Surgical-Prosthodontic Reconstruction of Advanced Maxillary Bone Compromise with Autogenous Onlay Block Bone Grafts and Osseointegrated Endosseous Implants: A 12-Year Study of 32 Consecutive Patients

Eugene E. Keller, DDS, MSD*/Dan E. Tolman, DDS, MSD**/Steven Eckert, DDS***

During a 12-year period (1984 to 1997), 32 consecutive patients with advanced maxillary bone compromise received surgical-prosthodontic rehabilitation. The most frequent procedure used was maxillary augmentation with a free nonvascularized autogenous onlay block bone graft, and the average time of prosthesis function was 67 months. Twenty-eight patients underwent a 1-stage procedure, in which endosseous implants were placed simultaneously for internal rigid skeletal fixation of the onlay bone graft, and 4 patients underwent a 2-stage procedure, in which endosseous implants were placed secondarily 6 months after complete healing of the previously placed onlay bone graft, which initially was stabilized by titanium miniplates and lag screws. Treatment success was evaluated separately for the first 7 consecutively treated patients (developmental group) and for the next 25 consecutive patients (routine group). Assessment was made of implant survival relative to etiology of bone loss, implant type and length, type of prosthesis, type of opposing occlusion, type of surgical procedure, and presence of discontinuity. The implant survival rate was 91% in the 25 routine patients and 65% in the 7 developmental patients. Implant type and length, prosthesis type, opposing occlusion, and the presence or absence of discontinuity significantly impacted treatment outcome. Onlay block bone graft success (96%) in all 32 treated patients and prosthetic success (96%) in the last 25 patients was recorded.

(INT J ORAL MAXILLOFAC IMPLANTS 1999;14:197–209)

Key words: autogenous bone graft, discontinuity, endosseous implant, maxilla, nonvascular, occlusion, onlay, prosthesis, reconstruction

Surgical-prosthodontic rehabilitation of the edentulous patient with advanced maxillary alveolar and basal bone resorption poses numerous biomechanical problems and obstacles. Historically, surgical efforts were directed toward improving the size and position of the edentulous ridge to permit successful fabrication of a removable soft tissue–supported conventional denture. Since 1981, through the development of predictable osseointegrated implant technology,[1] clinicians have improved severely compromised anatomic structure and have provided skeletal anchorage for a dental prosthesis using osseointegrated endosseous implants. This technology allows dental rehabilitation with a bone-anchored fixed prosthesis, rather than a soft tissue mucoperiosteal–supported removable prosthesis. Endosseous implants can also initially provide rigid stability to onlay block bone grafts, which theoretically increases revascularization and remineralization potential.[2–4] Skeletal anchorage rather than soft tissue mucoperiosteal support of a dental prosthesis is far superior in terms of function, longevity, esthetics, and patient

*Professor, Mayo Medical School, Mayo Medical Center, Rochester, Minnesota.
**Professor Emeritus, Mayo Medical School, Mayo Medical Center, Rochester, Minnesota.
***Assistant Professor, Mayo Medical School, Mayo Medical Center, Rochester, Minnesota.

Reprint requests: Dr E. E. Keller, Oral and Maxillofacial Surgery, Mayo Clinic, 200 First Street, SW, Rochester, MN 55905. Fax: 507-284-8082.

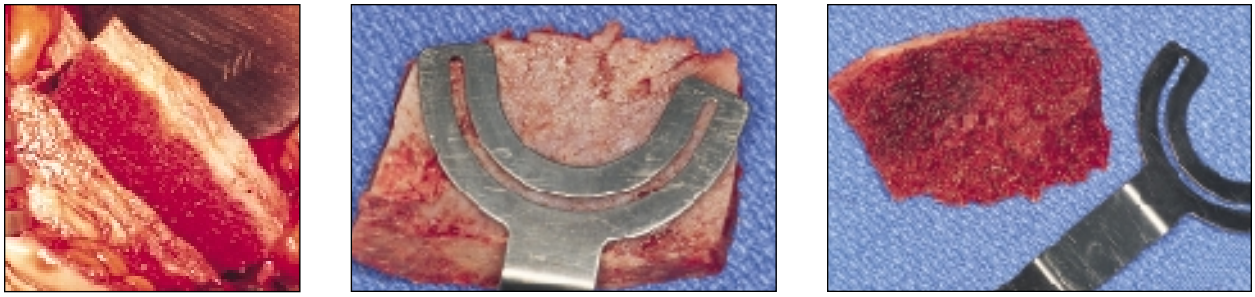


Fig 1a Surgical technique. *(Left)* Anterior-medial iliac crest donor site with mobilized corticocancellous block bone graft. *(Center)* A template assists the surgeon in obtaining adequate width and depth for full-arch reconstruction. Note cortical side *(center)* and cancellous side *(right)* of corticocancellous iliac block bone graft.

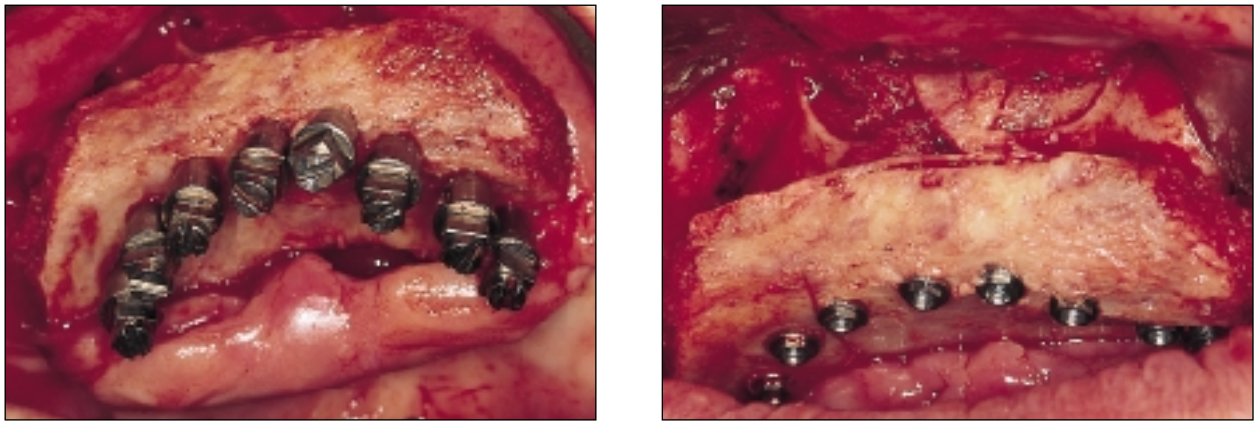


Fig 1b Corticocancellous block bone graft is secured to the residual edentulous maxilla with 8 titanium endosseous implants. *(Left)* Significant cortical bone graft lateral, anterior, and posterior to implants ensures bone grafting reconstruction of compromised nasal floor, piriform aperture, and palatal anatomy. *(Right)* Block bone grafts were placed in the nasal floor for reconstruction of bone discontinuity in this area.

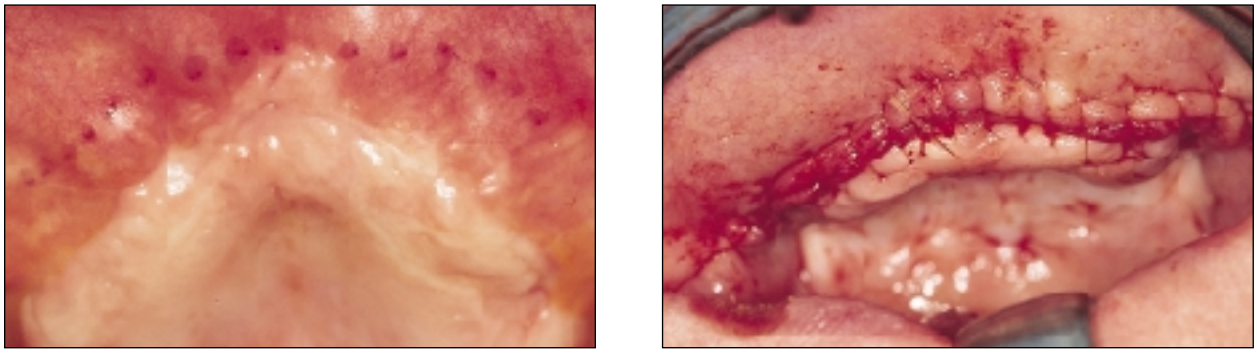
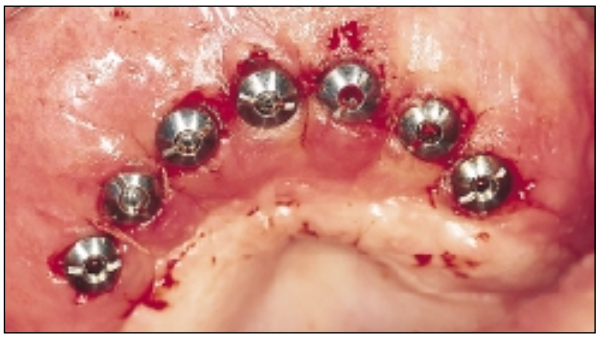


Fig 1c *(Left)* Incision line in alveolar mucosa just above mucogingival line and *(right)* typical everted, watertight, nontension wound closure after advancement of lip mucosa by a superior periosteal releasing incision.



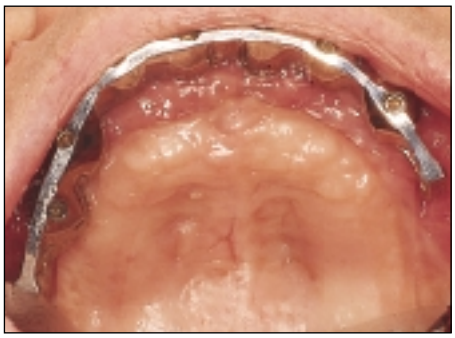


Fig 1d *(Left)* After stage 2 abutment surgery, implants are placed anterior to previous edentulous ridge. *(Right)* A typical continuous fixed bar connecting endosseous implants is anterior to the previous edentulous ridge in correct relation to upper lip and nasal anatomy.

satisfaction. This superiority is particularly true for patients with severely resorbed maxillae. However, major obstacles are encountered with these patients, as documented by the learning curve revealed in this retrospective study.

In 1980, Breine and Brånemark[5] were the first to describe onlay composite bone grafts for reconstruction of the compromised edentulous maxilla. They used autogenous, corticocancellous block tibial bone grafts that were secured to the residual jawbone with commercially pure titanium, noncoated, threaded, cylindric endosseous implants. The original technique involved a 2-stage preformation tibial corticocancellous block bone graft reconstruction, which in 1985 was replaced by a 1-stage reconstruction using anterior-lateral iliac crest bone graft.[6] For the initial 9 patients, who were treated with the preformation 2-stage procedure[5] (8 in the maxilla and 1 in the mandible), the rate of implant survival was higher for implants placed at the tibial bone graft transfer procedure (second stage) than for those placed at the initial tibial implant placement procedure (first stage). Brånemark[6] subsequently advocated a 1-stage procedure rather than a 2-stage preformation procedure and changed the donor site from the tibia to the lateral iliac crest, since the implant survival rate of 50% for 1-stage implants was better than the rate of 42% for 2-stage implants.[5] These results indicated that the 2-stage preformation procedure involved an unnecessary surgical step. Brånemark[6] utilized a high lip mucosal incision, rather than an alveolar or sulcus mucosal incision, to ensure that the incision line was anatomically removed from the underlying onlay bone graft.

In 1987, Keller et al[7] modified the Brånemark 1-stage onlay bone graft technique by utilizing the anterior medial rather than the anterior lateral iliac crest (Fig 1a). This modification was an important change because the corticocancellous block bone graft provided a more anatomically concave contour on the cortical side that faced the oral cavity; the cancellous portion was convex and interfaced with the concave resorbed residual alveolar and palatal bone (Fig 1b). This modified donor site technique also reduced the potential surgical morbidity.[8,9]

A number of authors have since reported clinical experience with the initially described 1-stage maxillary onlay bone graft procedure: Kahnberg et al[10] reported in 1989 on 10 consecutive patients; in 1990 Adell et al[11] described 23 consecutively treated patients during a mean observation period of 4.3 years; Isaksson and Alberius[12] in 1992 and Isaksson[13] in 1994, respectively, reported on 8 and 10 consecutively treated patients; in 1993 Nystrom et al[14] reported on 30 consecutively treated patients; in 1997 van Steenberghe et al[15] reported on 20 patients; and in 1997 Schliephake et al[16] reported on 66 patients. Jensen and Sindet-Pederson[17] in 1991 and Donovan et al[18] in 1994 described 13 and 15 patients, respectively, treated with the 1-stage block bone graft technique; however, calvarial (membranous) rather than iliac (endochondral) block bone grafts were utilized, which theoretically increased the onlay block bone graft healing potential.[4,19–21]

The current surgical technique (Figs 1 and 2) used in treating the patients in this retrospective study is detailed elsewhere.[22] The 1-stage procedure (in 28 of the current 32 patients) was utilized when residual bone volume and quality were adequate to support the onlay graft and allow simultaneous placement of a sufficient number of bone graft–stabilizing endosseous implants through the bone graft into residual bone. The 2-stage procedure (in 4 of the current 32 patients) was utilized when the residual bone was partially or totally absent, or

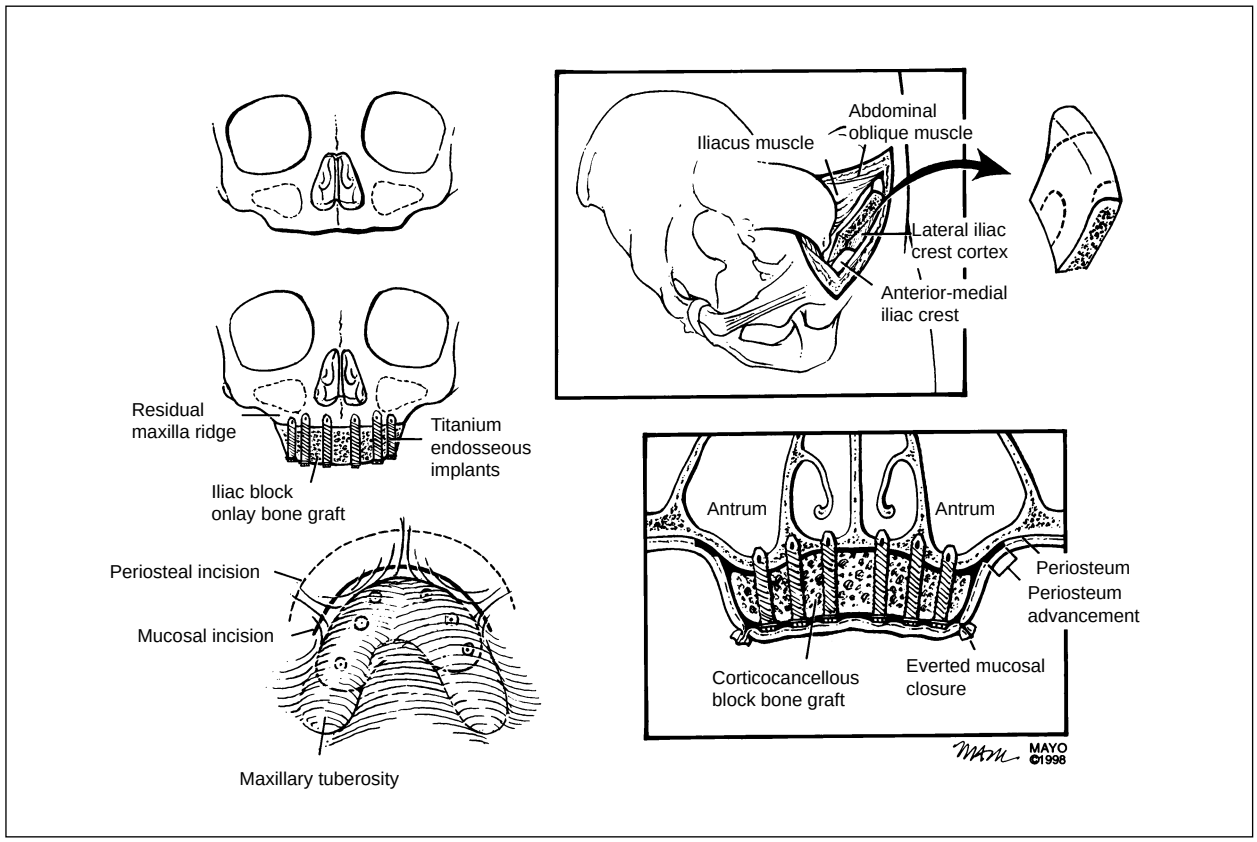


Fig 2 Drawing of 1-stage, full-arch onlay composite bone graft reconstruction of advanced bone compromise in the edentulous maxilla. Corticocancellous block onlay autogenous bone graft is harvested from the anterior-medial ilium. Cylindric, threaded, noncoated endosseous implants rigidly stabilize the onlay block bone graft at stage 1 surgery and 6 months later, after stage 2 abutment surgery, act as skeletal fixation for a tissue-integrated dental prosthesis.

when poor quality residual bone would not provide rigid stability to the onlay block bone graft. In these patients, titanium miniplates or lag screws attached the graft to adjacent regional (zygoma, palatal, pterygoid, piriform aperture) dense bone during the bone graft healing, and endosseous implants were placed secondarily into the healed graft 4 to 6 months later.

Materials and Methods

This retrospective clinical study involves 32 consecutively treated patients who presented with advanced horizontal and vertical bone loss and complete (28 patients) or partial (4 patients) maxillary edentulism. An autogenous, rigidly fixed block onlay bone graft was placed in all 32 patients. Endosseous titanium implants (Nobel Biocare USA, Westmont, IL) were used in all patients and supported a tissue-integrated prosthesis in all successfully rehabilitated patients. The initial patient received surgical treatment in October 1984, and the most recent patient was operated on in January 1996. Prosthesis and implant survival data collection continued through January 1997.

Data obtained from the patient's general medical records included age, gender, cause of maxillary defect, type of reconstruction (1- versus 2-stage), surgical dictation record, and prosthetic treatment record. All patients were treated surgically by two of the authors, oral and maxillofacial surgeons, who worked with several different experienced prosthodontists. A current clinical evaluation by the treating prosthodontist and current appropriate radiographs (laminogram, periapical, or both) were available on all patients.

The surgical dictation record provided the following data: type of donor bone (cortical or corticocancellous block), bone graft donor site (ilium or cranium), bone graft fixation type (endosseous implant, lag screw, miniplate, or transosseous wire), and implant data (type, length, number

placed or removed, number nonfunctional). Prosthetic records provided the following data: type of dental prosthesis (fixed, fixed removable, or overdenture); months of prosthesis function; opposing mandibular arch occlusion (natural teeth, removable partial or complete denture, fixed implant-supported prosthesis, or various combinations); and need to remake, modify, or return to soft tissue–supported maxillary prosthesis.

The criteria for determining the success of individual endosseous implants, as proposed by Smith and Zarb,[23] were utilized as completely as records would allow. Because implants were frequently rigidly attached by a substructure bar and this bar was not routinely removed at each patient examination, it was not possible to verify immobility of all implants in every patient at every visit unless a clinical or radiographic finding dictated removal. However, nonintegrated implants were easily detected when clinical, historic, and radiographic findings were evaluated at each patient visit. Marginal or peri-implant bone loss was assessed by radiographs on a yearly basis, but such radiographs were not routinely obtained after the second postsurgical year unless clinical conditions warranted. Comfort, esthetics, and peri-implant soft tissue health were evaluated on all patients and recorded by the examining surgeon or restorative dentist at annual intervals.

Implant survival data included nonfunctional (sleeping) implants as being successful, as they were all osseointegrated and their prosthetic utilization was controlled by numerous factors that may change during the lifetime of a given patient. Implant survival percentage was calculated by dividing the number removed by the number placed, subtracting from 1.00, and multiplying by 100. Bone graft and prosthesis survival percentage was calculated individually by dividing the number failed by the number placed, subtracting from 1.00, and multiplying by 100.

The success of surgical and prosthodontic treatment was determined for all 32 patients during the 12-year study period. In addition, data on the first 7 treated patients (developmental group) were compared with data on the 25 subsequent patients (routine group) to assess the effect of experience in treating this group of patients. Treatment results (implant, bone graft, and prosthesis) in 11 patients who had discontinuity secondary to oronasal or oral-antral osseous defects (with or without fistula) were compared with 21 patients who had osseous continuity.

Findings and Results

General. The mean age of the patients (20 females, 12 males) was 52 years (range, 18 to 76) (Table 1). Two patients were lost to follow-up; one (#7) was lost after 48 months of prosthesis function, and one (#29) died of natural causes during the study after 84 months of prosthesis function (data statistics ended for both patients at those times). The 32 patients had a mean time of prosthesis function of 67 months (range, 7 to 122). Of the 32 patients, 28 underwent a 1-stage surgical reconstruction (27 complete arches and 1 segmental), and 4 patients underwent a 2-stage surgical reconstruction procedure (1 complete arch and 3 segmental).

Etiology of Compromised Maxilla. Twenty-three patients (72%) had worn removable dentures long-term, which was most likely a major contributing factor to advanced maxillary bone resorption (Tables 1 and 2). Included in this group were 1 patient with cleft lip and palate and 1 with bilateral cleft lip and palate; neither patient had undergone previous alveolar-palatal bone grafting, and both patients had worn a complete denture long-term. Nine patients (28%) had posttraumatic bone loss; 4 from gunshot wounds, 3 from motor vehicle accidents, and 2 from postsurgical defects. Maxillary discontinuity was secondary to various causes in 11 of the 32 patients (34%). The causes were cleft lip and palate in 2 patients, motor vehicle accident in 2 patients, gunshot wound in 4 patients, postsurgical defect in 1 patient, and complete denture cause in 2 patients.

Bone Graft Data. Of the 32 patients treated, 30 (94%) received corticocancellous block bone grafts from the anterior ilium (endochondral bone), 29 from the medial ilium, and 1 from the lateral ilium (Tables 1 and 3). The remaining 2 patients received cortical block bone grafts from the cranium (membranous bone). Rigid internal skeletal fixation of the bone graft to the residual maxilla was accomplished with endosseous implants in all 28 patients who underwent 1-stage reconstruction. However, in 1 patient (#3), only 2 of the 6 endosseous implants engaged both residual and grafted bone. In this patient, who was treated in 1985, additional fixation of the bone graft was needed, and transosseous wires to the infraorbital rim were utilized. The 4 patients who underwent 2-stage reconstruction received a bone graft with internal rigid skeletal fixation using either titanium lag screws (patients 29 and 32) or a titanium miniplate (patients 30 and 31).

Of the 32 patients, 2 experienced partial bone graft failure. In both patients (#3 and 7), a 1-stage

Table 1 General, Bone Graft, Implant, and Prosthetic Data

				Bone graft			Implants		Prosthesis			
Patient no.	Age/ sex	Etiology	1- or 2-stage	Type	Donor site	Fixation	No. placed	No. removed (sleeping)	Type	Mo. in function	Opposing occlusion	Comments/complications
1	50/F	CLP, RFD	1	CC	I	EI	6	2	FR	144	NT ,RPD	Oronasal fistula, anterior wound dehiscence
2	48/M	RFD	1	CC	I	EI	6	0	OD	120	IF	Overdenture magnet retention, implants not connected
3	58/F	RFD	1	CC	I	EI-TW	6	3 (3)	NO	0	RFD	Large anterior osseous defect, anterior wound dehiscence, returned to RFD, bone graft infection (3/4 lost)
4	54/F	RFD	1	CC	I	EI	6	0	OD	108	IF	Overdenture magnet retention, implants not connected
5	62/F	RFD	1	CC	I	EI	4	0	OD	109	RFD	Overdenture O-ring retention, implants bar-connected
6	66/M	RFD	1	CC	I	EI	5	5	OD	36	NT, IF	Anterior osseous defect, overdenture O-ring retention, implants free standing, all implants fractured, patient returned to RFD
7	41/F	RFD	1	CC	I	EI	7	3	OD	48	NT	Late bone graft infection-1/2 out, overdenture O-ring retention, implants bar-connected, compromised prosthesis, patient lost to follow-up
8	44/F	TMVA	1	CC	I	EI	10	0 (2)	FR	96	NT-IF	Oronasal fistula, delayed placement of 5 implants (6 mo.)
9	76/F	RFD	1	CC	I	EI	6	1 (1)	OD	116	RFD	Overdenture O-ring retention, implants bar-connected
10	53/M	CLP, RFD	1	CC	I	EI	7	2	FR	94	NT	Oronasal fistula bilateral, anterior wound dehiscence
11	47/M	TPSD	1	CC	I	EI	9	0 (2)	F	99	NT ,IF	Anterior osseous defect
12	67/F	RFD	1	CC	I	EI	6	0	FR	96	NT ,IF	
13	46/F	RFD	1	CC	I	EI	6	6	OD	58	NT	Returned to RFD
14	59/F	RFD	1	CC	I	EI	6	0	OD	94	IF	Overdenture magnet retention, implants not connected
15	54/F	RFD	1	CC	I	EI	6	1	OD	86	IF	Overdenture Ceka retention, implants bar-connected
16	42/M	TGSW	1	CC	I	EI	3	0	A	67	IF	Oronasal fistula, large osseous defect, compromised prosthesis
17	53/F	RFD	1	CC	I	EI	6	0	FR	80	IF	
18	58/F	RFD	1	CC	I	EI	5	0	FR	81	NT	
19	69/M	RFD	1	CC	I	EI	6	0 (2)	FR	61	NT, IF	
20	59/M	RFD	1	CC	I	EI	8	0	FR	53	IF	
21	60/F	RFD	1	CC	I	EI	8	0	FR	33	IF	
22	48/M	TGSW	1	CC	I	EI	6	0	F	29	IF	Previous closure of oronasal fistula with bone graft
23	64/F	RFD	1	CC	I	EI	7	0 (1)	FR	30	IF	Anterior osseous defect, previous subperiosteal implant
24	59/F	RFD	1	CC	I	EI	9	1	FR	23	IF	
25	39/M	RFD	1	CC	I	EI	9	1	F	16	IF	Marginal bone loss noted on all implants at stage 2 surgery
26	67/F	RFD	1	CC	I	EI	8	0	F	12	IF	
27	18/F	TMVA	1	CC	I	EI	4	0	OD	7	IF	Anterior osseous defect, RPD over freestanding implants
28	60/M	RFD	1	CC	I	EI	8	0	F	59	NT, RPD	
29	47/F	TPSD	2	CC	I	LS	6	1 (2)	OD	84	IF	Oronasal fistula, large anterior osseous defect, patient died
30	33/M	TGSW	2	C	Cr	MP	3	0	OD	89	IF	Oronasal fistula, anterior osseous defect (premaxilla)
31	38/M	TGSW	2	C	Cr	MP	5	0 (1)	OD	97	IF	Oronasal fistula, anterior osseous defect (premaxilla)
32	18/F	TMVA	2	CC	I	LS	7	2 (0)	F	17	NT	Osseous defect (right posterior maxilla)

Etiology: CLP = cleft lip and palate; RFD = removable full denture; TMVA = trauma/motor vehicle accident; TPSD = trauma/postsurgical defect; TGSW = trauma/gunshot wound.
Bone graft type: CC = corticocancellous block; C = cortical block.
Bone graft donor site: I = ilium; Cr = cranium.
Bone graft fixation: EI = endosseous implants; TW = transosseous wires; LS = lag screws; MP = miniplates.
Prosthesis type: FR = fixed-removable; OD = overdenture; NO = no prosthesis; F = continuous fixed; A = abutments.
Opposing occlusion: NT = natural teeth; RPD = removable partial denture; IF = implant-supported continuous fixed prosthesis; RFD = removable full denture.

Table 2 Implant Survival and Prosthesis Success Relative to Discontinuity Type or Etiology and Discontinuity Compared to No Discontinuity Patients

	Maxillary discontinuity						
	Congenital	Acquired				Discontinuity	
	CLP	MVA	GSW	PSD	RFD	Yes	No
No. of patients	2	2	4	1	2	11	21
No. of implants	13	14	16	6	11	60	144
No. removed (sleeping)	4	(2)	(1)	1 (2)	8 (3)	13 (8)	15 (6)
% survival	69	100	100	83	27	78	90
No. not engaging residual bone	6	—	7	4	6	23*	
No. of prostheses	2	2	4	1	2	11	21
No. failed	—	—	—	—	2	2	2
% success	100	100	100	100	0	82	90

*Ten of the 23 implants not engaging residual bone in discontinuity patients were lost.
CLP = cleft lip and palate; MVA = motor vehicle accident; GSW = gunshot wound; PSD = postsurgical defect; RFD = removable full denture.

Table 3 Developmental Versus Routine Group Data, 1-Stage Versus 2-Stage Procedure Data, Compared to All (Total) Patients

	Implants			Bone graft			Prostheses		
Patient group (no.)	No. placed	No. removed (sleeping)	% survival	No. placed	No. failed	% survival	No. placed	No. failed	% success
Developmental group (7 patients)	40	13 (3)	67.0	7	1.25	82.0	7	3	57.0
Routine group (25 patients)	164	15 (11)	91.0	25		100.0	25	1	96.0
1-Stage									
Full-arch (27 patients)	179	25 (11)	86.3	27	1.25	95.6	27	4	86
Segmental (1 patient)	4			1			1		
2-Stage									
Full-arch (1 patient)	6	1 (2)	85.7	1		100.0	1		100.0
Segmental (3 patients)	15	2 (1)		3			3		
Total (32 patients)	204	28 (14)	86.3	32	1.25	96.0	32	4	87.5

procedure with iliac bone had been used, and both patients experienced prosthesis failures. The cause of the 75% bone graft failure in patient #3 was related to inadequate bone graft fixation secondary to compromised host bone and partial wound dehiscence 10 days after surgery. The cause of the 50% bone graft failure in patient #7 was infection, which was diagnosed 6 months after second-stage surgery (12 months after bone graft placement). Initial bone graft healing was uncomplicated.

Implant Data. A total of 204 endosseous implants was placed in the 32 patients (183 in 1-stage procedures and 21 in 2-stage procedures) (Tables 1 to 5). The types (and diameter) of Nobel Biocare implants were 18 regular 3.75-mm-diameter implants; 6 regular 4.00-mm-diameter implants; 146 regular self-tapping 3.75-mm-diameter implants; 17 Mark II self-tapping 3.75-mm-diameter implants; and 17 conical 3.75-mm-diameter implants (Table 4). Twenty-eight implants were removed in 12 patients, and 14 implants were not utilized (nonfunctional) in 8 patients, for an overall implant survival rate of 86.3%. The implant survival rates did not differ significantly between the 1-stage and 2-stage patients or between the segmental and the complete-arch patients. However, a clear difference was noted in implant survival between the first 7 patients treated (developmental group) and the last 25 patients treated (routine group) (67% versus 91%) (Table 3), and between the 11 patients with maxillary discontinuity and the 21 patients with maxillary continuity (78% versus 90%) (Table 2). The implant survival rate was 57% in the 23 implants that did not engage residual maxillary bone in patients with discontinuity.

Of the 28 lost implants, 10 were removed at or before stage 2 surgery because of failure to achieve initial osseointegration. An additional 5 implants

Table 4 Implant Survival Relative to Implant Type and Length

	Regular (3.75 mm)		Wide (4.00 mm)		Self-tapping (3.75 mm)		Self-tapping Mark II		Conical		Total	
Implant length (mm)	No. placed	No. removed (sleeping)	No. placed	No. removed (sleeping)	No. placed	No. removed (sleeping)	No. placed	No. removed (sleeping)	No. placed	No. removed (sleeping)	No. placed (removed)	% survival
10	5	1	0	0	30	3 (3)	0	0	5	2 (2)	40 (6)	85.0
13	5	1 (1)	1	0	40	7 (5)	1	0	8	3 (1)	55 (11)	80.0
15	3	0	4	1	36	4 (1)	5	1	4	3	52 (9)	82.7
18	1	0	1	1	40	1	11	0 (1)	0	0	53 (2)	96.2
20	4	0	0	0	0	0	0	0	0	0	4 (0)	100.0
Total	18	2 (1)	6	2	146	15 (9)	17	1 (1)	17	8 (3)	204 (28)	86.3
% survival	89.0		67.0		90.0		94.0		53.0			

Table 5 Implant and Prosthesis Survival Relative to Prosthesis Type and Opposing Occlusion

	Prosthesis type					Opposing occlusion				
	F	FR	OD	A	NO	NT	IF	NT+RPD	NT+IF	RFD
Implants										
No. placed	47	78	70	3	6	32	106	14	36	16
No. removed (sleeping)	3 (2)	5 (5)	17 (4)		3 (3)	13	4 (5)	2	(6)	4 (4)
% survival	94	94	76	100	50	60	96	86	100	75
Prostheses										
No. placed	6	11	13	1	1	5	17	2	5	3
No. failed			3		1	2			1	1
% success	100	100	77	100	0	60	100	100	80	67

F = fixed; FR = fixed removable; OD = overdenture; A = abutment-supported; NO = no prosthesis; NT = natural teeth; IF = implant-supported fixed; RPD = removable partial denture; RFD = removable full denture.

were lost during the first 6 months of prosthesis function. The 10 implants lost at stage 2 surgery combined with the 5 implants lost during the first 6 months of prosthetic loading indicate that 54% of the lost implants initially failed to attain osseointegration. Thirteen implants (46% of those removed) were long-term failures (typically considered "functional-prosthetic failures") and are discussed in the prosthetic data section.

Of the 204 implants placed, 146 were self-tapping implants 3.75 mm in diameter, and their survival rate was 90%. The standard 3.75-mm-diameter and Mark II self-tapping implants had similar survival rates (89% and 94%, respectively). The 4.00-mm-diameter regular and the conical 3.75-mm-diameter implants had low survival rates (67% and 53%, respectively).

The implant survival rate was noticeably better in the 57 longer (18 and 20 mm) implants (96.5%) than the 147 shorter (10, 13, and 15 mm) implants (82.0%). Also, the 53 implants that were 18 mm long had a noticeably better survival than the 55 implants that were 13 mm long (96.2% versus 80.0%, respectively). It is important to note, however, that all 8 conical and 5 of 6 wide-implant failures occurred in the 10-, 13-, and 15-mm length groups, which significantly reduced the overall survival rate in the shorter implant group (from 86.4% to 82.0%) (Table 4).

Prosthetic Data. The mean time of prosthesis function was 67 months (range, 7 to 144 months) (Tables 1, 2, 3, and 5). Of the 32 patients treated, 28 experienced successful prosthetic rehabilitation and 4 experienced prosthetic failure, for an overall prosthesis success rate of 87%. Only 1 of the failures was in the routine group (success rate of 96%), as compared with 3 in the development group (success rate of 57%). All 4 prosthesis failures occurred in the 28 patients who underwent 1-stage procedures.

The prosthesis type for the 13 implants removed after prosthesis loading was: *(1)* fixed removable (#25): 1 implant was removed after 11 months of function and the prosthesis was not affected; *(2)* overdenture supported by implant-connecting bar with Ceka retention (#13): 6 implants were removed (3 at 28 months and 3 at 47 months of function) and the patient returned to a complete denture; *(3)* overdenture supported by free-standing implants with O-ring retention (#6):

all 5 conical implants fractured (between 29 and 36 months of function), and the patient returned to a complete denture; *(4)* no final prosthesis (#3): 1 nonfunctional implant was removed 16 months after stage 2 surgery, and the patient continued with complete denture use.

The most frequent prosthesis used was an overdenture (13 patients), next in frequency was a fixed removable prosthesis (11 patients), and the least frequently used was a continuous fixed prosthesis (6 patients). The 17 patients with fixed or fixed removable prostheses experienced no prosthesis failure (100% success). However, the 13 overdenture patients experienced 3 prosthesis failures. All 3 patients experienced delayed implant loss (3 at 5 months, 5 at 29 months, 3 at 36 months, and 3 at 57 months). The causes of implant loss in the 3 patients who experienced prosthesis failure and wore a removable complete denture at the end of the study were probable implant overload, with fracture of 5 implants (patient 6); late bone graft infection (patient 7); and late implant loss (3 at 29 months and 3 at 57 months) resulting from idiopathic bone resorption (patient 13). The fourth patient (#3) who experienced prosthetic failure never received a prosthesis because of early (75%) bone graft loss and the loss of 3 of 6 implants placed.

Implant survival was 94% (125 placed, 8 removed) in 17 patients who had continuous fixed or fixed removable prostheses; in contrast, implant survival was 76% in the 13 patients who wore an overdenture (Table 5).

Two patients experienced significant prosthesis compromise. One patient (#16) underwent successful surgical treatment (bone graft and implants in 1 stage), with closure of a large oronasal fistula, and experienced significant functional improvement. However, a final dental prosthesis was not fabricated, and the patient had improved (but less than ideal) function with implant abutments and was not classified as having a prosthetic failure. The second patient (#7) lost 3 implants after 5 months of prosthesis function, required a prosthesis remake, had compromised function, and was classified as having a prosthetic failure.

The most common opposing occlusion was provided by a continuous fixed implant-supported prosthesis (17 patients). The other groups of opposing occlusion were: 5 patients with natural teeth only, 2 patients with natural teeth and a removable partial denture, 5 patients with natural teeth combined with a fixed implant-supported prosthesis, and 3 patients with removable complete dentures. For the 22 patients whose opposing dentition was a fixed implant-supported prosthesis, implant survival was 97% and prosthesis success was 96%. For the 12 patients whose opposing dentition was natural teeth, implant survival was 82% and prosthesis success was 75%. The 3 patients whose opposing occlusion was a complete removable denture experienced 75% implant survival and 67% prosthesis success (Table 5).

Discussion

The biologic factors of nonvascularized free bone grafts are critically important to understand.[24–32] Reports on these factors emphasize the importance of gentle harvesting techniques and describe the 3 basic healing mechanisms that are required for predictable bone graft healing: *(1)* "bone induction," which relies heavily on a healthy recipient site containing vital osteoprogenitor cells as well as the presence of active bone morphogenic protein in the donor bone graft; *(2)* "bone conduction," which relies on a well-vascularized, watertight closure recipient site to permit early revascularization[4] and secondary "creeping substitution" bone healing; and *(3)* "transfer osteogenesis," which involves the transfer of living osteoprogenitor stem cells in the marrow portion of the bone graft. Immediate transfer of the bone graft from the donor site to the recipient site is recommended to decrease extracorporal time and increase transplant cell survival.

Rigid fixation of the onlay bone graft and rigid stability of the endosseous implants is critically important (Fig 1b). Clinically, bone healing of osteotomy sites and survival of bone grafts are improved when the movable parts are rigidly fixed in a physiologic manner. This improvement has been confirmed experimentally.[2,3] However, nonphysiologic rigid fixation can lead to bone graft resorption during revascularization and remineralization[33,34] by the effective stress shielding of bulky rigid metal plates. The use of commercially pure titanium endosseous implants, miniplates, or lag screws in these study patients provided skeletal stability of the maxillary onlay bone grafts without simultaneously creating a stress-shielding environment during graft healing; only 1 patient (#25) exhibited marginal bone loss at stage 2 surgery.

The type of bone autograft (membranous or endochondral) is another factor that may affect grafting success, particularly of onlay bone grafts in the craniofacial skeleton. In 1974, Smith and Abramson[19] studied bone healing in rabbits by evaluating onlay bone grafts in 2 recipient sites (subcutaneous and subperiosteal). They found

that the recipient site was not a factor in bone graft healing. However, the membranous bone maintained a much greater volume during a 12-month period than did the endochondral bone. They cited the much larger percentage of cancellous bone in the endochondral bone grafts as a reason for increased loss of bone volume during the revascularization and remineralization of the bone graft specimen. In 1983, Zins and Whitaker[20] came to the same conclusion: "membranous bone undergoes less resorption than endochondral bone when autografted in the craniofacial complex of the rabbit and monkey." Using fluorescent microscopy, they found that the rate of bone formation was the same, so they theorized that bone "resorption must be occurring at a more rapid rate with endochondral grafting." In 1985, Kusiak et al,[21] using microangiographic techniques, documented that "membranous onlay bone grafts in the rabbit are more rapidly vascularized than endochondral grafts." A clinical study by Borstlap et al[35] comparing rib (endochondral) and mandible (membranous) autografts in 15 patients with alveolar cleft found that the "ectomesenchymal graft is better incorporated, significantly less resorbed." Their study, however, was flawed in that each group was treated in a different center with different surgical, orthodontic, and prosthetic regimens. For example, patients in one group (ectomesenchymal) had adjacent teeth moved into the bone-grafted site, whereas patients in the other group had prosthetic replacement over the bone-grafted site. Borstlap et al[35] demonstrated that functional loading internally was an important factor during the early revascularization and the remineralization of autogenous bone graft healing.

All 32 patients in the present study had advanced vertical and horizontal maxillary bone loss and were not candidates for an implant-supported prosthesis unless they received major simultaneous bone-deficient replacement using free autogenous bone grafting. The overall prosthesis success rate of 87% was acceptable for these patients, because other treatment options were limited and accompanied by functional and esthetic compromise. This prosthesis treatment success increased to 96% for the last 25 patients, who were treated after the surgical-prosthodontic team experienced a positive learning curve with the first 7 patients. Individual endosseous implant and bone graft survival also increased substantially (67% to 91% for implants and 82% to 100% for bone grafts) because of the experience gained with the first 7 patients. Surgical modifications incorporated after experience with the first 7 patients included modified incision placement, avoidance of implant placement in discontinuity site, and insistence on internal rigid skeletal fixation of onlay bone grafts (with endosseous implants, miniplates, or lag screws rather than transosseous wires).

Eleven patients with discontinuity presented unusual surgical challenges that would severely limit the success of bone grafting and endosseous implant placement.[16] Because residual bone is absent in the discontinuity segment, the onlay bone graft is not supported, and simultaneous endosseous implant placement will traverse through the bone graft only and potentially lack stability. Implant failures in the discontinuity patients occurred primarily in the bone graft segment (in which 10 of the 23 implants placed did not engage residual bone and eventually were removed, for a 43% loss). The surgical implant team subsequently decided against placing implants in the bone graft traversing a discontinuity site. Implants could later be placed into healed bone graft sites if needed prosthetically. Also, patent oronasal communications in these patients should ideally be closed 3 to 6 months before bone graft reconstruction to ensure added soft tissue coverage on both the nasal and oral sides of the osseous defect.

Other potential etiologic factors for implant loss previously noted in the compromised maxillary implant reconstruction include short implants[36,37] and prior nicotine use[38]; the latter affects the vascularity and cellularity during the healing process. Bone quality (or bone density) is another important predictor of success, as short implants do well in dense mandibular bone[39] but generally perform poorly in less mineralized maxillary bone.[36,37] A recent study[40] documented increased implant loss in patients with decreased bone mass density, as measured on the forearm by single-photon gamma absorptiometry in age- and sex-matched patients.

When endosseous implant placement is delayed (2-stage procedure), final prosthetic treatment is delayed an additional 4 to 6 months. This delay not only adds substantial cost and inconvenience but also may result in biologic compromise. Additional hardware is required to rigidly stabilize the bone graft, and the bone graft is not internally loaded by the dental prosthesis for an additional time (4 to 6 months). During this additional time, bone resorption may occur as a result of disuse, and nonphysiologic loading by an interim removable mucoperiosteal-supported denture may add to this early bone graft resorption. Resorption of onlay bone grafts is well documented.[19–21,41] The

ideal bone graft loading time is unknown and may vary from patient to patient. However, earlier (4 to 6 months after placement) internal bone graft loading[42] rather than later (12 months after placement) loading seems appropriate provided the surgical procedures are appropriately performed, and maximal bone healing involving osteoinduction, osteoconduction, and transfer osteogenesis have been allowed to occur. Bone graft healing was impressive in the patients with maxillary discontinuity, when the size of the osseous deficiency and presence of oronasal communication were considered.

Two partial bone graft failures occurred and led to 2 prosthetic failures. The first failure (in patient 3) was related to an inadequately stabilized bone graft and early (10 days postoperatively) wound dehiscence, whereas the second failure (in patient 7) occurred 6 months after stage 2 surgery and was related to sepsis of unknown cause. Wound dehiscence occurred 10 to 14 days after surgery in 4 patients. In 2 of the patients, the dehiscence was minor and related to a 4-corner wound closure in the midline of the cleft lip and palate. In the other 2 patients, the dehiscence was related to compromised blood supply of the labial flap (extensive posttrauma scar tissue and a high lip incision). The high lip-labial incision potentially compromised the blood supply to the remainder of the labial flap, which received very little if any collateral vascularity from the palate. This incision approach was modified (Fig 1c) after experience with the third patient, and no additional incision dehiscence was encountered in nontrauma patients.

The incision line problem leading to surgical modification represented additional experience, which enhanced future procedures. Obtaining an everted, watertight, nontension closure with the modified low incision requires a high incision in the periosteum, which allows the elastic fibers in the submucosa to lengthen (collagen fibers in the periosteum will not stretch), along with stretching of the nonkeratinized mucosa of the labial buccal sulcus. The authors believe that the position of the incision relative to the underlying bone graft is not as important as is the blood supply to the wound edges. If the surgeon provides minimal augmentation for the benefit of implant placement only, rather than large, bulky grafts (Figs 1a and 1b) extending under or replacing the anterior nasal spine and nasal aperture for cosmetic benefit, a periosteal incision may not be required.[15]

The implant survival rate (86.3%) in the 32 patients was acceptable and did not significantly affect the prosthesis success rate after the seventh patient was treated, provided that an adequate number of implants (7 to 9) was placed in the typical edentulous maxilla. After the seventh patient, the implant survival rate was 90.1%, and importantly for the patient, the prosthesis success rate was 96.0%, with the lone failure being long-term functional overload in 1 patient, who lost 3 implants at 29 months and another 3 implants at 57 months after loading.

In this study, implant survival data relative to implant type did not reveal an important difference; however, the 3 patients with 17 conical-type implants experienced 8 implant failures (including 5 implant fractures in patient 6). A previous report[41] documented significant marginal bone resorption (mean of 4.9 mm after 3 years in 30 patients) with the conical implant design, in which osseointegration does not begin until threads are present (approximately 4 mm inferior to the implant platform). Bone loss in this study did not vary with gender, and pocket probing depth did not increase in the same group of patients[43] in whom significant marginal bone loss was recorded.

Marginal bone loss in this retrospective study was not quantified because comparable consecutive radiographs were not consistently available for all patients. However, radiographic evidence of significant (marginal) bone loss was conspicuous by its absence. Only 1 patient lost multiple implants (6) after long-term use; this could have been related to progressive marginal bone loss over time. As an implant retention factor, implant length did not show the typical trend for this system, as longer implants in the maxilla yielded only marginally higher success rates; if the 10-mm implant is compared with all other lengths (13, 15, 18, and 20 mm), the difference in survival was 2% (85% versus 87%). If the shorter implants (10, 13, and 15 mm) are compared with the longer implants (18 and 20 mm), the difference in survival is 14.5% (82% versus 96.5%). More importantly, when the wide and conical implants were removed from the data, implant length was not a significant risk factor. This lack of significant difference indicates that reduced implant length in the presence of adequate bicortical implant stabilization of the 1-stage onlay procedure can still potentially provide acceptable results.

Prosthesis survival data revealed a number of interesting findings. The 17 patients with rigidly connected implants and continuous fixed or fixed removable prostheses (no tissue contact) had no prosthesis failures (100% success). In contrast, the 13 patients with overdenture-type prostheses had a much lower success rate (77%). One patient did not receive a prosthesis (early bone graft and

implant failure). The prosthesis success rate was also different in the first 7 patients (57%) compared to that in the subsequent 25 patients (96%). However, 2 of the 3 failures were related to early implant loss, and the third failure was related to prosthesis overload on nonconnected implants, which eventually fractured; therefore, the overdenture prosthetic treatment concept in itself cannot be implicated as the sole etiologic factor in prosthesis treatment failure.

An implant-supported prosthesis providing the opposing occlusion (totally or in combination with natural teeth) contributed to a prosthesis success rate of 96%. This rate was higher than in patients with natural teeth (totally or combined with a removable partial denture), for whom a prosthesis success rate of 75% was recorded. Although the opposing occlusion of an implant-supported prosthesis as compared to natural teeth gave an improved treatment outcome, the difference is not statistically significant. Importantly, once the surgical-prosthodontic team gained experience with this implant treatment, the more likely the treatment was to involve an implant-supported prosthesis in the opposing arch, and this modification allowed the prosthodontist more flexibility in controlling occlusal stress on the maxillary prosthesis.

Summary

During a 12-year study of 32 consecutive patients, composite bone graft reconstruction of edentulous maxillae with advanced bone loss gave acceptable implant and bone graft survival rates and prosthesis success rates. However, the surgical/prosthodontic learning curve was important. Prosthetic patients who had significantly higher treatment success were those with a fixed continuous or fixed-removable prosthesis, without associated maxillary discontinuity, and whose opposing occlusion was a fixed implant-supported prosthesis. Factors that improved surgical results included *(1)* modification of incision placement, *(2)* avoidance of implant placement without bicortical implant stabilization, and *(3)* utilization of self-tapping implants. The benefit of early internal functional loading using endosseous implants in the rigidly fixed onlay bone graft in the 1-stage procedure seems to counterbalance the theoretical benefit of improved bone graft healing of membranous rather than endochondral nonvascularized bone autografts.

References

1. Adell R, Lekholm U, Rockler B, Brånemark P-I. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:387–416.
2. Lin KY, Barlett SP, Yaremchuk MJ, Fallon M, Grossman RF, Whitaker LA. The effect of rigid fixation on the survival of onlay bone grafts: An experimental study. Plast Reconstr Surg 1990;86:449–456.
3. Phillips JN, Rahn BA. Fixation effects of membranous and endochondral onlay bone graft resorption. Plast Reconstr Surg 1988;82:872–877.
4. Lozano AJ, Cestero JH, Salyer KE. The early vascularization of onlay bone grafts. Plast Reconstr Surg 1976;58:300–305.
5. Breine U, Brånemark P-I. Reconstruction of alveolar jaw bone. An experimental and clinical study of immediate and preformed autologous bone grafts in combination with osseointegrated implants. Scand J Plast Reconstr Surg 1980;14:23–48.
6. Brånemark P-I. Introduction to osseointegration. In: Brånemark P-I, Zarb GA, Albrektsson T (eds). Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry. Chicago: Quintessence, 1985:41–42,47–49.
7. Keller EE, Van Roekel NB, Desjardins RP, Tolman DE. Prosthetic-surgical reconstruction of the severely resorbed maxilla with iliac bone grafting and tissue-integrated prostheses. Int J Oral Maxillofac Implants 1987;3: 155–165.
8. Keller EE, Triplett WW. Iliac bone grafting: Review of 160 consecutive cases. J Oral Maxillofac Surg 1987;45: 11–14.
9. Kalk WI, Raghoebar GM, Jansma J, Boering G. Morbidity from iliac crest bone harvesting. J Oral Maxillofac Surg 1996;54:1,424–1,429.
10. Kahnberg KE, Nystrom E, Bartholdsson L. Combined use of bone grafts and Brånemark fixtures in the treatment of severely resorbed maxillae. Int J Oral Maxillofac Implants 1989;4:297–304.
11. Adell R, Lekholm U, Grondahl K, Brånemark P-I, Lindstrom J, Jacobsson M. Reconstruction of severely resorbed edentulous maxillae using osseointegrated fixtures in immediate autogenous bone grafts. Int J Oral Maxillofac Implants 1990;5:233–245.
12. Isaksson S, Alberius P. Maxillary alveolar ridge augmentation with onlay bone grafts and immediate endosseous implants. J Cranio-Maxillofac Surg 1992;20:2–7.
13. Isaksson S. Evaluation of three bone grafting techniques for severely resorbed maxillae in conjunction with immediate endosseous implants. Int J Oral Maxillofac Implants 1994;9:679–688.
14. Nystrom E, Kahnberg K-E, Gunne J. Bone grafts and Brånemark implants in the treatment of the severely resorbed maxilla: A two-year longitudinal study. Int J Oral Maxillofac Implants 1993;8:45–53.
15. Van Steenberghe D, Naert I, Bossuyt M, DeMars G, Calberson L, Ghyselen J, Brånemark P-I. The rehabilitation of the severely resorbed maxilla by simultaneous placement of autogenous bone grafts and implants: A ten-year evaluation. Clinical Oral Investigations 1997;1(3):102–108.
16. Schliephake H, Newkam FW, Wichmann M. Survival analysis of endosseous implants in bone grafts used for the treatment of severe alveolar ridge atrophy. J Oral Maxillofac Surg 1997;55:1227–1233.

17. Jensen J, Sindet-Pederson S. Autogenous mandibular bone grafts and osseointegrated implants for reconstruction of the severely atrophied maxilla: A preliminary report. J Oral Maxillofac Surg 1991;49:1,277–1,287.
18. Donovan MG, Dickerson NC, Hanson LJ, Gustafson RB. Maxillary and mandibular reconstruction using calvarial bone grafts and Brånemark implants: A preliminary report. J Oral Maxillofac Surg 1994;52:588–594.
19. Smith JD, Abramson M. Membranous vs endochondral bone autographs. Arch Otolaryngol 1974;99:203–205.
20. Zins JE, Whitaker LA. Membranous vs endochondral bone autographs. Implications for craniofacial reconstruction. Plast Reconstr Surg 1983;72:778–785.
21. Kusiak JF, Zins JE, Whitaker LA. The early revascularization of membranous bone. Plast Reconstr Surg 1985;76:510–516.
22. Keller EE, Tolman DE, Brånemark P-I. Surgical reconstruction of advanced maxillary resorption with composite grafts. In: Worthington P, Brånemark P-I (eds). Advanced Osseointegration Surgery: Maxillofacial Applications. Chicago: Quintessence, 1992:146–161.
23. Smith DE, Zarb GA. Criteria for success of osseointegrated implants. J Prosthet Dent 1989;62:567.
24. Phemister DB. The fate of transplanted bone and regenerative power of its various constituents. Surg Gyn Obstet 1914;19(3):303–333.
25. Burwell RG. The fate of bone grafts. In: Recent Advances in Orthopaedics. London: Churchill, 1969:115.
26 Bohr H, Ravn HO, Werner H. The osteogenic effect of bone transplants in rabbits. J Bone Joint Surg [Br] 1968;50:866–873.
27. Abbott LC, Schottstaedt ER, Saunders JB, Bost FC. The evaluation of cortical and cancellous bone as grafting material. A clinical and experimental study. J Bone Joint Surg 1947;29:381.
28. Puranen J. Re-organization of fresh and preserved bone transplants. Acta Orthop Scand 1966;suppl 92.
29. Albrektsson T. The healing of autologous bone grafts after varying degrees of surgical trauma: A microscopic and histochemical study in the rabbit. J Bone Joint Surg [Br] 1980;62:403–410.
30. Albrektsson T. Response of bone tissue to surgical preparation and nonbiological material. In: Glantz P-O, Leach SA, Ericson T (eds). Oral Interfacial Reactions of Bone, Soft Tissue and Saliva. Oxford: IRL Press, 1985: 115–130.
31. Eriksson RA, Albrektsson T, Magnusson B. Assessment of bone viability after heat trauma. A histological, histochemical and vital microscopical study in the rabbit. Scand J Plast Reconstr Surg 1984;18:261–268.
32. Eriksson RA, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: A vital microscopic study in the rabbit. J Prosthet Dent 1983;50:101–107.
33. Kennedy MC, Tucker MR, Lester GE, Buckley MJ. Histomorphometric evaluation of stress shielding in mandibular continuity defects treated with rigid fixation plates and bone grafts. Int J Oral Maxillofac Surg 1989;18:170.
34. Tonino AJ, Davidson CL, Klopper PJ, Lindau LA. Protection from stress in bone and its effect. Experiments with stainless steel and plastics in dogs. J Bone Joint Surg [Br] 1976;58:107–113.
35. Borstlap WA, Heidbuchel K, Freihofer HPM, Juijpers-Jagtman AM. Early secondary bone grafting of alveolar cleft defects: A comparison of chin and rib grafts. J Craniomaxillofac Surg 1990;18:201–205.
36. Jaffin RA, Berman CL. The excessive loss of Brånemark fixtures in Type IV bone: A five-year analysis. J Periodontol 1991;62:2–4.
37. Tolman DE, Laney WR. Tissue integrated prosthesis: The first 78 months Mayo experience. Mayo Clin Proc 1993;68:323–331.
38. Crawford A. Smoking and implant failure—benefits of a smoking cessation protocol. Int J Oral Maxillofac Implants 1996;11:756–759.
39. Keller EE. Reconstruction of the severely atrophic edentulous mandible with endosseous implants: A 10-year longitudinal study. J Oral Maxillofac Surg 1995;53:305–320.
40. Blomqvist JE, Alberius P, Isaksson S, Linda A, Hansson B-G. Factors in implant integration failure after bone grafting (an osteometric and endocrinologic matched analysis). Int J Oral Maxillofac Surg 1996;25:63–68.
41. Nyström E, Ahlqvist J, Kahnberg K-E, Rosenquist JB. Autogenous onlay bone grafts fixed with screw implants for treatment of severely resorbed maxilla; radiographic evaluation of preoperative bone dimensions, postoperative bone loss, and changes in soft tissue profile. Int J Oral Maxillofac Surg 1996;25:351–359.
42. Koole R, Bosker H, Noorman VDD. Late secondary autogenous bone grafting in cleft patients comparing mandibular (ectomesenchymal) and iliac crest (mesenchymal) grafts. J Craniomaxillofac Surg 1989;17(suppl):28–30.
43. Gunne J, Nyström E, Kahnberg K-E. Bone grafts and implants in the treatment of the severely resorbed maxilla: A 3-year follow-up of the prosthetic restoration. Int J Prosthodont 1995;8:38–45.