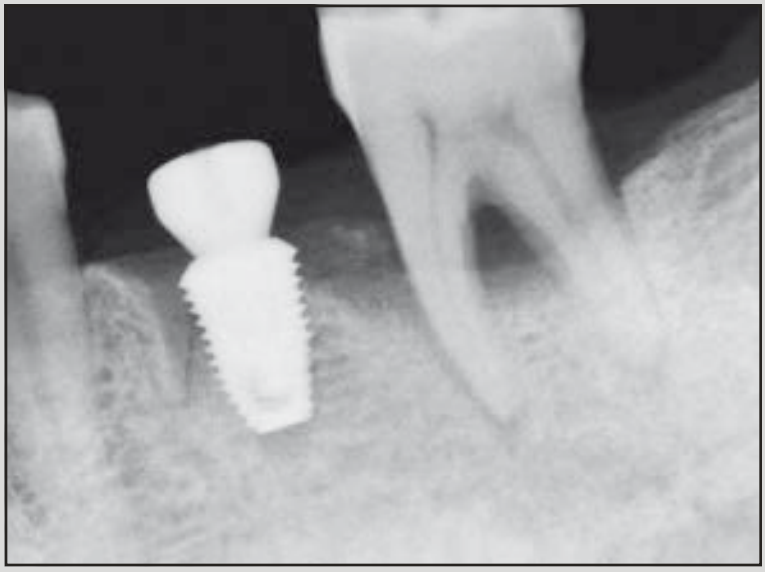

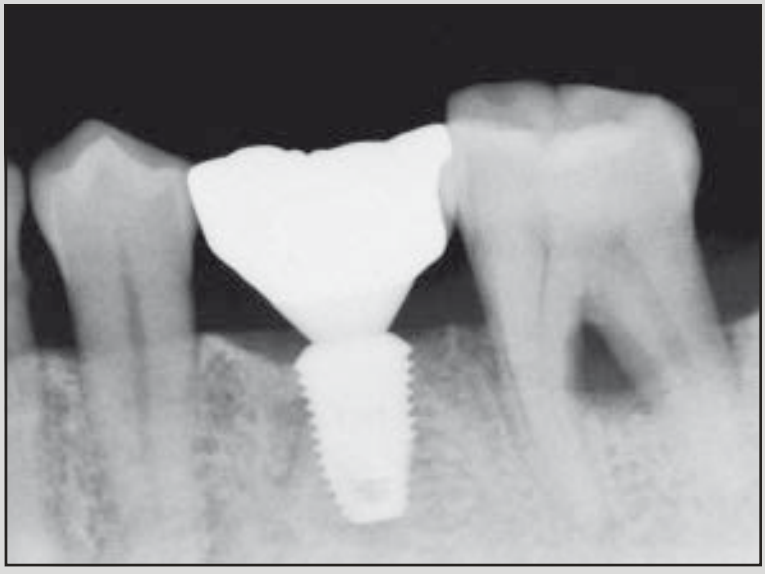

Prospective Observational Study of the Early Loading of Nanostructured Calcium Phosphate–Coated Tapered Implants in the Mandible and Maxilla

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The purpose of this study was to evaluate the prospective clinical results of early loading. Implants were inserted in 11 maxillae (group I, 23 implants) and 12 mandibles (group II, 19 implants). Six months after prosthetic loading, several factors were investigated. Significant differences between the primary and secondary stability were not observed in groups I and II. The primary stability in the mandible was 81.1 implant stability quotient (ISQ), which was significantly higher than the 73.3 ISQ value observed in the maxilla (P = .003). The survival rates were 100% in group I and 94.7% in group II for 9 and 10.4 months, respectively. The marginal bone loss was 0.07 mm in group I and –0.07 mm in group II. After the placement of nanostructured calcium phosphate–coated implants, excellent primary and second stability was obtained. (Int J Periodontics Restorative Dent 2014;34:695–703. doi: 10.11607/prd.1637)

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Satisfactory osseointegration is the most important factor in successful implant treatment. To improve osseointegration as well as early healing, diverse implant surface treatment techniques have been developed and commercialized. In attempts to accelerate early osseointegration, hydroxyapatite (HA)-coated surface implants were often used in the 1990s. However, many of these products disappeared from the market after studies reported high failure rates for these materials. After long-term assessments, some investigators have claimed that the coating of HA implants peels off or is absorbed, forming a space between the implants and bones. The implants then become dynamically unstable, disrupting the process of osseointegration. In addition, even if early osseointegration is excellent, the HA surface may be readily infected, potentially causing early failure due to the absorption (resorption) of the coating layer.[1,2] Nevertheless, numerous studies have reported that with the improvement of coating techniques, these previous problems can be resolved, and stable

Fig 1 *Nanostructured CaP-coated tapered implant.*

clinical outcomes have been observed over long periods of time.[3–6]

It has been reported that the binding force of calcium phosphate (CaP) coating is greater than that of HA and that the appropriate ratio of calcium to phosphate is readily obtained.[7] The most current method to achieve such coating is as follows: In a vacuum chamber, CaP is melted and vaporized with electronic beams, forming films with an excellent binding force after sandblasting with large grit and acid etching of the titanium implant surface on a sub-micron scale. After CaP coating, sharp sandblasted, large-grit, acid-etched peaks change to more smooth nanoscale clusters, and the CaP coating degrades slowly over a long time period. Excellent bioactivity was observed[8] after immersion in Dulbecco phosphate-buffered saline solution, even for only 1 day; CaP coating formed a typical biomimetic apatite, and many cells attached to the surface after 4 hours in cell culture.

The purpose of this study was to evaluate the clinical usefulness of early loading by placing nanostructured CaP-coated implants, examining their primary and secondary stability, and investigating the implant survival rate and marginal bone loss caused by early loading.

Method and materials

This study was conducted after obtaining approval from the Seoul National University Bundang Hospital's institutional review board (B-1008/053-002). The study participants were patients with more than one lost tooth in the posterior maxillary and/or mandibular area who satisfied the inclusion and exclusion criteria listed below. The purpose of the clinical study was explained to all patients, and surgery was performed after obtaining a signed informed consent form.

Inclusion criteria were *(1)* the loss of more than one tooth in the maxillary or mandibular posterior area; *(2)* nonsmoking status; *(3)* well-controlled chronic systemic disease, if present; *(4)* presence of opposing teeth; and *(5)* no need for augmentation beyond a simple bone graft and/or sinus elevation. Exclusion criteria were *(1)* major bony defect requiring comprehensive restorative procedures, such as ridge augmentation; *(2)* residual posterior maxillary bone absolutely insufficient in height (less than 5 mm); *(3)* implant primary stability lower than 50 ISQ.

Implant placement

According to the guidelines of the manufacturer, nanostructured CaP-coated tapered implants (Implantium Superline SLA+, Dentium) were placed (Fig 1). If small defects were present in the peri-implant area after placement, a bone graft was performed. Autogenous bone derived from human teeth (AutoBT, Korea Tooth Bank) and xenograft (BioOss, Geistlich) were used as bone graft materials; a membrane was not used.

For cases with 6 to 10 mm of residual bone in the maxillary molar area, maxillary sinus augmentation and bone grafting were performed with a crestal approach, and implants were placed simultaneously. One-stage or two-stage placement was determined at the discretion of the surgeons. The surgery was performed by one oral and maxillofacial surgeon and one periodontist. The prosthetic treatment was started after 3 months in the maxilla and after 6 weeks in the mandible. Prosthetic treatments were performed by a single prosthodontist.

Categories for observation and clinical tests

The implant stability quotient (ISQ) was measured immediately after implant placement and after the second surgery (or at the time of obtaining the first impression) by the application of the Osstell Mentor device (Integration Diagnostics). The ISQ was measured once on both the buccolingual and mesiodistal sides, and the average value was obtained. Postsurgical complications, implant survival rate, and the peri-implant marginal bone loss 6 months after implant loading were evaluated.

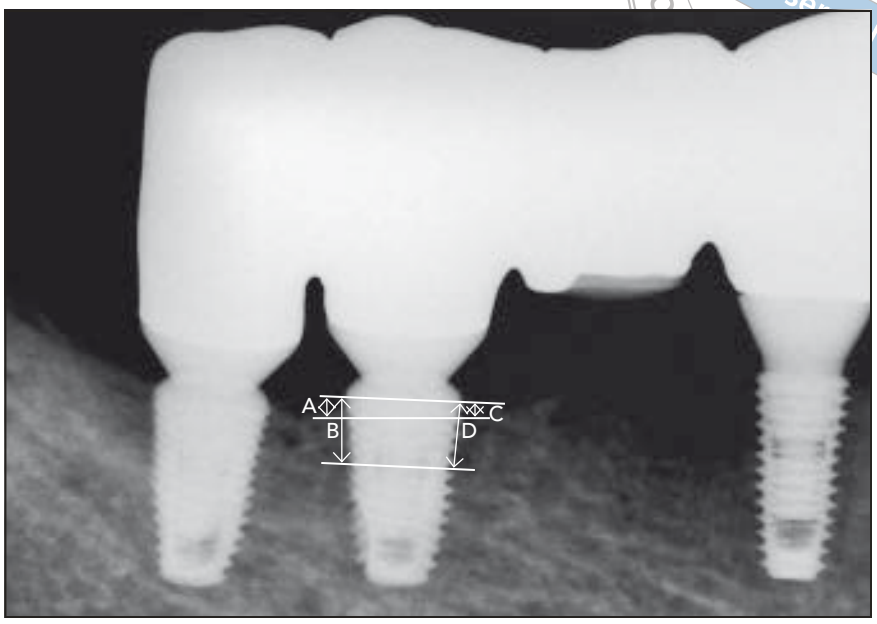

Fig 2 *Radiographic measurement of marginal bone loss. Marginal bone level was recorded on the (A) distobuccal, (B) distolingual, (C) mesiobuccal, and (D) mesiolingual aspects of the implant. Marginal bone loss = (A + B + C + D) / 4.*

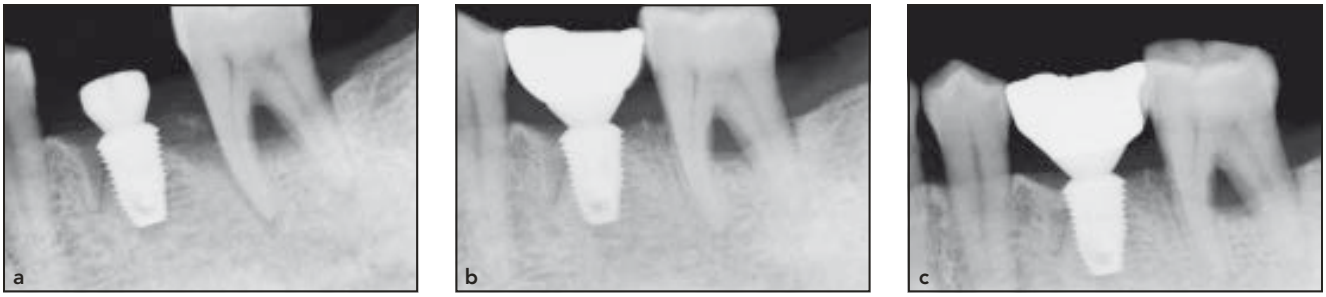

Fig 3 *An implant with a length of 8 mm and a diameter of 5 mm was placed using a flapless drilling technique immediately after extraction of a mandibular left second premolar from a 51-year-old male patient. AutoBT powder was placed in the area surrounding the implant, and a healing abutment was connected.* (a) *Periapical radiograph after surgery.* (b) *Periapical radiograph after placement of the definitive prosthesis.* (c) *Periapical radiograph at 6 months after placement of the definitive prosthesis.*

Marginal bone loss measurement

Crestal bone level was measured on digital periapical radiographs taken with a paralleling cone technique (Sirona, Heliodent) immediately after the implant placement and definitive prosthetic delivery and was compared with the crestal bone level measured on the radiographs taken 6 months after prosthetic loading. The prosthetic treatment was started approximately 12 weeks after implant placement in the maxilla and approximately 6 weeks after placement in the mandible. Marginal bone loss was defined as the average radiographic bone level changes on the mesial and distal sides of the implants. It was measured as the vertical distance between the implant shoulder and the first bone-implant contact area and was calculated by enlargement ratio. For the radiographic measurements, the IMPAX system (Agfa-Gevaert) software program was used (Figs 2 and 3).

Statistical analysis

Variables pertinent to the implant placement area, length, and diameter were organized by technical statistics. For the evaluation of the differences in primary and secondary stability values, a paired *t* test was applied. In addition, the differences in the primary and secondary stability of the maxilla and the mandible were analyzed separately by independent *t* test. The volume of the marginal bone loss

Table 1 Site distribution

Site	Number
Maxilla (group I; n = 23)	
Molar	14
Premolar	9
Mandible (group II; n = 19)	
Molar	10
Premolar	9
Total	42

Table 2 Implant diameter and length

Measurement (mm)	Implants (n)
Diameter	
4	14
4.5	5
5	23
Length	
8	7
10	35

according to prosthesis type and bone graft was analyzed with the Mann-Whitney *U* test. For statistical analysis, the PASW Statistics 18 for Windows (SPSS) was used, and the significance level was set at $P < .05$.

Results

From November 2010 to June 2011, the study included 11 maxillary cases (group I, 23 implants) and 12 mandibular cases (group II, 19 implants). They received implants and completed prosthetic treatment (Table 1). The mean age of group I was 61.5 years, with six male patients and five female patients. The mean age of group II was 49.7 years, with four male patients and eight female patients. In group I, two patients had cardiovascular diseases and diabetes, which were well controlled. All implants were placed in the maxillary and mandibular premolar or molar areas. In most cases, implants 10 mm in length and 5 mm in diameter were used (Table 2).

In group I, the mean primary stability of implants was 73.3 ISQ (range: 53 to 90 ISQ). A total of 14 nonsubmerged-type and 9 submerged-type implants were placed. For 12 implants, an additional simple bone graft was performed. For two implants, sinus elevation with a crestal approach was performed. The healing period from the time of implant placement to the second surgery (or the time of the first impression) was 11.8 to 13.4 weeks (12.5 weeks, on average). The secondary stability was 64 to 84 ISQ, with a mean ISQ value of 76.07. Significant differences in the primary stability and secondary stability were not observed (Table 3). Among the final prostheses, 15 implants were restored with splinted fixed prostheses, and eight implants were restored with single crowns. After implant placement, special postsurgical complications were not observed, and none of the implants failed. The follow-up observation period after the placement of the definitive prosthesis was, on average, 9 months (range: 6 to 14 months), with a 100% survival rate.

In group II, the mean primary stability of the implants was 81.05 ISQ (range: 59 to 88 ISQ). A total of 16 nonsubmerged-type implants and 3 submerged-type implants were placed. For 11 implants, an additional simple bone graft was performed in the peri-implant area. The healing period from the time of implant placement to the second surgery (or time of the first impression) was 5.5 to 6.4 weeks (mean: 6.0 weeks). The secondary stability was 61.5 to 88.0 ISQ, with a mean value of 79.69 ISQ. Significant differences in the primary stability and secondary stability were not observed (see Table 3). Among the final prostheses, 10 implants were restored with a splinted fixed prosthesis, and 9 implants were restored with single crowns. After implant placement, special postsurgical complications were not observed. However, in a 51-year-old male patient, a single submerged-type implant in the right mandibular second premolar area, placed simultaneously with a bone graft, developed mobility 2 weeks after implant loading, resulting in its removal. Of 19 implants, only this one implant failed, resulting in an overall survival rate of 94.7%. The follow-up period after the placement of the definitive prosthesis was, on average, 10.4 months (range: 6 to 13.5 months).

Implant stabilities were compared in the maxilla and the mandible. The primary stability in the mandible was 81.1 ISQ, which was

significantly higher than the 73.3 ISQ value observed in the maxilla (P = .003). However, secondary stability in the maxilla and the mandible did not show significant differences (Table 4).

Moreover, implant stabilities were compared in the sites with bone grafts and without bone grafts. The primary stability in the bone graft sites was 76.08 ISQ; it was 77.88 ISQ in the sites without bone grafts. There were no significant differences. The secondary stability in the bone graft sites and sites without bone graft also did not show significant differences (Table 5).

Compared with the bone level at implant placement, at 6 months after implant loading, the marginal bone loss of group I was, on average, 0.07 mm, and that of group II was –0.07 mm. One implant (group II) exhibited bone loss of more than 1 mm. This was an implant placed in the mandibular first molar area of a 56-year-old male patient. It received a splinted fixed prosthesis connected to the adjacent implants. The mean marginal bone losses according to the type of prosthesis were as follows: in maxillary single implants, 0.04 mm; in maxillary splinted fixed prostheses, 0.08 mm; in mandibular single implants, –0.27 mm; and in mandibular splinted fixed prostheses, 0.09 mm. Significant differences in marginal bone loss in each arch according to the type of prosthesis were not observed (Table 6). The marginal bone loss according to the use of bone graft was also compared, and no significant difference was observed (Table 7).

Table 3 Differences between primary and secondary stability (ISQ; mean ± SD)

Area	Primary stability	Secondary stability	*t*	*P* value
Maxilla (n = 23)	73.30 ± 8.80	76.07 ± 5.20	–1.480	.15
Mandible (n = 19)	81.05 ± 6.44	79.69 ± 6.34	0.461	.65

Table 4 Comparison of implant stability (ISQ; mean ± SD) between maxilla and mandible

Stability	Maxilla (n = 23)	Mandible (n = 19)	*t*	*P* value
Primary	73.30 ± 8.80	81.05 ± 6.44	–3.194	.003*
Secondary	76.07 ± 5.20	79.69 ± 6.34	–1.906	.07

*Statistically significant at $P < .05$.

Table 5 Comparison of implant stability (ISQ; mean ± SD) between sites with and without bone grafts

Stability	Bone graft (n = 25)	No bone graft (n = 17)	*t*	*P* value
Primary	76.08 ± 8.14	77.88 ± 9.52	–0.657	.52
Secondary	76.74 ± 5.76	78.81 ± 6.12	–1.057	.30

Table 6 Marginal bone loss according to the type of prosthesis

Area	Type of prosthesis	Marginal bone loss (mm; mean ± SD)	*P* value
Maxilla	Single (n = 8)	0.04 ± 0.11	.47
	Splinted fixed (n = 15)	0.08 ± 0.13	
Mandible	Single (n = 9)	–0.27 ± 0.68	.20
	Splinted fixed (n = 10)	0.09 ± 0.81	

Table 7 Marginal bone loss according to bone graft

Area	Bone graft	Marginal bone loss (mm; mean ± SD)	*P* value
Maxilla	Bone graft (n = 14)	0.09 ± 0.15	.73
	No bone graft (n = 9)	0.05 ± 0.11	
Mandible	Bone graft (n = 11)	–0.27 ± 0.48	.41
	No bone graft (n = 8)	0.19 ± 0.78	

Discussion

Implant surface treatment is a highly important factor, exerting profound effects on early loading. In efforts to accelerate the rate of osseointegration by fabricating a rough implant surface and consequently increasing the surface area, various methods have been developed and used in clinics, such as blasting and acid etching; resorbable blast media (RBM); sandblasting, large grit, acid etching; and oxidation. These improvements in implant surface treatment and design noticeably shorten the healing period, challenging Brånemark's concept.[9,10] It is very important to obtain excellent stability at the time of implant placement and to maintain the absence of micromotion during secondary bone healing.[11] In the past, early implant loading was considered to impede the osseointegration of implants. Therefore, the delayed loading procedure, which allows for a 3- to 6-month waiting period after implant placement, was frequently applied.[12,13] However, several recent studies on the stability of immediately or early loaded implants have reported success rates as high as 88% to 100%, as well as shortened postsurgical treatment periods.[14–19] At the third International Team for Implantology (ITI) consensus conference, immediate loading was defined as the loading that occurs during the occlusion of opposite teeth when a prosthesis is placed within 48 hours after implant placement. Early loading is defined as the loading that occurs when a prosthesis starts to function during a period that ranges from 48 hours to within 3 months after implant placement.[20] However, presently, due to these improvements in implant surface treatment procedures, the loading period tends to be shorter, and early loading tends to occur within 2 months in the mandible and within 4 months in the maxilla.

Numerous studies have revealed that the topography of the implant surface plays an important role in bone reactions. In early loading cases, implant surface treatment is a particularly important factor for the success of implants. The clinical outcomes of RBM surfaces have been reported in several studies. In 2003, Mazor and Cohen reported that in a single-tooth implant followed for 48 months, the marginal bone loss was observed to be less than 1 mm, and the success rate was 100%.[21] When dual acid-etched and sandblasted, large-grit, acid-etched surfaces were compared with machined surfaces, greater osseointegration was observed in the dual acid-etched and sandblasted, large-grit, acid-etched surfaces.[22,23] In the past, HA-coated implants were commercialized and used in clinics. However, numerous negative outcomes were reported, which were attributed to the shedding of the coating layer, the increased risk of infection, the coating crystallinity rate, and problems in the Ca/P ratio.[1,2] However, many studies have reported that with the improvement of coating techniques, most of these past problems have been solved, and long-term, stable clinical outcomes have been shown.[3–6]

To remedy these problems with HA coating, nano-CaP coating techniques were developed, introducing many advantages. It has been reported that the nano-CaP surface accelerates early peri-implant bone formation and osseoconduction, and it also accelerates the bone healing of poor-quality bone as a result of enhanced platelet activation.[24–30] Artzi et al[31] performed a clinical and histomorphometric study of implants with dual acid-etched and nano-CaP surfaces. Except for a significant increase in the bone-implant contact around nano-CaP implants over time, both exhibited similar clinical and histologic findings.

In addition to the application of surface treatments, the primary stability must be excellent to facilitate successful early loading. When primary stability is poor, if early loading is performed, the risk for failure may increase.[32] Numerous studies have investigated the success of early loading in partially edentulous cases. Schliephake et al[33] reported excellent preliminary results in implants with titanium oxide–blasted, fluoride-modified surfaces in the posterior mandible, in which early loading was performed after 6 weeks. Kim et al[34] reported that in cases in which the residual bone is greater than 3 mm and primary implant stability is obtained, early loading is possible within 4 months of the sinus bone graft and simultaneous implant placement. In this study, RBM-surface implants were used. Markovic et al[35] have reported that in cases in which resonance frequency analysis (RFA) values higher than 65 ISQ were

obtained using osteotome sinus floor elevation techniques, sandblasted, large-grit, acid-etched surface implants (SLActive, Straumann) placed in the maxillary molar area were loaded after 6 weeks, and a 100% survival rate was observed after 2 years. In a retrospective study, Nelson et al[36] reported that with sandblasted, large-grit, acid-etched surface implants loaded after 12 weeks in the maxilla and after 6 weeks in the mandible, the overall success rate was 99.4%. Cochran et al performed a 5-year prospective multicenter study of early-loaded titanium implants with a sandblasted and acid-etched surface.[37] The 5-year cumulative survival and success rates were 99.1% and 98.8%, respectively. In addition, implants with sandblasted, large-grit, acid-etched surfaces placed in type 3 bone were loaded after 6 weeks, and those in type 4 bone were loaded after 12 weeks.

Sennerby and Meredith noted that if the RFA value is higher than 60 to 65 ISQ, immediate or early loading may be performed, and in cases with RFA values lower than 40 ISQ, the risk for failure is very high.[38] In the present study, cases whose primary stability immediately after implant placement was lower than 50 ISQ were excluded. In addition, the healing time was approximately 3 months in the maxilla and 6 weeks in the mandible in this study. In other words, early loading was defined according to the criteria recommended at the third ITI consensus conference, held in 2003 in Gstaad, Switzerland, and modified by Cochran et al in 2004.[39]

In the tapered implants used in the present study, sandblasted, large-grit, acid-etched titanium surfaces were coated with a thin CaP film, without altering the topography, by the application of an electron-beam evaporation process. Immediately after implant placement, primary stability in the maxilla was, on average, 73.3 ISQ, and primary stability in the mandible was, on average, 81.05 ISQ; both are very high values. The average healing period in the mandible was 6 weeks and that in the maxilla was 12.5 weeks. In the maxilla, 100% survival rate was shown 6 months after implant loading. In the mandible, a 94.7% survival rate was shown. The failed case involved a 51-year-old male patient with an implant and single prosthesis placed in the mandibular second premolar area, in which mobility developed 2 weeks after implant loading. Specific postsurgical complications did not develop. However, the stability value decreased substantially from a primary stability of 85 ISQ to a secondary stability of 72 ISQ.

The secondary stability in the present study was slightly higher in the maxilla but slightly decreased in the mandible. However, there was no statistically significant difference. These data suggest that the excellent primary stability after implant placement was maintained during the healing period. RFA using Osstell Mentor could have been affected by many variables in the present study. The fixation of Osstell SmartPegs (Integration Diagnostics) using 4 to 5 Ncm of finger force was not constant. Also, there were issues that could have been affected by the diameter and length of the implant and the bone graft.

For all implants placed in the maxilla and the mandible, except one case, the marginal bone was maintained in a very stable condition 6 months after implant loading. When comparing the different prosthesis types, the marginal bone loss of single-implant prostheses and splinted fixed prostheses did not show significant differences. A simple bone graft was mainly applied to the small bony dehiscence after the implant placement, and a membrane was not used. However, the bone graft materials may have had a negative impact on the measurement accuracy of marginal bone loss adjacent to the implant. Due to the appropriate height of residual bone and sufficient initial fixation, sinus elevation did not have a significant impact on the marginal bone loss and implant prognosis.

This study was performed as a prospective clinical human study under institutional review board approval. Therefore, a possible limitation of this study is the insufficient number of patients for research. Particularly, it was difficult to obtain statistically significant results for the radiographic measurement of marginal bone loss due to the small sample size. In addition, even though the bone height seemed to slightly increase at 6 months after the final prosthesis in the mandible, these results were likely affected by the bone graft.

Conclusions

Excellent primary and secondary stability of nanostructured CaP-coated implants was obtained. It was determined that implant loading could be performed after average healing periods of 3 months in the maxilla and 6 weeks in the mandible.

Acknowledgments

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