Endosseous Implant and Autogenous Bone Graft Reconstruction of Mandibular Discontinuity: A 12-Year Longitudinal Study of 31 Patients

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Surgical, medical, and prosthodontic records of 61 consecutively treated patients with mandibular discontinuity were reviewed retrospectively. All 61 patients had undergone discontinuity reconstruction with autogenous bone grafts; 31 of 61 had also received endosseous dental implants and a dental osseoprosthesis. Of these 31 implant-reconstructed patients, 23 had free autogenous nonvascularized and 8 had vascularized bone grafts. The surgical-prosthetic protocol consisted primarily of secondary, free autogenous nonvascularized bone graft reconstruction and secondary root-form endosseous implant and fixed prosthesis dental reconstruction. Vascularized bone (8 patients) or soft tissue (4 patients) grafts were utilized selectively for severely compromised patients after extensive oncologic resection, avulsive trauma, or after previous radiation treatment. Endosseous implant survival (95.5% in 31 patients), autogenous bone graft success (98.4% in 61 patients), and dental osseoprosthesis success (100% in 31 patients) were favorable. A high incidence (9.1%) of nonfunctioning (sleeping) implants was recorded for this patient population. The need to remove the titanium mesh tray for various reasons (17.6%) and the need to reconstruct soft tissue in the irradiated patient (12%) were noteworthy.
(Int J Oral Maxillofac Implants 1998;13:767–780)

Key words: autogenous bone graft, discontinuity defect, endosseous implant, nonvascular, prosthesis, radiation, reconstruction, vascular

Mandibular discontinuity, whether caused by trauma, infection, or neoplasia, produces significant functional disability, cosmetic deformity, and psychologic impairment. Before 1985, surgical-prosthodontic reconstruction of the upper aerodigestive system of patients with mandibular discontinuity frequently involved multiple osseous and soft tissue reconstructive procedures followed by placement of a removable dental prosthesis supported by soft tissue.[1] The reconstructive surgical procedures prior to fabrication of the dental prosthesis restored mandibular continuity and created an edentulous ridge of sufficient size and form for prosthesis retention, stability, and uniform distribution of the imposed masticatory load on the mucoperiosteum. Although this treatment provided predictably good cosmetic and phonetic results and less predictably adequate deglutition function, mastication with a removable, soft tissue–supported dental prosthesis was frequently compromised.[2] This masticatory compromise in the patient with mandibular discontinuity reconstruction was in part the result of the unpredictability of placing and holding the food bolus on the occlusal table because of compromised tongue and lip function. The soft tissue–supported dental prosthesis, which lacked skeletal fixation, was also an important associated limiting factor. The instability of the dental prosthesis was secondary to functional remodeling of the soft/hard tissue foundation in response to nonphysiologic, mucoperiosteal loading of the prosthesis.

In 1985, the treatment protocol for patients with discontinuity was modified to include placement of endosseous root-form implants to support a fixed

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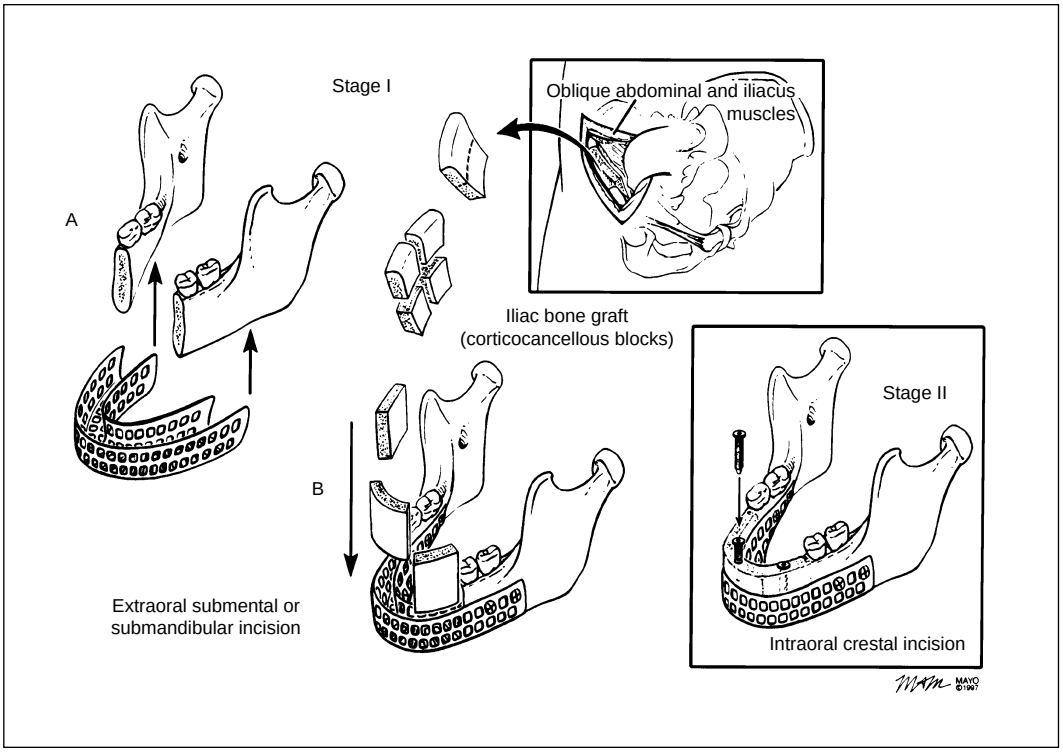


Fig 1 Two-stage composite bone graft reconstruction of mandibular discontinuity. A titanium mesh tray supports autogenous corticocancellous block bone grafts at stage I. Endosseous root form dental implants are placed 4 to 6 months later (stage II) in the revascularized and remineralized bone graft.

bone–anchored dental prosthesis rather than a conventional dental prosthesis. Initial experiences were reported in 1988[3] and 1991.[4] Recent experience with radiated and nonradiated patients[5,6] forms the basis of this retrospective study of 61 bone-grafted mandibular discontinuity patients, of whom 31 underwent secondary reconstruction with titanium endosseous implants supporting a dental prosthesis.

Materials and Methods

Clinical material was reviewed on 61 patients with mandibular discontinuity who had been treated with autogenous bone grafts through December 1997 at the Mayo Medical Center, Rochester, MN. Of these 61 patients, 53 received a free autogenous nonvascularized corticocancellous bone graft (Figs 1 and 2), and 8 received a free autogenous vascularized bone graft (Fig 3). Cylindric, threaded, noncoated endosseous implants of commercially pure titanium were placed in 31 of the 61 patients as a secondary procedure a minimum of 6 months after bone graft reconstruction (Fig 2). All endosseous implants were manufactured by Nobel Biocare USA, Westmont, Illinois. Of the 61 bone-grafted discontinuity patients, 30 received implant placement and 29 received prosthetic treatment at the Mayo Medical Center. Current clinical and radiographic records were available on all implant patients, and only 1 patient, who died during the study period, was lost to follow-up.

The medical and surgical records provided information regarding etiology of the mandibular discontinuity (oncologic, infection, vascular, or trauma), adjunctive surgical procedures, nonsurgical treatment (including irradiation in oncology patients), associated medical diagnoses and treatment, and intraoperative or postoperative surgical or medical complications.

The prosthodontic records provided information relative to prosthesis type (fixed, fixed removable, or overdenture), opposing dental occlusion (removable complete or partial denture, natural teeth, or implant-supported fixed or overdenture), prosthesis placement date, functional or esthetic compromises, and prosthetic complications.

Surgical implant reconstruction data included surgical dates (stages I and II) and their timing in relation to the bone graft reconstruction. Other recorded data included: bone quality at time of implant placement (type A—homogenous cortical bone; type B—thick cortical bone with marrow cavity; type C—thin

Figs 2a to 2c Secondary autogenous free nonvascularized corticocancellous block iliac bone graft reconstruction and endosseous implant placement. Mandibular discontinuity secondary to block resection of squamous cell carcinoma.

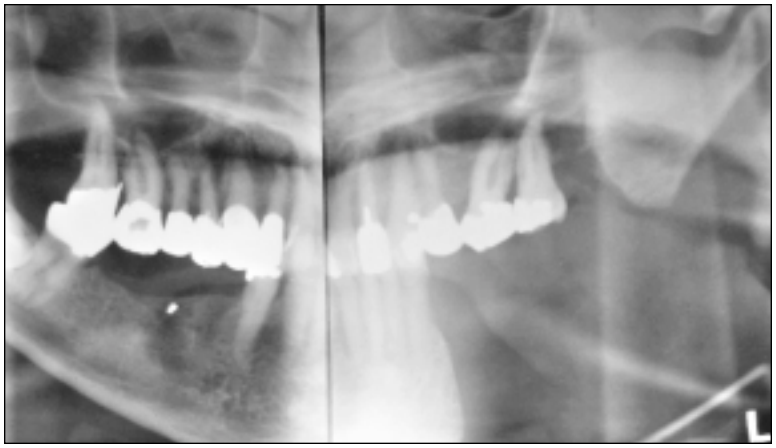


Fig 2a Preoperative panoramic radiograph.

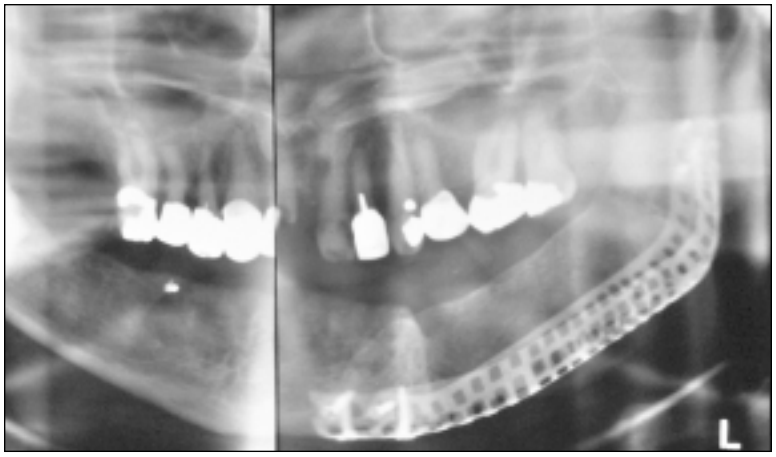


Fig 2b Bone graft supported by titanium mesh tray.

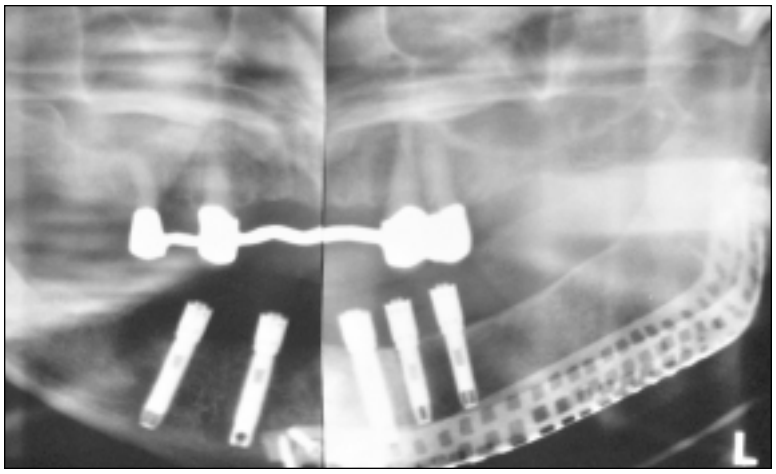
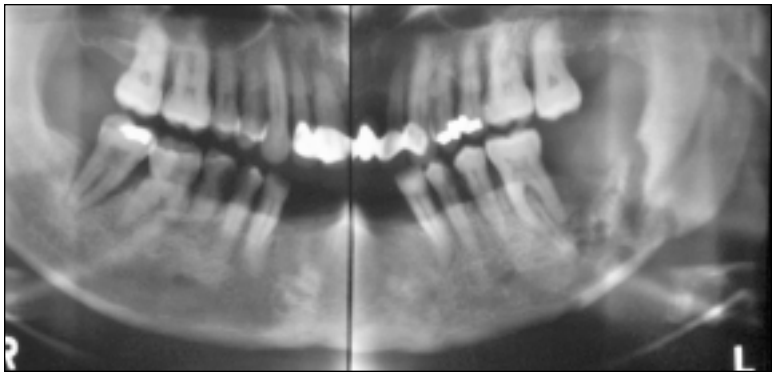


Fig 2c Radiograph showing 5 regular endosseous implants placed in remineralized and revascularized bone graft and residual mandible (patient #13).



Figs 3a to 3c Primary autogenous free vascularized corticocancellous block fibular bone graft reconstruction and endosseous implant placement. Mandibular discontinuity was secondary to osteoradionecrosis, which occurred after irradiation for oral squamous cell carcinoma.

Fig 3a Radiograph before resection showing osteoradionecrosis of left ramus.

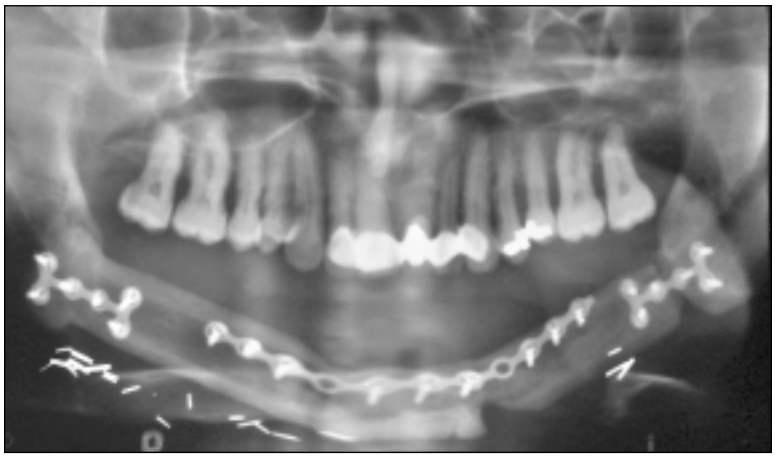


Fig 3b Bone graft supported by miniplates.

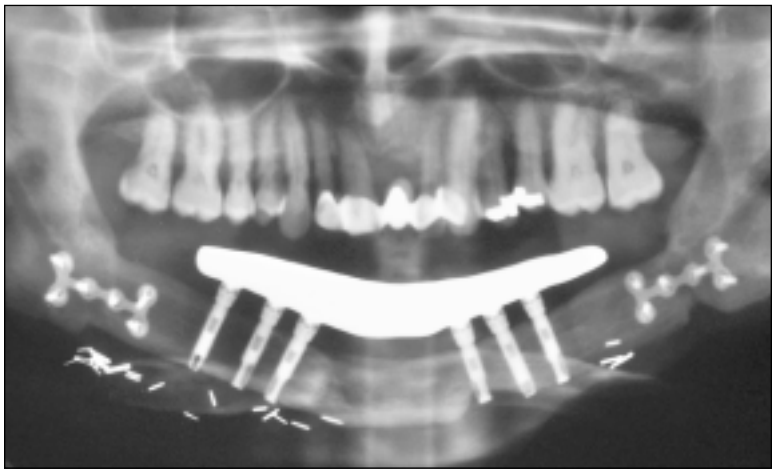


Fig 3c Radiograph after secondary endosseous implant placement showing 6 endosseous (Mark II self-tapping) implants in the grafted bone (patient #23).

cortical bone with dense trabecular bone of good strength; type D—very thin cortical bone with low-density trabecular bone of poor strength), anatomic location of implant (anterior or above neurovascular structures), implant diameter (3.75, 4.00, or 5.00 mm), implant length (10 to 20 mm), implant type (routine, self-tapping, rescue, or wide), and significant surgical complications requiring treatment (implant removal or prosthetic detachment). Implant survival was calculated by dividing the total number of implants into the number removed, multiplied by 100, and subtracted from 100%. A successful implant was defined as being nonmobile, free of peri-implant radiolucency, stable regarding implant marginal bone height, and not associated with pain, infection, or neurologic disorder.[7] In addition, the implant should allow placement of a functional and esthetic implant prosthesis.[8]

Data related to bone graft reconstruction included donor bone type (cortical, cancellous, or corticocancellous), donor bone form (block or particulate), donor bone site (ilium, fibula, cranium, or scapula), timing of reconstruction (primary or secondary), and reconstruction dates relative to resection or trauma.

Results

Of the 61 patients with mandibular discontinuity, 31 (16 male, 15 female) underwent both endosseous implant and autogenous bone graft reconstruction (Table 1). The mean age of the 31 implant patients was 50.5 years (range, 18 to 76). The causes of mandibular discontinuity of the 31 patient implant group were oncologic in 17 patients (15 with carcinoma, 2 with sarcoma), traumatic in 11 patients (7 with gunshot wounds, 4 with fracture nonunion), infectious in 3 patients (osteomyelitis), and vascular in 2 patients (arteriovenous malformation); two patients presented with both infectious and traumatic etiology. The discontinuity involved more than one-fourth of the mandible in all of the 31 implant patients and included 1 condyle in 3 patients. Prior surgical management of the original pathologic lesion involved block resections in the patients with oncologic and infectious causes and typical sequential trauma management in the patients with traumatic causes. Nine patients with malignant disease received adjunctive head and neck irradiation, and 8 of these have been discussed in detail in a previous publication.[6]

For implant analysis relative to bone graft type (vascular or nonvascular) and irradiation status, the patients have been placed into 4 groups: group 1, nonvascular bone-grafted nonirradiated patients; group 2, nonvascular bone-grafted irradiated patients; group 3, vascular bone-grafted nonirradiated patients; and group 4, vascular bone-grafted irradiated patients.

Group 1: Nonvascular Bone-grafted Nonirradiated Patients. Nineteen patients (12 male, 7 female; patients 1 to 10, 12, 13, 15, 17, 26 to 30; mean age, 41.5 years; range, 21 to 69) fell into this group (Tables 1 and 2). The defect etiology was traumatic in 9 patients, oncologic in 7 patients, vascular in 2 patients, and infectious in 3 patients; 2 patients had both trauma and infection etiology.

The discontinuity defects of all 19 patients were reconstructed secondarily at a mean time of 20.9 months (range, 3 to 124 months) after the defect occurred; 17 received iliac corticocancellous (CC) block bone grafts, 1 a cranial cortical (C) bone graft, and 1 an iliac cancellous particular (CaP) bone graft. The 17 iliac CC block grafts were supported with a titanium mesh tray, 2 of which included a metal condyle. The cranial cortical bone graft was supported with miniplates, and the particulate cancellous bone graft was supported with a free autogenous mandible tray.

Ninety-one implants were placed a mean of 16.4 months (range, 5 to 19 months) after bone graft reconstruction (72 in bone graft and 19 in residual bone). The implants were uncovered a mean time of 7.8 months (range, 4 to 22 months) after placement. Six implants were removed (survival rate of 93.4%) and 10 implants were not prosthetically utilized. If the 10 nonfunctional (sleeping) implants in this group were considered failures, the survival rate was 82.4%.

Of the 19 prostheses, 17 were fixed, 1 was fixed-removable, and 1 was an overdenture. Mean functioning times for the 19 fixed prostheses in this group of patients were 81.1 months (range, 9 to 136 months). The opposing occlusion was natural teeth in 11 patients, a removable complete denture in 5 patients, a removable partial denture and natural teeth in 2 patients, and an implant-supported overdenture and natural teeth in 1 patient.

Group 2: Nonvascular Bone-grafted Irradiated Patients. Group 2 comprised 4 female patients (patients 11, 14, 16, 31) whose ages were 60, 63, 70, and 69, respectively (Tables 1 and 2). The defect etiology in all patients was block resection for malignant disease.

Radiation doses were unknown (interstitial radon); 5,040; 6,600; and 8,000 cGy for the 4 patients. All 4 patients received radiation treatment before autogenous bone grafting and endosseous implant placement.

Secondary reconstruction with an iliac CC block bone graft supported with a titanium mesh tray was performed 11, 65, 40, and 66 months (after tumor resection) respectively, in the 4 patients.

Table 1 Mandibular Discontinuity Reconstruction: Patients Who Received Autogenous Bone Graft and Endosseous Implant Reconstruction

		Defect		Irradiation	Bone Graft				Implants				Prosthesis		
Patient no.	Sex/ age	Etiology	Tooth no./ anatomy	Dose (cGy)	Type	Timing (mo.)	Fixation	Donor site	No. in (+)	No. out (+)	No. sleeping (+)	Months after bone graft	Type	Months of function	Opposing occlusion
1	M/52	T	17/25	—	NV-CC	S (10)	T	I	5 (3)	0	1 (1)	5	FR	136	NT
2	M/39	T	17/27	—	NV-CC	S (19)	T	I	5 (5)	0	1 (1)	44	F	110	NT, RPD
3	M/47	T	19/22	—	NV-CC	S (60)	T	I	4 (3)	0	2 (1)	15	F	125	NT, RPD
4	M/59	T	R. angle/18	—	NV-C	S (19)	MP	CR	5 (5)	0	1 (1)	18	F	85	NT
5	F/24	V	R. angle/24	—	NV-CaP	P	AMT	I	3 (3)	0	0	17	F	78	NT
6	F/21	I	R. condyle/28	—	NV-CC	S (12)	T	I	3 (3)	0	0	10	F	96	NT
7	M/45	T	25/32	—	NV-CC	S (8)	T	I	4 (4)	0	0	5	F	89	I-OD, NT
8	M/23	V	17/25	—	NV-CC	S (11)	T	I	4 (4)	0	1 (1)	7	F	87	NT
9	F/40	O	L. notch/21	—	NV-CC	S (3)	T	I	3 (3)	0	0	9	F	88	NT
10	F/49	O	22/28	—	NV-CC	S (9)	T	I	6 (5)	0	0	5	F	76	RD
11	F/60	O	R. notch/25	Radon seeds	NV-CC	S (11)	T	I	6 (3)	0	1 (1)	7	F	71	RD
12	M/69	O	L. notch/30	—	NV-CC	S (28)	T	I	6 (6)	2 (2)	0	99	F	78	NT
13	M/67	O	L. notch/26	—	NV-CC	S (23)	T	I	5 (3)	3 (3)	0	6	F	28	NT-RPD
14	F/63	O	17/24	5,040	NV-CC	S (65)	T	I	5 (3)	0	0	12	FR	69	RD
15	M/27	T	20/28	—	NV-CC	S (5)	T	I	7 (5)	0	0	6	F	41	NT
16	F/70	O	R. condyle/24	6,600	NV-CC	S (40)	T	I	6 (3)	0	1 (1)	7	F	54	RD
17	M/59	O	R. condyle/26	—	NV-CC	S (16)	T	I	6 (3)	0	1 (1)	5	F	53	RD
18	M/39	O	L. angle/25	6,120	V-CC	S (28)	MP	I	6 (1)	0	0	13	F	73	I-F
19	M/45	O	20/29	6,000	V-CC	P	RP	I	4 (4)	0	0	11	OD	36	RD
20	M/18	T	20/31	—	V-CC	S (7)	RP	F	6 (6)	0	1 (1)	17	F	16	NT, RPD
21	F/76	O	26/32	6,000	V-CC	P	MP	S	4 (1)	1 (1)	0	19	F	45	RD
22	F/45	T	17/25	—	V-CC	S (3)	MP	S	6 (3)	0	0	7	F	36	I-F
23	M/65	O	18/31	6,300	V-CC	P	MP	F	6 (6)	0	0	28	F	21	NT
24	F/61	O	25/32	—	V-CC	P	MP	S	4 (0)	0	0	15	F	34	NT
25	F/60	O	R. to L. angle	6,000	V-CC	S (25)	LS	F	5 (5)	0	1 (1)	24	F	36	NT
26	M/33	T	L. angle/23	—	NV-CC	S (124)	T	I	4 (1)	0	2 (2)	10	F	78	NT
27	F/58	I, T	L. angle/23	—	NV-CC	S (7)	T	I	6 (2)	0	1 (0)	6	OD	9	RD
28	M/68	O	19/32	—	NV-CC	S (7)	T	I	5 (5)	1 (1)	0	10	F	92	NT
29	F/65	O	R. angle/28	—	NV-CC	S (9)	T	I	5 (4)	0	0	11	F	24	NT
30	F/50	I, T	L. angle/R. notch	—	NV-CC	S (36)	T	I	5 (5)	0	0	24	F	120	RD
31	F/69	O	R. angle/24	8,000	NV-CC	S (66)	T	I	5 (1)	0	0	24	F	6	RD

Defect etiology: T = trauma; O = oncologic; I = infectious; V = vascular
Bone graft type: NV-CC = nonvascular corticocancellous block; V-CC = vascular corticocancellous block; NV-CaP = nonvascular cancellous particulate; NV-C = nonvascular cortical block
Bone graft timing: P = primary; S = secondary (months after discontinuity defect occurrence)
Bone graft fixation type: T = titanium mesh tray; RP = reconstruction plate; MP = mini plate; LS = lag screws; AMT = autogenous mandible tray
Bone graft donor site: I = ilium; Cr = cranium; F = fibula; S = scapula
+ = no. of implants in bone graft
Prosthesis: F = fixed; FR = fixed removable; OD = overdenture
Opposing occlusion: RD = removable full denture; RPD = removable partial denture; NT = natural teeth; I-F = implant-fixed prosthesis; I-OD = implant overdenture prosthesis

Table 2 Implant Data Relative to Bone Graft Type and Irradiation Exposure

		Implants				
	Patient no.	No. placed (BG)	No. placed (RMB)	No. removed	No. nonfunctioning	Survival rate (%)
Nonvascular graft						
Group 1: Nonirradiated	19	72	19	6	10	93.4
Group 2: Irradiated	4	10	12	0	2	100.0
Subtotal	23	82	31	6	12	94.7
Vascular graft						
Group 3: Nonirradiated	3	9	7	0	1	100.0
Group 4: Irradiated	5	18	7	1	2	96.0
Subtotal	8	27	14	1	3	97.6
Total	31	109	45	7	15	95.5

*BG = bone graft; RMB = residual mandibular bone

Twenty-two implants were placed 7 to 24 months after the bone grafting procedure (10 in bone graft and 12 in residual mandible). The implants were uncovered 4 to 6 months after placement. None of the implants were removed and 2 remained nonfunctional (sleeping).

Fixed prostheses were used for 3 patients (functioning at 71, 54, and 6 months postplacement) and a fixed-removable prosthesis for 1 patient (functioning at 69 months). The opposing occlusion was a removable complete denture in all 4 patients.

In 3 of 4 patients, osteoradionecrosis had occurred previously and required treatment before discontinuity bone grafting and implant placement.

Group 3: Vascular Bone-grafted Nonirradiated Patients. Group 3 comprised 3 patients (1 male and 2 female; patients 20, 22, 24) ages 18, 45, and 61, respectively (Tables 1 and 2). The defect etiology was trauma in 2 patients and oncologic in 1 patient.

Secondary reconstruction was accomplished in 2 patients (fibular CC block bone graft 7 months after the trauma and scapular CC block bone graft 3 months after the trauma). The third patient had primary reconstruction with a scapular CC block bone graft at the time of oncologic resection. In the 2 trauma patients, 12 implants (6 in the bone graft in one patient, and 3 in bone graft and 3 in residual bone in the other patient) were placed 17 and 7 months after the bone graft. In the oncology patient, all 4 implants were placed in residual mandibular bone 15 months after bone grafting, as inadequate bone volume (width) of the scapular bone graft did not allow for implant placement. The implants were uncovered 5 to 6 months after placement. No implants were removed, and 1 remained nonfunctional (sleeping).

Fixed prostheses were fabricated for all 3 patients and functioned 16, 36, and 34 months, respectively, after placement. The opposing occlusion for the 3 patients was natural teeth, an implant-fixed prosthesis, and natural teeth plus a removable partial prosthesis, respectively. One patient required peri-implant tissue excision before the prosthesis was placed.

Group 4: Vascular Bone-grafted Irradiated Patients. Group 4 comprised 5 patients (3 male and 2 female; patients 18, 19, 21, 23, 25) ages 39, 45, 76, 65, and 60, respectively (Tables 1 and 2). The defect etiology was oncologic block tumor resection in all 5 patients.

The radiation doses were 6,000 cGy for 3 patients and 6,120 and 6,300 cGy for the other 2 patients. Three patients received irradiation before bone graft and implant placement (#18, 23, 25), 1 received irradiation after bone grafting but before implant placement (#21), and 1 received irradiation after both bone grafting and implant placement (#19).

Primary reconstruction involved grafts with fibular, scapular, and iliac bone in 3 patients (#19, 23, 25). Secondary reconstruction with iliac bone was done in one patient 28 months after resection (#18), and in one patient with fibular bone 25 months after resection (#25). Twenty-five implants (18 in bone graft and 7 in residual mandibular bone) were placed 13, 11, 19, 28, and 24 months, respectively, after the bone grafting procedure. Implants were uncovered 4 to 6 months after placement. No implants placed in residual mandible were lost, 1 implant in grafted irradiated bone was removed, and 1 was nonfunctional.

A fixed prosthesis was used for 4 patients (functioning at 73, 45, 21, and 36 months postplacement) and an overdenture prosthesis was used (functioning at 36 months) for 1 patient. The opposing occlusion was natural teeth in 2 patients, a removable complete denture in 2 patients, and an implant-supported fixed prosthesis in 1 patient.

Table 3 Implant, Prosthetics, and Bone Quality Data

	Nonvascular		Vascular				
	Iliac BG (RMB)	Cranial BG (RMB)	Scapular BG (RMB)	Iliac BG (RMB)	Fibular BG (RMB)	Total BG (RMB)	Total
Implants							
Placed	78 (30)	5 (0)	4 (10)	5 (5)	17 (0)	109 (45)	154
Lost	6 (0)		1 (0)			7 (0)	7
Sleeping	9 (2)	1 (0)	0 (0)	0 (2)	2 (0)	12 (4)	16
Prosthesis							
Fixed	19	1	3	1	3		27
Fixed-removable	2						2
Overdenture	1			1			2
Bone quality							
A	7 (3)	5 (0)				12 (3)	15
B	48 (21)		0 (10)	4 (4)	12 (0)	64 (35)	99
C	22 (7)		3 (0)	2 (0)	5 (0)	32 (7)	39
D	0 (0)		1 (0)			1 (0)	1

BG = bone graft; RMB = residual mandibular bone

Table 4 Implant Type and Length Data

Implant Length (mm)	10 BG (RMB)	13 BG (RMB)	15 BG (RMB)	18 BG (RMB)	20 BG (RMB)	Total BG (RMB)	Total
Implants							
No. placed	13 (2)	29 (15)	49 (21)	18 (6)	0 (1)	109 (45)	154
No. lost	1 (0)	0 (0)	5 (0)	1 (0)		7 (0)	7
No. sleeping	3 (6)	6 (0)	2 (1)	1 (1)		12 (8)	20
Implant type							
No. regular	4 (0)	13 (10)	22 (8)	4 (3)	0 (1)	43 (22)	65
No. rescue	4 (0)	4 (2)	0 (5)	4 (0)		12 (7)	19
No. self-tapping	4 (2)	12 (3)	27 (8)	10 (3)		53 (16)	69
No. wide	1 (0)					1 (0)	1

BG = bone graft; RMB = residual mandibular bone

Severe xerostomia occurred in 2 patients (#18 and 21), one of whom had recurrent monilial infection. The patient reconstructed with the scapular graft (#21) developed a stress fracture at the implant site in the bone graft 7 months after placement, resulting in the loss of the implant (the fracture healed without active treatment). In 1 patient (#23) osteoradionecrosis developed before block resection and bone grafting, and in another patient (#25) radiation-induced osteogenic sarcoma had developed, which led to oncologic block resection and eventual secondary bone grafting.

Combined Implant Data. A total of 154 implants were placed in 31 consecutive patients (Tables 2, 3, and 4). Seven implants in 3 patients were removed, for an implant survival rate of 95.5%, and 14 implants were not prosthetically utilized (sleeping). One patient died from recurrent malignant disease, the only patient (5 implants) lost to follow-up. Of the 7 implants removed, 4 were removed because of lack of osseointegration (2 implants failed to achieve osseointegration initially and were removed at or shortly after abutment connection surgery, and 2 implants lost osseointegration 3 and 4 months after prosthetic loading) and 3 osseointegrated implants were removed 6 months after prosthetic loading at the time of recurrent tumor resection in the patient (#13), who eventually died of metastatic disease. The implant survival rate was 97.4% when the 3 implants lost to recurrent tumor were excluded. All 7 removed implants had been originally placed in previously grafted bone (6 in free nonvascularized iliac bone and one in free vascularized scapular bone). Definite etiologic factors leading to implant loss were not identified for 4 implants removed in 3 patients without recurrent tumor; however, reduced bone density (not vascularity) was recorded at stage I surgery in these 3 patients (type C bone in 3 implant sites and type D bone in 1 implant site). Bone volume, however, was adequate, inasmuch as 3 of the 4 removed implants were at least 15 mm in length and the fourth was 10 mm in length

and 5 mm in width (Table 4). Of the total 154 implants placed, 109 were placed (7 removed) in previous bone-grafted sites (93.6% survival) and 45 were placed (0 removed) in residual mandibular bone sites (100% survival).

Anatomic location of implants, as expected in this type of patient, was not an issue in limiting implant placement, as only 6 of 154 implants were placed above the neurovascular canal or foramen (all in residual bone). The 149 remaining implants were placed either anterior to the mental foramen or where the neurovascular canal or foramen was resected.

Currently, 14 implants (9.1% of total placed) are not being used for dental prosthesis support for various reasons: thick overlying scar tissue (8 implants), bone overgrowth (1 implant), buccal malposition (3 implants), or peri-implantitis from frame misfit (2 implants). Eight of the nonfunctional implants are in posttrauma patients, and 6 are in patients who underwent oncologic resection. Twelve nonfunctioning implants (Table 4) were in bone grafts (3 were 10 mm in length, 6 were 13 mm in length, 2 were 15 mm in length, and 1 was 18 mm in length) and 2 nonfunctioning implants were in residual mandibular bone (1 was 15 mm in length, 1 was 18 mm in length). All nonfunctional implants were clinically and radiographically osseointegrated and could be utilized at a later date; additional surgical procedures or modified abutments (or both), along with additional prosthetic procedures, would be required.

Bone Quality Data. Seventy-six of 109 implants (70%) were placed into bone graft sites with type A or B bone, whereas 38 of 45 implants (85%) placed into residual mandibular bone had type A or B bone (Table 3). The 30% incidence of type C or D bone in bone-grafted sites is significant, as this is where the 4 nontumor-related implant loss occurred. The percentage of A or B versus C or D bone quality did not change significantly when comparing the vascularized and nonvascularized bone graft implant sites (both had approximately 70% A or B quality bone). However, the vascularized scapula was inferior to the vascularized fibula or ilium when comparing the bone quality type at implant sites, but numbers were too small to obtain statistical significance.

Implant Type. Of the 109 implants placed in bone grafted sites, 66 did not require bone tapping (self-tapping, rescue, or wide type), giving a theoretical 60% incidence of reduced mineralization of bone in the bone-grafted discontinuity sites (Table 4). Of the 45 implants placed in residual mandibular bone, 23 did not require bone tapping (self-tapping, rescue, or wide type), giving a 50% incidence of reduced mineralization of bone in the residual mandible.

Implant Length. Implant length was 13 mm or more in 96 of 109 (88%) implants placed in bone-grafted sites and in 43 of 45 (95%) implants placed in residual mandibular sites, which indicated a more than adequate bone height for implant reconstruction in both residual and bone-grafted mandibular implant sites (Table 4). Implant length in vascular versus nonvascular bone grafts was not included in the tables; however, only 13 of 109 implants placed into bone graft sites were 10 mm in length, and only 1 of these 13 was in a vascularized bone graft site.

Combined Prosthetic Data. Fixed prostheses (27 patients), fixed-removable prostheses (2 patients), or overdentures (2 patients) were placed and have been in continuous function in all 31 patients during the observation period of 6 months to 12 years (Tables 1 and 3). All prostheses were totally implant-supported except 1 overdenture (patient #18), for which partial soft tissue support was present (retromolar pad). The maxillary arch opposing occlusion varied considerably (Table 1). One prosthesis was remade; a fixed prosthesis was changed to a totally implant-supported overdenture to improve access for hygiene management (patient #27). One fixed prosthesis was recently removed from function when resection for recurrent tumor was required in an anatomic site away from the previous prosthesis and endosseous implants. This prosthesis was recently replaced following wound healing and occlusal modification (the patient, #31, currently functions with a hemi-mandible and a fixed prosthesis).

Combined Bone Graft Data. In 26 of 31 implant patients, bone-graft reconstruction was performed as a secondary procedure a mean of 25 months (3 to 124 range) after trauma or resection and in 5 patients it was performed as a primary procedure (Tables 1 and 2). In the 31 bone-grafted implant patients, the donor site was the ilium in 24 patients (example of nonvascularized ilium reconstruction, Fig 2), the fibula in 3 patients (example of vascularized fibular reconstruction, Fig 3), the cranium in 1 patient, and the scapula in 3 patients (example of vascularized scapula, Fig 4).

The time of endosseous implant placement after bone graft reconstruction varied considerably, with a mean of 16 months. Healing time after implant placement also varied, with a mean of 16 months; this variation was in part the result of treatment delays commonly encountered in this population group.

Complications. *Bone Grafts.* In 1 patient with a nonvascularized iliac bone graft, failure occurred. The bone graft failure was related to soft tissue compromised from previous irradiation. Four months after failure of the bone graft, a vascularized soft tissue graft was placed, and 6 months later a second

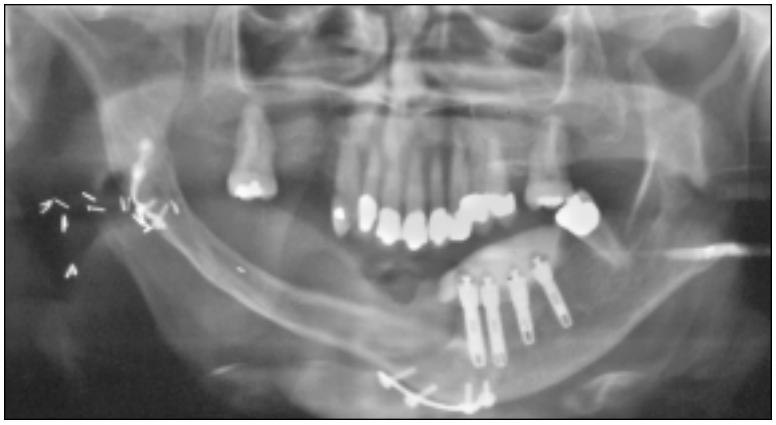


Fig 4 Radiograph after treatment illustrating free vascularized scapular bone-graft reconstruction of posttraumatic mandibular discontinuity. Note the adequate bone height for discontinuity reconstruction but the inadequate bone-graft volume for endosseous implant placement. All 4 endosseous implants are placed in residual mandibular bone (patient #24).

nonvascularized iliac bone graft was placed, which was successful. Currently this patient (#16) has experienced 54 months of prosthesis function without complication. In a second patient (#14), a free vascularized soft tissue graft was placed 6 months after a nonvascularized bone graft. The nonvascularized iliac bone graft was successful but required vascularized soft tissue coverage in this irradiated patient.

Soft Tissue. Rotational vascularized pectoral flaps were required in 2 patients. In 1 of these patients (#11), the rotational flap was placed 6 years after bone grafting, along with removal of the titanium mesh tray, and in the second patient (#31), the rotational flap was placed and the titanium mesh tray removed 6 months after bone grafting. Both of these patients had received substantial irradiation (interstitial radon and interstitial radon plus external beam of 4,500 cGy). Two patients required free vascularized soft tissue flaps to cover nonvascularized bone graft reconstructions (described above under bone-graft complications).

Titanium Mesh Tray. Removal of the titanium mesh tray was required in 9 of 51 patients with such trays (17.6% incidence). In 4 patients (#11, 31, 14, 16), tray removal was related to treatment of compromised, irradiated soft tissue (2 rotational and 2 free vascularized soft-tissue flaps described above); in 1 patient (#28), removal was related to treatment of a traumatic fracture; in 1 patient (#1), tray removal was done on an empirical basis and was performed at the time of implant placement (first implant patient with titanium mesh tray); in 1 patient (#9), a portion of the tray was removed to treat a subcondylar stress fracture superior to the bone graft; in 1 patient (#30), tray removal was related to an incidental soft tissue cosmetic procedure done 5 years after bone grafting; and in 1 patient (#27), tray removal was related to a fixed-removable prosthesis that caused an intraoral dehiscence and secondary sepsis 2 months after prosthetic treatment (9 months after successful bone grafting).

Peri-Implant Soft Tissue. Soft-tissue complications related to implants were common in this group of postsurgical or posttraumatic patients with discontinuity, but overall the complications were minor and related to previous irradiation (secondary xerostomia and monilial overgrowth) or to previous scar tissue secondary to prior surgery or trauma. Two patients who suffered discontinuity defects following gunshot wounds required split skin graft vestibuloplasty procedures after implant uncovering and before prosthesis placement. One additional patient required a labial full thickness palatal graft to the labial of an implant in the right cuspid position (to fix mobile peri-implant tissue during function).

Discussion

Predictable and complete bone graft healing for mandibular discontinuity is important for subsequent endosseous implant and prosthesis reconstruction. In 1867 Ollier[9] and in 1952 Urist and McLean[10] hypothesized from studies of autogenous bone grafting that periosteum at the recipient site had a decisive role in bone graft healing. In 1893 Barth[11] described bone conduction (or creeping substitution) healing. Both of these healing mechanisms rely heavily on the cellularity and vascularity of the soft and hard tissue of the recipient site and the presence of bone morphogenic protein (BMP). Important studies by Burwell in 1969[12] and Albrektsson in 1980[13] provided insight into bone-graft healing and the critical importance of early graft vascularization. Studies by Phemister in 1914[14] and Abbott et al[15] in 1947 on the mechanisms of bone-graft healing supplied evidence

that nontraumatized cancellous bone provided viable mesenchymal cells that produce osteoid shortly after transplantation. The importance of keeping the bone graft out of the body for as short a time as possible was documented by Puranen[16] and confirmed by Bohr et al. [17]

The importance of a gentle bone-harvesting technique has been well documented by Albrektsson,[18] who used a histochemical method to demonstrate earlier revascularization and bone remodeling in minimally (rather than moderately) traumatized bone grafts. Albrektsson[13] also discussed 3 types of autogenous bone-graft healing mechanisms (bone induction, bone conduction, and transfer osteogenesis). All 3 mechanisms can potentially occur simultaneously in the same grafting site, depending on the status (fresh) and type (cortical or cancellous) of bone graft and more importantly on the status of the recipient site to provide nutrition[13] (early revascularization) and cellular (periosteal and endosteal) viability.[18]

The presence of one type of bone-graft healing does not exclude other healing mechanisms. A free vascularized bone graft also must ultimately rely on all healing mechanisms in its various segments and theoretically will have a better chance for survival in tissue in which the blood supply is compromised than a nonvascularized graft, provided all other surgical and biologic factors have been satisfied (graft fixation, recipient site viability, and so forth). Vascularized bone grafts also contain segments of cortical nonvascularized bone and marrow, which ultimately heal and contribute to the final bone-graft healing in a similar if not identical manner as in the nonvascularized grafts. The advantage of the free or rotational vascularized bone graft is the ability to bring vascularized soft tissue and vascular-derived nutrition simultaneously to a hypovascular recipient site (previously infected or radiated tissue).

Discontinuity Bone Graft Reconstruction Surgical Principles. The surgical principles involved in bicortical bone grafting include aseptic surgical technique, rigid fixation of bony segments, and avoidance of intraoral contamination. Currently, health at the recipient site and cellular viability of the bone graft can be added to this important list. Various methods of fixation of the corticocancellous block bone grafts, including rigid plates, titanium mesh trays, or nonrigid transosseous wires have been utilized. Intermaxillary splints and wires have also been used. Currently, intermaxillary fixation is rarely utilized. Lack of fixation decreases stress on the bone reconstruction and patient and theoretically provides some functional stimulation to the healing bone graft (patient has free mandibular motion but is advised against occlusal loading).

Most bone-grafting techniques require a rigid allogenic stabilizing device for 2 reasons: first, to fix the bone graft to the residual bone segments of the recipient site, and second, to ensure acceptable ridge form and position. In this series of patients, semirigid titanium mesh trays as the allogenic stabilizing unit were utilized (Figs 1, 2b, and 2c) because they: (*1*) are highly biocompatible (commercially pure titanium) and their modulus of elasticity approaches that of cortical bone, allowing for physiologic function of the healing bone graft and reducing the theoretical possibility of bone stress shielding (which can occur with rigid alloy plates or bars)[19,20]; (*2*) are easily adapted and fixed to the residual mandible with self-tapping titanium screws; (*3*) provide harmonious mandible contours for acceptable esthetics and ridge form; (*4*) eliminate the necessity of rigid intermaxillary fixation in most patients (light intermaxillary guiding elastics are provided along with soft-diet function); (*5*) are generally user-friendly in the operating room; (*6*) allow placement of block or particulate bone graft material 10 to 15 mm above the superior tray edge, which enhances the probability that adequate bone will be present for secondary reconstruction with endosseous dental implants[3–5]; and (*7*) rarely require removal in the long term, except in irradiated oncology patients.[6]

Surgical technique at the donor site is crucial and more important than generally appreciated. The anterior portion of the ilium was used for autogenous bone donation in 54 of the 61 bone-grafted patients (2 vascularized and 52 nonvascularized). In most patients, the cortex of the lateral iliac crest and its gluteal muscle attachments are left intact. Large corticocancellous blocks are harvested using bone cutting methods (osteotome, oscillating saw, slow-speed rotary) that help control heat production and maintain cellular viability, especially in the cellular-rich cancellous portion of the graft. The blood supply to the cancellous portion of the graft is maintained during the cortex-cutting portion of the procedure, and the final graft separation (cancellous bone from the cortex of the lateral crest) is accomplished with a sharp osteotome. Finally, the fresh warm grafts are taken immediately to the previously prepared recipient site and shaped with rongeurs. Bone mills are not used because they are believed to injure delicate osteogenic stem cells. Adequate cellular density is provided by the blocks of cancellous ilium (attached to the anterior medial-superior iliac cortex), which also contain bone morphogenic protein for predictable bone-graft healing. To prove or disprove this clinical impression (adequate cellular density) would require a double-blind retrospective study. The bone grafting success and the risk-to-benefit ratio docu-

mented in the present report do not warrant a double-blind prospective study.

Maintaining cellular viability at the recipient site is crucial for enhancing the bone-induction healing that is needed for predictable success of free autogenous vascularized or nonvascularized bone grafting. Important surgical factors that enhance the potential for bone graft healing at the recipient site include: (*1*) proper incision placement to avoid extensive surgical undermining of the skin (dermis), since undermining reduces skin feeder vessels and subsequent vascularity of the skin edge and graft coverage; (*2*) conservative use of cautery or other tissue-destroying techniques; (*3*) conservative periosteal reflection, since the blood supply to the nonresected dense residual mandible is derived primarily from the enveloping periosteum; (*4*) avoidance of trauma (heat via high-speed burs, cautery, etc.) to the residual bone, as heat destroys the rich osteogenic cellular layer (cambium) left after periosteal reflection; (*5*) aseptic wound technique, especially the avoidance of communication between the intraoral and the extraoral microflora in the environment; (*6*) rigid skeletal anchorage of corticocancellous block bone graft (internal miniplates, screws, or mesh trays); (*7*) watertight, everted, nontension skin closure over a patent, active extraoral drain; and (*8*) meticulous hemostasis and elimination of dead space, since dead spaces may allow hematoma formation, which potentially reduces bone induction healing and interferes with early nutrition and vascularization of the transplanted viable stem cells in the cancellous and marrow portion of the fresh bone graft.

Endosseous Implant Placement Surgical Principles. Endosseous implant placement is delayed 4 to 6 months to permit initial bone graft revascularization and remineralization. With successful graft healing, the surgeon achieves a more predictable, appropriate implant location for prosthesis reconstruction. A longer healing period (of 4 to 6 months or more) may result in reduced volume (height and width) of the bone graft as it heals, especially the portion that is placed superior to the titanium crib edge, which may not receive functional loading as it heals. Ideally, the height of the bone graft above the allogenic crib should be more than 10 mm for eventual placement of implants that are 15 to 18 mm long, with the apex of the endosseous implants 3 mm above the inferior border of the allogenic stabilizing tray. Implants with the apex closer than 3 mm to the stabilizing tray have been observed without adverse effect on implant survival. Four implants 3.75 or 4.00 mm in diameter and more than 13 mm in length will provide an adequate bone-implant interface for functional support of a fixed prosthesis in hemimandibular reconstruction. For complete arch mandibular reconstruction in this setting, 5 or 6 endosseous implants are placed. Nonfunctioning implants represented a more frequent finding in this group of patients (14 of 154 implants placed), as there was frequently thick or mobile (or both) tissue in the alveolar region of the reconstructed mandible. In addition, the reconstructed mandible was frequently buccal or labial to the opposing maxillary occlusion.

Surgical preparation of the bone implant site is similar to that in routine mandibular implant reconstruction but includes a number of important modifications. First, periosteal reflection is minimized, since the cortical portion of the bone graft may still be undergoing osteoconduction replacement healing during this time, and the possibility of sequestra formation is increased if the periosteum is detached. Second, the drilling of bone with reduced mineralization (60% in grafted bone and 50% in residual bone in our study, based on implant type) is technically more difficult, so increased surgical precision is needed. Of 109 implants placed in the healed bone graft in this study, 65 were either self-tapping or rescue implants (Table 4). In addition, 30% of the bone graft implant sites had type C or D bone at the time of implant placement. Third, bone tapping is, as noted above, frequently not required in the healed bone graft sites, except occasionally for the initial superior cortex. Fourth, countersinking is not advised, since the cortex of the medical iliac bone graft is frequently thin (1 mm or less) and would be easily lost during drilling with a beveled bur. Countersinking the implants would result in the loss of important stabilization provided by the cortex; only one cortex is present on nonvascularized iliac bone graft supported with a mesh tray. In addition, abnormal early loading of the nonsubmerged (no countersinking) implant is generally not a problem in this patient population, since an interim prosthesis is rarely desirable or indicated. Fifth, soft tissue procedures are frequently performed in the soft tissue portion of vascularized composite grafts and in scar tissue to reduce bulk and to improve lip and tongue mobility. Fabrication of an interim prosthesis for cosmetic use is delayed for 2 or 3 weeks in this patient group. Sixth, implant placement in vascularized[21] or nonvascularized[4–6] ilium or vascularized[22–24] fibula (Fig 3) will result in unicortical or bicortical stabilization of endosseous implants of adequate length and diameter. This stabilization was true for the 17 implants placed in the 3 vascularized fibular bone grafts and for 5 implants placed in 2 vascularized iliac bone grafts (an additional 5 implants were placed in residual mandibular bone). In contrast,

vascularized radial[25] or scapular bone grafts (Fig 4) provide marginal or inadequate bone for endosseous implant reconstruction; we were able to place only 4 implants in 3 vascularized scapular bone grafts (an additional 10 implants were placed in residual mandibular bone).

Generally, endosseous implant exposure and abutment connection are routine. Frequently, increased scar tissue will make the soft tissue dissection more difficult and require soft tissue revisions to enhance the health (thickness and stability) of the peri-implant tissue. Because longer abutments are generally required, temporary healing abutments are placed to allow more precise abutment selection after 3 or 4 weeks of tissue healing. Healing time (prior to prosthetic treatment) is increased because of the additional soft tissue manipulation; also, soft tissue surgery is frequently more extensive in patients with vascularized bone grafts because of the need to remove excess intraoral skin and subcutaneous fat. Soft tissue procedures on all patients with discontinuity defects may be required to reduce or eliminate the effect of tongue and lip motion on peri-implant tissue.

Conclusions

Free autogenous bone-graft reconstruction utilizing vascularized or nonvascularized bone grafts resulted in 98.4% success in 61 consecutive patients with mandibular discontinuity. A second-stage implant procedure consisting of endosseous titanium implants for dentoalveolar reconstruction was used in 31 of the 61 patients; implant success criteria was applied to this group, and an overall implant survival rate of 95.5% was recorded. A survival rate of 97.4% was noted when tumor recurrence was excluded as a reason for implant failure. This success approaches that achieved for routine reconstruction of noncompromised edentulous mandible. Implant loss was confined to implant sites in previous bone grafts. This high rate of success in mandibular discontinuity reconstruction can be attributed to several factors: (*1*) using large corticocancellous block bone grafts (ilium, fibula) for discontinuity reconstruction (cortical bone for rigidity and form; cancellous bone for cellular elements and bulk); (*2*) using a 2-stage procedure, in which bone-graft reconstruction is performed 6 months before endosseous implant reconstruction; (*3*) providing physiologic bone-graft stabilization (titanium mesh trays) to allow functional stimulation and avoid stress shielding to the bone graft during its revascularization and remineralization; (*4*) using a nonviolent soft and hard tissue surgical technique at the bone-graft donor and recipient site and at the implant placement site, which preserves cellular viability to ensure primary (transfer osteogenesis) and secondary (bone induction and conduction) bone-graft healing, and predictable osseointegration of the titanium endosseous implants; (*5*) placing implants of sufficient length, number, and position to permit solid biomechanical prosthetic bone anchorage; and (*6*) providing a prosthesis of appropriate biomechanical design to distribute the imposed load for long-term stability.

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