Inferior Alveolar Nerve Transposition in Conjunction with Implant Placement

Nicola Ferrigno, DDS[1–3]/Mauro Laureti, MD, DDS[2,3]/Stefano Fanali, MD, DDS[1]

Purpose: *The aim of this prospective study was to determine the incidence of neurosensory disturbance and the cumulative survival and success rates of ITI solid-screw implants placed in conjunction with an inferior alveolar nerve (IAN) transposition technique.* **Materials and Methods:** *46 ITI implants were placed in 15 patients following transposition of the IAN. In 4 patients nerve transpositioning was performed bilaterally, so a total of 19 IAN mobilization surgeries were performed. Neurosensory dysfunction was objectively evaluated by using light touch (LT), pain (PT), and 2-point discrimination (2-DT) tests. In addition, patients were asked to answer a short questionnaire to investigate individual feelings of discomfort and advantages related to this surgical technique. The mean follow-up period was 49.1 months (range, 12 to 78 months).* **Results:** *The cumulative implant survival and success rates were 95.7% and 90.5%, respectively. Only 2 implants were lost. Neurosensory disturbance (ie, disturbance registered by the LT, PT, and 2-DT tests) was experienced in 4 of 19 cases. However, at the time of data analysis (12 to 78 months after surgery), all patients indicated that they would go through the surgery again.* **Discussion:** *The IAN transposition technique, when used in the severely atrophied posterior mandible, allowed placement of implants with adequate length and good initial stabilization. All patients felt that they had received significant benefits from their new prostheses.* **Conclusion:** *Based on the results of the present study, it can be concluded that lateral nerve transposition can be used as a surgical procedure to enable ITI implant placement in the severely resorbed posterior mandible.* (More than 50 references.) INT J ORAL MAXILLOFAC IMPLANTS 2005;20:610–620

Key words: *dental implants, inferior alveolar nerve, nerve transpositioning*

Bone atrophy of the posterior mandible following loss of dentition can represent a challenge for oral surgeons. Many patients, in fact, reject the use of removable prostheses, viewing them as a handicap with respect to oral function and psychosocial impact on quality of life. As a consequence, restoration of oral function through oral surgery and placement of implants is often welcome. Long-term studies have demonstrated that partially or completely edentulous jaws can be restored successfully with implant-supported fixed prostheses.[1–6] However, resorption of the alveolar ridge often leaves minimal bone superior to the inferior alveolar nerve (IAN), inhibiting placement of implants of favorable length. Although good success rates have been achieved with 8-mm short ITI implants (Institut Straumann, Waldenburg, Switzerland),[4,6] the placement of short implants often represents a high risk.[7–9] The use of 6-mm implants seems promising,[10] but sufficient scientific and clinical trials have not yet been conducted.

One approach to avoid nerve injury when placing implants in the severely atrophied posterior mandible is to reposition the IAN laterally and then place the implants medial to the nerve; this technique allows placement of longer implants and better initial stabilization. In 1987, Jensen and Nock[11] first documented restoration of the atrophic posterior mandible using endosseous implants in conjunction with IAN transposition; since then, several modifications of this method have been presented.[12–17] There are 2 basic methods of nerve transposition. One method involves transpositioning the nerve by creating a window that includes the mental foramen as well as the area of implant placement, then releasing the nerve from the mental foramen and replacing the nerve distal to its original location; the incisive nerve is severed to allow transposition of both the mental nerve and the IAN. In the second method, the IAN is lateralized by repositioning it through a posterior cortical window. Most of the studies on neurosensory disturbance and implant success rates associated with IAN transposition found in the literature have been carried out using Brånemark System implants (Nobel Biocare, Göteborg, Sweden) or cylindric implants. To date, to the authors' knowledge, such a study has never been done with ITI implants.

[1]Professor, Specialization Course in Clinical Implantology and Biomaterials, School of Dental Medicine, University of Chieti "G. D'Annunzio," Italy.
[2]Professor, Specialization Course in Oral Implantology, School of Dental Medicine, University of Rome "La Sapienza," Italy.
[3]ITI Fellow.

Correspondence to: Prof Nicola Ferrigno, Via Monteforte Irpino, 12, 00177 Rome, Italy. Fax: +39 0 6 2757397. E-mail: ferrigno.n@tiscali.it or nicolaferrigno@implantologiaorale.it

The purpose of the present study was to determine the incidence of neurosensory disturbance and the cumulative survival and success rates of ITI solid-screw implants placed in conjunction with IAN transposition.

MATERIALS AND METHODS

Between January 1996 and August 2002, a total of 15 patients, 6 male and 9 female, between 49 and 68 years old (average age, 58.1 years), were consecutively enrolled in this prospective study and treated with distal fixed partial dentures (FPDs) supported by ITI implants placed in conjunction with an IAN transposition technique. In 11 of 15 patients, nerve transpositioning was performed unilaterally; in 4 patients, it was performed bilaterally. A total of 46 ITI solid-screw implants were placed in conjunction with 19 IAN transpositioning procedures. The present study concerns only implants placed in conjunction with an IAN transposition technique, even if the same patient received other implants.

The medical status of patients regarding current and previous diseases and medications was noted; only healthy patients were considered suitable for receiving treatment. Patients who presented with poor oral hygiene, bruxism, heavy smoking habit (ie, more than 10 cigarettes a day), or drug or alcohol abuse were excluded, as were patients who had already received and lost implants, patients who received radiotherapy to the head and neck region for malignancies, and patients who were undergoing antiblastic chemotherapy.

Preoperative Workup

Preoperative workup included an assessment of the IAN using panoramic radiographs and a computerized tomographic scan,[18] casts, a diagnostic waxup, and surgical templates. The mean distance between the crest of the ridge and the mandibular canal measured on the preoperative radiographs was 6.8 mm (range of 6 to 8 mm). The patients were given oral and written information regarding the risk of postoperative neurosensory dysfunction, and their written informed consent was obtained.

Surgical Procedure

Local anesthesia was obtained by infiltrating 2% carbocaine containing 1:100,000 adrenaline. For 11 patients, intravenous sedation was used. A midcrestal incision extending from the initial segment of the anterior border of the mandibular ramus through the retromolar pad to the first remaining tooth (usually the canine) was made. After an anterior releasing incision was made, a labial mucoperiosteal flap was reflected, exposing the alveolar ridge and buccal cortex. Care was taken during flap reflection to preserve the integrity of the periosteum and the neurovascular bundle where it exits the mental foramen and enters the soft tissue.

With a round diamond bur with a diameter of 1.5 mm and profuse irrigation, a rectangular osteotomy approximately 8 by 30 mm (Fig 1a) was made 3 mm posterior to the mental foramen on the lateral aspect of the body of the mandible (Fig 1b). After removal of the entire outer rectangular cortical window, small curettes were used to carefully remove the medullary bone lateral to the neurovascular bundle along the entire length of the bony window. After the neurovascular bundle was identified, it was carefully released from the inferior alveolar canal for the entire length of the osseous window using small curettes. The mental nerve was left intact. The neurovascular bundle was then gently shifted to the side and protected with a smooth instrument. It was kept in that position just long enough to place implants using the standard technique. Once the implants were in place, the neurovascular bundle was repositioned so as to rest on the implants medial to the IAN (Figs 2 and 3). Following IAN transpositioning, the bone window was covered with a resorbable membrane (Bio-Gide; Geistlich, Wolhusen, Switzerland) to prevent mucosal penetration into the surgical site and promote bone regeneration. When necessary, a horizontal releasing incision was made in the periosteum to enable a tension-free closure. Concerning the healing modality, the submerged approach was utilized for all implants.

Postoperative Treatment and Healing Period

After surgery, all patients received oral antibiotics for either 5 or 8 days, nonsteroidal analgesics for 3 to 5 days, and detailed instructions about oral hygiene (mouth rinses with 0.2% chlorhexidine for 2 weeks). Sutures were removed 8 to 15 days after surgery.

All implants had titanium plasma-sprayed (TPS) or sand-blasted, large-grit, acid-etched (SLA) surfaces and were placed in the mandible in conjunction with IAN transposition. Implants were allowed a healing period of 3 months for osseointegration to be achieved before prosthetic rehabilitation began.

The prosthetic restorations comprised 13 splinted 3-unit FPDs, 4 splinted 4-unit FPDs, and 2 full-arch restorations. As previously reported, some implants

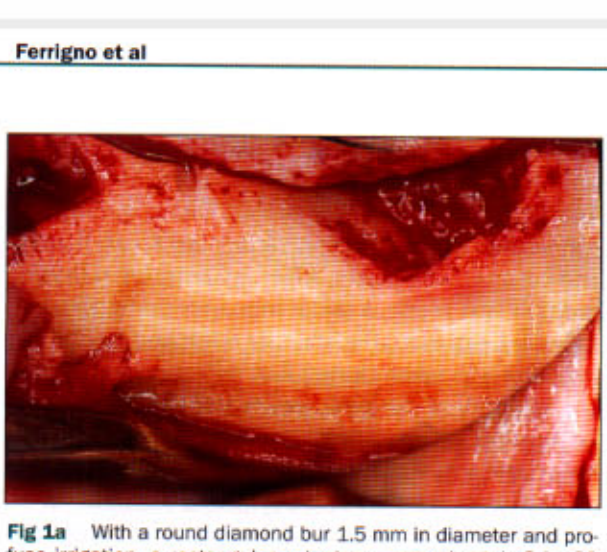

Fig 1a With a round diamond bur 1.5 mm in diameter and profuse irrigation, a rectangular osteotomy approximately 8 by 30 mm was created on the lateral surface of the mandible.

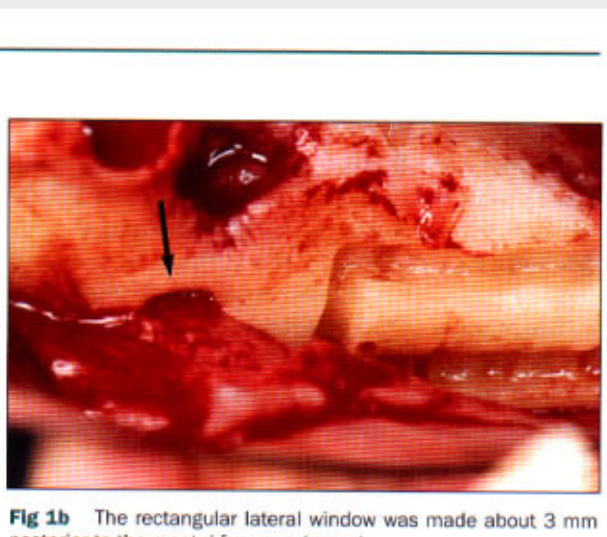

Fig 1b The rectangular lateral window was made about 3 mm posterior to the mental foramen *(arrow)*.

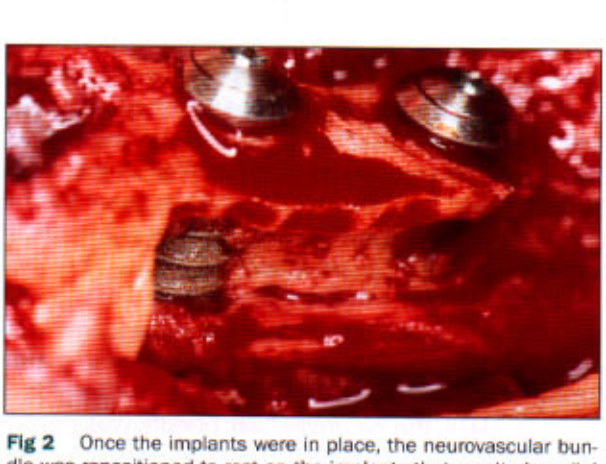

Fig 2 Once the implants were in place, the neurovascular bundle was repositioned to rest on the implants that resulted medial to the IAN. Nothing was interposed between the neurovascular bundle and the implants.

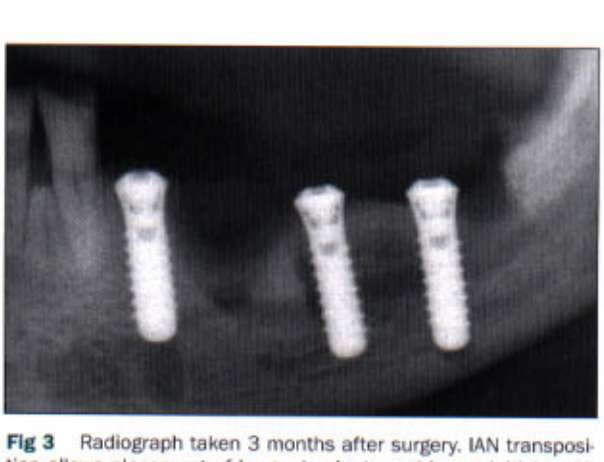

Fig 3 Radiograph taken 3 months after surgery. IAN transposition allows placement of longer implants and better initial stabilization.

were connected to implants placed without an IAN transposition technique; therefore, from the number of suprastructures, no conclusion could be reached regarding the number of implants assessed for the study. Among the available ITI implant configurations, in this study standard solid-screw implants with a diameter of 4.1 mm were always selected. Most of the placed implants had an SLA surface; however, 12 implants with a TPS surface were used during the first 2 years of the study period. Despite the implant surface characteristics, 12-mm-long implants were most frequently used (n = 23), followed by 10-mm-long (n = 21) and 8-mm-long (n = 2) implants.

Clinical Examination

Follow-up visits were scheduled for 2 weeks and for 1, 2, 3, 6, 12, 18, and 24 months postoperatively during the first 2 years, and annually thereafter. At each *annual recall* patients were given a clinical and radiographic examination to check pain and discomfort, neurosensory dysfunction, peri-implant soft tissue condition, and marginal bone loss.

Pain, Discomfort, and Neurosensory Dysfunction. One year postsurgery and at the time the data analysis was made (the end of August 2003), all patients were asked to verbally answer a short questionnaire (Table 1). Patients who had bilateral nerve transpositioning were asked to answer the questionnaire both 1 year after the first surgery and 1 year after the second surgery; the second surgery was performed 3 to 4 months after the first one. Their answers were considered separately for the 2 surgeries, so 19 answers were collected for each question.

Three tests were used to evaluate the neurosensory dysfunction of the IAN[19]:

- **Light touch (LT) test:** This test was performed with a soft feather that the patient could identify in a control site (the upper lip; Fig 4). With the patient's eyes closed, a stimulus was randomly applied to the test sites during 1 of 2 intervals, which were 10 seconds apart. The patient was asked to identify during which time interval the stimulus had been applied. Each site was tested in blocks of 10 trials. A response of 80% or greater was considered normal. Two sensitivity levels were used: 0 = normal sensitivity and 1 = abnormal sensitivity.

Table 1 Questionnaire

1. Did you have any sensitivity problem immediately after the surgery?
2. Do you still have any sensitivity problems with your lower lip or chin?
3. Has this sensitivity problem improved since the time of the surgery?
4. Would you have the surgery again or would you recommend this kind of surgery to your dear friend or relative?
5. Do you feel that you have received benefits from your new prosthesis in terms of improved comfort, chewing efficiency, and esthetics?

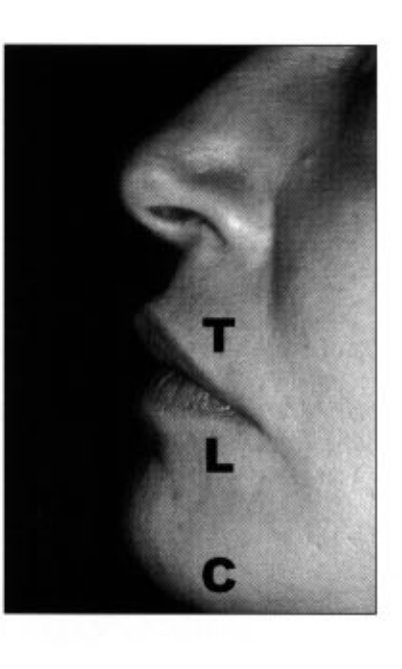

Fig 4 Sites for neurosensory dysfunction tests: T = control site, L = lower lip, C = chin.

- **Pain test (PT):** This test was performed using a sharp explorer. This test was assumed positive when patients could differentiate between the pressure pain elicited by a blunt tip having the same diameter as the explorer and the pain elicited by the sharp explorer. Three sensitivity levels were used: 0 = normal sensitivity, 1 = decreased sensitivity, and 2 = no sensitivity.
- **Two-point Discrimination Test (2-DT):** A pair of calipers was opened progressively in 2-mm increments until the patient could discriminate the caliper ends as 2 separate points of contact. The following scores were used: 0 = normal sensitivity (patients could discriminate between the 2 tips at a distance shorter than 14 mm); 1 = decreased sensitivity (patients could distinguish between tips only when the calipers were open between 14 and 20 mm); 2 = no sensitivity (patients could not distinguish between the tips even if they were more than 20 mm apart).

Each test site was made up of 2 areas; the upper lip was used as the control area for each test (Fig 4). Abnormalities in either test area detected by any single neurosensory dysfunction test or by a combination of the 3 tests were counted as neurosensory disturbance for that particular test site.[1]

The total neurosensory disturbance (LT + PT + 2-DT) is a sum of the neurosensory-disturbed sites. Since a certain degree of nerve injury may be expected to occur during the IAN surgical approach, all of the neurosensory disturbances that faded away in a short time (within 1 month) were not included.

Peri-implant Soft Tissue. The annual evaluation of the peri-implant soft tissue condition included the assessment of several clinical parameters using the following indices:

- **Modified Plaque Index (mPI):** Determined on the mesial, distal, buccal, and lingual surfaces of the implants.[20,21] For each implant, the mPI value was calculated based on the average of the 4 values obtained. The scores used were 0 = no plaque detected; 1 = plaque recognizable only by running a probe across the smooth marginal surface of the implant; 2 = plaque visible to the naked eye; 3 = abundance of soft matter.
- **Modified Bleeding Index (mBI):** Assessed at the same surfaces.[20,21] For each implant, the mBI value was calculated based on the average of the 4 values obtained. The scores used were 0 = no bleeding when a periodontal probe is passed along the gingival margin adjacent to the implant; 1 = isolate bleeding spot visible; 2 = blood forms a confluent red line on margin; 3 = heavy or profuse bleeding.
- **Probing depth (PD):** Measured to the nearest millimeter with a Hu-Friedy PGF-GFS periodontal probe (Hu-Friedy, Chicago, IL), at the same surfaces.[20–22] For each implant, the PD was calculated based on the average of the 4 values obtained.

- **Distance between implant shoulder and mucosal margin (DIM):** Measured to the nearest millimeter. In the presence of a subgingival implant shoulder, the measurement was recorded as a negative value. Measurements were taken with the same probe at the same surfaces.[22]
- **Attachment level (AL):** Computed for each site by adding PD and DIM.[22]
- **Width of keratinized mucosa (KM):** Measured in millimeters midbuccally and midlingually of implants in the mandible.[22] For each implant, the KM value was calculated based on the average of the 2 values obtained.
- **Suppuration:** Presence or absence evaluated for each implant.

Marginal Bone Loss. The first radiographic examination was made at the end of the healing period, 3 months after surgery. For most patients a panoramic radiograph was taken; periapical radiographs were only used for patients with a mouth floor that allowed the radiograph to be placed so as to capture an image of the implant apex, which was often located in the inferior cortex of the jaw. The radiographs were analyzed for the presence of continuous peri-implant radiolucencies and the levels of alveolar bone around the implants. Measurements were made mesial and distal to the implant sites using a transparent millimeter ruler. The distance between the implant shoulder and the first visible bone contact (DIB)[22] was measured, as well as the distance between the most coronal bone-implant contact and the apex of the implant. The measurements were made to the nearest 0.5 mm. To correct the dimensional distortion, the apparent dimension of each implant was measured on the radiograph and compared to the actual implant length.[1,18,23]

Criteria for Success and Implant Classification

The implants were examined for successful tissue integration using predefined criteria for success defined taking into account the success criteria established by Buser and colleagues[22] and Albrektsson and colleagues.[24] They were

1. Absence of persistent subjective complaints, such as pain, foreign body sensation, and/or dysesthesia
2. Absence of a recurrent peri-implant infection with suppuration
3. Absence of mobility
4. Absence of a continuous radiolucency around the implant
5. Marginal bone loss less than 0.2 mm per year after the first year of loading

First, distinction was made between implants that had not achieved osseointegration defined as "early failed implants" and those that had osseointegrated defined as "successfully integrated implants." Based on the clinical and radiographic examination, each implant was placed in 1 of 3 categories:

- **Failure:** An implant was regarded as a failed implant if it had to be removed for any reason.
- **Survival:** An implant was classified as a surviving implant if it was still in service but did not fulfill the success criteria.
- **Success:** An implant was classified as a successful implant if it fulfilled the criteria for success.

If a patient could not be followed at consecutive annual examinations, the corresponding implants were classified as dropouts.

Life Table Analysis

The statistical analysis included a life table analysis as described by Cutler and Ederer[25] in 1958. To obtain at least 1 year of follow-up for all 46 placed implants, the data analysis was made at the end of August 2003.

Cumulative Survival Rate. This analysis calculated the annual survival rate and the cumulative survival rate for the entire 6-year period. In this study, survival rate was defined as the percentage of load-bearing implants that did not fail, including implants that exhibited a suppurative peri-implant infection at the last annual examination.

Clinical Survival Rate. This analysis calculated the annual success rate and the cumulative success rate for the entire 6-year period. This analysis was more strict than the survival rate analysis, since all implants exhibiting a suppurative peri-implant infection at the last annual control were considered failures.

RESULTS

Results of the neurosensory examination are described in Table 2. The incidence of neurosensory disturbance detected was 15.8% (3/19) by LT, 15.8% (3/19) by PT, and 21.1% (4/19) by 2-DT. The total neurosensory disturbance (LT + PT + 2-DT) was 21.1% (4/19). After the 19 IAN transpositions, 9 patients experienced sensory recovery immediately after the local anesthesia. Ten patients had neurosensory disturbance. In 6 cases, the patient experienced a total return of sensation within 1 month. Two patients did not experience complete recovery until 6 months postsurgery, 1 patient waited 12 months to obtain complete recovery, and 1 patient was still experiencing neurosensory disturbance at the time of data analysis.

Table 2 Results of the Neurosensory Evaluation

Patient no.	Age	Time after surgery (mo)	Side	Test area	Neurosensory examination LT	PT	2-DT	LT+PT+2-DT	Time to sensory recovery (mo)	Implant loss
1	67	78	R	L	1	0	1	1	12	0/2
				C	0	0	0			
2	56	73	R	L	0	0	0	0	0	1/2
				C	0	0	0			
2	56	70	L	L	0	0	0	0	0	0/3
				C	0	0	0			
3	51	70	R	L	0	0	0	0	1	0/2
				C	0	0	0			
4	62	68	R	L	0	0	0	0	1	0/2
				C	0	0	0			
5	55	67	L	L	0	1	1	1	6	0/2
				C	0	0	0			
6	49	60	L	L	0	0	0	0	0	0/3
				C	0	0	0			
6	49	57	R	L	0	0	0	0	1	0/2
				C	0	0	0			
7	61	56	R	L	0	0	0	0	1	0/3
				C	0	0	0			
7	61	52	L	L	1	0	0	1	P	1/3
				C	1	1	1			
8	68	50	L	L	0	0	0	0	0	0/2
				C	0	0	0			
9	59	45	L	L	0	0	0	0	0	0/2
				C	0	0	0			
10	54	41	R	L	1	1	2	1	6	0/3
				C	0	0	2			
11	58	37	R	L	0	0	0	0	1	0/3
				C	0	0	0			
11	58	34	L	L	0	0	0	0	0	0/2
				C	0	0	0			
12	67	27	R	L	0	0	0	0	0	0/3
				C	0	0	0			
13	50	20	R	L	0	0	0	0	1	0/2
				C	0	0	0			
14	62	15	R	L	0	0	0	0	0	0/3
				C	0	0	0			
15	53	12	L	L	0	0	0	0	0	0/2
				C	0	0	0			

Time after surgery = number of months from the time of surgery to the data analysis.
Side: R = right, L = left.
Test areas: L = lower lip, C = chin.
Time to sensory recovery = number of months from the time of surgery to the complete sensory recovery. 0 = immediately after local anesthesia, P = permanent, still present at the time of data analysis.

During the healing period, 2 implants were lost and were classified as early failures. One implant was lost as the result of nonintegration; another implant was lost because of mobilization after the patient sustained a spontaneous mandibular fracture 3 weeks after surgery. The patient who sustained the fracture returned to the authors' office complaining of pain and swelling in the left region of the antegonial notch. Extraoral examination revealed small, firm, nontender areas of submandibular swelling on the left side of the mandible. Intraorally, there was little evidence of inflammation or swelling at the implant sites, but this was considered quite normal 3 weeks postsurgery. A panoramic radiograph revealed a fracture on the left side of mandible. Manipulation of the mandible did not reveal any preternatural movement at the fracture site. The patient was placed on amoxicillin (1g 2 times daily) for 10 days and on nonsteroidal analgesics for 5 days. The patient was advised to restrict his diet to soft, nonchewy foods and to stop wearing the mandibular denture. When the patient returned after 10 days, there was no evidence of extraoral swelling and the surgical sites had healed normally, except the site of the most posterior

implant on the left side. This implant had penetrated through the soft tissues and appeared mobile without any evidence of suppuration. The implant was removed, and after a month a panoramic radiograph showed healing and consolidation of the fracture.

As only 2 implants were lost during the healing period, the early failure rate was 4.3% (2/46). All the other implants were considered to be successfully osseointegrated. Therefore, 44 implants were considered suitable for prosthetic rehabilitation.

During the follow-up period, 2 implants were treated with mechanical debridement (carbon fiber curettes plus rubber cups and polishing paste; Hawe Neos, Bioggio, Switzerland), antiseptic treatment (local application of a 0.5% chlorhexidine dental gel for 15 days), and oral antibiotics (ornidazole [Tiberal; Roche, Basel, Switzerland] 500 mg twice daily or metronidazole [Flagyl, Rhone-Poulenc, Paris, France], 350 mg 3 times daily, for 10 days) because they presented infection with suppuration in the peri-implant sulcus and radiographic evidence of bone resorption at the last annual examination.[26,27] Implant infection was successfully controlled for the 2 implants.

During the study period, based on clinical and radiographic examinations (Table 3), all the remaining 42 implants fulfilled the predefined criteria for success (Table 2) and were classified as successful implants. All the patients were followed at consecutive annual examinations, so there were no dropout implants. The life table analysis of the 46 placed implants is shown in Tables 4 and 5. These tables show cumulative survival and success rates at 80 months (about 6.5 years) of 95.7% and 90.5%, respectively.

Concerning the peri-implant bone level data obtained for mesial and distal sites, this study has identified a mean bone loss pattern for ITI implants placed in a submerged approach of 1 to 1.5 mm in the first year following implant placement and less than 0.1 mm in subsequent years.

The mean width of the measured KM around the implants decreased from a mean of 2.6 mm in the first year to 1.9 mm at the end of the study period, for a rate of approximately 0.1 mm/y.

Patient answers to the questionnaire are summarized in Table 6. Regarding question 1, although numbness was reported by 10 patients immediately after surgery, after a longer period, ie, at the time of the data analysis, only 3 patients remembered this discomfort as important. Regarding question 2, the subjects' responses and the objective tests (Table 2) were not in agreement at the time of data analysis. The neurosensory tests were more sensitive in detecting neurosensory disturbance than the patients' evaluation. Regarding question 3, in no case was anesthesia or burning paresthesia reported, and the neurosensory disturbance did not increase since the time of the surgery and did not seem to affect the patients' daily life. Regarding question 4, only the patient who reported a mandibular spontaneous fracture after surgery answered that he would have declined the surgery had he known the consequence prior to surgery. Regarding question 5, all patients felt that they had received benefits from their new prostheses in terms of improved comfort, chewing efficiency, and esthetics.

Table 3 Results of 46 Implants During the Study Period

Parameter	Min	Max	Mean	SD
mPI	0	2	0.20	0.46
mBI	0	2	0.26	0.54
PD	1	5	2.76	0.80
DIM	−2	1	−0.16	1.02
AL	1	4	2.60	0.94
KM	0.5	4	1.20	0.80
DIB	1.5	3.5	2.40	0.50

DISCUSSION

Avoiding IAN damage during dental implant surgery is an important goal because of the forensic and ethical issues as well as the neurologic sequelae that may impair oral function.

Resorption of the posterior mandibular alveolar ridge often leaves minimal bone superior to the IAN, inhibiting the placement of implants of favorable length. Higher failure rates have been associated with short implants (< 10 mm)[28]; however, a high frequency of nerve complications (14% after stage-1 surgery; 4% 3 years later) has been reported for Brånemark System implants with a turned (machined) surface stabilized bicortically on the superior bony surface of the mandibular canal.[29]

In contrast, since bicortical stabilization is not necessary for ITI implants when treating mandibular posterior edentulous ridges, a security distance of 1 to 2 mm from the mandibular canal should be respected whenever possible. This conservative concept offers minimal risk of damaging the neurovascular bundle.[30] Nevertheless, the progressive bone resorption that occurs after tooth loss can result in a moderately or severely atrophied mandible; in such cases, bone height posterior to the mental foramen may be inadequate to allow such a security zone. In this situation, even the placement of 6- or 8-mm ITI implants can potentially injure the IAN. One approach to avoiding nerve injury when placing

Table 4 Life Table Analysis of 46 Implants for Implant Survival

Time interval (mo)	Implants at start of interval	Dropouts during interval	Implants under risk	Failures during interval	Survival rate within period (%)	Cumulative survival rate (%)
0–12	46	0	46	2	95.7	95.7
12–24	44	0	44	0	100	95.7
24–36	39	0	39	0	100	95.7
36–48	34	0	34	0	100	95.7
48–60	26	0	26	0	100	95.7
60–72	13	0	13	0	100	95.7
72–80	4	0	4	0	100	95.7

Table 5 Life Table Analysis of 46 Implants for Implant Success

Time interval (mo)	Implants at start of interval	Dropouts during interval	Implants under risk	Failures during interval	Survival rate within period (%)	Cumulative success rate (%)
0–12	46	0	46	2	95.7	95.7
12–24	44	0	44	1	97.7	93.4
24–36	39	0	39	0	100	93.4
36–48	34	0	34	1	97.1	90.5
48–60	26	0	26	0	100	90.5
60–72	13	0	13	0	100	90.5
72–80	4	0	4	0	100	90.5

Table 6 Patients' Answers to the Questionnaire

Question	1 y after surgery Yes	No	Time of data analysis Yes	No
1	10	9	3	16
2	2	17	0	19
3	0	19	0	19
4	18	1	19	0
5	19	0	19	0

implants in these situations is to reposition the IAN laterally and then place the implants medial to the nerve. The main risk of these surgeries is possible prolonged neurosensory dysfunction because of a certain degree of traction and/or pressure to the neurovascular bundle.

It has been documented that traction causing greater than a 5% increase in the length of the IAN can lead to permanent neurosensory disturbance[31] but even slight traction to the nerve may produce a neurosensory alteration.[32] Neurosensory disturbances may include, but are not limited to, anesthesia, paresthesia, hypoesthesia, tingling sensation, and burning sensation.

Neurosensory disturbance may be evaluated by specific neurosensory tests; in addition, from the clinical point of view, patients' answers to a questionnaire represent the best way to understand whether a surgical technique is well tolerated and can really benefit patients' daily life.

In the present study, light touch and pain tests were used to selectively discriminate for large-myelinated, quick-adapting A alpha fibers, which constitute 90% of the A axons. The 2-DT was used to selectively study large-myelinated, slow-adapting A alpha fibers, which constitute the remaining 10% of A axons.[33,34] The combined results of these 3 neurosensory tests were useful in evaluating the total extent of neurosensory deficit.

In no case was there prolonged anesthesia or burning sensation; these 2 situations are usually not well tolerated by patients. Most of patients experienced sensory recovery immediately after the local anesthesia or within 1 to 6 months. This discomfort, however, was well tolerated by patients because they were informed regarding the risk of postoperative neurosensory dysfunction and knew that a certain degree of nerve injury could be expected to occur during this particular surgical approach. Consequently, at the time of the data analysis, only 3 patients considered the initial discomfort as important.

The neurosensory tests detected that 1 patient had to wait 12 months to obtain complete recovery

and 1 patient still experienced neurosensory disturbance at the time of data analysis. Because the patients' answer to question 2 (Do you still have any sensitivity problems with your lower lip or chin?) may be used to evaluate patients' feeling of neurosensory disturbance, the results of question 2 were compared with the total neurosensory disturbance tests (LT + PT + 2-DT). Although at the time of data analysis the results of the objective tests (LT + PT + 2-DT) and the subjects' responses were mostly in agreement (18/19 = 94.7%), 1 patient who showed objective signs of hypoesthesia did not feel it or did not give it subjective importance. Overall, the total neurosensory disturbance tests (LT+PT+2-DT) seemed to be more sensitive in detecting neurosensory disturbance than was the patients' evaluation.

The total neurosensory disturbance results of this study (21.1%) can be considered quite satisfying if compared with previous studies involving IAN transposition in conjunction with implant placement in which a significantly higher percentage of neurosensory disturbance (from 30% to 76.5%) was reported.[13,35,36] This difference is most likely the result of the surgical technique used for nerve transposition. All 19 IAN lateralizations in the present study were performed with only a single window posterior to the mental foramen. In a recent comparative study, the reported incidence of neurosensory disturbance was significantly greater for the surgical technique that released the mental nerve from the mental foramen (77.8%) than for the surgical technique that did not release the mental nerve from the mental foramen (33.3%).[36] In a recent clinical study, a new surgical technique involving the use of 2 osteotomies, 1 in the posterior edentulous area and the other around the mental foramen, was proposed.[17] In this study the neurosensory disturbance incidence was particularly favorable; of the 10 patients who underwent repositioning of the IAN, 4 experienced sensory recovery immediately after the local anesthesia and the other 6 patients experienced total return of sensation within 3 to 6 weeks.

Concerning the type of implant used in this study, some authors have postulated that repositioning of the nerve directly against the implants resulted in very close nerve-to-implant contact and that in this situation the threads of an implant may be a source of chronic irritation that could induce longstanding edema and intraneural fibrotic scar tissue formation.[37,38] In other words, the direct contact between the IAN and the sharp implant threads could potentially induce symptoms[12,13,39]; thus, cylindric implants have been recommended when performing lateral nerve transposition.[17,31,36] Other authors, considering the great advantage in using threaded implants to obtain primary implant stability during this destructive surgical approach, have suggested interposing a barrier between the neurovascular bundle and implants, such as autogenous and/or allogenic bone graft[40] or a resorbable membrane.[41] In this study, only solid-screw ITI implants with a macroscopic shape showing sharp but not wide threads were used. During the surgical procedure, once the implants were in place, the neurovascular bundle was repositioned so as to rest directly on the implants that resulted medial to the IAN. This approach was decided with the hypothesis that direct but passive nerve-to-implant contact was unlikely to damage the nerve. The neurosensory disturbance incidence reported in the present study seems to confirm that the surgical technique used and not the implant shape can cause possible nerve injury.

The most important complication of this study was the mandibular fracture of a patient treated to receive 8 implants to support a fixed full-arch prosthesis. The height of the residual mandible at the point of the spontaneous fracture that the patient sustained 3 weeks after surgery was 13 mm. Fortunately, only 1 distal implant was lost because of mobilization so that it was possible to realize the planned fixed full-arch prosthesis with the remaining implants, ending the rehabilitation of the fractured hemi-arch at the second premolar. Fracture may represent a risk associated with nerve transpositioning, because the mandible is always weakened in the crestal and lateral wall by the bone removal associated with this surgical technique. It is also generally recommended that implants be placed in the inferior cortex of atrophic mandibles to obtain maximum stabilization[42] However, the strongest area of the atrophic mandible can be weakened when the inferior cortex is penetrated.[43]

Concerning the marginal bone loss data obtained for mesial and distal sites, it is important to note that all implants were placed with a submerged approach by placing them approximately 1 to 1.5 mm deeper into the hard tissue when compared to the standard nonsubmerged approach.[44] The deeper placement of ITI implants into the bone can lead to increased crestal bone resorption, as demonstrated in experimental and clinical studies.[45–47] These studies demonstrated that the vertical position of the implant shoulder, with its microgap at the implant-abutment connection, has a significant impact on crestal bone resorption. This bone resorption is not a pathologic condition but a physiologic reaction to the implant placement to create a "biologic width" observed not only around natural teeth[48] but also around dental implants.[49–52]

The marginal bone loss data are consistent with other previous works[53,54] and may suggest that statistically this implant system did not show any radiographically measurable bone loss following the initial period of bone loss associated with the soft tissues' reaching of the physiologic "biologic width."

The overall amount of peri-implant KM around the study implant decreased from a mean of 2.6 mm in the first year postimplantation to 1.9 mm at the end of the study period, at the rate of approximately 0.1 mm/y. Decreases in both buccal and lingual KM were seen, although the rate of loss of lingual KM was more than twice that of the buccal. This result is consistent with data published by Weber and colleagues[57] in 2000 but is in contrast with previous works that reported a similar decreased width in oral KM but an increase in buccal width.[55,56]

During a mean follow-up period of 49.1 months, the cumulative survival and success rates of implants were of 95.7% and 90.5%, respectively. This result is consistent with the long-term success rates reported for this implant placed in the partially or completely edentulous posterior mandible without the use of nerve-transpositioning surgery.[4–6] Thus, a lateral nerve transposition technique, when used in posterior severely atrophied mandibles, can permit the placement of implants with adequate length and with good initial stabilization as used in routine sites, with the same favorable prognosis.

CONCLUSION

Based on the results of the present study, it can be concluded that

- Lateral nerve transposition can be used as a surgical procedure to enable implant placement in the severely resorbed posterior mandible.
- The overall incidence of neurosensory disturbance was 21.1%. Only 1 of 19 IAN transposition procedures resulted in an objective permanent hypoesthesia. This disturbance was slight and well tolerated by the patient.
- In spite of the objective neurosensory disturbance identified during the study period, at the time of data analysis (12 to 80 months after surgery), all patients indicated that they would go through the surgery again.
- All patients felt that they had received benefits from their new prostheses in terms of improved comfort, chewing efficiency, and esthetics.

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. Adell R, Eriksson B, Lekholm U, Brånemark P-I, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants 1990;5:347–359.
3. Jemt T, Lekholm U. Oral implant treatment in posterior partially edentulous jaws: A 5-year follow-up report. Int J Oral Maxillofac Implants 1993;8:635–640.
4. Buser D, Mericske-Stern R, Bernard JP, et al. Long-term evaluation of non-submerged ITI implants. Part I: 8-year life table analysis of a prospective multi-center study with 2359 implants. Clin Oral Implants Res 1997;8:161–172.
5. Buser D, Mericske-Stern R, Dula K, Lang NP. Clinical experience with one-stage, non-submerged dental implants. Adv Dent Res 1999;13:153–161.
6. Ferrigno N, Laureti M, Fanali S, Grippado G. A long-term follow-up study of non-submerged ITI implants in the treatment of totally edentulous jaws. Part I: Ten-year life table analysis of a prospective multicenter study with 1286 implants. Clin Oral Implants Res 2002;13:260–273.
7. Wilke HJ, Claes L, Steinemann S. The influence of various titanium surfaces on the interface shear strength between implants and bone. Adv Biomater 1990;9:309–311.
8. Buser D, Nydegger T, Oxland T, et al. Interface shear strength of titanium implants with a sandblasted and acid-etched surface: a biomechanical study in the maxilla of miniature pigs. J Biomed Mater Res 1999;45:75–83.
9. Cochran DL. A comparison of endosseous dental implant surfaces. J Periodontol 1999;70:1523–1539.
10. ten Bruggenkate CM, Asikainen P, Foitzik C, Krekeler G, Sutter F. Short (6-mm) nonsubmerged dental implants: results of a multicenter clinical trial of 1 to 7 years. Int J Oral Maxillofac Implants 1998:13;791–798.
11. Jensen O, Nock D. Inferior alveolar nerve reposition in conjunction with placement of osseointegrated implants: A case report. Oral Surg Oral Med Oral Pathol 1987;63:263–268.
12. Rosenquist B. Fixture placement posterior to the mental foramen with transpositioning of the inferior alveolar nerve. Int J Oral Maxillofac Implants 1992;7:45–50.
13. Friberg B, Ivanoff CJ, Lekholm U. Inferior alveolar nerve transposition in combination with Brånemark implant treatment. Int J Periodontics Restorative Dent 1992;12:440–449.
14. Smiler DG. Repositioning the inferior alveolar nerve for placement of endosseous implants: Technical note. Int J Oral Maxillofac Implants 1993;8:145–150.
15. Jensen J, Reiche-Fischel O, Sindet-Petersen S. Nerve transposition and implant placement in the atrophic posterior mandibular alveolar ridge. J Oral Maxillofac Surg 1994;52:662–668.
16. Onstad MS. Repositioning of the inferior alveolar nerve for dental implants. Dental Implantol Update 1998;9:53–56.
17. Peleg M, Mazor Z, Chaushu G, Garg AK. Lateralization of the inferior alveolar nerve with simultaniaous implant placement: a modified technique. Int J Oral Maxillofac Implants 2002; 17:101–106.
18. Ferrigno N, Di Silvestro S, Fanali S. Conventional and computed tomography in dental implantation surgery. Proceedings of the 1st World Congress of Osseointegration, Venice. Gorizia, Italy: Ergon, 1994:245–249.
19. Campbell RL, Shamaskin RG, Harkins SW. Assessment of recovery from injury to inferior alveolar and mental nerves. Oral Surg Oral Med Oral Pathol 1987;64: 519–526.

20. Mombelli A, van Oôsten MA, Schurch E Jr, Lang NP. The microbiota associated with successful or failing osseointegrated titanium implants. Oral Microbiol Immunol 1987;2:145–151.
21. Mombelli A, Lang NP. Clinical parameters for the evaluation of dental implants. Periodontol 2000 1994;4:81–86.
22. Buser D, Weber HP, Lang NP. Tissue integration of non-submerged implants. One-year results of a prospective study with 100 ITI hollow-cylinder and hollow-screw implants. Clin Oral Implants Res 1990;1:33–40.
23. Brånemark P-I, Hansson BO, Adell R, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg 1977; 11(suppl 16):1–132.
24. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long-term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–25.
25. Cutler SJ, Ederer F. Maximum utilization of the life table method in analyzing survival. J Chronic Dis 1958;8:699–712.
26. Mombelli A, Lang NP. Antimicrobial treatment of peri-implant infections. Clin Oral Implants Res 1992;3:162–168.
27. Mombelli A, Lang NP. The diagnosis and treatment of peri-implantitis. Periodontol 2000 1998;17:63–76.
28. Lekholm U, van Steenberghe D, Herrmann I, et al. Osseointegrated implants in the treatment of partially edentulous jaws: A prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1994;9:627–635.
29. Higuchi KW, Folmer T, Kultje C. Implant survival rates in partially edentulous patients: A 3-year prospective multicenter study. J Oral Maxillofac Surg 1995;53:264–268.
30. Buser D, von Arx T. Surgical procedures in partially edentulous patients with ITI implants. Clin Oral Implants Res 2000; 11(suppl 1):83–100.
31. Bailey PH, Bays RA. Evaluation of long-term sensory changes following mandibular augmentation procedures. J Oral Maxillofac Surg 1984;42:722–727.
32. Samit A, Popowich L. Mandibular vestibuloplasty: a clinical update. Oral Surg Oral Med Oral Pathol 1982;54:141–147.
33. Buchthal F, Kuhl V. Nerve conduction, tactile sensibility, and the electromyogram after suture or compression of peripheral nerve: a longitudinal study in man. J Neurol Neurosurg Psych 1979:42:436–451.
34. Wilgis EF. Techniques for diagnosis of peripheral nerve loss. Clin Orthop Relat Res 1982;163:8–14.
35. Haers PE, Sailer HF. Neurosensory function after lateralization of the inferior alveolar nerve and simultaneous insertion of implants. Oral Maxillofac Surg Clin North Am 1994;7:707–716.
36. Kan JY, Lozada JL, Goodacre CJ, Davis WH, Hanisch O. Endosseous implant placement in conjunction with inferior alveolar nerve transposition: An evaluation of neurosensory disturbance. Int J Oral Maxillofac Implants 1997;12:463–471.
37. Rydevik B, Lundborg G, Nordborg C. Intraneural tissue reactions induced by internal neurolysis. An experimental study on the blood-nerve barrier, connective tissues and nerve fibres of rabbit tibial nerve. Scand J Plastic Reconstr Surg 1976;10:3–8.
38. Rydevik B, Brånemark P-I, Nordborg C, McLean WG, Sjöstrand J, Fogelberg M. Effects of chymopapain on nerve tissue. An experimental study on the structure and function of peripheral nerve tissue in rabbits and after local application of chymopapain. Spine 1976;1:137–148.
39. Ruskin JD. Inferior alveolar nerve considerations with dental implants. In: Block MS, Kent JN (eds). Endosseous Implants for Maxillofacial Reconstruction. Philadelphia: Saunders, 1995;368–381.
40. Nocini PF, De Santis D, Fracasso E, Zanette G. Clinical and electrophysiological assessment of inferior alveolar nerve function after lateral nerve transposition. Clin Oral Implants Res 1999;10:120–130.
41. Kahnberg KE, Henry PJ, Tan AE, Johansson CB, Albrektsson T. Tissue regeneration adjacent to titanium implants placed with simultaneous transposition of the inferior dental nerve: a study in dogs. Int J Oral Maxillofac Implants 2000;15:119–124.
42. Mason ME, Triplett RG, Van Sickels JE, Parel SM. Mandibular fractures through endosseous cylinder implants: Report of cases and review. J Oral Maxillofac Surg 1990;48:311–317.
43. Raghoebar GM, Stellingsma K, Batenburg RH, Vissink A. Etiology and management of mandibular fractures associated with endosteal implants in the atrophic mandible. Oral Surg Oral Med Oral Pathol 2000;89:553–558.
44. Buser D, von Arx T. Surgical procedures in partially edentulous patients with ITI implants. Clin Oral Implants Res 2000; 11(suppl):83–100.
45. Hämmerle CH, Bragger U, Burgin W, Lang NP. The effect of subcrestal placement of the polished surface of ITI implants on marginal soft and hard tissues. Clin Oral Implants Res 1996;7:111–119.
46. Hermann JS, Buser D, Schenk RK, Higginbottom FL, Cochran DL. Crestal bone changes around titanium implants. A histometric evaluation of unloaded non-submerged and submerged implants in the canine mandible. J Periodontol 2000; 71:1412–1424.
47. Hermann JS, Buser D, Schenk RK, Schoolfield JD, Cochran DL. Biologic width around one- and two-piece titanium implants. A histometric evaluation of unloaded nonsubmerged and submerged implants in the canine mandible. Clin Oral Implants Res 2001;12:559–571.
48. Gargiulo AW, Wentz FM, Orban B. Dimensions and relations of the dentogingival junction in humans. J Periodontol 1961; 32:261–267.
49. Berglundh T, Lindhe J, Ericsson I, Marinello CP, Liljenberg B, Thomsen P. The soft tissue barrier at implants and teeth. Clin Oral Implants Res 1991;2:81–90.
50. Berglundh T, Lindhe J. Dimension of the periimplant mucosa. Biological width revisited. J Clin Periodontol 1996;23:971–973.
51. Cochran DL, Hermann JS, Schenk RK, Higginbottom FL, Buser D. Biologic width around titanium implants. A histometric analysis of the implanto-gingival junction around unloaded and loaded nonsubmerged implants in the canine mandible. J Periodontol 1997;68:186–198.
52. Cochran DL. The scientific basis for and clinical experiences with Straumann implants including the ITI Dental Implant System: A consensus report. Clin Oral Implants Res 2000; 11(suppl):33–58.
53. Brägger U, Häfeli U, Huber B, Hämmerle CH, Lang NP. Evaluation of postsurgical crestal bone levels adjacent to non-submerged dental implants. Clin Oral Implants Res 1998;9:218–224.
54. Weber HP, Crohin CC, Fiorellini JP. A 5-year prospective clinical and radiographic study of non-submerged dental implants. Clin Oral Implants Res 2000;11:144–153.
55. Mericske-Stern R, Steinlin Schaffner T, Marti P, Geering AH. Peri-implant mucosal aspects of ITI implants supporting overdentures. Clin Oral Implants Res 1994;5:9–18.
56. Behneke A, Behneke N, d'Hoedt B, Wagner W. Hard and soft tissue reactions to ITI screw implants: 3-year longitudinal results of a prospective study. Int J Oral Maxillofac Implants 1997;12:749–757.