

Effects of Reinforcement on Denture Strain in Maxillary Implant Overdentures: An In Vitro Study Under Various Implant Configurations

Toshihito Takahashi, DDS, PhD¹/Tomoya Gonda, DDS, PhD²/Yoshinobu Maeda, DDS, PhD³

Purpose: Maxillary implant overdentures are often designed without palatal coverage to maximize wearer comfort. Although palateless dentures have been reported to be less rigid than conventional dentures, and require reinforcement to prevent complications, there is little documentation about the effects of such reinforcement. The purpose of this study was to examine the effects of reinforcement on the strain on maxillary implant overdentures supported by implants in a variety of configurations. **Materials and Methods:** A maxillary edentulous model with implants inserted in the anterior, premolar, and molar area was fabricated. Five types of experimental overdentures, with and without reinforcement, were fabricated, and two strain gauges were attached at the anterior midline of the labial and palatal sides. A vertical occlusal load of 98 N was applied through a mandibular complete denture, and the shear strain on the denture was measured. The measurements were compared using the Kruskal-Wallis test ($P = .05$). **Results:** On both the labial and palatal sides, the strain on the palateless dentures with reinforcement was significantly lower than the strain on palateless dentures without reinforcement in all implant configurations ($P < .05$). The labial strain on the palateless dentures with reinforcement was almost as low as the labial strain on dentures with palatal coverage in most implant configurations. **Conclusion:** Reinforcement of a palateless implant overdenture with residual ridge reinforcement and a palatal bar could reduce the strain in the anterior midline to almost the same level as a denture with palatal coverage. This type of reinforcement may prevent prosthetic and implant complications. *INT J ORAL MAXILLOFAC IMPLANTS* 2016;31:e162–e167. doi: 10.11607/jomi.4711

Keywords: implant distribution, implant number, maxillary implant overdenture, palateless denture, reinforcement

The design of maxillary implant overdentures (IODs) applied in clinical practice varies without specific guidelines. In the clinical practice, some clinicians tend to select a palateless IOD design to optimize the wearer's oral sensation and comfort, and because patients tend to prefer palateless dentures.^{1,2} However, palateless dentures are more susceptible to deformation and

fracture than dentures with complete palatal coverage.³ Implants supporting palateless dentures were subject to higher strain than implants supporting conventional dentures, and researchers have cautioned that palateless overdentures may be a risk factor for implant loss^{4,5} and prosthetic complications.^{6,7}

Considering these characteristics of palateless dentures, reinforcement of the palateless IOD would be expected to reduce the risk of complications, as has been documented in clinical reports.^{6,8,9,10} However, there has been little research to establish which type of reinforcement and design most effectively reduce maxillary IOD deformation. Apart from a previous report about reinforcement in maxillary IODs, which determined that the reinforcement should be placed over the residual ridge and over the top of the abutment,¹¹ there are few studies that have investigated the design of reinforcement in IODs.

In complete maxillary dentures, a cast cobalt-chrome reinforcement over the residual ridge has been shown to reduce the strain on the denture base.^{12,13} In the case of palateless complete dentures, a rigid palatal structure, such as a metal palatal bar and base, in

¹Assistant Professor, Department of Prosthodontics, Gerodontology and Oral Rehabilitation, Osaka University Graduate School of Dentistry, Osaka, Japan.

²Associate Professor, Department of Prosthodontics, Gerodontology and Oral Rehabilitation, Osaka University Graduate School of Dentistry, Osaka, Japan.

³Professor, Department of Prosthodontics, Gerodontology and Oral Rehabilitation, Osaka University Graduate School of Dentistry, Osaka, Japan.

Correspondence to: Dr Toshihito Takahashi, Department of Prosthodontics, Gerodontology and Oral Rehabilitation, Osaka University Graduate School of Dentistry, 1-8 Yamadaoka, Suita, Osaka 565-0871, Japan. Fax: +81-6-6879-2957. Email: toshi-t@dent.osaka-u.ac.jp

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addition to reinforcement over the residual ridge, was more effective.¹⁴ However, the degree of strain in maxillary IODs is different from that in complete dentures and varies depending on the underlying implant configuration in terms of the number and distribution of the implants.

This in vitro study with different numbers of implants and distribution patterns aimed to investigate the effectiveness of reinforcement in IODs with and without palatal coverage, and to determine which ones most favorably resist simulated masticatory deformation in maxillary IODs.

MATERIALS AND METHODS

Experimental Model

A maxillary edentulous model (G2-402U, Nissin) was duplicated using acrylic resin (Parapress Vario, Heraeus-Kulzer) and covered with vinyl polysiloxane material (Fit Checker, GC) to simulate a 2-mm-thick mucosal lining. An edentulous mandibular plaster cast (G2-402L, Nissin) was used as the opposing model. Both models were mounted on a semi-adjustable articulator (Proarch IIG, Shofu) with occlusal wax rim.

Six implants (Mk III TiUnite RP: 4.0 mm diameter × 10 mm length, Nobel Biocare) were inserted symmetrically in three regions of the maxillary model: two in the anterior region, two in the premolar region, and two in the molar region (Fig 1).

Experimental Denture

Maxillary and mandibular complete dentures to fit the mounted edentulous models were fabricated using acrylic resin (Parapress Vario, Heraeus-Kulzer). Composite resin teeth (Veracia SA, Shofu) were arranged in bilateral balanced occlusion. Five types of experimental dentures were fabricated by duplicating the maxillary complete denture with acrylic resin (Parapress Vario, Heraeus-Kulzer). These dentures were: (1) denture with palatal coverage but with no reinforcement; (2) denture with palatal coverage and with reinforcement over the residual ridge and the top of abutments; (3) palateless denture with no reinforcement; (4) palateless denture with reinforcement over the residual ridge and the top of abutments and a palatal bar; and (5) palateless denture with reinforcement over the residual ridge and the top of the abutments (Figs 2 and 3). The design of the palateless denture has been described previously.^{3,14}

Rosette-type strain gauges (KFG-02-120-C1-L1M3R, Kyowa Electronic Instruments) were attached to the labial and palatal polished surfaces of each experimental denture at the anterior midline (Fig 3) and connected to sensor interfaces (PCD-300B, Kyowa Electronic Instruments) controlled by a personal computer (Endeavor

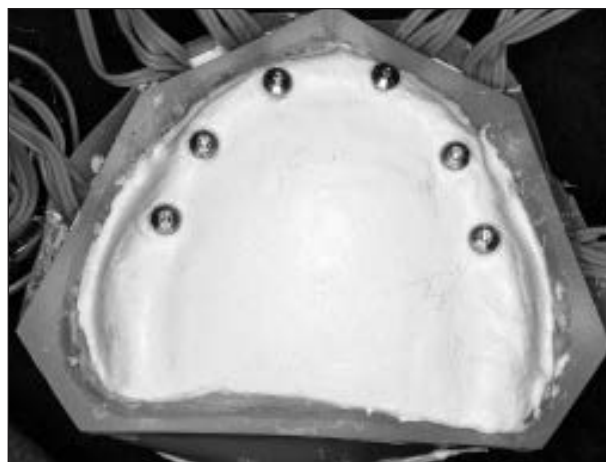


Fig 1 Maxillary edentulous model with simulated mucosa and six implants.

NJ5500, Epson). The strain of each axial gauge (ϵ_a , ϵ_b , ϵ_c) was measured, and the shear strain (γ_{max}) was calculated from these three measurements using the following formula:

$$\gamma_{max} = \sqrt{2\{(\epsilon^a - \epsilon^b)^2 + (\epsilon^b - \epsilon^c)^2\}}$$

Reinforcement and Palatal Bar

Three types of cast Co-Cr reinforcements, running over the residual ridge within the denture with palate, running over the residual ridge within the palateless denture, and running over the residual ridge with a palatal bar within the palateless denture, were fabricated as follows.

An alginate impression (Aroma Fine Plus Normal, GC) was taken of the mucosal surface of the maxillary experimental model with simulated mucosa and healing abutments mounted on the implants, and a working cast was fabricated using type II plaster (New Plastone, GC). A wax sheet (4 mm wide × 0.5 mm thick, Smooth Casting Wax, BEGO), acting as a spacer between the reinforcement and the residual ridge, was attached to the residual ridge except over the healing abutments, and die models were duplicated using refractory material (CD investment, Shofu).

A wax sheet (Smooth Casting Wax, BEGO) was attached to the refractory die model as the wax pattern of each reinforcement and palatal bar design. For the reinforcement, a wax sheet (4 mm wide × 0.5 mm thick) was attached over the residual ridge and healing abutments, and another wax sheet (5 mm wide × 1.5 mm thick) was attached over the palatal area connecting the palatal side of both first molars as the palatal bar. The models were then invested with investment material (Snow White, Shofu), and the metal reinforcement and palatal bar were cast with cobalt-chromium alloy (Co-Cr, Cobaltan, Shofu).

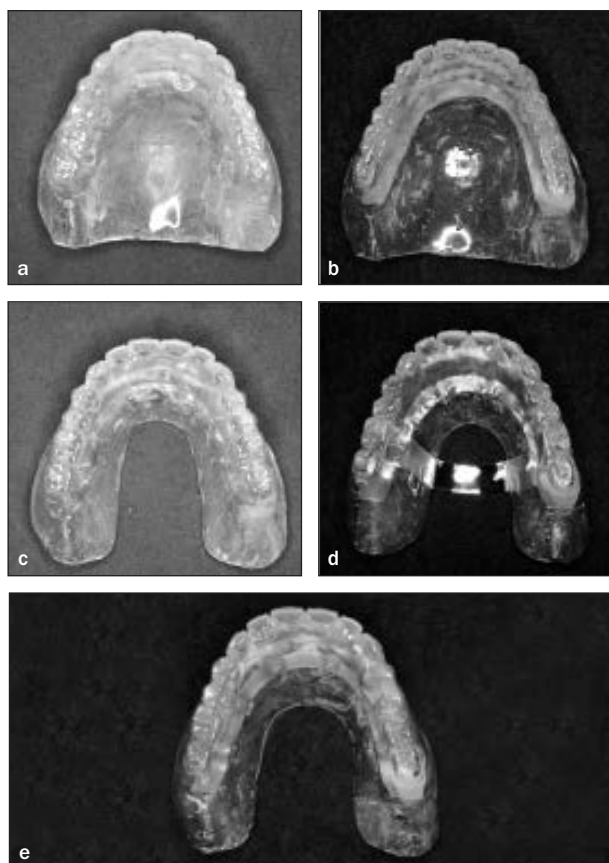


Fig 2 Maxillary experimental dentures. (a) CD: denture with palatal coverage, no reinforcement; (b) CDWR: denture with palatal coverage, with residual ridge reinforcement; (c) PD: palateless denture, no reinforcement; (d) PDWP: palateless denture, with residual ridge reinforcement and palatal bar; (e) PDWR: palateless denture, with residual ridge reinforcement.

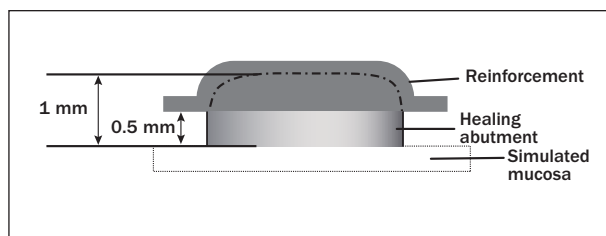


Fig 3 Schematic illustration showing the lateral view of the abutment and reinforcement. Each healing abutment protruded 1 mm from the simulated mucosa and was covered by 0.5 mm of reinforcement.

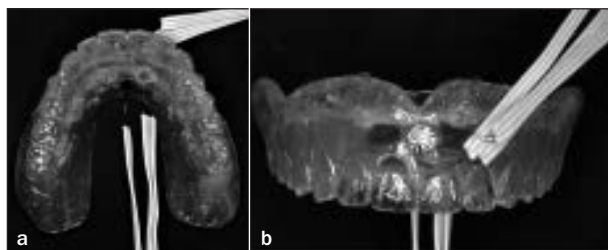


Fig 4 Experimental palateless denture with two strain gauges attached. (a) Occlusal view. (b) Labial view.

The cast Co-Cr reinforcements were sandblasted with 50 μ m alumina (Hi Allminas, Shofu), cleaned in an ultrasonic cleaner in distilled water for 15 minutes, wiped with 78% ethanol, and coated with metal primer (Metal Primer II, GC). They were then embedded in the experimental dentures during polymerization.

Loading and Measurement of Strain

Three main types of implant configurations were tested: one was supported by two implants (type II); one was supported by four implants (type IV); and another was supported by six implants (type VI). Types II and IV were subdivided into three types each: supported by two anterior implants only (type IIa); supported by two premolar implants only (type IIp); supported by two molar implants only (type IIm); supported by two anterior and two premolar implants (type IVap); supported by two anterior and two molar implants (type IVam); and supported by two premolar and two molar implants (type IVpm). These seven types of implant configurations were tested in the experimental dentures both with and without palatal coverage. In each implant configuration, healing abutments (Rp, 3 mm height, Nobel Biocare) were mounted on the supporting implants, and both types of experimental dentures were relined by denture relining material (Denture liner, Shofu) to fit the abutments and residual ridge.

After setting the maxillary and mandibular experimental dentures on the models with the articulator, a vertical load of 98 N, a load that was reported in past studies as the maximal occlusal force of patients with maxillary IODs,¹⁵ was applied to the lower dentition through the articulator with a loading apparatus (Ito Engineering; Fig 4). The strain on the denture was recorded for 10 seconds at 50-millisecond intervals, and all measurements were repeated five times for each condition. The shear strain at each measuring point was calculated using the aforementioned formula.

Statistical Analyses

The shear strain measurements for each denture type and implant configuration were compared using the Kruskal-Wallis test ($P = .05$). All statistical analysis was performed with SPSS Statistics Ver.22 (IBM).

RESULTS

Labial Shear Strain

The strain on the palateless denture with no reinforcement was the highest for all implant configurations. Most test values were much higher than those of the other four denture types. The strain on dentures with complete palatal coverage with reinforcement was the lowest for most of the implant configurations.

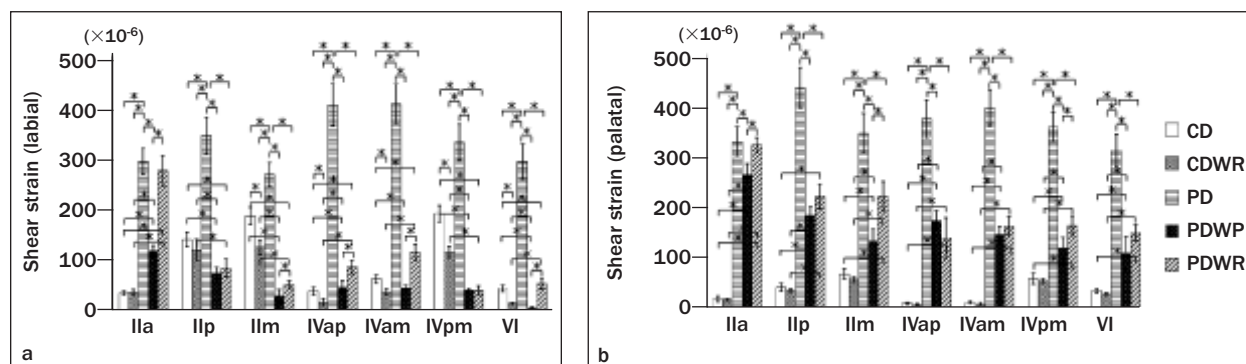


Fig 5 Graphs showing the shear strain (\pm SD) in dentures with different implant configurations. Differences in mean values were analyzed using ANOVA with Bonferroni post hoc comparison. *Denotes a significant difference ($P < .05$). (a) Shear strain on labial side. (b) Shear strain on palatal side. CD = denture with palatal coverage, no reinforcement; CDWR = denture with palatal coverage, with residual ridge reinforcement; PD = palateless denture, no reinforcement; PDWP = palateless denture, with residual ridge reinforcement and palatal bar; PDWR = palateless denture, with residual ridge reinforcement; IIa = supported by two anterior implants; IIp = supported by two premolar implants; IIIm = supported by two molar implants; IVap = supported by two anterior and two premolar implants; IVam = supported by two anterior and two molar implants; IVpm = supported by two premolar and two molar implants; VI = supported by six implants.

Table 1 Mean Values ($\times 10^{-6}$) of Shear Strain (\pm SD) in Dentures with Different Implant Configurations

	CD	CDWR	PD	PDWP	PDWR
Labial					
IIa	36.49 \pm 3.80	37.86 \pm 5.90	292.92 \pm 25.01	117.89 \pm 11.37	274.72 \pm 29.81
IIp	141.05 \pm 14.50	121.05 \pm 20.50	343.77 \pm 35.19	74.69 \pm 11.82	85.07 \pm 17.42
IIIm	187.05 \pm 16.65	125.89 \pm 14.40	267.26 \pm 23.90	31.02 \pm 12.59	52.67 \pm 8.15
IVap	40.65 \pm 7.83	19.31 \pm 6.85	403.11 \pm 40.33	47.61 \pm 13.21	87.44 \pm 13.19
IVam	63.79 \pm 8.45	39.18 \pm 5.86	404.74 \pm 38.65	46.67 \pm 5.08	115.77 \pm 16.35
IVpm	191.46 \pm 15.89	116.81 \pm 11.55	329.90 \pm 35.00	42.84 \pm 2.32	42.24 \pm 9.00
VI	45.24 \pm 6.11	16.62 \pm 2.24	292.88 \pm 34.08	7.53 \pm 1.78	54.90 \pm 10.48
Palatal					
IIa	21.09 \pm 5.49	20.20 \pm 2.12	329.01 \pm 28.89	264.00 \pm 21.74	321.69 \pm 14.49
IIp	44.07 \pm 7.84	38.07 \pm 3.84	434.43 \pm 39.40	185.09 \pm 16.03	221.79 \pm 24.57
IIIm	70.23 \pm 9.91	59.40 \pm 4.65	344.91 \pm 38.78	134.45 \pm 22.73	221.22 \pm 29.08
IVap	12.77 \pm 1.56	10.18 \pm 1.73	373.83 \pm 36.61	174.88 \pm 18.20	139.88 \pm 39.96
IVam	14.04 \pm 2.35	11.86 \pm 2.28	394.62 \pm 34.69	147.73 \pm 14.22	163.67 \pm 18.17
IVpm	61.44 \pm 10.50	56.58 \pm 3.38	357.56 \pm 29.23	121.04 \pm 20.33	164.01 \pm 19.23
VI	37.06 \pm 4.20	31.06 \pm 2.05	311.24 \pm 31.59	111.24 \pm 32.87	150.66 \pm 15.03

CD = denture with palatal coverage, no reinforcement; CDWR = denture with palatal coverage, with residual ridge reinforcement; PD = palateless denture, no reinforcement; PDWP = palateless denture, with residual ridge reinforcement and palatal bar; PDWR = palateless denture, with residual ridge reinforcement; IIa = supported by two anterior implants; IIp = supported by two premolar implants; IIIm = supported by two molar implants; IVap = supported by two anterior and two premolar implants; IVam = supported by two anterior and two molar implants; IVpm = supported by two premolar and two molar implants; VI = supported by six implants.

Palateless dentures with both types of reinforcement exhibited lower strain than palateless dentures with no reinforcement for all implant configurations. The strain on palateless dentures with reinforcement and a palatal bar was almost the same or significantly lower than the strain on dentures with complete palatal coverage and reinforcement for types IIp, IIIm, IVap, IVpm, and VI configurations ($P < .05$). Dentures with complete palatal coverage with reinforcement exhibited significantly lower strain in types IIIm, IVap, IVam, IVpm, and VI configurations than in dentures with complete coverage and no reinforcement ($P < .05$) (Fig 5; Table 1).

Palatal Shear Strain

In the palatal area, the strain on palateless dentures without reinforcement was also the highest for all implant configurations, and the values were much higher than those for dentures with complete palatal coverage.

Palateless dentures with both types of reinforcement exhibited significantly lower strain than those without reinforcement, but unlike labial strain, the palatal strain was significantly higher than in dentures with palatal coverage ($P < .05$). For dentures with complete palatal coverage, there was no significant difference between those with and without reinforcement for all implant configurations (Fig 5; Table 1).

DISCUSSION

The literature regarding maxillary IODs is divided into two main categories, relating either to the underlying implants or to overdentures. Most of the latter studies focus on patient satisfaction^{1,2,16} or are longitudinal studies about prosthetic maintenance after overdenture insertion.^{8,17–19} These studies generally conclude that maxillary IODs are a satisfactory treatment method with an excellent prognosis.

However, the longitudinal clinical reports have shown that maxillary IODs require a high level of prosthetic maintenance, especially denture repairs due to denture fracture when functional forces are applied.^{6,20} These studies also report underlying implant complications, such as implant loss, loosening of attachment, and ulcer formation, all of which cause patient dissatisfaction and bone resorption. This, in turn, causes loss of retention. Another factor is denture deformation that transmits harmful stress to the underlying implant, tissue, and bone supporting the IOD. In other words, a denture base that is insufficiently rigid will cause not only prosthetic complications, but also implant complications and patient dissatisfaction with their maxillary IOD.

Palateless dentures provide less rigidity than dentures with palatal coverage, and present a higher risk of implant loss.^{4,5} It has been suggested that reinforcement of the denture base may prevent such problems. Some clinical studies have achieved improved outcomes using dentures with reinforcement when compared with dentures without reinforcement.^{21,22} However, there are few studies investigating reinforcement of maxillary IODs, and these generally relate to the reinforcement of complete dentures or tooth-supported overdentures.²³

A previous study showed that the degree of deformation of IODs varied depending on the configuration of the supporting implants and the denture design. Therefore, this study investigated the effects of reinforcement on midfacial and midpalatal strain in maxillary IODs.

The reinforcement design used was consistent with previous studies.^{11–13} In IODs, the strain on the denture is highest around the abutments, and dentures tend to fracture in this location.²³ Therefore, the reinforcement should cover the abutment to decrease the strain on the denture around the implant.²⁴ The reinforcement used in the present investigation was placed over the residual ridge and the abutments.

The maximal occlusal force of patients with maxillary IODs was about three times higher than for patients with conventional complete dentures, reaching 60 to 160 N.²⁴ Consequently, a load of 98 N was applied to the center of the dentition to be distributed evenly.

However, various functional forces are generated during jaw movement and would be applied to denture teeth during a real masticatory cycle. To clarify the actual level of stress under mastication, further studies applying a more realistic force are necessary.

The present study found that both types of reinforcement in palateless dentures decreased the strain on the labial side to the same level or lower than dentures with palatal coverage. On the palatal side, the strain on palateless dentures with reinforcement was higher than on dentures with palatal coverage, but was significantly lower than the strain on palateless dentures without reinforcement for about half of the implant configurations. Comparing the two types of reinforcement in palateless dentures, those with the palatal bar exhibited lower strain than those with residual ridge reinforcement only.

The experimental maxillary edentulous model used in the present investigation was symmetrical and had a substantial residual ridge. It is likely that the difference in the effect between residual ridge reinforcement only and reinforcement with a palatal bar would be greater in cases with a severely resorbed ridge.²⁵ These findings are in line with the results of other maxillary palateless complete denture studies, suggesting that the palatal bar can also increase the rigidity of palateless maxillary implant overdentures.^{14,24} This reinforcing effect was seen to some extent in all implant configurations, and this reinforcement design is suitable for all types of implant distributions.

These results suggest that a maxillary palateless IOD design incorporating reinforcement over the residual ridge and the top of the abutment, together with a palatal bar, is the most effective design to prevent problems after insertion of the prosthesis. However, reinforcement in dentures with palatal coverage decreases the strain only on the labial side. Even without reinforcement, the strain on dentures with palatal coverage is not high on the palatal side. With larger loads generating more strain, the effect of reinforcement may also be desirable in dentures with palatal coverage.

This study supports the effectiveness of reinforcement of the denture base and which reinforcement design can most effectively prevent denture deformation.

CONCLUSIONS

Within the limitations of this study, residual ridge reinforcement together with a palatal bar embedded in a palateless implant overdenture reduced the strain on the anterior midline to the same level as a denture with palatal coverage, regardless of the implant configuration. The results suggest that a palateless IOD

using this type of reinforcement evenly distributes functional forces to the underlying structure and can reduce the incidence of complications.

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REFERENCES

1. Zembic A, Tahmaseb A, Wismeijer D. Within-subject comparison of maxillary implant-supported overdentures with and without palatal coverage. *Clin Implant Dent Relat Res* 2015;17:570–579.
2. Al-Zubeidi MI, Alsabeeha NH, Thomson WM, Payne AG. Patient satisfaction with maxillary 3-implant overdentures using different attachment systems opposing mandibular 2-implant overdenture. *Clin Implant Dent Relat Res* 2012;14:e11–e19.
3. Mizuno Y, Takahashi T, Gonda T, Maeda Y. Mechanical analysis of a palateless denture. *Int J Prosthodont* 2013;26:419–422.
4. Palmqvist S, Sondell K, Swartz B. Implant-supported maxillary overdentures: Outcome in planned and emergency cases. *Int J Oral Maxillofac Implants* 1994;9:184–190.
5. de Albuquerque Júnior RF, Lund JP, Tang L, et al. Within-subject comparison of maxillary long-bar implant-retained prostheses with and without palatal coverage: Patient-based outcomes. *Clin Oral Implants Res* 2000;11:555–565.
6. Andreietelli M, Att W, Strub JR. Prosthodontic complications with implant overdentures: A systematic literature review. *Int J Prosthodont* 2010;23:195–203.
7. Widbom C, Söderfeldt B, Kronström M. A retrospective evaluation of treatments with implant-supported maxillary overdentures. *Clin Implant Dent Relat Res* 2005;7:166–172.
8. Osman RB, Payne AG, Ma S. Prosthodontic maintenance of maxillary implant overdentures: A systematic literature review. *Int J Prosthodont* 2012;25:381–391.
9. Salvi GE, Brägger U. Mechanical and technical risks in implant therapy. *Int J Oral Maxillofac Implants* 2009;24:69–85.
10. Kiener P, Oetterli M, Mericske E, Mericske-Stern R. Effectiveness of maxillary overdentures supported by implants: Maintenance and prosthetic complications. *Int J Prosthodont* 2001;14:133–140.
11. Takahashi T, Gonda T, Maeda Y. Influence of reinforcement on strain within maxillary implant overdenture. *Int J Oral Maxillofac Implants* 2015;30:1327–1332.
12. Takahashi T, Gonda T, Maeda Y. The influence of reinforcement on strain in maxillary complete dentures: A preliminary report. *Int J Prosthodont* 2011;24:273–276.
13. Takahashi T, Gonda T, Maeda Y. Influence of reinforcing materials on strain of maxillary complete denture. *Acta Odontol Scand* 2013;71:307–311.
14. Takahashi T, Mizuno Y, Gonda T, Maeda Y. Metal reinforcement of a complete maxillary denture without a palate: A preliminary report. *Int J Prosthodont* 2015;28:188–190.
15. Mericske-Stern R, Venetz E, Fahrlander F, Bürgin W. In vivo force measurements on maxillary implants supporting a fixed prosthesis or an overdenture: A pilot study. *J Prosthet Dent* 2000;84:535–547.
16. Zembic A, Wismeijer D. Patient-reported outcomes of maxillary implant-supported overdentures compared with conventional dentures. *Clin Oral Implants Res* 2014;25:441–450.
17. Karabuda C, Yaltirik M, Bayraktar M. A clinical comparison of prosthetic complications of implant-supported overdentures with different attachment systems. *Implant Dent* 2008;17:74–81.
18. Zou D, Wu Y, Huang W, et al. A 3-year prospective clinical study of telescopic crown, bar, and locator attachments for removable four implant-supported maxillary overdentures. *Int J Prosthodont* 2013;26:566–573.
19. Bergendal T, Engquist B. Implant-supported overdentures: A longitudinal prospective study. *Int J Oral Maxillofac Implants* 1998;13:253–262.
20. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications with implants and implant prostheses. *J Prosthet Dent* 2003;90:121–132.
21. Slot W, Raghoobar GM, Vissink A, Huddleston Slater JJ, Meijer HJ. A systematic review of implant-supported maxillary overdentures after a mean observation period of at least 1 year. *J Clin Periodontol* 2010;37:98–110.
22. Smedberg JI, Nilner K, Frykholm A. A six-year follow-up study of maxillary overdentures on osseointegrated implants. *Eur J Prosthodont Restor Dent* 1999;7:51–56.
23. Gonda T, Ikebe K, Dong J, Nokubi T. Effect of reinforcement on overdenture strain. *J Dent Res* 2007;86:667–671.
24. Gonda T, Maeda Y, Walton JN, MacEntee MI. Fracture incidence in mandibular overdentures retained by one or two implants. *J Prosthet Dent* 2010;103:178–181.
25. Takahashi T, Gonda T, Maeda Y. Influence of palatal morphology on strain in maxillary complete dentures: A preliminary report. *Int J Prosthodont* 2012;25:619–621.