



저작자표시-비영리-변경금지 2.0 대한민국

이용자는 아래의 조건을 따르는 경우에 한하여 자유롭게

- 이 저작물을 복제, 배포, 전송, 전시, 공연 및 방송할 수 있습니다.

다음과 같은 조건을 따라야 합니다:



저작자표시. 귀하는 원저작자를 표시하여야 합니다.



비영리. 귀하는 이 저작물을 영리 목적으로 이용할 수 없습니다.



변경금지. 귀하는 이 저작물을 개작, 변형 또는 가공할 수 없습니다.

- 귀하는, 이 저작물의 재이용이나 배포의 경우, 이 저작물에 적용된 이용허락조건을 명확하게 나타내어야 합니다.
- 저작권자로부터 별도의 허가를 받으면 이러한 조건들은 적용되지 않습니다.

저작권법에 따른 이용자의 권리는 위의 내용에 의하여 영향을 받지 않습니다.

이것은 [이용허락규약\(Legal Code\)](#)을 이해하기 쉽게 요약한 것입니다.

[Disclaimer](#)

치의학박사 학위논문

Comparison of short and long
single implants placed in the
posterior mandible using a
complete digital workflow : a
randomized controlled clinical trial

하악 단일 구치 상실부에 디지털 방식으로 수복한
짧은 임플란트와 긴 임플란트에서의
무작위 대조 임상 연구

2019년 2월

서울대학교 대학원

치 의 학 과 치 과 보 철 학 전 공

백 연 화

Abstract

Comparison of short and long single implants placed in the posterior mandible using a complete digital workflow : a randomized controlled clinical trial

Yeon-Wha Baek

Department of Prosthodontics

The Graduate School

Seoul National University

Objectives: The purpose of this randomized clinical trial is to evaluate immediately loaded single implants with varying lengths placed in the posterior mandible using a fully digital pathway and to compare clinical and radiological outcomes of short and long implants.

Materials and methods: 52 patients with a single tooth missing in the posterior molar region of the mandible were randomly assigned to the control and experimental groups. We used implants of CMI IS-III active® (Neobiotech, Seoul, Korea), 5.0 mm diameter and 10 mm length implants for the control group and 5.5 mm diameter and 6.6,

7.3 or 8.5 mm length implants for the experimental group. Each implant was inserted and immediately loaded using the digitally pre-fabricated surgical template and provisional restoration. The CAD-CAM monolithic zirconia crown was delivered at 3 months after surgery as a definitive restoration. The ISQ values, periapical radiographs and peri-implant soft tissue parameters were evaluated at 1, 3, 4, 8, 12, 24, 36 and 48 weeks after surgery.

Results: 19 long implants and 27 short implants were finally included for the statistical analysis. Successful results in terms of ISQ value, marginal bone loss and peri-implant soft tissue parameters were achieved with both groups. There was no significant difference between the groups in terms of ISQ value (except at 3 weeks after surgery), marginal bone loss, and peri-implant soft tissue parameters during observation period ($p > 0.05$). Both groups exhibited no stability dip during the early phase of healing.

Conclusions: Both long and short implants supporting single crown in the mandible showed successful outcomes in terms of stability and marginal bone loss during 48 week follow up period. Within the limits of the short term follow up, immediate loading of short single implants appeared to be a predictable treatment modality in mandible with reduced bone height when primary stability can be achieved.

Keywords : short implant, immediate loading, digital workflow, primary stability, marginal bone loss

Student Number : 2010-31196

Table of Contents

1. Introduction	1
2. Materials and methods	4
3. Results	18
4. Discussion	28
5. Conclusions	38
References	39
Abstract in Korean	53

1. Introduction

Due to advancements in 3-dimensional (3D) imaging and computer-aided design/computer-aided manufacturing (CAD/CAM) technology, clinicians can not only obtain required diagnostic information in a single visit, but also complete the entire process from implant surgical template to the definitive prosthesis installation with a fully digital, model-free pathway (Joda et al. 2014). A virtual model of the patient is easily created by merging DICOM files obtained from CBCT imaging and standard tessellation language (STL) files obtained from intraoral scanning via the virtual implant planning software (Joda et al. 2013). Conventional surgical templates fabricated on the diagnostic cast can direct the bone entry point and angulations of the drill, but they neither reference the underlying anatomical structures nor provide exact 3D guidance (Widmann et al. 2006). On the other hand, stereolithographic surgical guides utilizing computed tomography and digital virtual model, can provide optimal 3D implant positioning with respect to both anatomical and prosthetic parameters. Moreover, the associated computer guided surgery offers patients the benefits of minimally invasive implant placement without flap elevation (flapless surgery). This procedure also provides multiple advantages, including decreased postoperative pain and trauma, short recovery time, reduced intraoperative bleeding, and further preserved soft

and hard tissue (Brodala 2009, Sicilia et al. 2012). Furthermore, the virtual implant planning and the CAD/ CAM implant-supported, interim restorations can be designed and fabricated digitally according to the planned implant placements on the same program (Arunyanak et al. 2016).

In the posterior mandible, the bone height is limited by the inferior alveolar nerve as well as physiologic bone atrophy after tooth extraction. Numerous techniques, such as guided bone regeneration (GBR), block bone grafts, distraction osteogenesis, and transposition of the inferior alveolar nerve, have been used to increase residual ridge dimensions, where significant horizontal and vertical bone loss has occurred (Neldam et al. 2012, Tonetti et al. 2008). Although bone augmentation techniques are proven to be predictable and successful (Urban et al. 2009), patients may not accept such treatments fearing donor site morbidity, invasive operation, additional cost and longer treatment time (Felice et al. 2011, Scarano et al. 2015). In these cases, short implants can be considered an effective alternative treatment option in reduced bone height to avoid invasive bone augmentation procedures.

A number of early articles showed lower survival rates for short implants than those for standard length implants (Bahat 2000, Chan et al. 1998, Naert et al. 2002). However, with the technological improvements in implant designs, surface treatments, and surgical techniques, recent studies have demonstrated that implant length

did not appear to significantly influence on the survival rate (Kotsovilis et al. 2009, Mangano et al. 2014, Rossi et al. 2016). Despite positive results of short implants studies, some clinicians still have doubts about them, because of insufficient bone-to-implant contact area and unfavorable crown-to-implant ratio.

With an emerging demand for reduced implant treatment time and advances in implant surface, immediate and early loading protocols have gained predictability among the recent studies as well as clinicians (Cochran et al. 2004, Esposito et al. 2013). Generally, immediately loaded single implants are considered to be in greater risk of failure than full arch restorations, because occlusal forces may impact directly on the implant without cross arch stabilization (Sanz-Sanchez et al. 2015). But some authors have reported immediately and conventionally loaded single implant crowns to exhibit equal implant survival and marginal bone loss when implants are inserted with a torque ≥ 20 to 45 Ncm or an implant stability quotient (ISQ) ≥ 60 to 65 (Benic et al. 2014).

The purpose of this randomized clinical trial is to evaluate immediately loaded single implants with varying lengths in the posterior mandible using a fully digital, model-free prosthetic-driven implant planning pathway, and to compare clinical and radiological outcomes of short and long implants during 48 weeks of observation period.

2. Materials and methods

2.1 Clinical study design

CMI IS-III active® (Neobiotech Co., Seoul, Korea) implant system, which features internal connection type and SLA (Sandblasted with Large grit and Acid etched) surface, is used in this study. Figure 1 shows the characteristics of the implants used in this study. The control implants were 5.0 mm in diameter and 10 mm in length, while the experimental implants were 5.5 mm in diameter and 6.6, 7.3 or 8.5 mm in length. All procedures were performed according to the Declaration of Helsinki on experimentation involving human subjects (Association 2013). The study protocol was reviewed and approved by the Institutional Review Board of Seoul National University Dental Hospital (IRB No. CDE16004) and reported according to the CONSORT (Consolidated Standards of Reporting Trials) (Schulz et al. 2010). The participants were informed about the nature of the study and signed the informed consent.

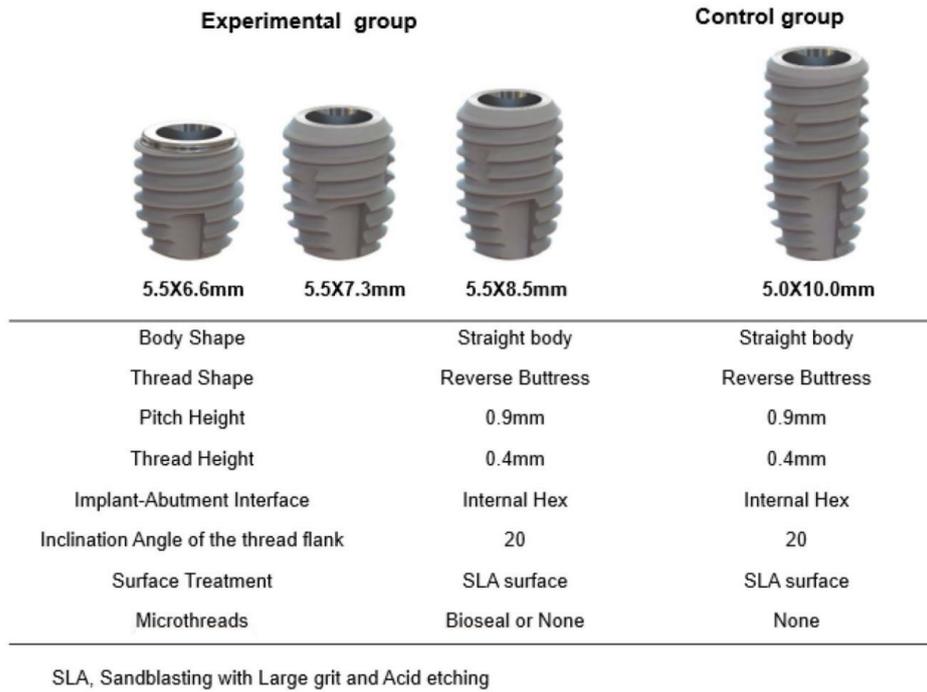


Figure 1. Characteristics of CMI IS-III active® implants used in the experimental and control groups

2.2 Study population and entry criteria

The required sample size was estimated based on the non-inferiority test using Chi-squared formulas;

$$N = \frac{\{ Z_{\alpha} [(1 + \lambda)P^{\circ}(1 - P^{\circ})]^{0.5} + Z_{\beta} [\lambda P_c(1 - P_c) + P_t(1 - P_t)]^{0.5} \}^2}{\lambda (P_c - P_t - d)}$$

$$\cong 18.133 = 19 \text{ subject.}$$

where $Z_{\alpha} = 5 \%$, $Z_{\beta} = 20 \%$, $\lambda = 1$, $P^{\circ} = P_t = 0.968$, $P_c = 0.971$, $d = 0.145$. A dropout rate of 30% was assumed. Since each subject received 1 implant, the number of participants required for each group was approximately 26.

A total of 108 potential participants were recruited via a subway car advertising and 56 of a total 108 screened candidates were excluded by the entry criteria.

The inclusion criteria were (1) 18 years of age or older, (2) single tooth missing in the posterior molar regions of the mandible at least 3 months ago, (3) ability of patient to undergo surgical and restorative procedures, (4) sufficient bone volume in the site to allow implant placement without the need for bone augmentation, (5) the presence of the intact occlusal plane opposed with the edentulous surgical site and (6) a lack of TMD or any other occlusal disorders. The exclusion criteria were (1) general contraindications to implant treatment (2) psychiatric conditions, (3) advanced periodontal diseases, (4) bone quality D4, (5) parafunctional habits and (7) a lack of interocclusal space.

2.3 Pre-surgery preparation

Figure 2 illustrates the flow diagram of this clinical study. Patients were randomly assigned to one of the groups before surgery. All patients underwent CBCT scan (CS9300®; Carestream Health, Rochester, NY) and intraoral scan (Trios3®; 3Shape, Copenhagen, Denmark) for virtual surgical planning and the assessment of the bone dimension around the implant site. The two scans were matched and the surgical templates were designed using the Implant Studio™ (3Shape, Copenhagen, Denmark) (Figure 3). According to this virtual planning, the surgical templates were produced by stereolithography (Objet 30®; Stratasys Ltd, Minnesota, USA). At the aimed implant positions, titanium guiding sleeves were inserted. The height of the guiding sleeves was 4 mm; the distance from the lower margin of the sleeve and the coronal end of the implant was 5.0 mm (Figure 4). 3D design of both customized titanium abutment and temporary prostheses was performed using the Dental Designer™ (3Shape, Copenhagen, Denmark) and fabricated by means of a CAD/CAM system. In order to use the customized titanium abutment as a scan body for digital impression, the surface of the abutment was airborne particle-abraded with 50 µm aluminum oxide (0.4 MPa, 10 mm in distance for 10 seconds).

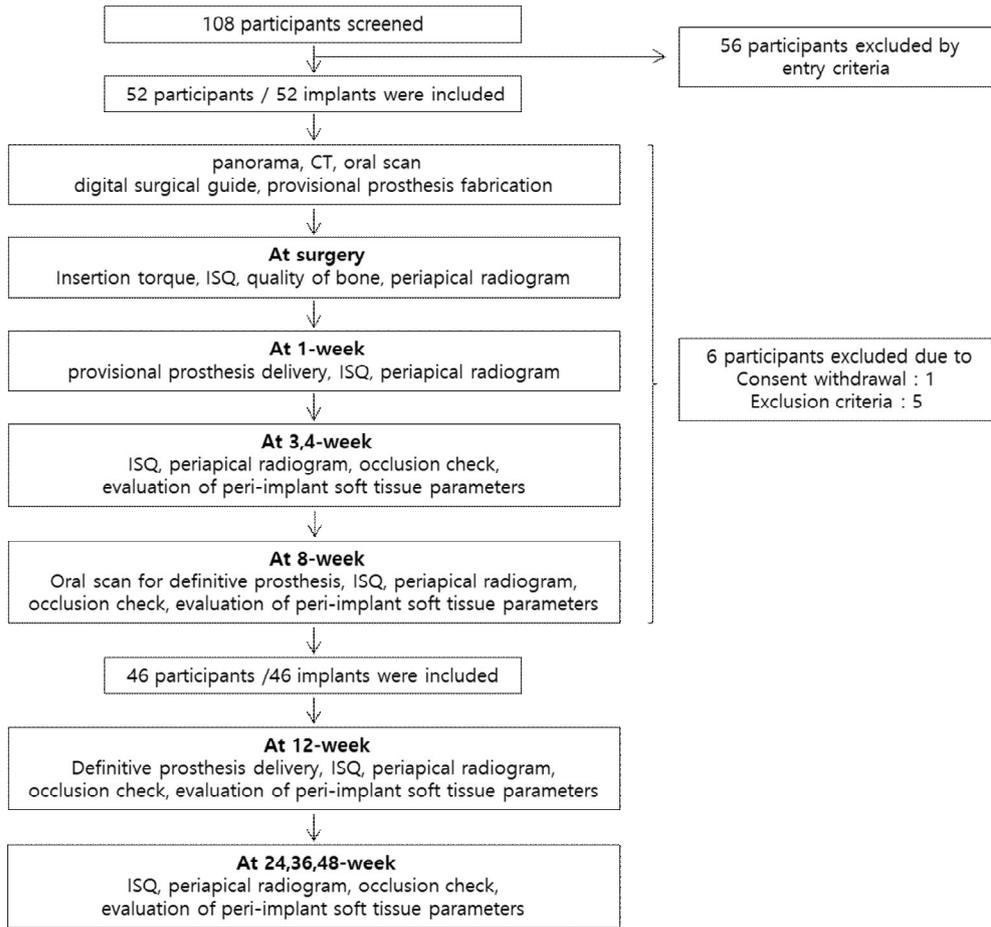


Figure 2. Flow-chart depicting visits, timeline, evaluation items and included patients.

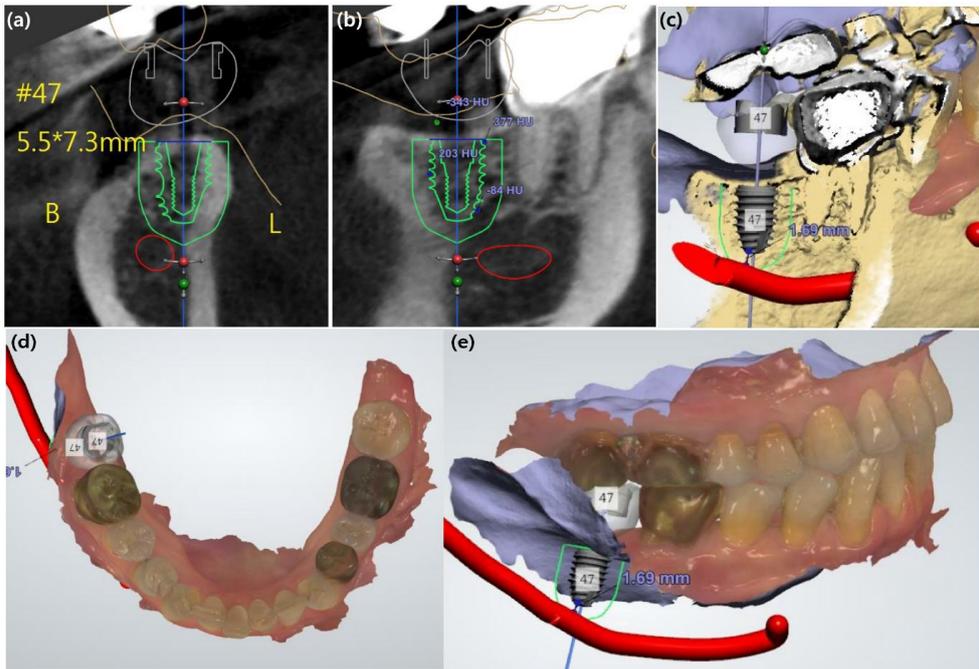


Figure 3. 3D digital implant planning with software, Implant studio™: (a) frontal view, (b) axial view, (c)-(e) images of superpositioned CT and oral scans, (c),(e) axial view with bite registration, (d) occlusal view

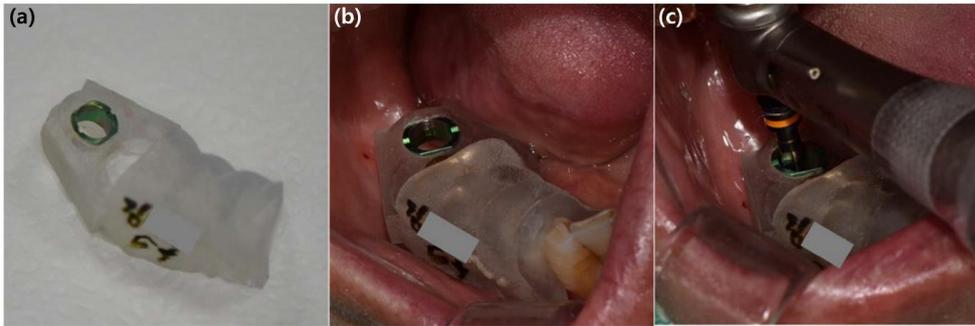


Figure 4. Surgical template produced by 3D printer, Objet 30®; 4mm height of the Ti guiding sleeve, 5mm distance from the lower margin of the sleeve and the coronal end of the implant : (a) surgical template, (b) surgical template placed at the surgical site, (c) implant placement using surgical template

2.4 Implant placement surgery and evaluation of implant stability

Antimicrobial prophylaxis was administered with 500 mg amoxicillin twice daily for 3-7 days starting 1 hour prior to surgery. For each patient, a single implant was placed in the mandibular molar region under local anesthesia, guided by pre-fabricated surgical template according to the manufacturer's protocol (NeoGuide® procedure). The implant bed was prepared in a minimally invasive procedure (flapless) using surgical template. The bone quality of the surgical sites was identified as D1, D2 or D3 based on Misch classification (Misch 1993) during the drilling sequence. During initial drilling using a straight drill with a diameter of 2.2 mm, the drilling depth was divided into three parts to indicate bone quality depending on the depth. For example, D113 indicates that the bone density is D1 at upper 1/3 part, D1 at middle 1/3 part and D3 at lower 1/3 part.

The peak insertion torque value was recorded as the maximum torque value (Ncm) reached at the end of the insertion of the implant. Primary stability was assessed by measuring implant stability quotient (ISQ) as an outcome variable. The ISQ value was recorded using the Osstell™ Mentor® (Integration Diagnostics AB, Göteborg, Sweden).

The target values for the peak insertion torque and ISQ were 35-45

Ncm and greater than 65 respectively. A healing abutment was installed and the periapical radiograph was taken.

2.5 Post-surgery care and follow-up procedures

Adequate oral hygiene and soft diet was recommended. The patients were instructed to use 0.1% chlorhexidine mouthwash and if necessary, analgesics for pain control. The patients were scheduled to follow up at 1, 3, 4, 8, 12, 24, 36 and 48 weeks after implant surgery for the clinical and radiographic examination. The ISQ value was measured and periapical radiograph was taken at every appointment. In addition, occlusion and soft tissue parameters such as plaque and calculus indices, sulcus bleeding index and widths of keratinized mucosa (KM) were assessed.

2.6 Prosthetic procedures

At 1 week after implant placement, the fixtures that showed ISQ value of 65 or more were functionally loaded with pre-fabricated Ti customized abutments and provisional restorations. Occlusion was adjusted to prevent any eccentric occlusal contact and a periapical radiograph was taken.

After 8 weeks from implant installation, the final prosthetic procedure was commenced with a digital workflow. Intraoral digital impression was taken on the pre-abraded Ti customized abutment

with the Trios 3® (3Shape, Copenhagen, Denmark) and monolithic zirconia definitive prosthesis was fabricated by means of a CAD/CAM system. On the day of delivery, after 12 weeks from the surgery, the definitive screw & cement retained prostheses (SCRPs) were delivered on the fixtures that showed ISQ value of 65 or more. The occlusion was adjusted for the even distribution of the occlusal force over the fixed prosthesis.

2.7 Measurement of marginal bone loss

Peri-implant marginal bone loss was evaluated using standard periapical radiographs taken at surgery, 12 and 48 weeks after implant installation (Figures 5 and 6). In order to obtain the marginal bone loss, the enlargement ratio of each image was calculated from the manufacturer-specified thread pitch of 0.9 mm that is known for implant system used in this study. The distance from the fixture platform top (reference point) to the level of the alveolar bone crest was measured in the mesial and distal surfaces of the implant and converted to the actual value using the enlargement ratio. This value was then compared with the measurement taken at surgery (baseline)(Figure 7).



Figure 5. Standard periapical radiographs of implants placed in the control group: CMI IS-III active® diameter 5 mm × length 10 mm, (a) at surgery, (b) at 12 weeks, (C) at 48 weeks

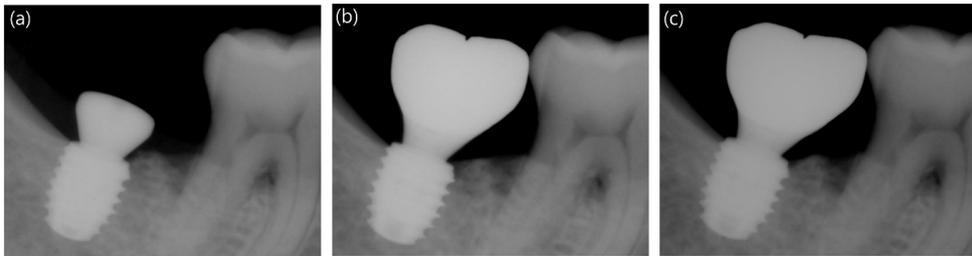


Figure 6. Standard periapical radiographs of implants placed in the experimental group: CMI IS-III active® diameter 5.5 mm × length 6.6 mm, (a) at surgery, (b) at 12 weeks, (C) at 48 weeks

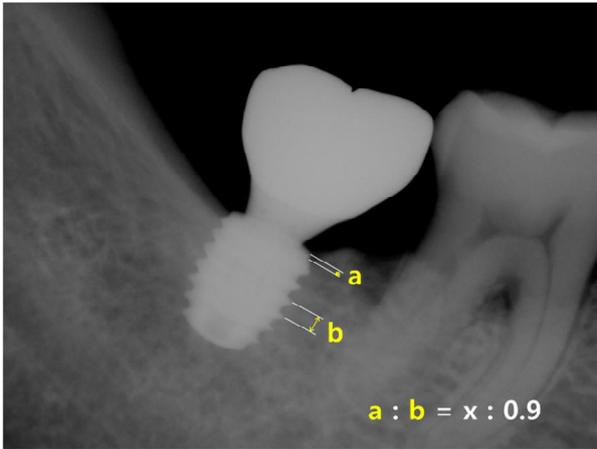


Figure 7. Measurement of marginal bone loss on periapical radiograph, a: distance from the fixture platform top to the alveolar bone crest measured from radiograph, b: pitch distance measured from radiograph, 0.9: real pitch distance between the threads(mm), x: real distance from the fixture platform top to the alveolar bone crest

2.8 Evaluation of implant success and outcomes

The following criteria described by Buser et al. (Buser et al. 1997) were applied to evaluate implant success: (1) absence of clinically detectable mobility; (2) absence of pain or other symptoms of discomfort or ongoing pathologic processes; (3) absence of recurrence of peri-implantitis with suppuration; (4) no evidence of continuous radiolucency around the implant.

We compared the ISQ value, marginal bone loss and peri-implant soft tissue parameters between control and experimental groups.

2.9 Statistical analysis

The statistical analysis comparing the two groups was performed based on the Intention to Treat (ITT) and the Per Protocol (PP) analyses. The χ^2 test for categorical variables and the independent two-sample t-test or the Mann-Whitney test for continuous variables were used for comparative evaluation depending on the normality of the distribution. For continuous variables, the mean values and standard deviation were calculated, and significant differences were detected by use of the generalized linear model. Two-way repeated measures analyses of variance in the generalized linear model were performed after the verification of sphericity using the Huynh-Feldt method to evaluate differences in the patterns of ISQ change over time. The level of significance was set at P value <

0.05 (Sigma Plot 12.0, Systat Software Inc. San Jose, CA, USA).

3. Results

3.1 Participants included in the analysis

52 of total 108 screened candidates were included by the entry criteria. During 2 months after surgery, 6 participants were dropped out because they could not fulfill the protocol standards. On the day of surgery, one subject withdrew the consent to continue participating in the study and 5 additional subjects were excluded due to low bone density (D4) or low initial stability values (ISQ < 65, insertion torque <35) (Figure 2). As a result, the data from 46 implants in 46 participants were used for the final statistical analysis of the present study.

3.2 Demographic characteristics of the participants

The demographic and clinical characteristics of the study population for each implant system are presented in Table 1. The mean age of 19 patients (15 males and 4 females) in the control group was 55.42 ± 11.75 , while the experimental group was composed of 27 patients (18 males and 9 females) with the mean age of 52.06 ± 11.05 years. The statistical analysis showed that there were no significant differences in age, sex and bone quality between the two groups ($p > 0.05$).

	Variables	Control (long implant)	Experimental (short implant)	P-value
Participant based (N=46)	Participant number	19	27	0.514
	Age (mean±SD)	55.42±11.75	52.06±11.05	0.305
	20-60	13	18	0.740
	Over 60	6	9	
	Sex			
	Male /Female	15 / 4	19 / 8	0.514
Implant based (N=46)	Implant number	19	27	
	1 st molar/2 nd molar	9 / 10	4 / 23	
	Implant Type			
	Ø5.0X10mm	19	/	
	Ø5.5X8.5mm	/	10	
	Ø5.5X7.3mm	/	9	
	Ø5.5X6.6mm	/	8	
	Bone quality			
	D112	0	4	
	D122	3	3	
	D211	0	1	
	D222	6	7	0.378
	D223	1	1	
D232	0	1		
D233	3	7		
D333	6	3		

‘Control’ indicates the Neobiotech CMI IS-III active® long implant and ‘Experimental’ the Neobiotech CMI IS-III active® short implant.

Data, except for age are presented as the number of implants or participants. The units of age are year.

The P-values were calculated using the χ^2 test (Pearson Chi-Square) for all variables except age. The P-value for age was calculated using the Mann–Whitney test.

Bone quality was assessed based on the classification system of Misch (1993) during the drilling sequence. While drilling, divide the depth of the bone into three parts and evaluate the bone quality. D113 indicates that the bone is D1, D1, and D3 depending on the depth.

SD, standard deviation.

Table 1. Demographic data of participants in the control and experimental groups

3.3 Comparison of implant stability between long and short implants

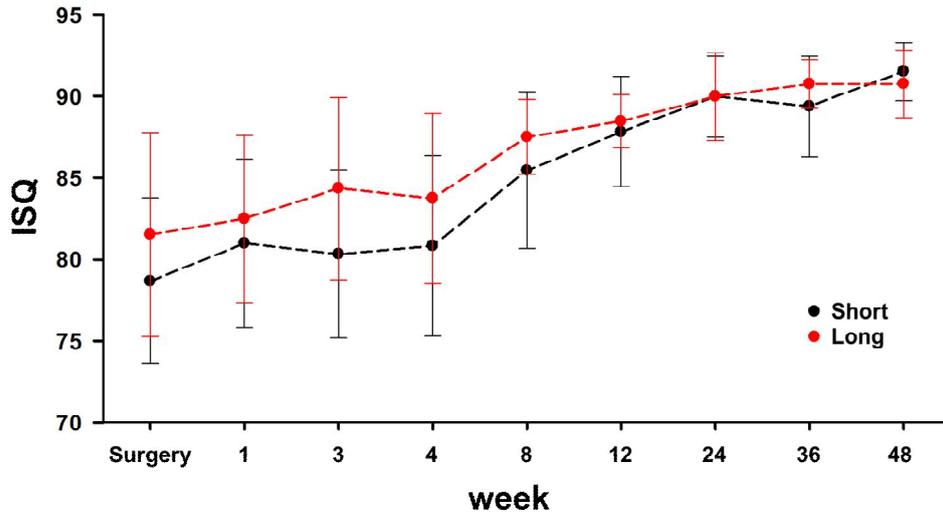
Primary stability was evaluated using the peak insertion torque and ISQ at surgery (Table 2). The control group had slightly greater average insertion torque and ISQ value at implant insertion than the experimental group, but no statistically significant differences were observed between the groups ($p > 0.05$).

The ISQ values continued to be assessed during follow-up appointments for the post-operative period of 48 weeks, as shown in Figure 8. Up to 12 weeks after surgery, the ISQ values of the control group were steadily greater than those of the experimental group, but there was no statistically significant difference between the two groups ($p > 0.05$) except 3rd week measurement ($p = 0.018$). At 24 and 48 weeks after surgery, ISQ values were slightly higher in the experimental group, but there was no statistically significant difference, either ($p > 0.05$). The ISQ value gradually increased with time, not showing significant decrease even after the provisional restoration at 1 week after the surgery. These results suggest that the stability dip, which usually appears within 2-6 weeks after surgery, did not occurred in both implant groups.

	Control Neobiotech CMI IS-III active® long Implant			Experimental Neobiotech CMI IS-III active® short Implant			<i>P</i> -value*
	Number	Mean	± SD	Number	Mean	± SD	
Insertion Torque (Ncm)	19	40.53	± 5.35	27	38.89	± 4.85	0.298
ISQ at surgery		81.53	± 6.26		78.69	± 5.08	0.120

The P-values for insertion torque and ISQ were calculated by the t-test.
ISQ, implant stability quotient; SD, standard deviation.

Table 2. Comparison of primary stability in terms of insertion torque and ISQ at surgery between the control and experimental groups



	N	Surgery	1-week	3-week	4-week	8-week	12-week	24-week	36-week	48-week
Control long implant (Mean ± SD)	19	81.53 ± 6.26	82.49 ± 5.14	84.34 ± 5.57	83.74 ± 5.21	87.51 ± 2.29	88.46 ± 1.62	89.98 ± 2.67	90.75 ± 1.47	90.76 ± 2.09
Experimental short implant (Mean ± SD)	27	78.69 ± 5.08	80.99 ± 5.17	80.33 ± 5.16	80.83 ± 5.54	85.46 ± 4.80	87.82 ± 3.38	89.99 ± 2.46	89.39 ± 3.07	91.51 ± 1.79
P-value between implant groups		0.105	0.348	0.018	0.087	0.098	0.454	0.994	0.086	0.207
Within-subjects effects (visits)		P < 0.01 (Huynh-Feldt, Sphericity Assumed)								
Within-subjects effects (visits & implant groups)		P = 0.074 (Huynh-Feldt, Sphericity Assumed)								

*The P-values were calculated using the two-way repeated measures ANOVA. ISQ, implant stability quotient; SD, standard deviation.

Figure 8. Comparison of stability pattern change in terms of ISQ during the 48-week observation period between the control and experimental groups

3.4 Comparison of marginal bone loss between long and short implants

Marginal bone loss after the implant insertion was evaluated for 46 implants using periapical radiographs taken at surgery, 12 weeks and 48 weeks after surgery (Table 3 and Figures 5-7). The average marginal bone loss from baseline of implant placement for the control and experimental groups were -0.07 ± 0.78 mm and 0.03 ± 0.63 mm after 12 weeks and 0.06 ± 0.82 mm and 0.05 ± 0.77 mm after 48 weeks respectively. No difference in marginal bone loss between the two groups gained statistical significance ($p > 0.05$). At both 12 and 48 weeks after surgery, the distal surface exhibited slightly greater bone loss, while minor marginal bone level increase was observed in the mesial side.

Duration	Area	Control Neobiotech CMI IS-III active® long Implant				Experimental Neobiotech CMI IS-III active® short Implant				P-value*
		N	Mean (mm)	±	SD	N	Mean (mm)	±	SD	
12-week follow up	Mesial	19	-0.22	±	0.98	27	-0.15	±	0.79	0.893
	Distal		0.08	±	0.81		0.20	±	0.78	0.728
	Avg		-0.07	±	0.78		0.03	±	0.63	0.885
48-week follow up	Mesial		-0.15	±	0.94		-0.13	±	0.82	0.719
	Distal		0.27	±	0.80		0.23	±	0.92	0.573
	Avg		0.06	±	0.82		0.05	±	0.77	0.655

*The P-values were calculated using the Mann–Whitney test..

Normality test was failed (Shapiro-Wilk, $P < 0.05$)

Area, the radiographic measurement area for calculation of marginal bone loss; Avg, the average value of mesial and distal bone loss; SD, standard deviation.

Table 3. Comparison of marginal bone loss (mm) between the control and experimental groups at 12-week and 48-week follow ups

3.5 Evaluation of peri-implant soft tissue parameters and success rate

All of the mean values of the soft tissue parameters were clinically healthy within normal limits throughout the clinical trial (Table 4). There were no statistically significant differences in the soft-tissue parameters between the two implant groups ($p > 0.05$). The success criteria described by Buser et al. (1997) were applied to evaluate implant success. The implants that did not fulfill the success criteria were considered failures. At the end of 48 week follow up period, all 46 implants fulfilled the strict success criteria.

Parameters	Control Neobiotech CMI IS-III active® long Implant		Experimental Neobiotech CMI IS-III active® short Implant		P- value*
	N	Mean ± SD	N	Mean ± SD	
Plaque index	19	0.22 ± 0.20	27	0.32 ± 0.22	0.168
Calculus index		0.00 ± 0.02		0.02 ± 0.05	0.465
Sulcus bleeding index		0.03 ± 0.07		0.09 ± 0.11	0.051
Pocket Depth		3.38 ± 0.63		3.31 ± 0.47	0.760
Width of keratinized mucosa (mm)		2.17 ± 0.54		2.18 ± 0.42	0.928

*The P-values were calculated using the Mann–Whitney test.

Plaque index: score 0, no detection of plaque; score 1, plaque only recognized by running a probe across the smooth marginal surface of the implant; score 2, plaque can be seen by the naked eye; score 3, abundance of soft matter.

Calculus index: score 0, no detection of calculus; score 1, supragingival calculus covering ≤ 1/3 exposed tooth surface; score 2, supragingival calculus covering > 1/3 but < 2/3 tooth surface, flecks of subgingival calculus in cervical margin; score 3, supragingival calculus covering > 2/3 surface, continuous band of subgingival calculus

Sulcus bleeding index: score 0, no bleeding when a periodontal probe is passed along the gingival margin adjacent to the implant; score 1, isolated bleeding spot visible; score 2, blood forms a confluent red line on margin; score 3, heavy or profuse bleeding.
SD, standard deviation.

Table 4. Comparison of peri-implant soft tissue parameters between the control and experimental groups after 48 week - follow up

4. Discussion

This clinical study has been performed with a complete digital workflow which includes computer aided implant surgery, immediate provisionalization, and definitive restoration. Computer aided implant surgery has been defined as a surgical technique using static surgical template that provides optimal 3D implant positioning based on the surgical plan formulated in virtual implant planning software considering both prosthetic and anatomical parameters (Tahmaseb et al. 2014). Previous studies demonstrated that the use of a surgical template significantly increases the accuracy and predictability of implant bed preparation compared to non-guided drilling (Noharet et al. 2014, Scherer et al. 2015, Tahmaseb et al. 2014). The digital workflow can provide required diagnostic information in a single visit, and reduce treatment time, cost, and manual labor, eliminating conventional impressions and stone casts. Moreover, computer-aided surgery offers patients the benefits of successful implant placement without flap elevation as well as reduced postoperative pain and discomfort compared with conventional implant surgery (Sicilia et al. 2012).

There is no consensus in the literature concerning its definition of a short implant. Authors have defined short implants as ≤ 7 mm (Neldam et al. 2012, Piero et al. 2015), ≤ 8 mm (Renouard et al. 2006), ≤ 10 mm (Feldman et al. 2004, Morand et al. 2007, Sun et al.

2011, Tawil et al. 2003), or ≤ 11 mm (das Neves et al. 2006) long. The current study placed 6.6, 7.3 or 8.5 mm implants to the experiment group to compare with standard 10mm implant group as a control.

It is generally claimed that short implants have been associated with lower survival rates than standard length implants (Winkler et al. 2000, Naenni et al. 2018, Weng et al. 2003). Winkler et al. studied 3-year survival and stability of various implant lengths (7, 8, 10, 13 and 16mm) and concluded that shorter implants have statistically lower survival rates than longer implants (Winkler et al. 2000). Naenni also reported that 6-mm implants exhibited significantly lower 5-year survival rates (91%) than 10-mm implants (100%) but supported the use of 6-mm single implants as a reasonable alternative to implants of standard length due to the minority of difference (Naenni et al. 2018). However, a majority number of recent studies revealed no apparent difference in performances between short and long implants and suggested that the use of short implants may be a viable and effective alternative treatment option (Lai et al. 2013, Rossi et al. 2015, Camps-Font et al. 2016, Lemos et al. 2016, Mezzomo et al. 2014, Thoma et al. 2015). Lai found that high survival rates for both implants and prostheses could be achieved for short SLA implants (intra-bony length of 8 mm) supporting single crowns, without severe marginal bone loss and complications after 5–10 years. He warned, however,

that short implants in type IV bone sites should be applied with caution (Lai et al. 2013). Rossi reported, in a prospective 5-year cohort study, that 6mm implants with a SLActive moderately rough surface supporting single crowns in the posterior region, loaded after 6–7 weeks, maintained full function for at least 5 year with low marginal bone resorption (Rossi et al. 2015). These results seem to be due to the technical innovations in both the surface characteristics and geometry (macro-, micro) design of the implant, which helped to compensate for the unfavorable crown-to-implant ratio and lower surface area available for bone to implant contact (Annibali et al. 2012). Several authors concluded that short implants appeared to be the preferable method for atrophic regions compared with the use of longer implants in augmented sites, due to similar survival rates with less morbidity (Morand et al. 2007, Neldam et al. 2012, Piero et al. 2015).

In our study, short implants showed successful outcomes comparable to long implants in success rates, stability, and changes in marginal bone level, despite unfavorable conditions such as short length, immediate loaded, and not splinted single implant. Peri-implant soft tissue observed was also clinically healthy with negligible plaque and calculus deposits and minimal tendency to bleed. These results were comparable to those of previous studies on immediately loaded single short implants (Anitua et al. 2016, Cannizzaro and Felice et al. 2012, Cannizzaro and Leone et al.

2012). Cannizzaro et al. (Cannizzaro and Felice et al. 2012) evaluated 6.5 mm-long flaplessly placed single implants immediately or early loaded at 6 weeks and concluded that flaplessly placed 6.5 mm-long single implants can be immediately loaded and remain successful up to 4 years after loading. Other previous study compared the outcomes of immediately loaded single implants inserted with medium (from 25 to 35 Ncm) and high insertion torques (>80 Ncm). The study concluded that single implants with a high insertion torque was preferable to minimize early implant failures when loading immediately (Cannizzaro and Leone et al. 2012). Anitua (Anitua et al. 2016) reported the successful long term (over 5 years) performance of immediate loading of short implants and concluded that immediate loading is not a risk factor for short implant success when related to good bone quality and adequate primary stability.

4.1 Implant length and stability

Implant stability is a necessary factor for osseointegration and, therefore, success of implant. Implant stability consists of primary and secondary stability (Simunek et al. 2010). Primary stability is obtained by mechanical engagement in the bone upon implant insertion, whereas secondary stability is related to the biological response to bone healing (Atsumi et al. 2007). Primary stability is

an important factor for implant success, especially when immediate loading is planned, because transmission of micromotion to the implant body can cause peri-implant bone loss or osseointegration failure (Javed et al. 2010, Simunek et al. 2010). For same reasons, a high degree of primary stability is more strictly required for single implant (Atsumi et al. 2007, Romanos 2009). Absolute optimal insertion torque or ISQ value is not identified in previous publications. Most publications proposed 30–35 Ncm to be the minimum insertion torque (Grandi, Garuti, and Guazzi et al. 2012, Grandi, Garuti, and Samarani et al. 2012, Margossian et al. 2012, Meloni et al. 2012) and 60-65 as minimum ISQ value for successful early or immediate loading (Degidi et al. 2009, Esposito et al. 2013, Guncu et al. 2008, Sennerby et al. 2008).

In our experiment, the target value at surgery for the peak insertion torque and ISQ were 35-45 Ncm and greater than 65 respectively. To achieve target primary stability, we excluded patients with D4 bone quality under strict inclusion criteria and applied the surgical procedure variations such as under-drilling when bone density was D3. Under-preparation of implant site, not following the whole standard drilling steps, has been suggested as a means to improve primary stability (Cannizzaro and Felice et al. 2012, Norton 2011). Renouard et al. (Renouard et al. 2006) also stressed the importance of surgical preparation, which conforms to bone quality and careful patient selection in terms of biomechanical

conditions for short implant.

As a result, both the long and short implant groups showed the mean insertion torque of 40.53 ± 5.35 Ncm and 38.89 ± 4.85 Ncm and the mean ISQ value of 81.53 ± 6.26 and 78.69 ± 5.08 respectively at surgery which is assumed to be sufficient primary stability. There was any significant difference between two groups in neither insertion torque nor ISQ value ($p > 0.05$).

During the early healing period, primary stability constitutes most proportion of total stability, but thereafter biologic stability becomes dominant with new bone apposition (Simunek et al. 2010). Total stability is reported to decrease at the initial healing stage and rebound as healing progresses, showing a transient dip in total stability curve (Bischof et al. 2004, Huwiler et al. 2007). We monitored the ISQ values longitudinally for 48 weeks to evaluate the course of stability and healing pattern. Short implant group showed excellent ISQ value high enough for required stability during the whole observation period, without statistically significant difference to long implant group except at 3 weeks after surgery. Additionally, both groups showed values far above the minimum ISQ value of 65, and an increasing tendency throughout 48-week monitoring period without a distinct stability dip which is found to occur usually at 2-6 weeks after dental implant placement and frequently pointed out as one of the major causes of early loading failure. This result runs counter to previous studies reporting a transient dip in total

stability during initial stage of healing (Bischof et al. 2004, Huwiler et al. 2007, Schliephake et al. 2006), which occurs when primary mechanical stability decrease is not compensated enough by secondary biologic stability increase (Lai et al. 2008, Simunek et al. 2012, Schliephake et al. 2006).

4.2 Implant length and marginal bone loss

Both the control and the experimental groups showed minimal marginal bone loss and there was no statistically significant difference during the whole observation period.

Marginal bone loss is a key factor in long term implant stability and survival rate (Pommer et al. 2012) and we need to pay more attention to bone loss in short implant because of its relatively higher risk as a result of less reserve in bone height for implant to engaged in. Several authors insisted that the first-year marginal bone loss should be included in the reports on marginal bone loss, because bone resorption rate is highest during first year of loading (Bragger et al. 1998, Davies 2003, Hartman et al. 2004, Misch et al. 2008, Simons et al. 2015, Weber et al. 2000). The criteria for implant success are known as that vertical bone loss should be less than 1.5 mm/yr during the first year after loading and 0.2 mm/yr following the implant's first year of service (Albrektsson et al. 1986). Therefore, minimal marginal bone loss shown in our samples during

initial 48 weeks after loading may be interpreted positively for aftercoming prognosis.

4.3 Factors contributing to success of implants

The successful outcomes of this study regardless of implant length may be explained by several conditions of experiment as follows.

Under strict patient selection criteria, we screened out patients with smoking habit, parafunctional habits known as disadvantageous factors for implant success and we performed CT taking on all candidates to exclude D4 bone density. The bone density is known as an important factor of the primary stability of implants and is reported to be strongly related with the ISQ value (Turkyilmaz et al. 2009). During the surgery, as mentioned previously, we tried to achieve 35-45 Ncm insertion torque with surgical procedure variations such as under-drilling when bone density is D3. Two patients who could not obtain the aimed insertion torque or ISQ, were excluded from the study. Additionally, we measured ISQ value at every appointment and loaded with prostheses only on implants which showed $ISQ \geq 65$.

The implant used in the present study, Neobiotech CMI IS-III active®, features SLA (Sandblasted with Large grit and Acid etched) surface. SLA is one of the most reliable and widely used surface treatment and proved to increase the roughness, bone to implant

contact and bone apposition on the surface (Bornstein et al. 2008, Buser et al. 2004, Schwarz et al. 2007). The implant used in our study is designed with various macrodesign features such as deep reverse buttress shaped thread, conical implant-abutment seal, upside micro grooves and self-tapping tapered apex. One of the key factors for successful stability and osseointegration is even stress distribution within peri-implant bone (Geng et al. 2001, Kim et al. 2011, Kim et al. 2011). Previous studies have reported that the aforementioned macroscopic components diminish undesirable stress and strain around the implants and improve mechanical retention during the early phase of the healing process after operation (Aloy-Prosper et al. 2011, Hansson 2003, Kim et al. 2013, Kumar et al. 2013, Ryu et al. 2014). For such reasons, a sharp drop of primary stability could be avoided not showing stability dip during healing period and it is concurrent with the result of our previous study using the same implant system (Ryu et al. 2016).

In this study, we placed implants with wider width (5.5mm) for short implant group than control group (5.0mm). Strictly speaking, comparing outcomes of different diameter implants may be improper and regarded as the limit of this study. The reason for this uneven experimental condition is that we intended to make up for the bone to implant contact surface of short length implants, within an acceptable tolerance, in an effort to reduce the risk to harm the patients. Wide diameter implant has been used to improve the

success rate in compromised situations such as poor bone quality and/or quantity and replacement of a failing standard implant (Langer et al. 1993, Renouard et al. 1999). Previous studies reported that failure rate was higher with standard-diameter short implants compared to wide-diameter short implants (Bahat 2000, Langer et al. 1993). A study about the relations between ISQ and implant length or diameter, found the wider implants presented the higher ISQ while there was no correlation between the length and ISQ (Horwitz et al. 2003). In addition, Simunek and coworkers (Simunek et al. 2010) concluded that primary stability was more influenced by diameter than length. Accordingly with those studies, wider width of short implant group is assumed to be one of the contributing factors for the successful performance in our study and is expected to be a usefully applied to clinical cases.

The improper placement of a dental implant and, consequently, the improper direction of the occlusive forces may lead to increased stress and strain distribution on the bone around the dental implants; therefore, the marginal bone loss and recession of the soft tissues may occur (Dominiak et al. 2014, Yazicioglu et al. 2015). We placed implants with the digitally prefabricated surgical template which provides optimal 3D implant positioning considering both prosthetic and anatomical parameters. It could minimize the improper direction of occlusive forces, leading to minimal marginal bone loss and therefore a successful result of implants.

5. Conclusions

In the present study performed with immediate loading protocol and complete digital pathway, short and standard length implants supporting single prosthesis in the posterior mandible, showed no significant differences in terms of success rate, ISQ values, marginal bone loss, and peri-implant soft tissue parameters during 48 week follow up period. Within the limitations of short term follow up of the present study, the short implant supporting single crown with immediate loading protocol seems to be the possible treatment alternative in the limited bone height mandible as long as adequate primary stability can be achieved; insertion torque of 35-45 Ncm and ISQ of more than 65. To consolidate this alternative solution for reduced bone height, however, additional randomized controlled trials with larger sample sizes and longer follow-up periods are required.

References

Albrektsson T, Zarb G, Worthington P and 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**, 1, 11-25.

Aloy-Prosper A, Maestre-Ferrin L, Penarrocha-Oltra D and Penarrocha-Diago M. Marginal bone loss in relation to the implant neck surface: an update, *Med Oral Patol Oral Cir Bucal*, 2011, **16**, 3, e365-368.

Anitua E, Flores J, Flores C and Alkhraisat MH. Long-term Outcomes of Immediate Loading of Short Implants: A Controlled Retrospective Cohort Study, *Int J Oral Maxillofac Implants*, 2016, **31**, 6, 1360-1366.

Annibali S, Cristalli MP, Dell'Aquila D, Bignozzi I, La Monaca G and Pilloni A. Short dental implants: a systematic review, *J Dent Res*, 2012, **91**, 1, 25-32.

Arunyanak SP, Harris BT, Grant GT, Morton D and Lin W-S. Digital approach to planning computer-guided surgery and immediate provisionalization in a partially edentulous patient, *J Prosthet Dent*, 2016, **116**, 1, 8-14.

Atsumi M, Park SH and Wang HL. Methods used to assess implant stability: current status, *Int J Oral Maxillofac Implants*, 2007, **22**, 5, 743-754.

Bahat O. Branemark system implants in the posterior maxilla:

clinical study of 660 implants followed for 5 to 12 years, *Int J Oral Maxillofac Implants*, 2000, **15**, 5, 646-653.

Benic GI, Mir-Mari J and Hammerle CH. Loading protocols for single-implant crowns: a systematic review and meta-analysis, *Int J Oral Maxillofac Implants*, 2014, **29**, Suppl, 222-238.

Bischof M, Nedir R, Szmukler-Moncler S, Bernard JP and Samson J. Implant stability measurement of delayed and immediately loaded implants during healing, *Clin Oral Implants Res*, 2004, **15**, 5, 529-539.

Bornstein MM, Valderrama P, Jones AA, Wilson TG, Seibl R and Cochran DL. Bone apposition around two different sandblasted and acid-etched titanium implant surfaces: a histomorphometric study in canine mandibles, *Clin Oral Implants Res*, 2008, **19**, 3, 233-241.

Bragger U, Hafeli U, Huber B, Hammerle CH and Lang NP. Evaluation of postsurgical crestal bone levels adjacent to non-submerged dental implants, *Clin Oral Implants Res*, 1998, **9**, 4, 218-224.

Brodala N. Flapless surgery and its effect on dental implant outcomes, *Int J Oral Maxillofac Implants*, 2009, **24**, Suppl, 118-125.

Buser D, Brogini N, Wieland M, Schenk R, Denzer A, Cochran D, Hoffmann B, Lussi A and Steinemann S. Enhanced bone apposition to a chemically modified SLA titanium surface, *J Dent Res*, 2004, **83**, 7, 529-533.

Buser D, Mericske-Stern R, Pierre Bernard JP, Behneke A, Behneke

N, Hirt HP, Belser UC and Lang NP. Long-term evaluation of non-submerged ITI implants. Part 1: 8-year life table analysis of a prospective multi-center study with 2359 implants, *Clin Oral Implants Res*, 1997, **8**, 3, 161-172.

Camps-Font O, Burgueno-Barris G, Figueiredo R, Jung RE, Gay-Escoda C and Valmaseda-Castellon E. Interventions for Dental Implant Placement in Atrophic Edentulous Mandibles: Vertical Bone Augmentation and Alternative Treatments. A Meta-Analysis of Randomized Clinical Trials, *J Periodontol*, 2016, **87**, 12, 1444-1457.

Cannizzaro G, Felice P, Leone M, Ferri V, Viola P and Esposito M. Immediate versus early loading of 6.5 mm-long flapless-placed single implants: a 4-year after loading report of a split-mouth randomised controlled trial, *Eur J Oral Implantol*, 2012, **5**, 2, 111-121.

Cannizzaro G, Leone M, Ferri V, Viola P, Gelpi F and Esposito M. Immediate loading of single implants inserted flapless with medium or high insertion torque: a 6-month follow-up of a split-mouth randomised controlled trial, *Eur J Oral Implantol*, 2012, **5**, 4, 333-342.

Chan MF, Narhi TO, de Baat C and Kalk W. Treatment of the atrophic edentulous maxilla with implant-supported overdentures: a review of the literature, *Int J Prosthodont*, 1998, **11**, 1, 7-15.

Cochran DL, Morton D and Weber H-P. Consensus statements and recommended clinical procedures regarding loading protocols for

endosseous dental implants, *Int J Oral Maxillofac Implants*, 2004, **19**, Suppl, 109-113.

das Neves FD, Fones D, Bernardes SR, do Prado CJ and Neto AJF. Short implants-an analysis of longitudinal studies, *Int J Oral Maxillofac Implants*, 2006, **21**, 1, 86-93.

Davies JE. Understanding peri-implant endosseous healing, *J Dent Educ*, 2003, **67**, 8, 932-949.

Degidi M, Piattelli A, Shibli JA, Perrotti V and Iezzi G. Bone formation around immediately loaded and submerged dental implants with a modified sandblasted and acid-etched surface after 4 and 8 weeks: a human histologic and histomorphometric analysis, *Int J Oral Maxillofac Implants*, 2009, **24**, 5, 896-901.

Dominiak M and Gedrange T. New perspectives in the diagnostic of gingival recession, *Adv Clin Exp Med*, 2014, **23**, 6, 857-863.

Esposito M, Grusovin MG, Maghaireh H and Worthington HV. Interventions for replacing missing teeth: different times for loading dental implants, *Cochrane Database Syst Rev*, 2013,3, CD003878.

Feldman S, Boitel N, Weng D, Kohles SS and Stach RM. Five-Year Survival Distributions of Short-Length (10 mm or less) Machined-Surfaced and Osseotite® Implants, *Clin Implant Dent Relat Res*, 2004, **6**, 1, 16-23.

Felice P, Soardi E, Pellegrino G, Pistilli R, Marchetti C, Gessaroli M and Esposito M. Treatment of the atrophic edentulous maxilla: short implants versus bone augmentation for placing longer

implants. Five-month post-loading results of a pilot randomised controlled trial, *Eur J Oral Implantol*, 2011, **4**, 3, 191-202.

Geng JP, Tan KB and Liu GR. Application of finite element analysis in implant dentistry: a review of the literature, *J Prosthet Dent*, 2001, **85**, 6, 585-598.

Grandi T, Garuti G, Guazzi P, Tarabini L and Forabosco A. Survival and success rates of immediately and early loaded implants: 12-month results from a multicentric randomized clinical study, *J Oral Implantol*, 2012, **38**, 3, 239-249.

Grandi T, Garuti G, Samarani R, Guazzi P and Forabosco A. Immediate loading of single post-extractive implants in the anterior maxilla: 12-month results from a multicenter clinical study, *J Oral Implantol*, 2012, **38**, Spec No, 477-484.

Guncu MB, Aslan Y, Tumer C, Guncu GN and Uysal S. In-patient comparison of immediate and conventional loaded implants in mandibular molar sites within 12 months, *Clin Oral Implants Res*, 2008, **19**, 4, 335-341.

Hansson S. A conical implant-abutment interface at the level of the marginal bone improves the distribution of stresses in the supporting bone. An axisymmetric finite element analysis, *Clin Oral Implants Res*, 2003, **14**, 3, 286-293.

Hartman GA and Cochran DL. Initial implant position determines the magnitude of crestal bone remodeling, *J Periodontol*, 2004, **75**, 4, 572-577.

Horwitz J, Zuabi O and Peled M. Resonance frequency analysis in immediate loading of dental implants, Refu'at ha-peh vaha-shinayim (1993), 2003, **20**, 3, 80-88, 104.

Huwiler MA, Pjetursson BE, Bosshardt DD, Salvi GE and Lang NP. Resonance frequency analysis in relation to jawbone characteristics and during early healing of implant installation, Clin Oral Implants Res, 2007, **18**, 3, 275-280.

Javed F and Romanos GE. The role of primary stability for successful immediate loading of dental implants. A literature review, J Dent, 2010, **38**, 8, 612-620.

Joda T and Bragger U. Complete digital workflow for the production of implant-supported single-unit monolithic crowns, Clin Oral Implants Res, 2014, **25**, 11, 1304-1306.

Joda T and Buser D. Digital implant dentistry—a workflow in five steps, CAD/CAM, 2013, **4**, 16-20.

Kim DR, Lim YJ, Kim MJ, Kwon HB and Kim SH. Self-cutting blades and their influence on primary stability of tapered dental implants in a simulated low-density bone model: a laboratory study, Oral Surg Oral Med Oral Pathol Oral Radiol Endod, 2011, **112**, 5, 573-580.

Kim JH, Yang JY, Kim YK, Heo YK and Yeo IS. Retrospective results of implants for partially edentulous posterior jaws according to time points of early loading, Int J Oral Maxillofac Implants, 2013, **28**, 5, 1293-1299.

Kim YS and Lim YJ. Primary stability and self-tapping blades: biomechanical assessment of dental implants in medium-density bone, *Clin Oral Implants Res*, 2011, **22**, 10, 1179-1184.

Kotsovilis S, Fourmoussis I, Karoussis IK and Bamia C. A systematic review and meta-analysis on the effect of implant length on the survival of rough-surface dental implants, *J Periodontol*, 2009, **80**, 11, 1700-1718.

Kumar ABT, Khalia N, Gayathri GV, Kumar BHD and Mehta DS. Peri-implant crestal bone preservation: Where do we stand?, *The International Journal of Oral Implantology & Clinical Research*, 2013, **4**, 2, 72-77.

Lai HC, Si MS, Zhuang LF, Shen H, Liu Yl and Wismeijer D. Long-term outcomes of short dental implants supporting single crowns in posterior region: a clinical retrospective study of 5–10 years, *Clin Oral Implants Res*, 2013, **24**, 2, 230-237.

Lai HC, Zhang ZY, Wang F, Zhuang LF and Liu X. Resonance frequency analysis of stability on ITI implants with osteotome sinus floor elevation technique without grafting: a 5-month prospective study, *Clin Oral Implants Res*, 2008, **19**, 5, 469-475.

Langer B, Langer L, Herrmann I and Jorneus L. The wide fixture: a solution for special bone situations and a rescue for the compromised implant. Part 1, *Int J Oral Maxillofac Implants*, 1993, **8**, 4, 400-408.

Lemos CAA, Ferro-Alves ML, Okamoto R, Mendonça MR and

Pellizzer EP. Short dental implants versus standard dental implants placed in the posterior jaws: A systematic review and meta-analysis, *J Dent*, 2016, **47**, 8-17.

Mangano FG, Shibli JA, Sammons RL, Iaculli F, Piattelli A and Mangano C. Short (8mm) locking-taper implants supporting single crowns in posterior region: a prospective clinical study with 1 to 10 years of follow-up, *Clin Oral Implants Res*, 2014, **25**, 8, 933-940.

Margossian P, Mariani P, Stephan G, Margerit J and Jorgensen C. Immediate loading of mandibular dental implants in partially edentulous patients: a prospective randomized comparative study, *Int J Periodontics Restorative Dent*, 2012, **32**, 2, e51-58.

Meloni SM, De Riu G, Pisano M, De Riu N and Tullio A. Immediate versus delayed loading of single mandibular molars. One-year results from a randomised controlled trial, *Eur J Oral Implantol*, 2012, **5**, 4, 345-353.

Mezzomo LA, Miller R, Triches D, Alonso F and Shinkai RSA. Meta-analysis of single crowns supported by short (< 10 mm) implants in the posterior region, *J Clin Periodontol*, 2014, **41**, 2, 191-213.

Misch CE, Density of bone: effect on treatment planning, surgical approach, and healing. *Contemporary implant dentistry*. St Louis, Mosby-Year Book, Inc. 1993: 469-485.

Misch CE, Perel ML, Wang HL, Sammartino G, Galindo-Moreno P,

Trisi P, Steigmann M, Rebaudi A, Palti A, Pikos MA, Schwartz-Arad D, Choukroun J, Gutierrez-Perez JL, Marenzi G and Valavanis DK. Implant success, survival, and failure: the International Congress of Oral Implantologists (ICOI) Pisa Consensus Conference, *Implant Dent*, 2008, **17**, 1, 5-15.

Morand M and Irinakis T. The challenge of implant therapy in the posterior maxilla: providing a rationale for the use of short implants, *J Oral Implantol*, 2007, **33**, 5, 257-266.

Naenni N, Sahrman P, Schmidlin PR, Attin T, Wiedemeier DB, Sapata V, Hammerle CHF and Jung RE. Five-Year Survival of Short Single-Tooth Implants (6 mm): A Randomized Controlled Clinical Trial, *J Dent Res*, 2018, **97**, 8, 887-892.

Naert I, Koutsikakis G, Duyck J, Quirynen M, Jacobs R and Van Steenberghe D. Biologic outcome of implant-supported restorations in the treatment of partial edentulism: Part 1: A longitudinal clinical evaluation, *Clin Oral Implants Res*, 2002, **13**, 4, 381-389.

Neldam CA and Pinholt EM. State of the art of short dental implants: a systematic review of the literature, *Clin Implant Dent Relat Res*, 2012, **14**, 4, 622-632.

Noharet R, Pettersson A and Bourgeois D. Accuracy of implant placement in the posterior maxilla as related to 2 types of surgical guides: a pilot study in the human cadaver, *J Prosthet Dent*, 2014, **112**, 3, 526-532.

Norton MR. The influence of insertion torque on the survival of

immediately placed and restored single-tooth implants, *Int J Oral Maxillofac Implants*, 2011, **26**, 6, 1333-1343.

Piero P, Lorenzo C, Daniele R, Rita G, Luca P and Giorgio P. Survival of short dental implants ≤ 7 mm: A review, *Int J Contemp Dent Med Rev*, 2015, **2015**, 011015.

Pommer B, Heuberer S, Nahler L and Watzek G. How much bone loss can be prevented by alveolar ridge preservation? Systematic literature review and meta-analysis, *Implant News*, 2012, **9**, 6, 795-799.

Renouard F, Arnoux JP and Sarment DP. Five-mm-diameter implants without a smooth surface collar: report on 98 consecutive placements, *Int J Oral Maxillofac Implants*, 1999, **14**, 1, 101-107.

Renouard F and Nisand D. Impact of implant length and diameter on survival rates, *Clin Oral Implants Res*, 2006, **17**, Suppl 2, 35-51.

Romanos GE. Bone quality and the immediate loading of implants-critical aspects based on literature, research, and clinical experience, *Implant Dent*, 2009, **18**, 3, 203-209.

Rossi F, Botticelli D, Cesaretti G, De Santis E, Storelli S and Lang NP. Use of short implants (6 mm) in a single-tooth replacement: a 5-year follow-up prospective randomized controlled multicenter clinical study, *Clin Oral Implants Res*, 2016, **27**, 4, 458-464.

Rossi F, Lang NP, Ricci E, Ferraioli L, Marchetti C and Botticelli D. Early loading of 6-mm short implants with a moderately rough surface supporting single crowns—a prospective 5-year cohort study,

Clin Oral Implants Res, 2015, **26**, 4, 471-477.

Ryu HS, Namgung C, Heo YK, Lee JH and Lim YJ. Early loading of splinted implants supporting a two-unit fixed partial denture in the posterior maxilla: 13-month results from a randomized controlled clinical trial of two different implant systems, Clin Oral Implants Res, 2016, **27**, 8, 1017-1025.

Ryu HS, Namgung C, Lee JH and Lim YJ. The influence of thread geometry on implant osseointegration under immediate loading: a literature review, J Adv Prosthodont, 2014, **6**, 6, 547-554.

Sanz-Sanchez I, Sanz-Martin I, Figuero E and Sanz M. Clinical efficacy of immediate implant loading protocols compared to conventional loading depending on the type of the restoration: a systematic review, Clin Oral Implants Res, 2015, **26**, 8, 964-982.

Scarano A, Piattelli A, Murmura G, Iezzi G, Assenza B and Mancino C. Delayed expansion of the atrophic mandible by ultrasonic surgery: a clinical and histologic case series, Int J Oral Maxillofac Implants, 2015, **30**, 1, 144-149.

Scherer U, Stoetzer M, Ruecker M, Gellrich N-C and von See C. Template-guided vs. non-guided drilling in site preparation of dental implants, Clin Oral Investig, 2015, **19**, 6, 1339-1346.

Schliephake H, Hüls A and Müller M. Early loading of surface modified titanium implants in the posterior mandible—preliminary results, Appl Osseointegration Res, 2006, **5**, 56-58.

Schulz KF, Altman DG and Moher D. CONSORT 2010 statement:

updated guidelines for reporting parallel group randomised trials, BMC medicine, 2010, **8**, 1, 18.

Schwarz F, Herten M, Sager M, Wieland M, Dard M and Becker J. Histological and immunohistochemical analysis of initial and early osseous integration at chemically modified and conventional SLA® titanium implants: Preliminary results of a pilot study in dogs, Clin Oral Implants Res, 2007, **18**, 4, 481-488.

Sennerby L and Meredith N. Implant stability measurements using resonance frequency analysis: biological and biomechanical aspects and clinical implications, Periodontol 2000, 2008, **47**, 1, 51-66.

Sicilia A and Botticelli D. Computer-guided implant therapy and soft- and hard-tissue aspects. The Third EAO Consensus Conference 2012, Clin Oral Implants Res, 2012, **23**, Suppl 6, 157-161.

Simons WF, De Smit M, Duyck J, Coucke W and Quirynen M. The proportion of cancellous bone as predictive factor for early marginal bone loss around implants in the posterior part of the mandible, Clin Oral Implants Res, 2015, **26**, 9, 1051-1059.

Simunek A, Kopecka D, Brazda T, Strnad I, Capek L and Slezak R. Development of implant stability during early healing of immediately loaded implants, Int J Oral Maxillofac Implants, 2012, **27**, 3, 619-627.

Simunek A, Strnad J, Kopecka D, Brazda T, Pilathadka S, Chauhan R, Slezak R and Capek L. Changes in stability after healing of

immediately loaded dental implants, *Int J Oral Maxillofac Implants*, 2010, **25**, 6, 1085-1092.

Sun HL, Wu YR, Huang C and Shi B. Failure rates of short (≤ 10 mm) dental implants and factors influencing their failure: a systematic review, *Int J Oral Maxillofac Implants*, 2011, **26**, 4, 816-825.

Tahmaseb A, Wismeijer D, Coucke W and Derksen W. Computer technology applications in surgical implant dentistry: a systematic review, *Int J Oral Maxillofac Implants*, 2014, **29**, Suppl, 25-42.

Tawil G and Younan R. Clinical evaluation of short, machined-surface implants followed for 12 to 92 months, *Int J Oral Maxillofac Implants*, 2003, **18**, 6, 894-901.

Thoma D, Zeltner M, Hüsler J, Hämmerle C and Jung R. EAO Supplement Working Group 4–EAO CC 2015 Short implants versus sinus lifting with longer implants to restore the posterior maxilla: a systematic review, *Clin Oral Implants Res*, 2015, **26**, Suppl 11, 154-169.

Tonetti MS and Hämmerle CH. Advances in bone augmentation to enable dental implant placement: Consensus Report of the Sixth European Workshop on Periodontology, *J Clin Periodontol*, 2008, **35**, Suppl 8, 168-172.

Turkyilmaz I, Sennerby L, McGlumphy EA and Tozum TF. Biomechanical aspects of primary implant stability: a human cadaver study, *Clin Implant Dent Relat Res*, 2009, **11**, 2, 113-119.

Urban IA, Jovanovic SA and Lozada JL. Vertical ridge augmentation using guided bone regeneration (GBR) in three clinical scenarios prior to implant placement: a retrospective study of 35 patients 12 to 72 months after loading, *Int J Oral Maxillofac Implants*, 2009, **24**, 3, 502-510.

Weber HP, Crohin CC and Fiorellini JP. A 5-year prospective clinical and radiographic study of non-submerged dental implants, *Clin Oral Implants Res*, 2000, **11**, 2, 144-153.

Weng D, Jacobson Z, Tarnow D, Hürzeler MB, Faehn O, Sanavi F, Barkvoll P and Stach RM. A prospective multicenter clinical trial of 3i machined-surface implants: results after 6 years of follow-up, *Int J Oral Maxillofac Implants*, 2003, **18**, 3, 417-423.

Widmann G and Bale RJ. Accuracy in computer-aided implant surgery-a review, *Int J Oral Maxillofac Implants*, 2006, **21**, 2, 305-313.

Winkler S, Morris HF and Ochi S. Implant survival to 36 months as related to length and diameter, *Ann Periodontol*, 2000, **5**, 1, 22-31.

World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects, *Jama*, 2013, **310**, 20, 2191.

Yazicioglu D, Bayram B, Oguz Y, Cinar D and Uckan S. Stress Distribution on Short Implants at Maxillary Posterior Alveolar Bone Model with Different Bone-to-Implant Contact Ratio: Finite Element Analysis, *J Oral Implantol*, 2015, **42**, 1, 26-33.

국문초록

하악 단일 구치 상실부에 디지털 방식으로 수복한 짧은 임플란트와 긴 임플란트에서의 무작위 대조 임상 연구

목적 : 본 연구의 목적은 하악 구치부 단일 치아 상실 부위에 다양한 길이의 임플란트 고정체를 디지털 방식으로 식립 수복하여 짧은 임플란트와 긴 임플란트의 임상 및 방사선 평가 결과를 비교하기 위함이다.

연구 재료 및 방법 : 연구대상자로 하악 구치부에 단일치를 상실한 52명의 환자를 선별하여 대조군(긴 임플란트)과 실험군(짧은 임플란트)에 배정하였다. 임플란트는 CMI IS-III active®(Neobiotech, Seoul, Korea)를 사용하였고 대조군에는 직경 5.0 mm, 길이 10 mm, 실험군에는 직경 5.5 mm 길이 6.6, 7.3, 8.5 mm의 고정체를 각각 식립하였다. 각각의 임플란트를 디지털 방식으로 미리 계획하고 제작한 수술용 가이드와 임시 보철물을 이용하여 식립 및 즉시 부하하였고 술 후 3개월에 CAD-CAM 방식으로 제작한 지르코니아 크라운으로 최종 수복하였다. 술 후 1,3,4,8,12,24,36,48 주에 ISQ 값 측정, 방사선 사진 촬영 및 임플란트 주변 연조직 평가를 각각 시행하였다.

결과 : 최종적으로 19개의 긴 임플란트와 27개의 짧은 임플란트가 결과 분석에 포함되었다. 두 그룹 모두 ISQ 값, 주변골 흡수량, 주변 연조직 평가 면에서 성공적인 결과를 나타내었다. 관찰 기간 동안 측정된 ISQ

값(술후 3주 제외), 주변골 흡수량, 임플란트 주변 연조직은 두 그룹 간 유의성 있는 차이가 없었다($p > 0.05$). 두 그룹 모두에서 48주 관찰 기간 동안 ISQ 값은 증가하는 추이를 보였고 뚜렷한 stability dip은 관찰되지 않았다.

결론 : 실험 결과 하악 단일 구치 상실부에 식립된 긴 임플란트와 짧은 임플란트 모두 48주 관찰기간 동안 안정성 및 주변골 흡수량 측면에서 성공적인 결과를 나타내었다. 본 실험의 48주간 관찰 결과 내에서, 골높이가 부족한 하악 구치부에 단일 임플란트 수복 시, 적절한 초기 안정성을 확보할 수 있다면 짧은 임플란트는 가능한 치료 방안이 될 수 있다고 제안할 수 있다.

주요어 : 짧은 임플란트, 즉시 부하, 디지털 workflow, 초기 안정성, 주변골 흡수량

학 번 : 2010-31196