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RESEARCH AND EDUCATION

Effects of clip materials on stress distribution to maxillary implant overdentures with bar attachments

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ABSTRACT

Statement of problem. Fracture of maxillary implant overdentures (IODs) is a frequent complication. However, no studies have examined the effects of clip materials on the stress applied to maxillary IODs.

Purpose. The purpose of this study was to investigate the effects of clip materials for bar attachments on the stress applied to maxillary IODs without palatal coverage.

Material and methods. This study included finite element analysis and a model study. An edentulous maxillary model with 4 implants and an experimental overdenture with bar attachments was fabricated. Strain gauges were attached on the denture surface adjacent to the end of each clip. Four clip conditions (n=5) were prepared: 3 plastic clips, 1 plastic clip, 3 metal clips, and 1 metal clip. A vertical load of 50 N was applied on the IOD. The maximum principle strain (MPS) was statistically analyzed by 2-way ANOVA and the post hoc Tukey HSD tests with clip materials and clip numbers as factors (α=.05).

Results. The greatest stress was observed on the resin surface around the end of the clip on the loaded side. The MPSs between both clip materials (P=.048) and numbers (P<.001) differed significantly on the palatal side of the end of the center clip on the loaded side: the MPSs of the metal clips were significantly larger than those of the plastic clips, and the MPS of 1 clip was significantly larger than for 3 clips.

Conclusions. The stress around plastic clips tended to be lower than that around metal clips. (J Prosthet Dent 2016;115:283-289)

Maxillary implant overdentures (IODs) have been regarded as an effective, predictable, and reliable treatment option for the edentulous maxilla.[1] Maxillary IODs have enabled adequate retention and design without palatal coverage.[2] IODs offer significant cost reduction compared with implant-supported fixed dental prostheses.[2] Moreover, in patients with strong gagging problems or large palatal tori, dentures without palatal coverage improve patient satisfaction.[3] Considering the growing number of patients with an edentulous maxilla,[4] maxillary IODs are expected to play an important role in achieving quality dental prostheses.

For maxillary IODs, at least 4 implants should be placed and splinted by bar attachments because the bone quality and quantity are often compromised.[2,5] When 4 implants are placed, bar attachments with 1 or 3 metal or plastic clips are generally used.

With this treatment, fractures of IODs are one of the most frequent clinical complications.[6] Thus, reinforcement of IODs is necessary to prevent fracturing. With regard to maxillary conventional complete dentures, early reports have revealed that tensile strain is generated at the midline, where denture fractures also often occur.[7,8] Many studies have evaluated various methods for reinforcing the maxillary complete denture base.[7-11] However, few clinical reports have described maxillary reinforced IODs.[12,13] Slot et al[12] reinforced a palateless 4-IOD with a cobalt-chromium alloy structure supported by milled bars and retained with metal clips. After

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Clinical Implications

A maxillary bar-retained 4-implant overdenture without palatal coverage presumably requires denture base reinforcements around the end of clips. The use of plastic clips may prevent fractures to the denture base better than metal clips, regardless of the number of clips.

2 years, the patient remained satisfied with this reinforced IOD. Moreover, Duncan et al[13] described a fiber-reinforced composite resin framework for a Dolder bar-retained 5-IOD without palatal coverage. Clinical complications with this IOD were not observed for more than 1 year. These reports showed that reinforcing maxillary IODs made the denture base more resistant to fracture.[12,13] Many previous studies have demonstrated stress concentration on the implants or periimplant bone supporting maxillary 4-IODs by finite element analysis (FEA)[14-18] or photoelastic analysis.[19] However, no detailed information is available regarding stress concentration on the denture base in 4-IODs and the effects of clip materials on such stress.

In this study, the effects of clip materials on the stress applied to the denture base in IODs were examined. The null hypothesis was that the clip materials and numbers would have no effect on stress distribution to maxillary IODs with bar attachments.

MATERIAL AND METHODS

To investigate where to attach strain gauges on the experimental IOD, a simple finite element model was created to simulate the IOD plate around a round bar (Fig. 1). The model was assembled from a Ti-6Al-4V round bar, a platinum-added gold alloy, clips, and acrylic resin using computer-aided design and computer-aided manufacturing (CAD/CAM) software (SolidWorks Professional 2010; Dassault Systèmes SolidWorks Corp). The round bar designed for modeling was 1.9 mm in diameter and 10 mm in length. The clip was modeled at a length of 5 mm to cover the bar. A vertical load of 50 N, regarded as the average occlusal force applied in patients with an edentulous maxilla,[20] was applied to the resin around the end of the bar to measure stress distribution (SolidWorks Simulation Professional; Dassault Systèmes SolidWorks Corp). The model was constrained around the round bar. The surface-to-surface contact between the resin and clip was bonded. The von Mises equivalent stress at the resin interface was computed and analyzed by linear static analysis. The values of material properties and nodes of different components are listed in Table 1.[15,21-23]

An experimental model of an edentulous maxilla was fabricated from acrylic resin (Acron Clear; GC Corp)

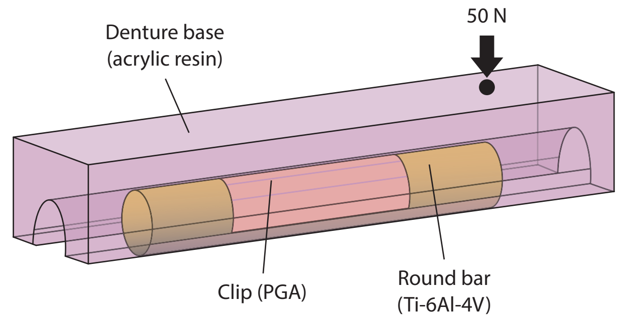

Figure 1. Finite element model (lateral view). Model was assembled from round bar (Ti-6Al-4V), metal clip (platinum-added gold alloy), and denture base (acrylic resin). Vertical load of 50 N was applied on resin.

Table 1. Material properties of different components used in FEA

Material	Poisson Ratio	Elastic Modulus (GPa)	Density (g/cm^3)	Tensile Strength (MPa)
Denture base (acrylic resin)	0.35	3.5	1.2	45
Round bar (Ti-6Al-4V)	0.34	113	4.4	930
Clip (PGA)	0.30	100	16	1015

FEA, finite element analysis; PGA, platinum-added gold alloy.

Figure 2. Edentulous maxillary model and artificial mucosa. Four implant analogs were placed parallel to each other. Diameter of round bar was 1.9 mm.

(Fig. 2). A 2 mm thick layer of the model surface was replaced with silicone impression material (Examixfine Regular; GC Corp) to simulate the mucosa. Four implant analogs (Implant Replica RP; Nobel Biocare) were placed parallel to each other in the lateral incisor and first premolar regions bilaterally.[5] A Ti-6Al-4V triple round bar with a diameter of 1.9 mm was fabricated with CAD/CAM (NobelProcera Genion; Nobel Biocare) and screwed into the implant analogs at 15 Ncm.

An experimental IOD without palatal coverage was fabricated from an autopolymerizing resin (Procast DSP; GC Corp). Artificial teeth (Veracia SA; Shofu Inc) were placed at the recommended position,[24] while bilateral molars were not arranged in order to simplify the occlusal

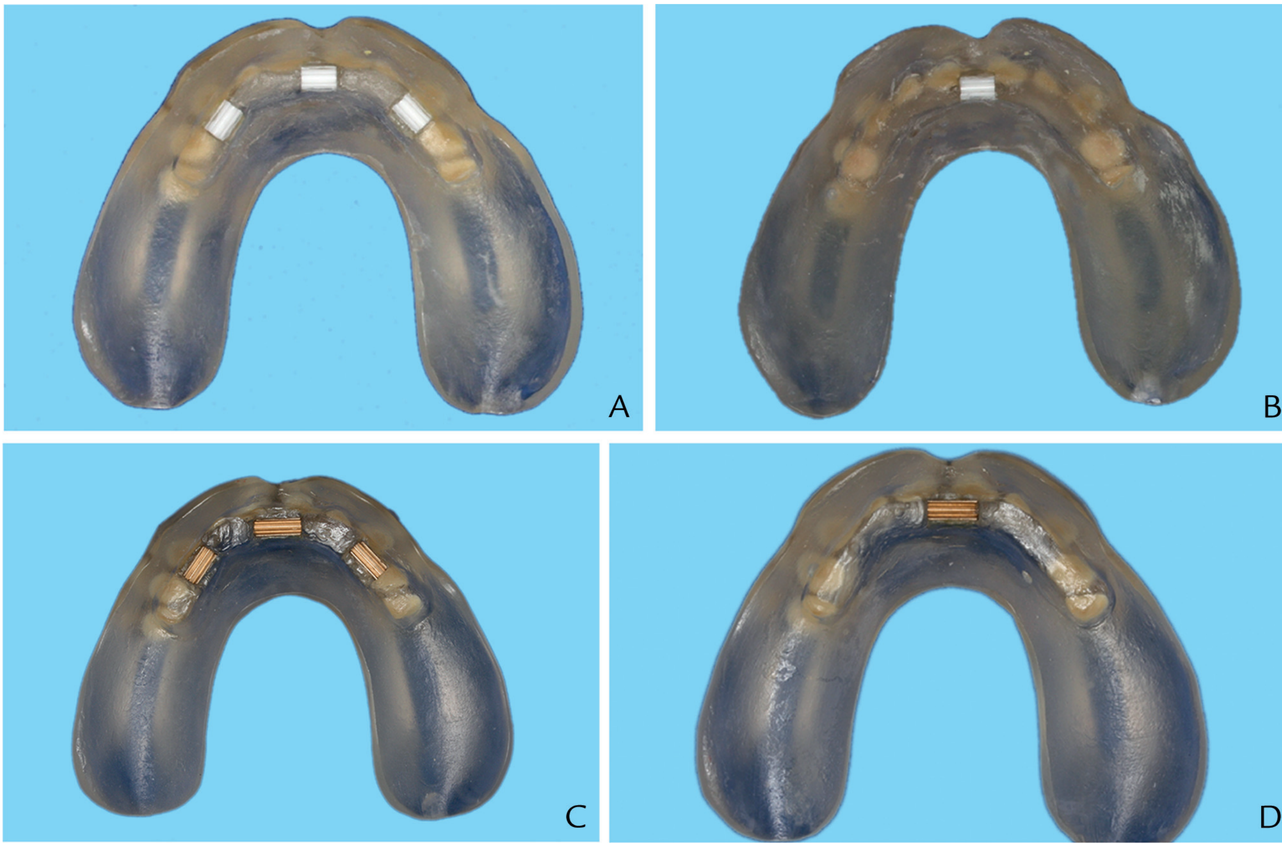

Figure 3. Four clip conditions. A, 3 plastic clips. B, 1 plastic clip. C, 3 metal clips. D, 1 metal clip.

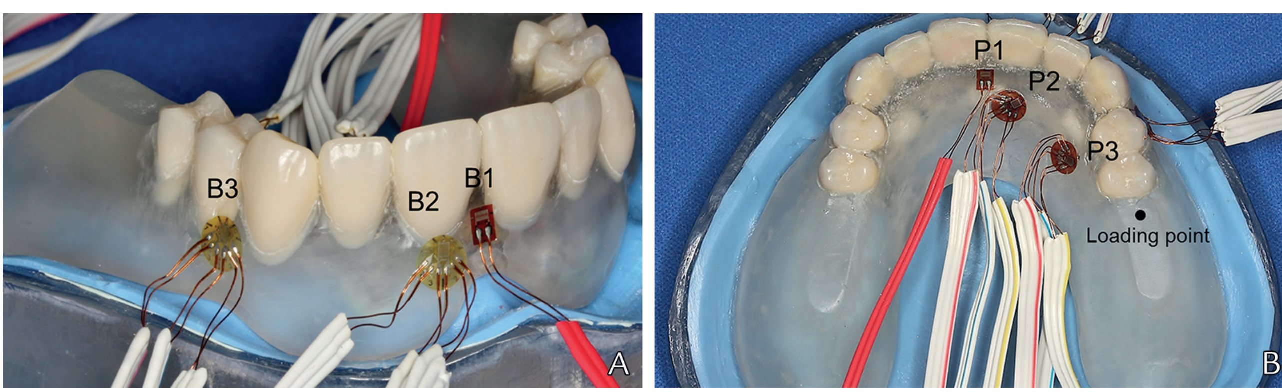

Figure 4. Positions of strain gauges. A, Lateral view. B, Palatal view. B1, Buccal side of midline (uniaxial gauge). B2, Buccal side of end of center clip (rosette gauge). B3, Buccal side of end of left clip (rosette gauge). P1, Palatal side of midline (uniaxial gauge). P2, Palatal side of end of center clip (rosette gauge). P3, Palatal side of end of left clip (rosette gauge).

force loading. The length of the clips was 5 mm. Four clip conditions were used (Fig. 3): 3 plastic clips (MP-Clip; Cendres+Métaux SA), 1 plastic clip, 3 metal clips (CM round bar female; Cendres+Métaux SA), and 1 metal clip. Five loading measurements were made for each of the 4 clip conditions. The used clips were exchanged for new ones after each measurement. All measurements were performed using 1 experimental IOD.

Two uniaxial strain gauges (KFG-02-120-C1; Kyowa Electronic Instruments Co Ltd) were attached on the resin surface on the buccal side (B1) and palatal side (P1) at the midline of the resin surface of the denture (Fig. 4). Four rosette strain gauges (KFG-1-120-D17; Kyowa Electronic Instruments Co Ltd) were attached on the buccal side of the end of the center clip (B2), the buccal side of the end of the left clip (B3), the palatal side of the end of the center clip (P2), and the palatal side of the end of the left clip (P3). The left side of the overdenture was assumed to be the loaded side (L), while the right side, where strain gauges were not attached, was assumed to be the nonloaded side (NL). All

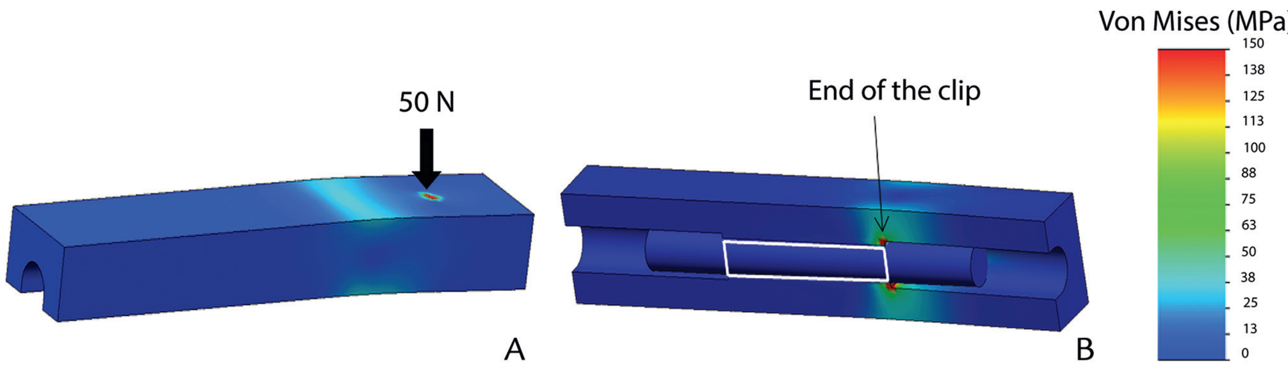

Figure 5. Results of finite element analysis. A, Lateral view. B, bottom view. Highest von Mises stress value (338 MPa) under vertical loading of 50 N was observed on resin surface around end of clip.

Table 2. Magnitude of MPS (με) at each strain gauge according to 2-way ANOVA

			Plastic				Metal				*P* for:		
			3 Clips		1 Clip		3 Clips		1 Clip				
Position	Abbreviation		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Clip Material	Clip Number	Clip Material× Clip Number
Center	B1	B1	52	21	57	14	56	13	64	24	.518	.445	.893
	P1	P1	-170	50	-325	66	-112	65	-369	122	.856	<.001*	.175
Loaded side	B2	B2-L	79	25	42	7	174	53	2	25	.072	<.001*	<.001*
	B3	B3-L	57	14	97	42	53	50	109	39	.819	.014*	.638
	P2	P2-L	433	39	538	45	440	107	688	111	.048*	<.001*	.070
	P3	P3-L	505	139	310	63	530	87	382	74	.265	.001*	.591
Nonloaded side	B2	B2-NL	178	30	54	20	343	64	87	24	<.001*	<.001*	.001*
	B3	B3-NL	37	11	12	9	83	17	22	21	.001*	<.001*	.020*
	P2	P2-NL	256	31	331	24	253	36	288	75	.293	.017*	.347
	P3	P3-NL	35	12	107	13	53	23	97	23	.620	<.001*	.100

*Significantly different (*P*<.05).

strain gauges were connected to a computer with sensor interface boards (PCD-300B and 300A; Kyowa Electronic Instruments Co Ltd).

Loading tests were performed using a universal testing machine (Instron Model 5544; Instron Corp). A vertical load of 50 N was applied in the left first molar region. The maximum principle strain (MPS) and its direction at each strain gauge were measured and analyzed by analysis software (DCS-100A v04.19; Kyowa Electronic Instruments Co Ltd). Similarly, a vertical load of 50 N was applied in the right first molar region to measure the MPS and its direction on the NL side. Five measurements were performed with each of the 4 clip conditions.

The magnitudes of MPSs and their directions were statistically analyzed with 2-way ANOVA and the post hoc Tukey HSD tests with clip materials and clip numbers as factors (SPSS v16.0; IBM Corp) (α=.05).

RESULTS

The results of FEA show the highest von Mises stress (338 MPa) on the resin surface around the end of the clip at the loaded point (Fig. 5). Therefore, in the model study, rosette strain gauges were attached on the denture surface adjacent to the distal end of each clip.

Table 3. Result of MPS at strain gauges at which interaction effect was detected according to post hoc Tukey tests at different positions

	Plastic				Metal			
	3 Clips		1 Clip		3 Clips		1 Clip	
Position	Mean	SD	Mean	SD	Mean	SD	Mean	SD
B2-L	79^{A}	25	42^{AB}	7	174	53	2^{B}	25
B2-NL	178	30	54^{A}	20	343	64	87^{A}	24
B3-NL	37^{A}	11	12^{A}	9	83	17	22^{A}	21

Values with same uppercase letters were not statistically different (*P*<.05; post hoc Tukey test).

Table 2 shows the magnitude of MPS at each strain gauge according to 2-way ANOVA. The positive numerical values denote the tension strain and the negative numerical values denote the compressive strain. The strains at P1 were compressive, while the strains at the other locations were tensile.

Two-way ANOVA did not provide evidence of an interaction between clip materials and numbers, except for B2-L (*P*<.001), B2-NL (*P*=.001), and B3-NL (*P*=.020).

At P2-L, the MPSs between both clip materials (*P*=.048) and numbers (*P*<.001) differed significantly: the MPSs of metal clips were significantly larger than those of plastic clips, and the MPSs of 1 clip were significantly larger than those of 3 clips. Regardless of the clip

Table 4. Direction (degree) of MPS of each strain gauge

			Plastic				Metal				*P* for:		
			3 Clips		1 Clip		3 Clips		1 Clip				
Position	Abbreviation		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Clip Material	Clip Number	Clip Material× Clip Number
Loaded side	B2	B2-L	-40	7	90	20	-34	2	93	22	.542	<.001*	.845
	B3	B3-L	95	8	102	10	99	9	98	3	.884	.478	.348
	P2	P2-L	-10	3	-10	5	-15	4	-10	4	.194	.245	.355
	P3	P3-L	-26	5	-32	8	-25	4	-28	9	.475	.163	.705
Nonloaded side	B2	B2-NL	64	2	81	11	61	1	71	5	.049*	<.001*	.303
	B3	B3-NL	92	4	98	8	84	7	90	8	.026*	.099	.995
	P2	P2-NL	28	4	14	5	38	1	19	5	.001*	<.001*	.294
	P3	P3-NL	-6	11	-15	6	32	9	-10	6	<.001*	<.001*	.001*

*Significantly different (*P*<.05; 2-way ANOVA).

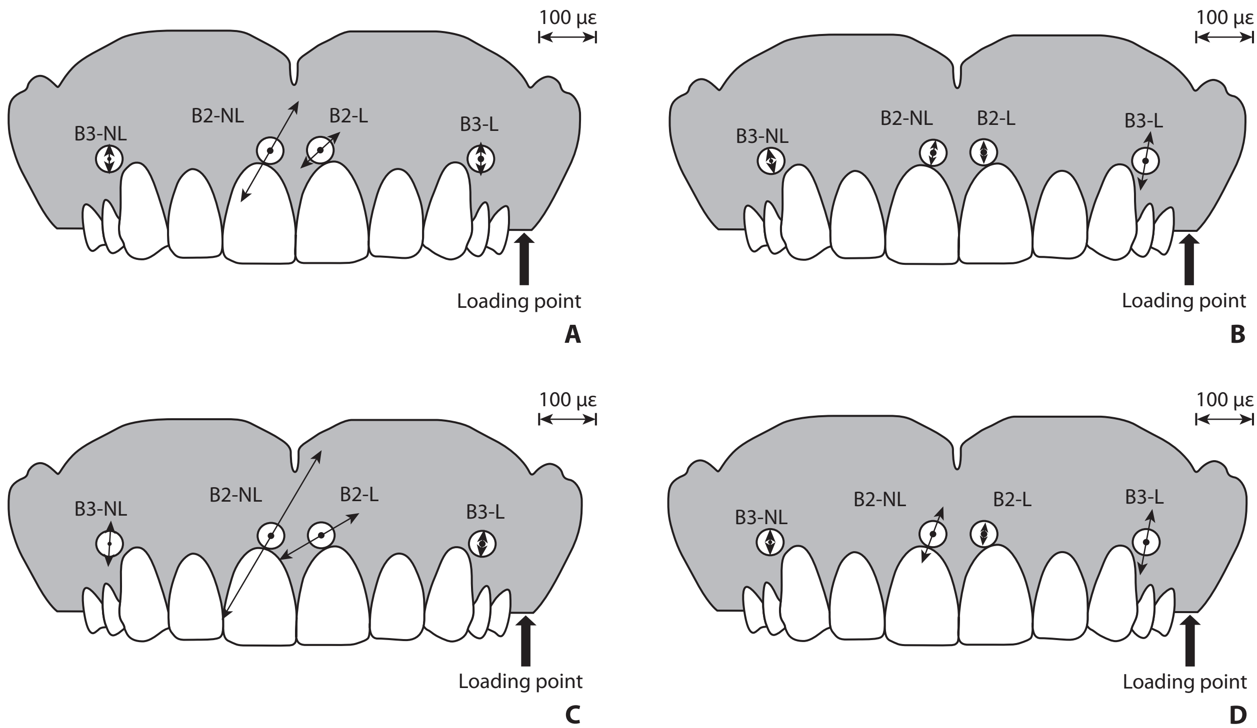

Figure 6. Examples of magnitudes of MPSs and their directions at each strain gauge position (front view). A, 3 plastic clips. B, 1 plastic clip. C, 3 metal clips. D, 1 metal clip. Double-ended arrows denote directions of MPSs. Lengths of arrows represent magnitudes of MPSs.

material, the MPSs of 1 clip were significantly larger than those of 3 clips at P1 (*P*<.001) and P2-NL (*P*=.017). Meanwhile, the MPS of 3 clips was significantly larger than that of 1 clip at P3-L (*P*=.001).

Table 3 shows the results of MPSs at each strain gauge, with detection of the interaction effect according to the post hoc Tukey HSD tests. At B2-L, B2-NL, and B3-NL, the Tukey HSD tests indicated that the MPS of 3 metal clips was significantly larger than those of the other clip conditions. Regardless of the clip materials, the MPS of 1 clip was significantly larger than that of 3 clips for the other clip conditions at B3-L (*P*=.014) and P3-NL (*P*<.001); however, those values were small.

Table 4 shows the direction (degree) of the MPS at each strain gauge. The parallel line to the occlusal plane of the denture was 0 degrees. According to 2-way ANOVA, directional values showed a statistically significant difference between clip numbers at B2- L (*P*<.001). At all NLs, the direction values showed significant differences between clip materials and/or numbers. Examples of the magnitudes of MPSs and their directions are shown in Figures 6 and 7.

DISCUSSION

The results of this study support the research hypothesis that clip materials and clip numbers affect stress distribution to maxillary IODs with bar attachments.

The greatest stress was observed on the resin surface around the end of the clip in FEA. The elastic modulus of

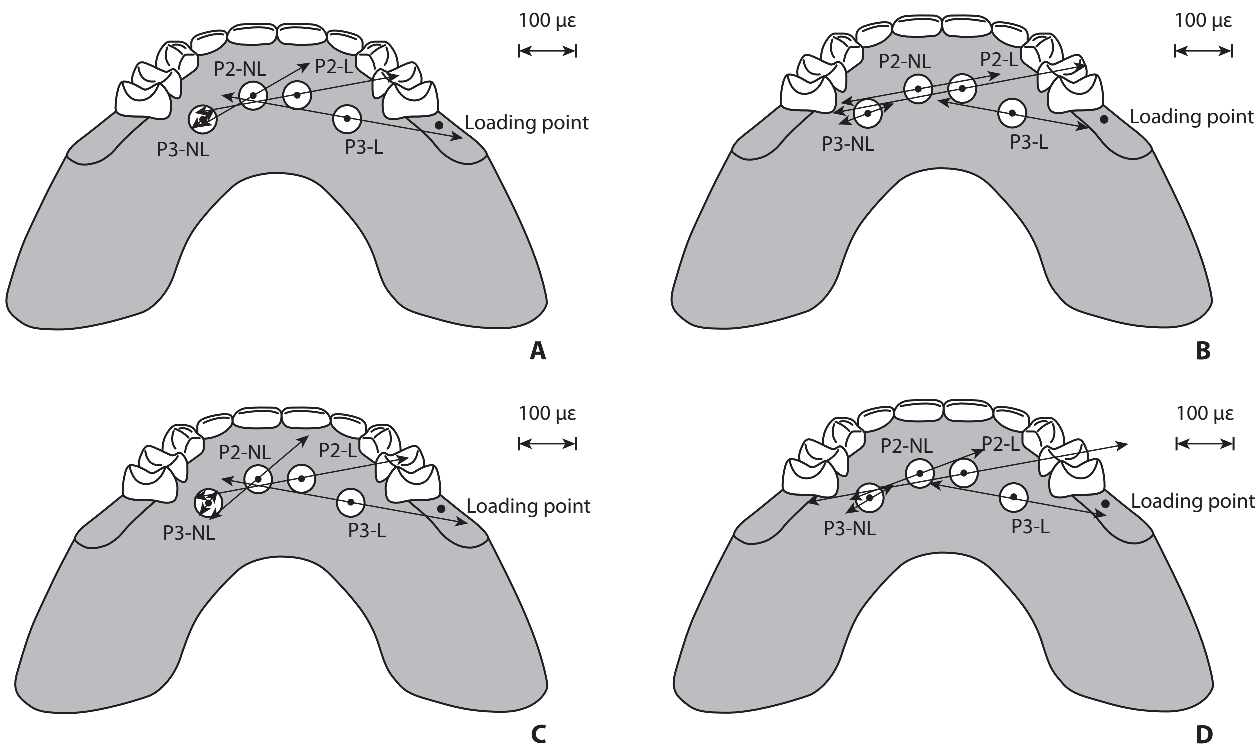

Figure 7. Examples of magnitudes of maximum principle strains (MPSs) and their directions at each strain gauge position (palatal view). A, 3 plastic clips. B, 1 plastic clip. C, 3 metal clips. D, 1 metal clip. Double-ended arrows denote directions of MPSs. Lengths of arrows represent magnitudes of MPSs.

acrylic resin is lower than that of metal.[16,17,22] On the basis of this property, acrylic resin with a metal lining tends to be stable, whereas resin without a metal lining tends to deform. Therefore, the acrylic resin at the end of the clip may act as the flexion point at which stress concentrates.

In the model study, the MPSs of metal clips were significantly larger than those of plastic clips at P2-L. In addition, the MPSs of 3 metal clips were significantly larger than those of other clip conditions on the buccal side (B2-L, B2-NL, and B3-NL). The plastic clip may absorb the loading force on the surrounding resin plate because of its elasticity. Moreover, the resin was thicker on the buccal side than on the palatal side. Therefore, metal clips, which have lower elasticity than plastic clips, may be able to easily transmit the loading force to the buccal side. Accordingly, maxillary IODs using plastic clips appeared to prevent denture base fractures better than those using metal clips.

The strains at P1 were compressive, while others were tensile. This result that the strain at palatal side of the midline is compressive is in agreement with those of previous studies examining the stress concentration on maxillary complete dentures.[8] With regard to the properties of acrylic resin, the compressive strength was 3 to 4 times higher than the tensile strength.[8,22] Consequently, the effective use of a maxillary bar-retained 4-IOD without palatal coverage presumably requires denture base reinforcements around the ends of clips rather than at the midline.

Regardless of the clip material, the MPSs of 1 clip were significantly larger than those of 3 clips around the center clip (P1 and P2-NL). However, the reverse was true closer to the loading point (P3-L). Those results indicate that the use of 1 clip allowed the denture to rotate around the center bar and that the mucous membrane may have absorbed the loading force. Therefore, the use of 1 clip allowed for further stress reduction by the supporting mucosal area but was associated with a high risk of stress concentration around the center clip.

In all clip conditions, MPSs on the palatal side tended to be larger than those on the buccal side. In the maxilla, the buccal alveolar bone resorbs much faster than the palatal bone, and implants tend to be placed on the close palatal side.[25] Thus, the thinness of the resin base in the palatal side may cause high stress.

With regard to the stress direction, in all clip conditions, MPSs on the buccal side, except for B2-L, were generally vertical to the occlusal plane, while the palatal side was generally parallel, which corresponds to the results of a previous study on maxillary complete dentures.[7] Therefore, if a crack occurs on the palatal side, the fracture is expected to be parallel to the midline, and reinforcement of this area would be necessary.

In the stress analysis of maxillary 4-IODs, plastic clips have been shown to generate a greater stress reduction of the denture base than metal clips. In the present study, these findings suggested a potential solution for the observed frequent fractures of maxillary IODs. This study examined stress only under vertical loading regarded as the occlusal force. However, fractures of maxillary IODs generally occur because of complex elements, such as occlusal force, thickness of dentures, fatigue of denture materials, and marked bone resorption. Prospective clinical studies are required to confirm these in vivo results.

CONCLUSIONS

Within the limitation of this FEA and the model study with strain gauges for the maxillary 4-IODs with bar attachments, it was concluded that the stress around plastic clips tended to be lower than that around metal clips.

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