 3.5-mm-wide osteotome. *D*, Three implants placed into the expanded ridge with primary stability. *E*, A native collagen membrane is fixated and stabilized by a single cover screw.

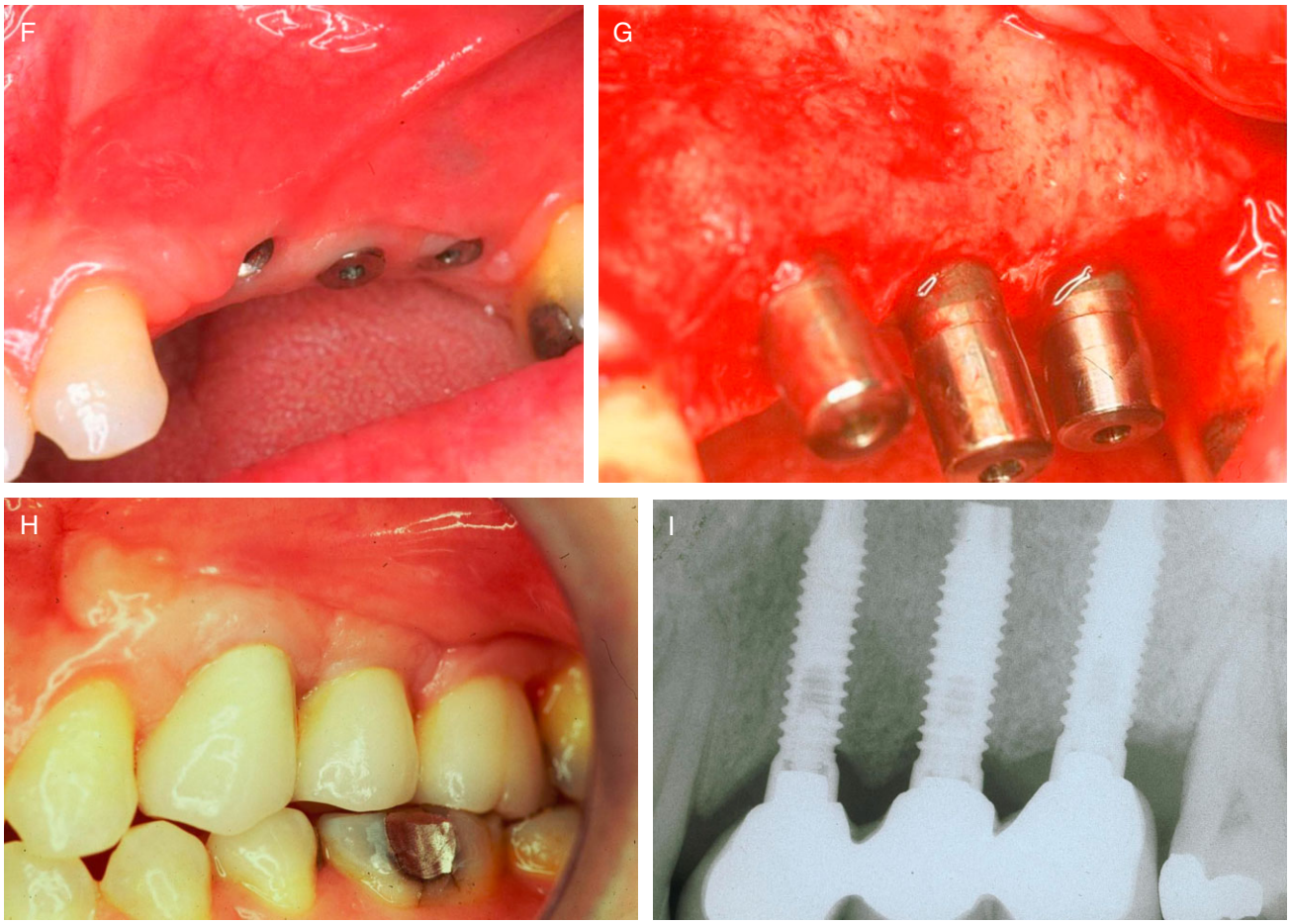

Figure 2 (*continued*) *F*, Clinical view at 6 months. Implants were spontaneously exposed 2 months after placement. There is a lack of buccal keratinized gingiva. *G*, Clinical view of the exposed implants during grafting of masticatory mucosa shows complete healing of the previously fractured buccal bone. Mild bone recession is associated with the early exposed implants. *H*, Twelve years of clinical view of the final ceramometal implant-supported bridge presents healthy keratinized gingival at the restored site. *I*, Final x-ray (12-year follow-up).

previously been described.[11–16] The technique, originally reported by Summers,[11] takes advantage of the fact that bone is a viscoelastic material that can be compressed and manipulated. Unlike drills, osteotomes do not excise bone during osteotomy preparation; rather, they exert lateral compression, which increases bone density and encourages primary retention and implant initial stability.[11–16] The technique is particularly useful in the upper maxilla, due to the lower bone density and thinner cortical buccal plate in this jaw, qualities that allow lateral compression and expansion. Our results have shown that bony expansion using osteotomes is a reliable and a relatively less invasive way of widening narrow ridges. We further enhanced the technique aiming to achieve critical thickness of more than 2 mm of the buccal plate.[22] It was claimed that this "critical thickness" reduces the incidents and amount of facial bone loss.[22] Our implant survival rate (100%) is noteworthy especially because in the present study implants were placed in expanded ridges rather than in native bone.

In comparison with the split-crest procedure that can be performed when the ridge width is as narrow as 1.5 mm,[30] ridge expansion using osteotomes could be applied only in cases in which ridge width was at least 2.5 mm. Nevertheless, the added bony volume in the present technique was similar (3.35 mm) to that achieved with the ultrasonic bone surgery split osteotomy technique,[31] where an intentional fracture of the buccal plate was produced aiming to create a "green stick" fracture. In the present study, fissures of bone or green stick fractures occurred only in 21 out of one hundred twenty-two sites (17.2%). In 15 sites (12.3%), primary stability was possible, thus enabling

the combined procedure. The gradual use of escalating diameter osteotomes allowed a more gradual widening of the ridge in contrast with the split-crest technique in which the fractured buccal plate may reduce the surgeon's ability to achieve primary stability of the simultaneously placed implant.

The osteotome procedure is limited only to ridges that present spongy bone between the cortical plates.[11,32] Another limitation is the need of at least 2.5-mm ridge width or else, performing GBR procedure as previously described necessary, postponing implant placement by 4 to 6 months.

Collagen was the first bioabsorbable membrane material to be widely used in GBR. Collagen membranes have been used in combination with autogenous bone,[33] xenografts,[34] hydroxyapatite,[9] and other bone substitutes[35] and have been associated with success rates comparable with those achieved with nonresorbable expanded polytetrafluoroethylene (e-PTFE) membranes.[36–38] Such findings support the use of a bioabsorbable barrier membrane for the regeneration of bone. Moreover, the use of a bioabsorbable membrane decreases the risk for membrane infection if a soft-tissue dehiscence occurs postoperatively[39,40] (14% in our study). The premature exposure of these membranes that were managed by an infection prevention protocol using local application of 0.12% chlorhexidine did not lead to diminished results. Collagen membranes have some limitations especially their relatively short survival, thus losing their barrier function within 2 or 3 months[7]; therefore, it may not provide sufficient time for completion of the bone-regeneration process. There is also some evidence that collagen does not adequately exclude soft tissue.[37]

Our results may be compared with previous clinical studies,[6,33] which evaluated changes in ridge width after GBR. In a series of 40 subjects, Buser and colleagues[6] used corticocancellous autografts, bone chips, and nonresorbable e-PTFE membranes to augment the ridge in 66 potential implantation sites narrower than 5 mm. Before the augmentation procedure, the mean ridge width, measured 2 mm apical to the alveolar crest, was 3.5 mm (range 2–4.5 mm). When the e-PTFE membranes were removed 7 to 13 months later, the mean width was 7 mm (range 5–10 mm). Subsequent placement of titanium implants was successful in all 40 subjects. The mean increase in ridge width achieved by Buser and colleagues[6] was comparable with the present study (3.50 mm); however, their technique required a bone-harvesting procedure and frequently a second operation for membrane removal. In the study conducted by Von Arx and Buser,[33] autogenous block grafts, anorganic bovine bone mineral, and collagen membranes were used for horizontal ridge augmentation of 58 sites in 42 subjects. The mean ridge width at the crest was 3 mm (range 0.5–5 mm) before the GBR procedure and 8 mm (range 6–10 mm) after an average of 5.8 months (range 4.5–13.5 months). Although their mean gain in ridge width (4.6 mm)[33] was greater than that attained in our study (3.50 mm), their augmentation technique was much more complex than the present one and required harvesting of block grafts from the symphysis or the retromolar area. Moreover, we consider the final ridge width obtained in our series (7.2 mm ± 0.80 at the crest) adequate for endosseous implant placement. It is worth noting that the former value achieved in our cases is lower than the ridge width (7.9 mm) achieved by Nissan and colleagues[25] who used cancellous block allograft for lateral and vertical augmentation in the posterior mandible. Using similar cancellous bone block allografts in the anterior maxilla resulted in a mean horizontal bone gain of 5 mm, i.e., higher than that achieved in the present study (3.50 mm ± 0.93).[26] However, the technique used in our study is easier for both the operator and the patient, cheaper, less time-consuming, and enabled simultaneous placement of implants.

Marginal bone loss to a certain degree is considered unavoidable soon after two-stage dental implants are uncovered, loaded, and placed into function.[41,42] This phenomenon is believed to be a sequel of the reestablishment of the "peri-implant biological width," i.e., soft-tissue attachment characterized by junctional epithelium and suprabony connective tissue adhesion; these are being noted regardless the type of implant[43] or surgical technique.[44] Therefore, 1 year after loading, crestal bone level stabilized at 1.5 to 2 mm below the implant/abutment junction is considered part of the normal healing.[45] Our data regarding mean peri-implant bone loss followed-up period from 0.5 to 12 years (average 4.3 years) were 1.9 mm, thus falling within the expected figures. These data are similar to those presented in the longitudinal studies of Albrektsson and colleagues[28] and Attard and Zard,[46] who reported mean bone loss of 2 mm 1 year following loading, but are higher than those claimed by Jemt and Johansson,[47] who reported a mean peri-implant bone

loss of 1.02 and 0.5 mm, respectively, after 1 to 16 years in function. For these reasons, we believe that the present bone loss (<2 mm) that was frequently observed during the first year may partially be attributed to the surgical technique but mainly to the expected formation of the biological width. Smoking is a significant risk factor regarding failure of dental implant therapy and augmentation procedure associated with implant placement.[48] In the present study, most patients were nonsmokers, and the remaining were light smokers (<20 cigarettes per day) and these committed to a smoking cessation protocol[23] (1 week before surgery and first month). It is noteworthy that in three light smoking patients who were diagnosed as having severe adult periodontitis, peri-implantitis level was severe.

Within the limitations of this retrospective study, i.e., the limited sample size that was monitored over a 5-year period of time, and the complications associated with very narrow ridges, we suggest that in properly selected cases the procedure is relatively simple, reducing patient's morbidity compared with other techniques. The main limitations of this technique are that it is suitable mainly for bony ridges that contain spongy bone and to bony crests that are not less than 2.5 mm in width.

REFERENCES

1. Atwood DA. Reduction of residual ridges: a major oral disease entity. J Prosthet Dent 1971; 26:266–279.
2. Bartee BK. Extraction site reconstruction for alveolar ridge preservation. Part 1: rationale and materials selection. J Oral Implantol 2001; 27:187–193.
3. Lekovic V, Camargo PM, Klokkevold PR, et al. Preservation of alveolar bone in extraction sockets using bioabsorbable membranes. J Periodontol 1998; 69:1044–1049.
4. Hämmerle CH, Karring T. Guided bone regeneration at oral implant sites. Periodontol 2000 1998; 17:151–175.
5. Fiorellini JP, Nevins ML. Localized ridge augmentation/preservation. A systematic review. Ann Periodontol 2003; 8:321–327.
6. Buser D, Dula K, Hirt HP, Schenk RK. Lateral ridge augmentation using autografts and barrier membranes: a clinical study with 40 partially edentulous patients. J Oral Maxillofac Surg 1996; 54:420–432.
7. Buser D, Dula K, Hess D, Hirt HP, Belser UC. Localized ridge augmentation with autografts and barrier membranes. Periodontol 2000 1999; 19:151–163.
8. Beitlitum I, Artzi Z, Nemcovsky CE. Clinical evaluation of particulate allogenic with and without autogenous bone grafts and resorbable collagen membranes for bone augmentation of atrophic alveolar ridges. Clin Oral Implants Res 2010; 11:1242–1250.
9. Brunel G, Brocard D, Duffort JF, et al. Bioabsorbable materials for guided bone regeneration prior to implant placement and 7-year follow-up: report of 14 cases. J Periodontol 2001; 72:257–264.
10. Jung RE, Windisch SI, Eggenschwiler AM, Thoma DS, Weber FE, Hammerle CH. A randomized-controlled clinical trial evaluating clinical and radiological outcomes after 3 and 5 years of dental implants placed in bone regenerated by mean of GBR techniques with or without the addition of BMP-2. Clin Oral Implants Res 2009; 20:660–666.
11. Summers RB. The osteotome technique: part 2 – the ridge expansion osteotomy (REO) procedure. Compendium 1994; 15:422–434.
12. Saadoun AP, Le Gall MG. Implant site preparation with osteotomes: principles and clinical application. Pract Periodontics Aesthet Dent 1996; 8:453–458.
13. Hahn J. Clinical use of osteotomes. J Oral Implantol 1999; 25:23–29.
14. Komarnyckyj OG, London RM. Osteotome single-stage dental implant placement with and without sinus elevation: a clinical report. Int J Oral Maxillofac Implants 1998; 13:799–804.
15. Rambla FJ, Penarrocha DM, Guarinos CJ. Analysis of the use of expansion osteotomes for the creation of implant beds. Technical contributions and review of the literature. Med Oral Patol Oral Cir Bucal 2006; 11:267–271.
16. Demarosi F, Leghissa GC, Sardella A, Lodi G, Carrassi A. Localised maxillary ridge expansion with simultaneous implant placement: a case series. Br J Oral Maxillofac Surg 2009; 47:535–540.
17. Qahash M, Susin C, Polimeni G, Hall J, Wikesjo UM. Bone healing dynamics at buccal peri-implant sites. Clin Oral Implants Res 2008; 19:166–172.
18. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int J Oral Maxillofac Implants 2004; 19:43–61.
19. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005; 25:113–119.
20. Esposito M, Ekestubbe A, Grondahl K. Radiological evaluation of marginal bone loss at tooth surfaces facing single Branemark implants. Clin Oral Implants Res 1993; 4:151–157.
21. Cardaropoli G, Lekholm U, Wennstrom JL. Tissue alterations at implant-supported single-tooth replacement: a 1-year prospective clinical study. Clin Oral Implants Res 2006; 17:165–171.

22. Spray JR, Black CG, Morris HF, Ochi S. The influence of bone thickness on facial marginal bone response: stage 1 placement through stage 2 uncovering. Ann Periodontol 2000; 5:119–128.
23. Bain CA. Smoking and implant failure – benefits of a smoking cessation protocol. Int J Oral Maxillofac Implants 1996; 11:756–759.
24. O'leary TJ, Drake RB, Naylor JE. The plaque control record. J Periodontol 1972; 43:38.
25. Nissan J, Ghelfan O, Mardinger O, Calderon S, Chaushu G. Efficacy of cancellous block allograft augmentation prior to implant placement in the posterior atrophic mandible. Clin Implant Dent Relat Res 2011; 13:279–285.
26. Nissan J, Mardinger O, Calderon S, Romanos GE, Chaushu G. Cancellous bone block allografts for the augmentation of the anterior atrophic maxilla. Clin Implant Dent Relat Res 2011; 13:104–111.
27. Schwartz D, Levin L. Intraoral autogenous block onlay bone grafting for extensive reconstruction of atrophic maxillary alveolar ridges. J Periodontol 2005; 76:636–641.
28. 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.
29. Mombelli A, Lang NP. Clinical parameters for the evaluation of dental implants. Periodontol 2000 1994; 4:81–86.
30. Blus C, Szmukler-Moncler S. Split-crest and immediate implant placement with ultra-sonic bone surgery: a 3 year life-table analysis with 230 treated sites. Clin Oral Implants Res 2006; 17:700–707.
31. Anitua E, Begona L, Orive G. Clinical evaluation of split-crest technique with ultrasonic bone surgery for narrow ridge expansion: status of soft and hard tissues and implant success. Clin Implant Dent Relat Res 2011. DOI: 10.1111/j.1708-8208.2011.00340.x.
32. Sethi A, Kaus T. Maxillary ridge expansion with simultaneous implant placement: 5-year results of an ongoing clinical study. Int J Oral Maxillofac Implants 2000; 15:491–499.
33. Von Arx T, Buser D. Horizontal ridge augmentation using autogenous block grafts and the guided bone regeneration technique with collagen membranes: a clinical study with 42 patients. Clin Oral Implants Res 2006; 17:359–366.
34. Zitzmann NU, Scharer P, Marinello CP, Schüpbach P, Berglundh T. Alveolar ridge augmentation with Bio-Oss: a histologic study in humans. Int J Periodontics Restorative Dent 2001; 21:288–295.
35. Wang HL, Boyapati L. "PASS" principles for predictable bone regeneration. Implant Dent 2006; 15:8–17.
36. Hurzeler MB, Kohal RJ, Naghshbandi J, et al. Evaluation of a new bioresorbable barrier to facilitate guided bone regeneration around exposed implant threads. An experimental study in the monkey. Int J Oral Maxillofac Surg 1998; 27:315–320.
37. Bunyaratavej P, Wang HL. Collagen membranes: a review. J Periodontol 2001; 72:215–229.
38. Schwartzmann M. Use of collagen membranes for guided bone regeneration: a review. Implant Dent 2000; 9:63–66.
39. Stavropoulos F, Dahlin C, Ruskin JD, Johansson C. A comparative study of barrier membranes as graft protectors in the treatment of localized bone defects. An experimental study in a canine model. Clin Oral Implants Res 2004; 15:435–442.
40. Buser D, Dula K, Lang NP, Nyman S. Long-term stability of osseointegrated implants in bone regenerated with the membrane technique. 5-year results of a prospective study with 12 implants. Clin Oral Implants Res 1996; 7:175–183.
41. Hermann JS, Buser D, Schenk RK, Cochran DL. Crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged and submerged implants in the canine mandible. J Periodontol 2000; 71:1412–1424.
42. Hermann JS, Buser D, Schenk RK, Higginbottom FL, Cochran DL. Biologic width around titanium implants. A physiologically formed and stable dimension over time. Clin Oral Implants Res 2000; 11:1–11.
43. Abrahamsson I, Berglundh T, Wennström J, Lindhe J. The peri-implant hard and soft tissues at different implant systems. A comparative study in the dog. Clin Oral Implants Res 1996; 7:212–219.
44. Abrahamsson I, Berglundh T, Moon IS, Lindhe J. Peri-implant tissues at submerged and non-submerged titanium implants. J Clin Periodontol 1999; 26:600–607.
45. Cochran DL, Nummikoski PV, Schoolfield JD, Jones AA, Oates TW. A prospective multicenter 5-year radiographic evaluation of crestal bone levels over time in 596 dental implants placed in 192 patients. J Periodontol 2009; 80:725–733.
46. Attard NJ, Zard GA. Long-term treatment outcomes in edentulous patients with implant-fixed prostheses: the Toronto study. Int J Prosthodont 2004; 17:417–424.
47. Jemt T, Johansson J. Implant treatment in the edentulous maxillae: a 15-year follow-up study on 76 consecutive patients provided with fixed prostheses. Clin Implant Dent Relat Res 2006; 8:61–69.
48. Strietzel FP, Reichart PA, Kale A, Kulkarni M, Wegner B, Kuchler I. Smoking interferes with the prognosis of dental implant treatment: a systematic review and meta-analysis. J Clin Periodontol 2007; 34:523–544.