

Prospective Evaluation of Implants Connected to Teeth

Michael S. Block, DMD¹/Denise Lirette, RDH²/Diana Gardiner, PhD³/Linxiang Li, PhD⁴/Israel M. Finger, BDS⁵/
J. Hochstedler, DDS⁶/Gerald Evans, DDS⁷/John N. Kent, DDS⁸/Dale J. Misiek, DMD⁹/
Arturo J. Mendez, DDS⁵/Luis Guerra, DDS⁵/Harold Larsen, DDS⁵/William Wood, DDS¹⁰/Pat Worthington, BA²

Purpose: This prospective clinical trial examined the effect on teeth and implants when rigidly or non-rigidly connected in a cross-arch model. **Materials and Methods:** Thirty patients received 2 implants, 1 on each side of the mandible, and were restored with 3-unit fixed partial dentures connected either rigidly or non-rigidly to an abutment tooth. Patients were followed for at least 5 years post-restoration. **Results:** Repeated-measures analysis revealed no significant difference in crestal bone loss at implants (rigid versus non-rigid methods). An overall significant difference ($P < .001$) was found comparing methods for teeth. Paired *t* tests revealed no significant differences in crestal bone levels for implants or teeth at the 5-year recall. Kaplan-Meier methods and the Cox proportional hazards model showed no differences between attachment methods with regard to success based on survival and bone loss criteria. During the 5-year recall period, 1 implant (rigid side) was removed. Four implants developed bone loss greater than 2 mm during the course of this trial. One tooth on the rigid side and 2 teeth on the non-rigid side had greater than 2 mm of crestal bone loss and were removed secondary to fractures. In all, 5 abutment teeth were removed, all of which had been treated with root canal therapy and fractured at the interface of the post within the tooth. There was no clear relationship of tooth fracture to attachment. Repeated-measures analysis of mobility values revealed no significant changes over the time course of this study, and paired *t* tests revealed no statistically significant differences between implants for mobility. Repeated-measures analysis and paired *t* tests for probing depth revealed no significant changes over the time course of this study. There were no significant differences in soft tissue indices for either attachment method. The percentage of patients who had measurable intrusion was 66% for the non-rigid group, and 44% for the rigid group; 25% of the non-rigid teeth had greater than 0.5 mm intrusion, compared with 12.5% for the rigid group. For the 2 time periods evaluated, there was no significant increase in intrusion over time. The non-rigid-side implant required more nonscheduled visits to treat problems than the rigid implant and the teeth. **Discussion:** Most patients were treated successfully with rigid or non-rigid attachment of implants to teeth. **Conclusion:** The high incidence of intrusion and non-scheduled patient visits suggest that alternative treatments without connecting implants to teeth may be indicated. (INT J ORAL MAXILLOFAC IMPLANTS 2002;17:473–487)

Key words: cross-arch experimental design, dental abutments, dental implants, fixed partial denture, prospective analysis

¹Professor, Director of Residency Training, Department of Oral and Maxillofacial Surgery, Louisiana State University (LSU) School of Dentistry, New Orleans, Louisiana.

²Research Associate, LSU School of Dentistry.

³Professor, Director of Instructional Services, LSU School of Dentistry.

⁴Associate Professor, Department of Mathematics, University of New Orleans, Louisiana.

⁵Professor, Department of Prosthodontics, LSU School of Dentistry.

⁶Associate Professor, Department of Prosthodontics, LSU School of Dentistry.

⁷Professor, Department of Periodontics, LSU School of Dentistry.

⁸Boyd Professor and Head, Department of Oral and Maxillofacial Surgery, LSU School of Dentistry.

⁹Former Professor, Department of Oral and Maxillofacial Surgery, LSU School of Dentistry; now in Private Practice, Charlotte, North Carolina.

¹⁰Former Professor, Department of Oral and Maxillofacial Surgery, LSU School of Dentistry; now in Private Practice, Omaha, Nebraska.

Reprint requests: Dr Michael Block, Department of Oral and Maxillofacial Surgery, LSU School of Dentistry, 1100 Florida Ave, New Orleans, LA 70119. E-mail: mblock@lsuhsc.edu

Endosseous dental implants are being used to support fixed and removable prostheses for completely and partially edentulous patients. Currently, there are 2 methods of attaching natural abutment teeth to an implant when the latter is used to support a distal-extension prosthesis. One technique is to rigidly connect the natural abutment tooth and the implant, and the second method is to non-rigidly connect the natural abutment tooth to the implant using attachments (Figs 1 and 2). A review of the literature has not found objective or clinical evidence that substantiates manufacturers' and clinicians' claims that one technique is superior to the other.¹⁻¹⁴ Clinicians who prefer the retrievability of non-rigidly attached implant-to-tooth prostheses spend more time and incur extra expense because of the added cost of the attachment.

Osseointegrated implants develop a rigid connection to bone, with nearly complete lateral immobility. Adell and colleagues¹⁵ and Albrektsson and associates¹⁶ demonstrated that a titanium screw implant could support fixed prostheses in completely edentulous arches, with 84% implant retention in the maxilla and 93% implant survival in the mandible over 15 years. One of the most significant findings with osseointegrated implants is their limited mobility of approximately 0.004 mm in response to a 500-g lateral force, reflecting bone-to-implant ankylosis.¹⁷ Integrated, clinically non-mobile, ankylosed implants can provide enough mechanically significant retention to functionally rehabilitate edentulous patients. However, because of the presence of a periodontal ligament and tooth mobility greater than that of an ankylosed implant, and based on Skalak's discussion,¹⁸ clinicians are using various interlocking devices to attach natural abutment teeth to osseointegrated implants, without the benefit of clinical data to justify Skalak's rec-

ommendations, to break stress between an ankylosed implant and a natural tooth.

Previous reports involving the connection of implants to teeth have indicated the use of interlocking attachments to the natural teeth to help support the abutment tooth, provide motion between the immobile ankylosed implant and the tooth, and provide molar occlusion in areas where 2 implants cannot be placed because of space limitation.¹⁹ Small series did not report differences between the 2 types of connections because sample size was small. Bone loss, mobility, gingival health, and clinical success were similar between the abutment teeth and the implants, except that the implants had deeper soft tissue probing depths (3.3 ± 0.7 mm for implants versus 2.3 ± 0.5 mm for teeth).²⁰ van Steenberghe²¹ presented 5-year prospective data on Brånemark System implants (Nobel Biocare, Göteborg, Sweden) rigidly connected to teeth in mixed clinical cases with no adverse effects on the natural dentition. Literature references concerning the decision on whether to rigidly or non-rigidly connect an abutment tooth to an osseointegrated implant involve clinical case reports without data analysis to confirm either technique.^{22,23}

Kirsch and Ackermann²⁴ have recommended that when an implant is to be connected to a natural tooth, a shock-absorbing element be used in the implant. Others,^{19,25-27} using the Brånemark System implant, recommend that a slot-type attachment be used on the natural teeth with the implant prosthesis abutment retained by screws, allowing retrievability and presumably preventing disuse atrophy or other damage to the natural tooth. Finger and Guerra²² suggest that cementation of prostheses with rigid connections between implants and natural teeth is acceptable and teeth will not be deleteriously affected. It has been suggested that natural



Fig 1a Master cast of prepared natural abutment and implant in molar location.



Fig 1b Gold coping and rigid prosthesis. Note that the prosthesis is screw-retained to the implant and will be cemented to the gold coping.

teeth serving as abutments on implant-supported restorations have a metal coping placed over them and simply serve as a support, with no cement between the crown and copings.²⁵⁻²⁸ However, because of the intrusion of teeth connected to ankylosed implants, cement may be indicated. Recent studies imply that rigidly connected implants lose more bone (0.7 mm) than non-rigidly connected implants, with a greater number of problems with teeth using either connection compared to implants.^{29,30} These studies involved a variety of uses in many clinical situations and were not well focused in regards to controls within the population studied.

The authors' hypothesis is that both methods for attaching teeth to implants are equivalent in terms of crestal bone loss, intrusion, and postrestorative time involved with maintaining the prostheses. The primary objective of this study was to compare and contrast the rate and extent of tooth and peri-implant bone loss when abutment teeth are connected rigidly or non-rigidly to osseointegrated implants. The secondary objectives of this study were: (1) to compare the rate and extent of mobility and probing depth of implants and teeth that are connected rigidly or non-rigidly; (2) to compare the cumulative success rate of rigidly and non-rigidly connected implants to teeth using success criteria modified from Albrektsson and associates¹⁶; (3) to determine, for abutment teeth and implants, whether soft tissue changes correlate with changes in bone loss and mobility; (4) to establish the incidence and amount of tooth intrusion when attaching teeth to implants; and (5) to compare, between methods, the number of nonscheduled post-restoration visits when implants are connected to teeth. Excessive and progressive bone loss was considered a negative result, indicating that clinical use of that method was to be reconsidered. Mobility of the

implants was an indication of failure. The primary endpoint of this study was bone loss.

MATERIALS AND METHODS

Inclusion and Exclusion Criteria

All patients (either sex) were at least 20 years old and not older than 65, and were willing to present for examination 2 times a year for 5 years. All patients were ASA I or II, free of uncontrolled or insulin-dependent diabetes, and existing malignancy. In addition, they were not osteoporotic or receiving any therapy that suppressed their immune system, such as radiation, chemotherapy, or chronic steroid usage.

Patients had an intact healthy mandibular dentition except for missing premolars and molars bilaterally. They were totally edentulous in the maxilla. Maxillomandibular ridge relationships indicated that a Class I molar relationship could be established. All patients had adequate interarch space for



Fig 2a Non-rigid prosthesis. Note the Beyeler attachment, which connects the implant to the natural tooth.



Fig 2b The non-rigid prosthesis on the master cast. Note that the framework is separated between the tooth and the poetic of the prosthesis.



Fig 2c Both prostheses inserted in the mouth. Note that both are screw-retained to the implant.

satisfactory restoration of the edentulous regions with a complete maxillary denture restorable to an ideal occlusal plane.

Each patient's existing dentition was free of active periodontal disease or exhibited controllable periodontal disease. Abutment tooth probing depth was less than 3 mm, the Bleeding Index (BI)³¹ less than 1, the Plaque Index (PI) less than 1, and there was less than 2 mm of vertical bone loss from the cemento-enamel junction. A crown-root ratio of at least 1:2 existed on the abutment teeth. All first premolars had at least 2 mm of attached keratinized tissue. All patients had adequate bone superior to the neurovascular bundle to accommodate a 10-mm-long implant on each side, and had at least 6 mm of crestal bone width.

Patient Availability, Recruitment, and Retention

Forty-two patients were entered into the study. Ten were men (7 Caucasian and 3 African American) and 32 were women (17 Caucasian and 15 African American).

The plan of this study involved a cross-arch design (Figs 1 and 2), with each patient serving as his or her own control. The decision as to which method was to be used on each side was randomized by a statistician. The choice of prosthetic design was based on several conditions. A significant factor was that both prostheses needed to be operator-retrievable to evaluate mobility and soft tissue health (including probing) and able to accommodate standardized radiographic holders based on the implants. To allow removal, the rigid side was temporarily cemented to a metal coping, with the coping permanently cemented to the tooth. For both the rigid and non-rigid sides, the prostheses were screwed onto the implants. Techniques for establishing rigid and non-rigid attachment of the first premolar abutment tooth to the implant allowed for the retrieval of all fixed partial dentures (FPDs) for mobility testing of both the natural abutment teeth and each individual implant.

Each patient was assigned to 1 oral and maxillo-facial surgeon and 1 prosthodontist for treatment. All patients were evaluated post-restoration by a periodontist who was not involved in the surgical or prosthetic treatment of the patient. Maxillary final impressions were made, casts mounted, and maxillary denture fabrication taken through the tooth arrangement and try-in stage. A diagnostic waxup of the FPD was made and a surgical template fabricated to place the implants and occlusal screws through the central fossa of the first molar. One laboratory technician was used for all steps of the

workup and prosthesis fabrication in 37 patients, so as to standardize the study and minimize operator bias; because of scheduling conflicts, a second technician was used for 3 patients. At the initiation of the study, all treatment personnel met and discussed as a group the planned procedures. The use of a surgical guide and strict adherence to the surgical drilling sequence by all surgeons minimized deviations from the surgical protocol. The preparation of the abutment teeth was agreed upon for a specific type of finishing line and form. The laboratory technicians used the same materials and tooth forms for all prostheses.

Calibration of the Evaluator

The data evaluator performed 2 data collections on the same patient during the same visit. This was done on 7 different patients. The evaluator would see the patient and record data, leave the clinic for a minimum of 15 minutes, then return for a second data collection session. Intrarater reliability was assessed for the measures of keratinized gingiva (KG), free gingival margin (FGM), and probing depth (PD). Reliability was assessed in 2 ways. Percentage of agreement was calculated for each measure separately. All data collection locations (mesial, distal, buccal, lingual) were included for each measure. Agreement was defined as equal values and not greater than 1 point separating the values. With these criteria, agreements were KG = 100%, FGM = 99%, and PD = 98%. In addition, the raw data were used to compute a Kappa statistic for the 2 examinations of each of the measures. The Kappa values were KG = .781, FGM = .692, and PD = .613. These values represent good to excellent agreement.³² To train the evaluator to minimize differences, if a value was more than 2 measures apart, he reexamined the patient to calibrate himself on the final value. This occurred 2 times.

The evaluator was not involved in the treatment of the patient and was not told who placed or restored the patient. However, when the evaluation was performed, it was obvious which method was used. Operator bias or variability may have affected the study and thus an analysis was performed to determine if a specific clinician may have had different results than the whole study cohort (no operator bias found).

Implants

The implant system used for this study was the Omniloc Implant (formerly Calcitek; now Sulzer Dental, Carlsbad, CA). This is a hydroxyapatite-coated titanium cylinder. All implants were 10 mm in length and either 3.25 mm or 4.0 mm in diameter.

Surgical Procedure

Local anesthesia (2% xylocaine with 1:100,000 epinephrine; Astra USA, Westborough, MA) with or without conscious sedation was used. A crestal incision bisecting the keratinized tissue was made over the edentulous site, with anterior and posterior release. A full-thickness mucoperiosteal flap was raised, exposing the crestal bone. The surgical template was placed in the mouth and the implant site prepared per the manufacturer's protocol. One 10-mm implant was placed on each side. The implants were seated with gentle tapping and countersunk 1 mm. The site was irrigated and the incision closed with silk or chromic suture. After 12 weeks both implants were exposed. A 3-, 5-, or 7-mm healing abutment was placed. Two weeks later, fixed removable 2- to 5-mm gingival cuff abutments were placed into each implant, so as to maintain supragingival margins 1 mm superior to the gingival margin.

Prosthetic Procedures

Rigidly Attached FPD. For the rigidly attached FPD, the natural tooth abutment of the 3-unit FPD was restored with a telescopic crown. The coping for this telescopic crown was cemented with permanent cement and the telescopic crown was cemented with temporary cement (Fig 1). The implant abutment of the 3-unit FPD was restored by using a shouldered abutment placed into the implant body. Removal of the FPD was accomplished by removing a screw that inserted through the posterior abutment crown, and by removing the anterior telescopic crown from the coping on the natural tooth by gently tapping the prosthesis. The temporary cement (Temp Bond, Kerr, Romulus, MI), mixed 1:1 with petroleum jelly, was replaced every 6 months to ensure that there was a continuation of connection between the implant and the tooth.

Non-Rigidly Attached FPD. For the non-rigid side, a crown was placed and cemented over the natural tooth with zinc phosphate cement. This crown had a precision connector, a Beyeler attachment (Attachments International, San Mateo, CA) (Fig 2). A shouldered abutment was placed into the implant body, so that with the removal of the occlusal screw that held the FPD onto the implant, the FPD could be removed and both the tooth and the implant evaluated individually.

The Beyeler attachment was chosen after considering several criteria. It is a 2-part connector with the matrix located on the tooth crown and the matrix located on the implant-retained prosthesis. The attachment selected has parts that are standard and interchangeable. The attachment is also easy to repair. This precision attachment's components are

fabricated to precise tolerances and are predictable.³³ The predictability of each casting was known and the space between the male and female portions of each attachment was predictable. The Beyeler attachment is a slot attachment that is precise and allows removal of the prosthesis from the implant after the screw is removed; it also allows some movement of the natural tooth.

Metal occlusal surfaces were used on the mandibular restorations. In all cases, an occlusion was developed to assure maximum intercuspation in centric occlusion and a supportive relationship in eccentric movements. Thirty-three-degree acrylic resin teeth (Trubyte, Dentsply, York, PA) were used for the maxillary denture. A unilateral balanced scheme of occlusion was generated to achieve a compatible relationship, with the lingual cusp of the maxillary teeth maintaining a centric relation. Metal occlusal surfaces were polished and sandblasted. Any faceting would therefore be visible and easily seen on follow-up visits.

Data Collection

Each patient was examined at the time of FPD placement and every 6 months for 5 years. The data, after transfer to the statistician, were reviewed by the research associate to ensure accuracy. The following clinical indices were recorded with the prostheses removed.

- **Soft tissue probing depths:** The abutment teeth and implants were examined with a calibrated probe. Six sites were probed with the prosthesis removed: the direct buccal and lingual and the 4 mesial and distal line angles. These 6 measurements were averaged as well as evaluated individually.³⁴
- **Gingival Bleeding Index:** This modified index³¹ was graded as 0 = tissue color normal, no bleeding on probing; 1 = tissue color normal to slightly erythematous, no bleeding on probing; 2 = tissue color red, bleeds on probing; 3 = tissue color markedly red and edematous, bleeds on finger pressure or spontaneously.
- **Plaque and Calculus Index:** This measured the supra- and subgingival plaque or calculus accumulation on the implant and tooth and was graded as 0 = no plaque, no calculus; 1 = plaque can be scraped off but is not visible to the clinician, or supragingival calculus extending no more than 1 mm below the free gingival margin; 2 = visible plaque within the gingival crevice or on the tooth and gingival margin, or subgingival calculus extending more than 1 mm into the crevice or moderate amounts of supragingival and subgingival calculus; 4 = heavy accumulation of

plaque within the crevice or on the tooth and gingival margin, or heavy accumulation of supra- and sub-gingival calculus.

- *Presence of attached gingiva:* This was graded as present or absent on the mid-labial and mid-lingual surfaces. The width of attached gingiva was determined by measuring the width of the keratinized gingiva with a periodontal probe in millimeters, for both the tooth and the implant, and subtracting the probing depth for that location. The level of attachment was determined by measuring from standardized landmarks, which included the shoulder of the abutment on the implants and the margin of the crown or coping on the teeth, to the FGM. The attachment level on the teeth was determined by subtracting the probing depth from the "landmark to FGM" measurement. For the implants, the attachment level was determined by converting the probing depths to negative numbers, and adding the height of the abutment and the "landmark to FGM" measurement.
- *Vertical bone levels:* Custom-fabricated film holders were made after the implants had been exposed. The implants retained the film holder, providing a stable reference point for subsequent data collection recalls. At each visit the prosthesis was removed and the film holder placed over the shouldered abutment and secured with a screw to provide duplication of film placement. The bone level measurements were measured as the distance from a reference point on the implant or tooth to the crestal bone. The crestal bone level was referenced to the interface of the implant and abutment; for the teeth, the reference point was the margin of the coping or crown. These measurements from the periapical radiographs were made using the Olympus Cue-2 image analysis computer system (Olympus, New York, NY).
- Mobility testing was done with the Periotest device and the prostheses removed.³⁵⁻⁴¹

A questionnaire was developed by the study team, based on the team's clinical experience with satisfaction questionnaires,^{42,43} which asked a variety of questions related to comfort and satisfaction. The patients completed the questionnaire prior to examination by the evaluator, immediately after the restoration was placed (recall 0), and every 6 months thereafter until 5 years follow-up was reached. The frequency of responses was collated and presented as qualitative data.

Statistical Evaluation

To compare bone loss for rigidly connected abutment teeth and implants with bone loss for non-

rigidly connected abutment teeth and implants, the measurements for the vertical crestal bone level were taken, and the rigid observation was subtracted from the non-rigid observation to obtain the difference for each follow-up time period. A 1-way repeated-measures analysis of variance (ANOVA) was used to determine the statistical significance of changes in this quantity for implants and teeth separately. All analyses were performed using the standard computer programs of SAS (Cary, NC).⁴⁴ In addition, the vertical crestal bone level measurements for the rigid and non-rigid observations were subtracted from the baseline values for each record, respectively. The rigid and non-rigid values were then subtracted. A 1-way repeated-measures ANOVA was used to determine the statistical significance of changes in this quantity for implants and teeth separately. The differences from baseline values were also analyzed using 2-way repeated-measures ANOVA with a mixed model for an overall test of the hypothesis that a treatment difference exists between rigid and non-rigid implants and teeth, respectively.

A paired *t* test was used to determine whether there was a statistically significant difference in vertical bone loss for rigidly versus non-rigidly connected abutment teeth and implants at each recall visit ending at 5 years of follow-up. Paired *t* tests were also used to compare the difference from baseline values.

To compare mobility and probing depth (average of 6 measures), the rigid observation was subtracted from the non-rigid observation to obtain a difference in mobility and probing depth between the 2 for each period. A 1-way repeated-measures ANOVA was used to determine the statistical significance of changes in this quantity for teeth and implants separately. The analysis was done for rigid subtracted from non-rigid values, and done for each type of restoration versus baseline values.

Comparison of the cumulative success rate of rigidly and non-rigidly connected implants to teeth was based on criteria for success modified from Albrektsson and coworkers.¹⁶ The success criteria used included implant or tooth function, as well as less than 1.5 mm of bone loss after 18 months of loading, followed by less than 0.2 mm bone loss yearly. Unsuccessful cases were those that developed bone loss greater than that listed above for any recall time period or those cases where implants or abutment teeth were removed secondary to extensive bone loss, pain, or tooth fracture. Using these criteria, survival analyses were used to estimate the success rate of the 2 treatments. The Kaplan-Meier method was used to determine success probability for each group, for all teeth and implants, all teeth



Fig 3a Intrusion of the abutment tooth in a rigid prosthesis. Note the inferior migration of the tooth with the gold coping in place.



Fig 3b Intrusion of the non-rigid side. Note the discrepancy of the marginal ridge at the location of the Beyeler attachment.

Table 1 Patient Data

Category	No. of patients
Patients restored	40
Patients restored for less than 1 year	1
Patients restored for over 1 year	39
Patients restored for over 2 years	39
Patients restored for over 3 years	37
Patients restored for over 4 years	33
Patients restored for over 5 years	30

that had root canal therapy, and all teeth without root canal therapy. The Cox proportional hazards model, known as Cox PH regression, was used to investigate the root canal effects.⁴³

The data for each soft tissue index were summarized using descriptive statistics, means, and standard deviations. When more than 1 surface was evaluated for each tooth or implant, these values were averaged. Wilcoxon sign rank *t* tests were used to compare the soft tissue indices (rigid versus non-rigid) at each recall for implants and teeth separately.

The bone loss measurement served as the dependent variable for a stepwise multiple regression analysis. The regression was used to determine whether soft tissue changes correlated with changes in bone loss. Each clinical index—probing depths, BI, plaque and calculus, and presence of attached gingiva—was tested individually by the regression procedure.

The amount of natural tooth intrusion (Figs 3a and 3b) was measured by photographing the natural tooth abutments at a ratio of 1:1 and including a millimeter scale in the photograph. This produced a printed image 3.5 times actual size. For the precision attachment abutment, intrusion was determined by measuring with dividers the evident occlusal discrepancy of the precision attachment on the photograph. The 3.5 ratio was confirmed by the millimeter scale in the photograph, and the distance

between the divider tips was measured and divided by 3.5. For the telescoping crown abutment, the discrepancy between the margin of the FPD and a reference point on the cemented telescopic gold coping was measured on the photograph using dividers. The 3.5 ratio was again confirmed on the millimeter scale, and the distance between the divider tips was divided by 3.5. Thirty-two patients had satisfactory records with follow-up to 53 months. Two measurements were available for each patient. Descriptive statistics were used to demonstrate the extent and incidence of tooth intrusion for each method. The study's original design did not include intrusion analyses. Once the intrusion of teeth became evident, this data collection method was initiated. Because of the extended time required for recruitment, not all visits had sufficient data for analysis at each time period.

The number and type of visit were recorded for every patient encounter. For each non-scheduled patient visit, the type of visit was logged. At the end of the 5-year period of study, the total number of visits relating to pain, mechanical failures, bone loss, or other problems were recorded. The number of visits was described using Friedman and Wilcoxon sign rank parametric analyses.

RESULTS

Patients Restored

Forty patients were restored; 30 patients were followed for 5 years post-restoration (Table 1). Three patients were not evaluated for the full 5 years because of implant or tooth failure. Seven were lost to follow-up because of relocation ($n = 4$) or death ($n = 3$). Of the 10 patients lost from the study population, 1 was a man (Caucasian) and 9 were women (5 Caucasian, 4 African American). The resultant

	Average Crestal Bone Level (mm) from Reference Point (SD)										
	Recall visit										
	0	1	2	3	4	5	6	7	8	9	10
Rigid implant	0.55 (0.26)	0.60 (0.36)	0.69 (0.38)	0.70 (0.33)	0.80 (0.37)	0.83 (0.44)	0.93 (0.51)	0.92 (0.57)	0.96 (0.87)	0.85 (0.55)	0.83 (0.54)
Rigid tooth	1.61 (0.65)	1.62 (0.66)	1.67 (0.64)	1.73 (0.64)	1.79 (0.51)	1.86 (0.70)	1.86 (0.69)	2.10 (0.73)	2.00 (0.71)	2.03 (0.76)	1.99 (0.67)
Non-rigid implant	0.53 (0.23)	0.57 (0.26)	0.58 (0.28)	0.60 (0.37)	0.71 (0.42)	0.93 (1.17)	0.79 (0.36)	0.98 (0.56)	0.86 (0.65)	0.92 (0.60)	0.98 (0.83)
Non-rigid tooth	1.75 (0.66)	1.62 (0.68)	1.67 (0.72)	1.65 (0.70)	1.75 (0.74)	1.79 (0.71)	1.78 (0.75)	1.90 (0.75)	1.94 (0.76)	2.01 (0.75)	1.97 (0.76)

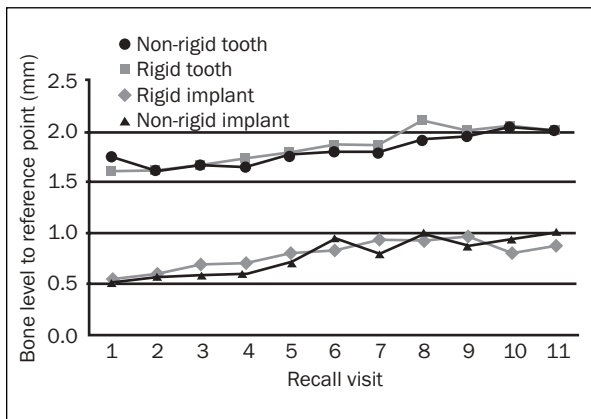


Fig 4 Average crestal bone levels from reference points on implants and teeth.

	n	Mean	SD	Probability
Implants	28	-0.21	0.92	0.24
Teeth	28	-0.003	0.87	0.16

study population after 5 years of follow-up included 8 men (5 Caucasian, 3 African American) and 22 women (12 Caucasian, 10 African American). The subject composition of this trial did not change considerably over the course of the trial.

Crestal Bone Level Changes

A power analysis for repeated measures was performed with the effect size of 0.3 (mean = 0.2 mm/SD = 0.6), alpha = .05, generic mode, numerator df = 9, and the non-centrality parameter = 0.600*N. With a sample size of 25, the power is 0.537. For a sample size of 30, the power is 0.684. For a sample size of 35 the power is 0.797. This trial had 30 patients reaching the 5-year follow-up.

Repeated Measures. Repeated-measures analysis for crestal bone levels for implants revealed no significant changes for rigid versus non-rigid over the time course of the study (F = .53; df = 10, 250; P = .86). Repeated-measures analysis for crestal bone levels for teeth revealed no significant changes for rigid versus non-rigid over the time course of the study (F = .95; df = 10, 260; P = .48) The average crestal bone levels from the reference points are listed in Table 2 and

depicted in Fig 4. Paired t tests revealed no significant differences for rigid versus non-rigid, for implants or teeth, at the 5-year recall (Table 3).

Differences from Baseline, Repeated Measures. The results of the 2-way repeated-measures analysis using a mixed model (SAS/mixed procedure) for the crestal bone levels at each recall versus baseline values (time of restoration) revealed no significant difference between treatments for implants (F = 0.04, df = 38, P = .83) and a significant difference between treatments for teeth (F = 39.10; df = 1, 38; P < .001). For both implants and teeth, the changes from baseline were significant over time (F = 46.48, P < .001 for implants and F = 57.68, P < .001 for teeth) (Fig 5). When the differences from baseline values for rigid and non-rigid were subtracted from each other and compared over time, there was no significant difference between methods for implants or teeth (1-way repeated-measures analysis for implants: F = 1.51; df = 9, 225; P = .15; for teeth: F = .76; df = 9, 243; P = .65).

The difference from baseline values for bone levels around implants for the rigid side was compared to that for the non-rigid side using paired t tests at

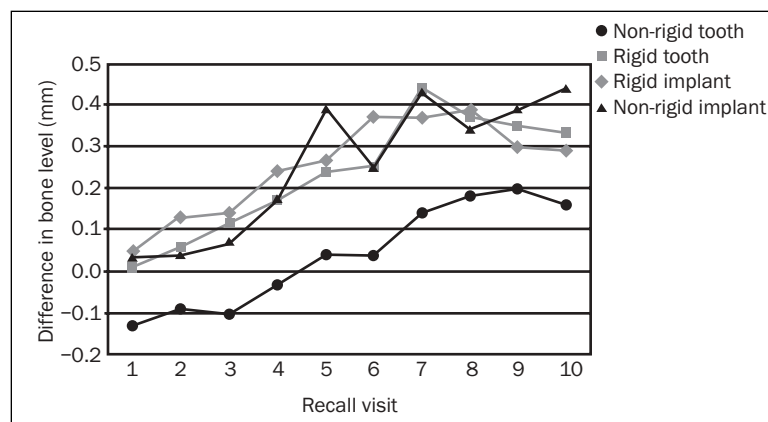


Fig 5 Mean changes in crestal bone level from baseline.

Table 4 Bone Level Changes (mm) for Implants*

Recall visit	Mean	SD	Probability	n
1	0.01	0.37	0.83	39
2	0.09	0.4	0.17	39
3	0.07	0.38	0.24	39
4	0.07	0.52	0.42	37
5	-0.12	0.99	0.45	38
6	0.07	0.53	0.42	36
7	-0.06	0.66	0.6	34
8	0.04	1.03	0.84	30
9	-0.11	0.85	0.49	30
10	-0.19	0.99	0.31	28

*Rigid subtracted from non-rigid differences at baseline.

Table 5 Bone Level Changes (mm) for Teeth*

Recall visit	Mean	SD	Probability	n
1	0.14	0.51	0.09	39
2	0.15	0.57	0.11	39
3	0.22	0.53	0.015	39
4	0.20	0.53	0.022	38
5	0.20	0.69	0.09	37
6	0.17	0.67	0.15	35
7	0.32	0.59	0.004	33
8	0.17	0.68	0.19	30
9	0.14	0.85	0.20	31
10	0.15	0.64	0.31	29

*Rigid subtracted from non-rigid differences at baseline.

each recall time (Table 4). There were no statistically significant differences between the rigid and non-rigid implants for the bone loss measure over the 5 years of follow-up in this study.

The measured bone level values for teeth, rigid versus non-rigid, were compared for each recall visit using paired *t* tests (Table 5). There were 2 statistically significant differences between the rigid and non-rigid teeth for the bone loss measure over the 5 years of follow-up in this study.

Implant and Tooth Success (Survival and Bone Loss Criteria)

In this study, the success time is the time to failure. The success time is censored if it did not fail by the end of the study (60 months) or was lost to follow-up. There are 4 groups in the study: rigid tooth, rigid implant, non-rigid tooth, and non-rigid implant. Each of the groups has 40 observations. Table 6 presents the Kaplan-Meier success probability based on modified criteria¹⁶ for each group.

Table 6 Kaplan-Meier Success Based on Modified Criteria¹⁶

Group	No. of failures	Success probability after 48 months (SE)	Mean survival time (limited to 60 months)
Rigid tooth	2	0.945 (0.038)	59.10
Rigid implant	2	0.944 (0.038)	59.17
Non-rigid tooth	3	0.915 (0.047)	58.26
Non-rigid implant	2	0.922 (0.043)	57.75
All teeth with root canal treatment	5	0.808 (0.078)	56.35
All teeth without root canal treatment	0	1.000	60.00
All teeth	5	0.932 (0.029)	58.73
All implants	4	0.934 (0.029)	58.47

The Kaplan-Meier method was used to obtain an estimate of the probability of success for each of the groups—all teeth, all teeth with root canal treatment, and all teeth without root canal treatment. Since the failure rate was low, success probabilities are high. Table 6 indicates the success probability after 48 months, since no failures occurred between 48 and 60 months. The Cox proportional hazards model was used to investigate the effects of root canal treatment.⁴³ Cox regression analysis showed that regardless of whether a tooth had had root canal therapy, the difference in success rates was not significant for either rigid or non-rigid teeth ($P > .30$). The power of the test was calculated to be 0.72.⁴⁶ This implies that root canal therapy does not affect the probability of survival for both rigid and non-rigid teeth.

Implant Removal. During the 5-year recall period, 1 implant on the rigid side was removed because of loss of integration without inflammation. This implant was not mobile at the time of restoration and failed during the third year of follow-up.

Treatment of Crestal Bone Loss Greater than 2 mm. Four implants developed bone loss greater than 2 mm during the course of this trial. Two implants on the rigid side had crestal bone loss greater than 2 mm, and 1 of these was removed. Two implants on the non-rigid side had crestal bone loss greater than 2 mm. For each of these cases, the implants were grafted with dense, particulate hydroxyapatite particles to the level of the adjacent cortical bone. As a result of this therapy, 3 of the 4 implants were maintained to reach the fifth year of the trial. One implant was removed when the graft did not remain in position; further bone loss was found. One tooth on the rigid side and 2 teeth on the non-rigid side had greater than 2 mm of crestal bone loss and were removed secondary to fractures.

Removal of Abutment Teeth. During 5 years of post-restoration follow-up, 5 abutment teeth were removed. Two teeth were removed from a patient after 3.25 and 3.5 years. One non-rigid tooth was lost in a second patient at 3.5 years after restoration. Two teeth in 1 patient were lost between 3.5 and 4 years of follow-up. All of the lost teeth had been treated with root canal therapy and fractured at the interface of the post within the tooth. Two were on the rigid side and 3 were on the non-rigid side. There was no clear relationship of tooth fracture to attachment.

Mobility. The values were subtracted from the baseline measures and the rigid side subtracted from the non-rigid side. Paired t tests were run at different recall visits. For teeth, the Periotest values were positive, correlating to the movement of the tooth

within the periodontal membrane space. The Periotest values for implants were typically negative, correlating to the ankylosis or integration of the implant to bone.

Repeated-measures analysis was used to compare these difference values over time. The average mobility, as measured using the Periotest, did not change significantly during the course of this study. Repeated-measures analysis for mobility values for rigid versus non-rigid implants revealed no significant changes over the time course of this study ($F = 0.80$; $df = 10, 120$; $P = .63$), and for teeth ($F = 1.84$; $df = 10, 130$; $P = .06$). There were no significant differences in mobility when subtracting the values from baseline: for implants, $F = 1.04$; $df = 9, 108$; $P = .41$; and for teeth, $F = 0.66$; $df = 9, 126$; $P = .75$). The average Periotest mobility values are included in Table 7.

Paired t tests revealed no statistically significant differences between the rigid and non-rigid implants or between the rigid and non-rigid teeth for the mobility measure over the 5-year follow-up in this study.

Probing Depth. Repeated-measures analysis of probing depth for rigid versus non-rigid implants revealed no significant changes over the time course of this study ($F = 1.77$; $df = 10, 250$; $P = .07$) or for teeth ($F = 1.23$; $df = 10, 260$; $P = .27$). When the probing depth values were compared to baseline, repeated-measures analysis revealed a difference over time for the rigid minus non-rigid values for implants ($F = 2.29$; $df = 9, 225$; $P = .018$) but not for teeth ($F = .49$; $df = 9, 243$; $P = .88$).

There were no statistically significant differences between the rigid and non-rigid implants or between the rigid and non-rigid teeth for the probing depth measure over the 5-year follow-up in this study.

Soft Tissue Indices. Table 8 represents the average values recorded at the final recall visit at the 5-year follow-up. Table 9 represents the 5-year recall data with values subtracted from baseline, indicating the difference between the initial and the 5-year measures. The average lingual attachment levels were not different when compared between the rigid and non-rigid groups. The average lingual probing depth did not change over the time course of this study, and there were no significant differences between the lingual probing depths when the rigid and non-rigid teeth or implants were compared. The average facial attachment levels showed no significant differences between the rigid and non-rigid groups over the time course of this study. The average facial probing depth showed no significant differences between the rigid and non-rigid groups over the course of this study. For GI, the

Table 7 Average Periotest Mobility Values (SD)

	Recall visit										
	0	1	2	3	4	5	6	7	8	9	10
Rigid implant	-3.86 (2.05)	-4.13 (1.76)	-4.09 (1.58)	-3.69 (1.96)	-4.07 (1.81)	-3.82 (1.57)	-3.72 (2.30)	-3.82 (2.11)	-3.54 (3.64)	-4.15 (1.45)	-4.24 (1.37)
Rigid tooth	2.87 (3.40)	2.05 (3.84)	1.78 (3.47)	1.77 (3.14)	1.47 (3.30)	1.85 (3.38)	2.69 (5.27)	2.53 (4.45)	2.17 (2.76)	3.00 (4.78)	2.46 (4.45)
Non-rigid implant	-4.37 (1.43)	-4.05 (1.91)	-4.10 (1.91)	-4.05 (1.64)	-3.97 (1.75)	-4.23 (1.81)	-4.00 (1.77)	-4.18 (1.54)	-3.94 (1.72)	-4.00 (2.48)	-3.96 (2.46)
Non-rigid tooth	2.46 (3.49)	2.22 (3.42)	3.33 (5.51)	2.27 (3.41)	1.97 (2.69)	3.69 (4.75)	4.38 (6.68)	3.03 (2.91)	3.03 (2.91)	2.72 (3.15)	3.43 (3.04)

Table 8 Average Soft Tissue Indices Recorded at the 5-Year Recall Visit

Variable	Rigid implant	Rigid tooth	Non-rigid implant	Non-rigid tooth
Lingual attachment level	0.21 ± 1.09	-1.34 ± 0.81	0.05 ± 1.69	-1.44 ± 0.85
Lingual probing depth	2.51 ± 0.99	2.44 ± 0.54	2.56 ± 1.27	2.64 ± 0.66
Facial attachment level	0.44 ± 1.16	-1.03 ± 0.77	0.37 ± 1.57	-1.22 ± 0.96
Facial probing depth	2.74 ± 0.87	2.46 ± 0.54	3.06 ± 1.65	2.43 ± 0.64
Gingival Index	0.97 ± 0.68	1.22 ± 0.54	1.21 ± 0.60	0.82 ± 0.50
Plaque Index	0.57 ± 0.47	0.55 ± 0.50	0.61 ± 0.51	0.58 ± 0.54
Mobility	-4.24 ± 1.37	2.46 ± 4.45	-3.96 ± 2.46	3.43 ± 3.04
Bone levels	0.84 ± 0.54	1.99 ± 0.67	0.98 ± 0.83	1.97 ± 0.76

Table 9 Soft Tissue Indices Subtracted from Baseline, Indicating Difference Between Initial and 5-Year Measures

Variable	Rigid implant	Rigid tooth	Non-rigid implant	Non-rigid tooth
Lingual attachment level	0.19 ± 1.11	0.70 ± 0.71	0.25 ± 1.06	0.46 ± 0.99
Lingual probing depth	-0.14 ± 0.92	0.20 ± 0.44	0.22 ± 1.41	0.29 ± 0.57
Facial attachment level	0.65 ± 0.98	0.72 ± 0.87	0.25 ± 1.06	0.47 ± 1.24
Facial probing depth	-0.25 ± 0.82	0.29 ± 0.57	0.30 ± 1.55	0.27 ± 0.53
Gingival Index	-0.06 ± 0.90	0.16 ± 0.58	0.27 ± 0.91	-0.02 ± 0.60
Plaque Index	0.09 ± 0.80	0.19 ± 0.72	0.18 ± 0.68	0.27 ± 0.66
Mobility	-0.11 ± 2.28	0.32 ± 4.53	0.44 ± 2.66	1.41 ± 3.38
Bone levels	0.29 ± 0.55	0.33 ± 0.50	0.44 ± 0.85	0.16 ± 0.42

rigid and non-rigid differences were compared for implants and teeth separately at each recall using Wilcoxon sign rank tests. There were no significant differences found between the rigid and non-rigid groups for the implants at any recall visit. The GI difference from baseline was significant for teeth at recall visits at 2, 2.5, 3, 3.5, 4, and 5 years post-restoration delivery. PI was compared between the rigid and non-rigid implants and teeth at each recall using Wilcoxon sign rank tests. There were no significant differences between the rigid and non-rigid groups in PI for the implants. There was a significant difference for teeth at the 6-month recall visit only.

A stepwise regression analysis used 4 dependent variables each analyzed separately. These variables were the bone levels of the rigid implant, rigid tooth, non-rigid implant, and the non-rigid tooth. The soft tissue indices compared in this stepwise regression analysis included lingual attached tissue, lingual keratinized tissue, mean lingual attachment level, mean lingual landmark to the FGM, probing depth (worst 2 of 6), attached gingiva, mean facial landmark to FGM, mean facial attachment level, facial keratinized tissue, facial attached tissue, mean GI, mean PI, and mean mobility.

Stepwise regression analyses were performed for each recall visit. Using a $P < .05$ level of significance,

Amount of intrusion	Non-rigid tooth (30 months)	Non-rigid tooth (53 months)	Rigid tooth (30 months)	Rigid tooth (53 months)
0 mm	13	11	18	18
< 0.5 mm	14	13	10	10
> 0.5 mm	5	8	4	4
Average	0.23 ± 0.3	0.28 ± 0.4	0.17 ± 0.3	0.18 ± 0.3

Reason for visit	Rigid implant	Rigid tooth	Non-rigid implant	Non-rigid tooth
Pain	5	36	10	29
Bone loss	15	0	29	4
Abutment fix	6	0	20	0
Loose screws	7	0	18	0
Other	0	1	0	0
Total	33	37	77	33

the significant findings varied and did not follow a consistent pattern with variables significant at different recall visits.

Prosthetic Complications

Broken Abutments. At 5 years of follow-up, a total of 18 abutments had fractured; 13 were on the non-rigid side and 5 on the rigid side. All fractured at the laser weld of the Omniloc abutment. This occurred in a total of 9 patients. Eventually, all of the abutments were replaced with abutments that were fabricated without the laser weld.

Intrusion of Abutment Teeth. Intrusion of the abutment teeth was determined using clinical examination, combined with magnified photographic techniques. After careful examination, it was determined that a large number of teeth intruded. The first sign of intrusion was noted as early as 6 months. The amount of intrusion was monitored to evaluate the time sequence of the intrusion and its relationship with success and failure of the restorations and teeth. The number of patients with intrusion and the average amount of intrusion are listed in Table 10.¹⁸ The percentage of patients who had measurable intrusion was 66% for the non-rigid group and 44% for the rigid group; 25% of the non-rigid teeth had greater than 0.5 mm intrusion, compared with 12.5% for the rigid group. For the 2 time periods evaluated, there was no significant increase in intrusion over time. One patient with excessive intrusion had the prostheses remade. Other patients with greater than 0.5 mm of intrusion were followed without significant changes over time in regard to bone loss or symptoms.

Time Considerations

The number of visits for each patient was tabulated for the post-restoration period. The data collection visits were not included in the calculation for extra visits. The reasons for extra visits are included in Table 11. Subjective reasons for visits, including pain, were separated from mechanical reasons (screw loosening, fractures of teeth or abutments, porcelain fracture). The number of visits was then collated and examined to determine whether one method or abutment (tooth or implant) required more extra visits (Table 11).

The reasons for return visits for implants included excessive bone loss, which required treatment (increased hygiene and/or grafting procedures) or implant removal. Fractured abutments and loose screws were also reasons for non-scheduled return visits. The non-rigid implant, with 77 nonscheduled visits to treat problems, required more attention than the rigid implant (33 visits) and both tooth sides (37 for rigid teeth, 33 for non-rigid teeth). The return visits for teeth concerned sensitivity, which was often treated with root canal therapy as indicated. One crown required recementation.

The number of extra visits was compared among the 4 groups using Friedman non-parametric ANOVA. This indicated an overall significant difference (chi-squared = 18.88, df = 3, $P < .001$) among the groups in number of extra visits. Paired comparisons using Wilcoxon sign rank test revealed that there was a significant difference between extra visits for non-rigid implants versus rigid implants ($P = .036$), and for non-rigid implants versus non-rigid

teeth ($P = .018$). None of the other paired comparisons were significant.

Patient Satisfaction

A questionnaire was given to each patient at each data collection recall visit. The questionnaire was completed prior to the evaluator's examination. Concerning comfort, at the final recall visit, 24 of 30 patients were perfectly comfortable (rated 10 on a scale of 1 to 10), and 4 of 30 rated their comfort as 9. When asked if they had pain when chewing, only 1 patient had pain. For the question, "Is the prosthesis comfortable to wear?" 29 of 30 were comfortable. For the question, "Are there problems with looseness of the prosthesis?" 29 of 30 said there were no problems. For the question, "Do you have pain in the abutment tooth?" 27 of 30 said they had no pain in the abutment tooth, and 3 said they had occasional pain in the abutment tooth. For the question, "Would you do it again?" all 30 said yes. For the question, "Do you have chronic pain that disrupts function?" all 30 said no.

DISCUSSION

Based on this study, which considered bone loss as the most important variable, there were no differences for implants between rigidly and non-rigidly attaching implants to natural teeth. Rigidly attached teeth had a significant overall difference, with more crestal bone loss than the non-rigid attached teeth. The baseline levels of crestal bone were compared as a total group, for each site, and for the differences between methods. For all analyses, both sides were comparable. The amount of crestal bone level change is within the criteria for success as suggested by Albrektsson and associates.¹⁶ Thus, it could be concluded that attaching implants to teeth, using either a rigid or non-rigid precision attachment, is a viable method. Comparison to literature using this implant system indicates favorable comparison with free-standing implants,⁴⁷ based on the crestal bone levels on the implants. The bone level changes around the teeth were also not different for either method, for any analysis performed.

However, there were differences noted for the teeth involved in this trial. Teeth that had undergone prior root canal therapy fractured more commonly than abutment teeth that had no prior root canal therapy, regardless of the method of attachment. The only teeth lost in this trial were those that had had root canal therapy with posts placed. Five of 27 such treated teeth fractured at the level of the post, resulting in removal of the tooth. Based

on the Kaplan-Meier method of success, there was no difference between groups with and without root canal therapy. The power is 72%. If the sample size were higher, with over 100 subjects, this difference may have become significant. From a clinical aspect, this finding, although not statistically significant with the analysis method chosen, is interesting.

Intrusion of the natural tooth abutment was a common finding for both methods of attachment, and in several cases it necessitated FPD removal and refabrication. The authors believe that small differences in fit or flexure of the framework resulted in orthodontic forces on the teeth and thus intrusion. The intrusion was a 1-time event, without progression over time. With the photographic technique, the incidence of intrusion was higher than otherwise reported. The number of patients who had greater than 0.5 mm of intrusion was clinically significant.

Clinicians should be aware of the possibility of tooth intrusion (both amount and percentage) when connecting natural teeth to implants with either rigid or non-rigid connections. The possibility of tooth intrusion should be considered when treatment planning. A conventionally fabricated and cemented FPD might in fact overcome the orthodontic forces associated with intrusion by the presence of an extremely retentive preparation. If the intrusive forces exceeded the retentive forces of the preparation and cement, even a small amount of intrusion could prove extremely detrimental to the tooth through the loss of a cement seal and subsequent leakage of oral fluids. Long-term consequences of tooth intrusion have not been studied in a controlled population.

One of the questions facing clinicians is the time involved with performing implant-restorative procedures. When attachments are added to the prosthesis, and the prosthesis is screw-retained, is there an increase in non-scheduled patient visits for mechanical or tissue-related reasons? When the number of visits for these patients was tabulated, and the reasons were evaluated, it was found that there were different reasons for non-scheduled visits for teeth and implants. The teeth-related reasons were for pain, which often resulted in root canal therapy, or for tooth extraction if the tooth had fractured. For the implants, there were predominantly mechanical reasons. The interesting finding that there were more visits for the non-rigid attachment method, compared to the rigid method, may be useful to clinicians when deciding on a specific treatment method. The addition of a precision attachment resulted in a more technique-sensitive procedure, which may be associated with more non-scheduled patient visits.

From the questionnaires, it is apparent that the patients were satisfied with the treatments. Concerning pain on chewing, between 10% and 20%, depending on the recall visit, had intermittent discomfort, which was associated with the teeth, not the implant sites. Less than 10% complained about looseness of the prostheses. Less than 1% had complaints of chronic pain that interfered with function. Over 99% indicated they would have the procedures performed again. Based on the patient surveys, both methods were well accepted by patients.

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