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Original Article

In Vitro Study of Reduction of Stress Transferred onto Tissues around Implants Using a Resilient Material in Maxillary Implant Overdentures

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The purpose of this *in vitro* study was to investigate the effect of hardness on the reduction of stress transferred to tissues around implants using a resilient material applied to the female parts of the ball attachment in maxillary implant overdentures. A cast chrome-cobalt framework was mounted onto a maxillary acrylic edentulous model, which contained two implants and four strain gauges attached to the implant. Ball abutments were screwed into the implant. One abutment was connected to a dedicated metal cap embedded in the housing, while the others were connected to resilient test materials with four different hardnesses. Loads were applied using a universal testing machine with a magnitude of 50 N. The sums of the absolute values recorded from the four strain gauges were used for stress evaluation. The measured strains were analyzed statistically using two-way ANOVA and multiple comparisons. A resilient material with hardness 90 exhibited strains that did not differ significantly from the control. In contrast, the other resilient materials showed significantly reduced strains under all conditions. In this limited study, application of resilient silicone materials with approximate hardness 80 to the female parts of ball attachments significantly reduced the stress on the tissues around the implant.

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Introduction

Distal extension of the palatal plate to the vibrating line is essential in order to enhance the retention of conventional maxillary complete dentures. This distal extension, which involves full coverage of the palate, results in a superfluous projection into the mouth, as morphological changes of the palate are less comparing the residual ridges over the denture-wearing period[1,2]. Therefore, it is suspected that full coverage of the palate impairs its natural contours, leading to disturbance of the oral motor functions[3]. In order to avoid impairment of the oral motor functions of maxillary complete denture wearers, a roofless denture is possibly one of the ideal designs for a maxillary complete denture. However, decreases in the tissue surface contact area with the mucosa cause loss of retention[4], and this problem needs to be overcome.

Implant-retained maxillary overdentures represent one of the solutions for obtaining sufficient retention. In the current literature regarding implant-retained maxillary overdentures, at least four implants are recommended for support[5]. However, this is not always a feasible treatment plan, and a lower number of implants is preferable in order to minimize the surgical invasion for the patient as well as the economical burden. The maxillary sinus and nasal cavity often complicate the placement of four implants in severe atrophic residual ridges. Even in such cases, bone remains between the anterior wall of the maxillary sinus and the lateral wall of the nasal cavity[6], and placement of only two implants is possible.

However, two-implant-retained maxillary overdentures require mechanical stress reduction on the tissues surrounding the implant in order to achieve a longitudinally successful outcome. Previous reports have confirmed that the implant survival rate in the maxilla is lower than that in the mandible[7,8]. Furthermore, the implant survival rate in removable overdentures is much lower than that in fixed restorations in the maxilla[9,10]. Overloading of occlusal stress transferred to the poor quality maxillary bone around the implant has been indicated as one of the causes of this phenomenon. Furthermore, inadequate stress concentration in the tissues around the implant leads to microdamage in the bone, and consequently to loss of osseointegration[11-13]. Accordingly, in order to treat maxillary edentulous patients with two-implant-retained overdentures without a palatal plate inserted into severely atrophic residual ridges, the stress transferred from the implant overdenture to the surrounding bone should be extensively reduced.

Applying resilient materials to the female parts of the ball attachment may possibly enable two-implant-retained overdentures without a palatal plate to become a more predictable treatment, and may also be a great advantage for both patients and dentists. A previous study investigated stress reduction following the application of silicone impression materials to the female parts of the ball attachment[14]. However, there is no detailed information regarding the relationship between the hardness of the resilient materials and the effect on stress reduction.

The purpose of this *in vitro* study was to investigate the effect of hardness of materials applied to the female parts of the ball attachment on the reduction of stress transferred onto the tissue around the implant.

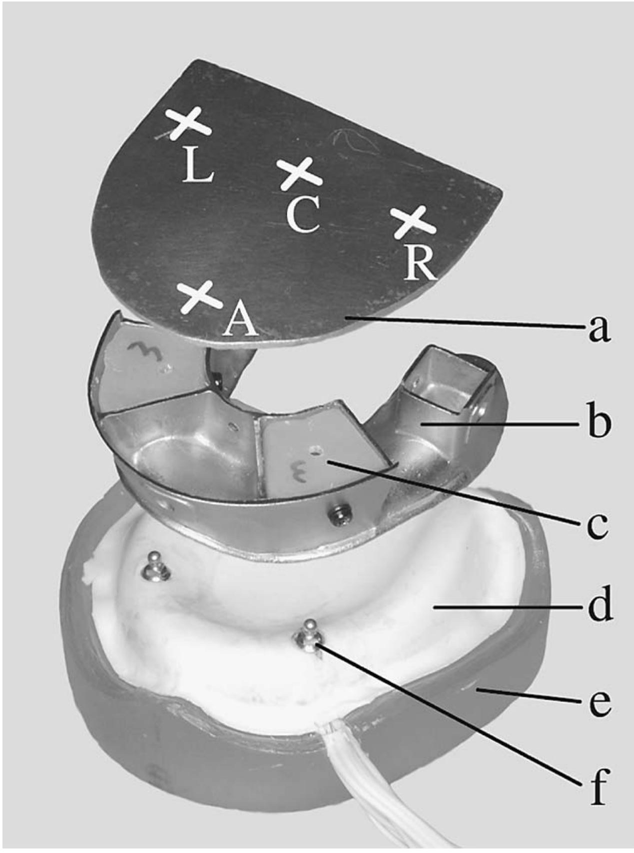

Fig. 1. The experimental maxillary model, chrome-cobalt framework and loading components. a: metal plate; b: chrome-cobalt framework; c: housings made of autopolymerized acrylic resin; d: silicone material simulating the oral mucosa; e: heat-polymerized acrylic resin; f: implant and ball abutment. A, C, R and L indicate the loading points.

Materials and Methods

Figure 1 shows the experimental maxillary model, chrome-cobalt framework and loading components. A test model was constructed using an acrylic resin (Acron; GC, Tokyo, Japan) covered with a 2 mm thick silicone layer (Fit Checker; GC) to simulate the oral mucosa. Two implants (Standard Implant ϕ 4.1 mm RN; Straumann AG, Waldenburg, Switzerland), 8.0 mm in length, were embedded in both canine regions vertical to the residual ridge using an autopolymerized resin (Repairsin; GC). Housings made from another autopolymerized resin (Unifast Trad; GC) were fixed to the framework with screws. Four strain gauges (SKF-23441; Kyowa Electronic Instruments, Tokyo, Japan) were attached to the mesial, distal, buccal and palatal surfaces of the implant and connected to a sensor interface (PDC-300; Kyowa Electronic Instruments). Ball abutments (Anchor Head ϕ 2.0 mm; Straumann AG) were screwed into the implant (Fig. 2). One abutment was connected to a dedicated metal cap embedded in the housing, while the others (Fig. 3) were connected to resilient test materials with different hardnesses (Table 1). The housing contained a cylindrical void for the resilient materials (ϕ : 4, 6 and 8 mm; height: 3 mm). The distances from the ball abutment to the surface of the void were 3 mm vertically and 1, 2 and 3 mm horizontally, and the space was filled with each resilient material. The resilient test materials consisted of vinyl polysiloxane, silicon dioxide, hydrogen polysiloxane and pigment as a base and vinyl polysiloxane, silicon dioxide and platinum as a catalyst. The hardness

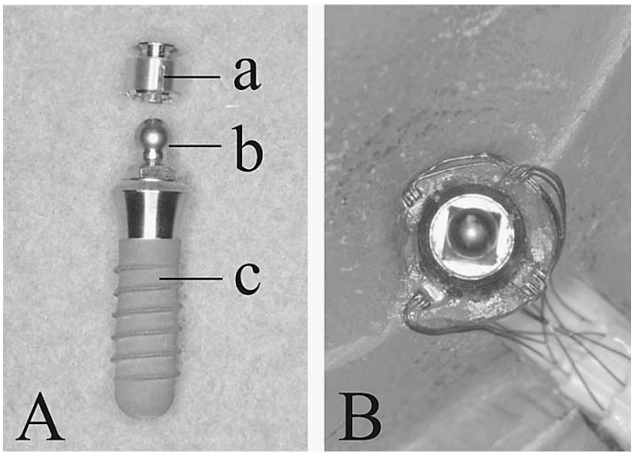

Fig. 2. The attachment system used and the locations of the strain gauges. (A) a: metal cap; b: ball abutment; c: implant. (B) Four strain gauges are attached to the mesial, distal, buccal and palatal surfaces of the implant.

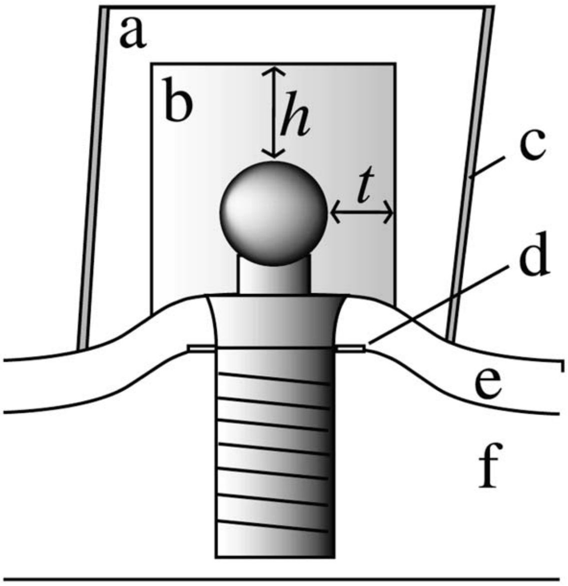

Fig. 3. Cross-sectional scheme of the ball abutment and the test component of the framework. a: housing made of autopolymerized resin; b: resilient material; c: chrome-cobalt framework; d: strain gauges; e: silicone layer; f: heat-polymerized acrylic resin; *h*: 3 mm height; *t*: 1, 2 or 3 mm in thickness.

of the resilient materials was controlled by the silicon dioxide, and measured using a durometer (Type A durometer; Kobunshi Keiki Co. Ltd., Kyoto, Japan) conforming to ISO7619. The experiments were performed 30 minutes after placement and setting of the resilient materials in the space.

The cast chrome-cobalt framework was mounted onto a maxillary model, and compressive loading tests were performed. A metal plate for loading was

Table 1. Hardness values of the resilient materials tested (ISO 7619).

Code	Hardness
RM1	90
RM2	78
RM3	68
RM4	58

Table 2. Loading conditions.

Condition	Loading point	Loading direction
CV	C	Vertical
RV	R	Vertical
LV	L	Vertical
AV	A	Vertical
RO	R	Oblique
LO	L	Oblique

"Oblique" means that the model was rotated buccally by 15 degrees on the midline.

placed on the framework, and loads were applied using a universal testing machine (Instron 5544; Instron Corporation, Norwood, MA) with a magnitude of 50 N and a crosshead speed of 10 mm/min. Table 2 shows the loading conditions. Vertical loads were applied at four different points, namely 2 points on the midline (A and C) and 1 point each in the right and left molar regions (R and L, respectively). Oblique loads were also applied at points R and L as the maxillary model was rotated by 15 degrees on the midline, resulting in loading towards the buccal region. The sums of the absolute values recorded from the four strain gauges around the implant were used for stress evaluation.

In all examinations, the sample size of the attachments was set at 3. Each measurement was performed 3 times with an interval of at least 10 minutes for recovery, and the mean value was calculated and analyzed. The strains measured around the implant under each loading condition were analyzed statistically using Dunnett's test, for which the values for the dedicated metal cap were considered to be the control. Alternatively, when resilient materials were used, the strains measured under each loading condition were analyzed statistically using two-way ANOVA. When no interaction was found, multiple comparisons were performed using the Scheffe test, while the contrast test was employed when an interaction was found. The significance level was set at $P<0.05$.

Results

Table 3 shows the means and standard deviations of the summed strains around the implant under each loading condition. The largest strain was recorded under condition AV, followed by those under conditions RO, RV, CV, LO and LV. Dunnett's multiple comparison tests revealed that only RM1 exhibited strains that did not differ significantly from the control, and 6 of 18 values failed. The other resilient materials showed significantly reduced strains by 25-60% (mean: 50%) under all conditions. The values of the strains decreased as the hardness of the resilient materials decreased.

Table 4 shows the two-way ANOVA results for the strains under each loading condition. The strain was significantly influenced by the hardness of the resilient materials under all the loading conditions. On the other hand, the thickness of the resilient materials only

Table 3. Mean values of the summed strains around the implant under the different loading conditions.

Thickness	Resilient material	CV Mean	CV (SD)	RV Mean	RV (SD)	LV Mean	LV (SD)	AV Mean	AV (SD)	RO Mean	RO (SD)	LO Mean	LO (SD)
	Control	286	(17)	363	(25)	118	(7)	770	(8)	461	(46)	149	(19)
1 mm	**RM1**	278*	(12)	342*	(5)	108*	(9)	497	(10)	341*	(18)	132*	(12)
	RM2	218	(27)	235	(43)	65	(10)	409	(53)	215	(48)	70	(12)
	RM3	210	(12)	215	(19)	51	(10)	372	(43)	183	(69)	61	(8)
	RM4	174	(8)	220	(32)	54	(8)	352	(31)	169	(50)	46	(6)
2 mm	**RM1**	265*	(13)	341*	(23)	105*	(5)	411	(9)	314	(9)	114	(20)
	RM2	125	(15)	204	(46)	62	(22)	325	(45)	174	(42)	64	(14)
	RM3	106	(10)	210	(43)	50	(18)	298	(10)	156	(55)	62	(7)
	RM4	108	(16)	195	(50)	53	(18)	278	(50)	144	(68)	41	(11)
3 mm	**RM1**	223*	(15)	331*	(10)	86*	(6)	324	(23)	332	(17)	117*	(6)
	RM2	108	(14)	213	(19)	63	(30)	304	(49)	169	(87)	58	(22)
	RM3	100	(14)	189	(29)	39	(7)	260	(99)	149	(55)	53	(12)
	RM4	93	(4)	165	(23)	40	(11)	234	(92)	114	(53)	32	(11)

Loading condition: CV, RV, LV, AV, RO, LO.

*: No significant difference by Dunnett's test for any of the loading conditions (p >0.05).

Table 4. Two-way ANOVA results for the strain of each resilient material.

Loading condition	Source	Sum of squares	df	Mean square	F	p value
RV	Resilient materials	122379	3	38	38.0	<0.0001
	Thickness	4784	2	2392	2.2	0.1278
	Resilient materials × Thickness	2529	6	421	0.3	0.8745
RO	Resilient materials	193211	3	64403	23.2	<0.0001
	Thickness	8836	2	4418	1.5	0.2231
	Resilient materials × Thickness	2466	6	411	0.1	0.9875
LV	Resilient materials	16207	3	5402	25.0	<0.0001
	Thickness	1096	2	546	2.5	0.1006
	Resilient materials × Thickness	416	6	69	0.3	0.9194
LO	Resilient materials	33089	3	11029	68.2	<0.0001
	Thickness	875	2	437	2.7	0.0869
	Resilient materials × Thickness	3878	6	54	0.3	0.9088
CV	Resilient materials	96785	3	32261	159.0	<0.0001
	Thickness	52380	2	26190	129.1	<0.0001
	Resilient materials × Thickness	7716	6	1286	6.3	0.0004
AV	Resilient materials	78080	3	26026	9.7	0.0002
	Thickness	99071	2	49535	18.6	<0.0001
	Resilient materials × Thickness	5315	6	885	0.3	0.9129

Table 5. *P* values for each multiple comparison among the resilient materials and among the thicknesses of the resilient materials.

Variables compared	Loading condition					
	CV	**RV**	**LV**	**AV**	**RO**	**LO**
RM1/RM2	<0.001	<0.001	0.0030	0.0137	<0.001	<0.001
RM1/RM3	<0.001	<0.001	<0.001	0.0042	<0.001	<0.001
RM1/RM4	<0.001	<0.001	<0.001	0.0005	<0.001	<0.001
RM2/RM3	0.0864	0.8829	0.1540	0.5391	0.8273	0.8545
RM2/RM4	<0.001	0.5083	0.2415	0.1544	0.3939	0.0054
RM3/RM4	0.0566	0.9084	0.9941	0.8435	0.8785	0.0371
1 mm/2 mm	<0.001	-	-	<0.001	-	-
1 mm/3 mm	<0.001	-	-	<0.001	-	-
2 mm/3 mm	0.0221	-	-	0.1012	-	

The strain was not significantly influenced by the thickness of the resilient materials under loading conditions RV, LV, RO and LO.

significantly influenced the strain under conditions CV and AV.

Table 5 shows the *p* values of multiple comparisons among the resilient materials and among the thicknesses of the resilient materials under each loading condition. Under all the loading conditions, the *p* values were significant for comparisons of RM1/RM2, RM1/RM3 and RM1/RM4. RM1 showed a significantly larger strain than all the other resilient materials. The *p* values were significant for RM2/RM4 under conditions CV and LO and for RM3/RM4 under condition LO. This means that RM2 produced significantly higher strains than RM4 under conditions CV and LO, and that RM3 transferred significantly higher strains than RM4 under condition LO.

There were significant differences between thicknesses of 1 mm/2 mm and 1 mm/3 mm under condition AV. Under condition CV, significant differences were found among all the thicknesses of the resilient materials.

Discussion

The McGill consensus stated that a two-implant-retained overdenture should be applied as the first choice treatment for an edentulous mandible[15], which means that it can be considered to be a well-established prosthetic procedure. In contrast, using a two-implant-retained overdenture for an edentulous maxilla is suspected to be less predictable due to the poor bone quality[9,10]. At present, the optimal amounts of force transferred to both the implant and the surrounding hard tissues are not well defined. However, minimizing the forces on the implant and surrounding soft tissues is important to safeguard the longevity, especially for the maxilla[16].

The attachment should be taken into account in order to reduce the transferred force. Both ball and bar attachments are regarded as typical attachments used for implant overdentures. In general, the former attachment is often used in two-implant-retained overdenture cases[5]. Among the stud attachments, a ball attachment transfers the lowest forces and loading moments on the implant and may prolong the longevity of the health of the surrounding bone[16]. Applying silicone resilient materials to the ball attachment system produces an additional reduction in the stress transferred onto the tissues around the implant. Furthermore, a previous report confirmed that application of elastic impression materials reduced the stress transferred onto tissues around the implant[14]. There is little doubt that this method could reduce the stress transferred onto tissues around an implant in patients.

In this vitro study, the tests were performed under 50 N loads because these loads were within the average range of occlusal force observed in denture wearers with poor masticatory performance[17]. Among the resilient materials used, RM1 was only the material that did not show any significant differences from the control under several conditions. RM2, RM3 and RM4 showed significant differences under the conditions at thicknesses of 2 or 3 mm, showing approximately 50% reduction. Accordingly, ISO7619 hardness values over 90 (RM1) are likely to have little effect on stress reduction, whereas values less than approximately 80 are likely to have an effect. In maxillary implant overdentures, four implant supports are recommended[5]. However, poor ridge conditions often require a reduction in the number of implants. If the patient can only afford two implants, which is quite likely, the applied load on each implant doubles mathematically, which is why large resiliency is desirable. Certainly, harder resilient materials can more easily tolerate larger deformation forces[18], which may be advantageous in terms of enhancement of retention. Among the resilient materials with hardness values of 80 or less, RM2 was the hardest and therefore has an advantage for denture retention. These considerations indicate that resilient materials with an identical hardness value to RM2 may be appropriate for overdentures with lower numbers of implants in order to reduce the load transferred onto the implant.

The following results obtained in this study also denoted the advantages of RM2. Under condition AV, in which the largest strain was recorded among all the loading conditions, the use of RM2 reduced the stress effectively. Since the loading point A is labial to the residual ridge, the loading may induce a bending moment which may increase the transferred stress onto tissues around the implant, as shown in the control with a recorded value of 770, whereas RM2 could reduce the stress by 55% under the same condition, even though its resiliency increased the displacement of the denture. Moreover, the stress reduction for lateral force indicated another advantage of RM2. Under conditions RO and LO, in which the lateral force was applied, RM2 reduced the stress by 53-64% (mean: 58%) compared with the control. On the other hand, under conditions RV and LV, where a vertical force was applied to the same loading points, RM2 reduced the stress by 35-47% (mean: 42%). These results indicate that RM2 may reduce the stress more effectively when a large stress is applied laterally by denture displacement in various directions. However, the mean values under condition AV were equal to or bigger than the values under all conditions. Therefore, we should be cautious about providing occlusal contacts at anterior teeth in order to avoid overloading the tissues surrounding the implant.

The significant influence of the thickness of the resilient materials under both conditions AV and CV may be explained inthe following way. Under condition AV, the large displacement of the denture probably brings the inner surface of the housing parts close to the ball abutment, leading to an increase in the strain on the tissues when the thickness of the resilient materials is thin. The significant reduction in strain observed with no less than 2 mm thickness may represent one of the solutions for designing housing parts. There were also significant differences among all thicknesses of the resilient materials under condition CV, since the values of strain for each thickness ranged from 174 to 278 for 1 mm thickness, followed by 2 and 3 mm thicknesses in decreasing order. However, all these values were smaller than those for 2 mm under condition AV. And there were not significant differences between thicknesses of 2 mm/ 3mm under condition AV. The above analysis means that there is less effective enhancement of the stress reduction with a 3 mm thick layer of the resilient materials. The results under both conditions AV and CV indicate that approximately 2 mm thickness is appropriate for stress reduction. In some clinical cases, it is difficult to maintain the cylindrical space of resilient materials at 8 mm in diameter. Even in severe clinical cases, a space of at least 6 mm in diameter seems to be possible.

The results of this *in vitro* study clearly revealed that applying an approximately 2 mm thick layer of resilient materials could reduce the stress on tissues around the implant by adjusting the hardness compared with the conventional combination with a ball abutment and dedicated metal cap. The present *in vitro* study can be adapted to patients by modifying the material properties, even if the thickness of the mucosa varies in the clinical condition. The above considerations may indicate that applying resilient materials with adjusted hardness can reduce the stress on tissues around the implant in implant-retained roofless overdentures.

A decrease in the hardness of the resilient materials induces a decrease in retention[18]. This problem can be solved by not only hardening the resilient materials but also changing the ball radius of the ball abutment male part. Numerous studies have reported that resilient materials deteriorate with time and lose their softness after soaking in water[19], and it was not examined in the present study. The optimal structural design of the ball abutment and the effects of deterioration of the resilient materials should be investigated in future studies.

Conclusions

In this limited study, the following conclusions were revealed.

1. Applying silicone resilient materials with approximately 80 hardness to the female parts of ball attachments significantly reduces the stress on tissues around the implant.
2. The stress is significantly reduced following

application of a 2 mm thick layer of the resilient materials.

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