

Influence of Implant Distribution and Palatal Coverage on the Strain of Splinted Implant and Overdenture in Maxillary Implant Overdentures



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Purpose: Implant overdentures with splinted attachments have been used in clinical practice, and the effect of splinting on implants has been reported frequently. However, the effect of implant configuration of more than four implants and covering the palate with an overdenture has not been sufficiently examined. The purpose of this study was to reveal the effects of implant configuration and palatal coverage on both implant and denture strain in maxillary implant overdentures using **splinted implants**. **Materials and Methods:** Six implants were placed in the anterior, premolar, and molar areas in a maxillary edentulous model. Four strain gauges were attached to the implant surface, and Dolder bar attachments were used to splint implants distributed in various configurations. **Two types of maxillary experimental dentures (with/without palatal coverage)** were fabricated, and **two strain gauges were attached at the midline**. A vertical load of **98 N** was applied, and **the strains on the dentures and implants were measured**. The strain measurements were compared using one-way analysis of variance and *t* test ($P = .05$). **Results:** When comparing the implant strains, **the strain was significantly smaller on the anterior and premolar implants when six implants were used, but there was no significant difference among the different implant configurations in the strain on the molar implants**. **Strains on anterior implants of the palateless overdenture were significantly greater than those of the overdenture with palatal coverage**. When four implants were used, the strain on the palatal side of dentures without palate was significantly greater than that on those with palatal coverage. When six implants were used, there was no significant difference in the strain on either side between two types of dentures. **Conclusion:** When implants were splinted to each other using **a denture without palatal coverage, the strain of dentures when six or two anterior and two posterior implants were used was lower**. **The difference of denture strains between two types of dentures was not significant when six implants were used**, but was significant for all other configurations. Also, the difference of implant strains between two dentures was significant in anterior implants regardless of implant configuration. *Int J Oral Maxillofac Implants* 2021;36:281–288. doi: 10.11607/jomi.8558

Keywords: bar attachment, implant configuration, maxillary implant overdenture, palateless denture, splinted implants, strain

When designing an **implant overdenture (IOD)**, clinicians have to choose from the various options, such as the **number, location, attachment type** of the implant, and the style and material of the **components of the overdenture**. Other factors to be considered include the cost, duration of treatment, anatomical factors, and the dexterity and desires of the patient. In the

literature about treatment choices, many researchers have focused on the complications of implants, such as the success or survival ratio,^{1,2} stress,³ and peri-implantitis,⁴ and the measures⁵ to mitigate complications. Therefore, recommendations or consensus about implant overdentures seem to also involve choices to protect the implants. Consensus about the design of maxillary IODs has not yet been reached, although there is consensus about the design of mandibular IODs.^{6,7} However, **the effect of treatment options on the overdenture to protect implants is unclear**. The present authors' previous studies examined the differences caused by various options on the strain on overdentures.^{8–11} The present study focused on several treatment options for splinted implants and examined the effect on maxillary IODs.

Two main types of attachment designs are usually applied in IODs: One is **splinted with bar attachments**,^{12,13} and the **other is unsplinted using isolated attachments**

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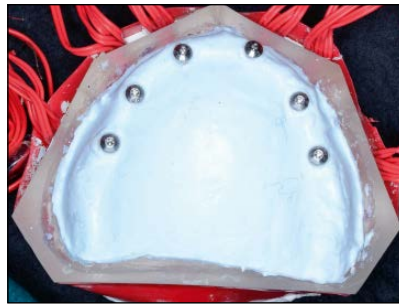


Fig 1 (Left) Image of the implant with strain gauges attached to the four surfaces of the implant.

Fig 2 (Right) Image of maxillary edentulous model with six implants.

such as ball,¹⁴ locator,¹⁵ and magnet attachments.¹⁶ In previous studies investigating IODs, splinted attachments were found to be superior to other attachments in decreasing the implant stress,¹⁷ and fewer complications may occur. However, recent studies found no significant difference in complications between implants with splinted and unsplinted attachments, and they were also almost equal in terms of patient satisfaction.¹⁸ In maxillary IODs, four or six implants splinted to each other were recommended to prevent implant complications.¹⁹ However, there was no clear superiority between four and six implants, and their influence on the overdenture has rarely been reported. When bar attachments are used to splint implants, the implants complement each other and can resist functional forces. It is important to provide enough clearance between the bar and the residual ridge to allow the area around the implants to be cleaned. As a result, the overdenture may be made thinner, leading to a higher risk of overdenture deformation and fracture. In other words, splinted implants may not necessarily enhance the effectiveness of the overdenture.

Another point to be considered when designing a maxillary IOD is whether or not to include palatal coverage. Past studies have stated that patients often prefer palatless dentures because they improve comfort and pronunciation.²⁰ However, dentures with palatal coverage are reported to be superior to palatless dentures in terms of mechanical aspects such as retention,²¹ rigidity, and strength.²² In fact, in the present authors' previous studies using unsplinted attachments, when the palatal coverage was removed, the overdentures deformed more easily and the stress on the underlying implants was greater regardless of the attachment type.^{23,24} In previous studies comparing the presence or absence of palatal coverage using several attachments under various implant configurations, it was recommended to use more than four implants and to splint each implant in the case of a denture without palatal coverage.^{19,25} On the other hand, a denture without palatal coverage is also reported to be inferior from the patients' point of view in terms of comfort,²⁶ pronunciation,²⁷ and taste.²⁸ Of these factors, a lack of retention would seem to be the most serious problem

for both patients and clinicians. Clinicians tend to select palatless maxillary IODs to enhance patients' comfort because they are retained by the underlying implants and attachments. However, the differences in implant stress between the two types of overdentures under various implant configurations have not yet been clarified, and there has been no consensus about whether or not to include palatal coverage in a maxillary IOD; the recommendations that do exist relate to the prevention of implant complications rather than to denture problems.^{5,29}

Therefore, this study aimed to reveal the influence of implant distribution and palatal coverage on both splinted implants and overdentures, and the strains of implants and overdentures were compared using an experimental model.

MATERIALS AND METHODS

Experimental Model with Implants

A maxillary edentulous model that was covered by simulated mucosa and an opposing model under the same experimental conditions as the present authors' previous studies^{8,9,22,23} were used. Four strain gauges (KGF-1N-120-C1-11L1M2R, Kyowa Electronic Instruments) were attached to the four surfaces of the implants (Mk III TiUnite RP: 4.0-mm diameter × 10-mm length, Nobel Biocare) at 2 mm below the shoulder, and the grooves were filled with acrylic resin (Unifast III, GC; Fig 1). Six implants were placed bilaterally and symmetrically in the positions of the lateral incisor, first premolar, and first molar in the maxillary experimental model using the duplicated maxillary denture as a surgical guide (Fig 2). The strain gauges were connected to sensor interfaces (PCD-300B, Kyowa Electronic Instruments), which were controlled by a personal computer (Endeavor NJ5500, Seiko Epson).

Experimental Denture

Both maxillary and mandibular complete dentures were fabricated using acrylic resin (Palapress Vario, Heraeus-Kulzer). Composite resin teeth (Veracia SA, Shofu) were arranged in bilateral balanced occlusion.

Fig 3 Images of experimental denture with strain gauges. (a) Occlusal view. (b) Labial view.

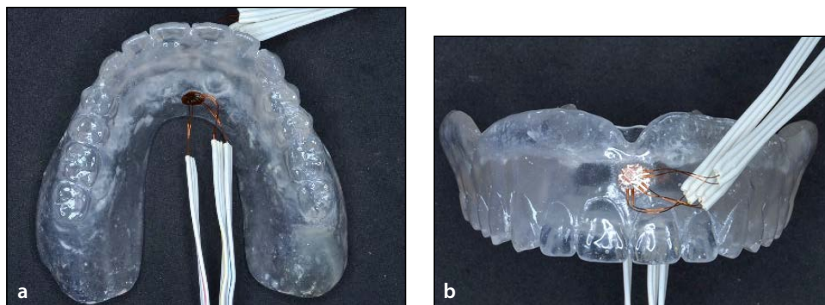
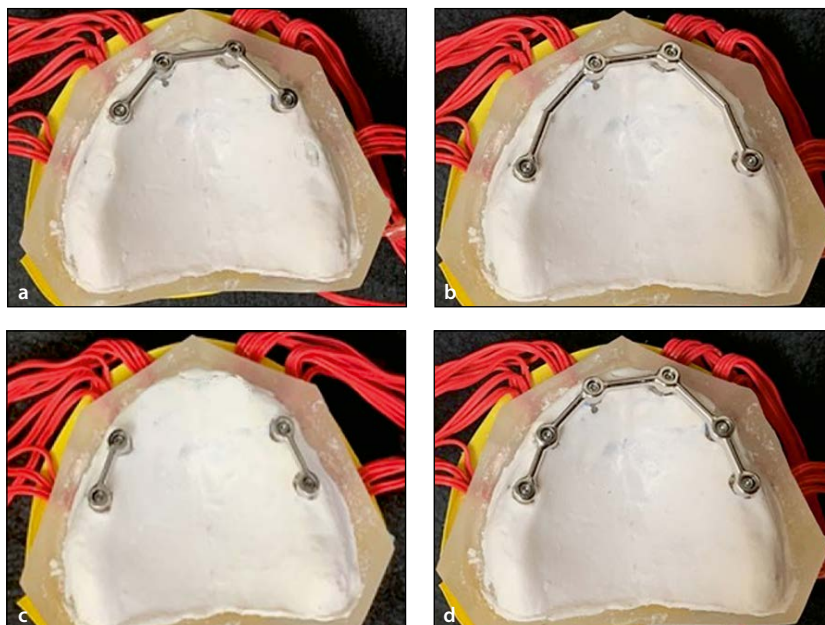



Fig 4 Four types of bar attachments. (a) Splinting of two anterior and two premolar implants (IVap). (b) Splinting of two anterior and two molar implants (IVam). (c) Splinting of a premolar and a molar implant on each side (IVpm). (d) Splinting of six implants (VI).



The experimental palateless dentures were fabricated, trimming away the palatal section from the experimental complete denture. The design of the denture without palatal coverage was the same as in the authors' previous studies.^{8,10,22}

 A rosette-type strain gauge (KFG-02-120-C1-L1M3R, Kyowa Electronic Instruments) was attached to both the labial and palatal sides of polished surfaces at the anterior midline of the experimental denture (Fig 3) and connected to sensor interfaces (PCD-300B, Kyowa Electronic Instruments).



Bar Attachments

Dolder bar attachments (50-mm micro male and 50-mm micro female, Cendres+Métaux) were used to splint implants in various implant distributions as follows: (1) splinting of two anterior and two premolar implants (IVap); (2) splinting of two anterior and two molar implants (IVam); (3) splinting of a premolar and a molar implant on each side (IVpm); and (4) splinting of all implants (VI; Fig 4). All procedures were conducted in accordance with the manufacturer's manual.



Fig 5 Image of loading. A vertical load of 98 N was applied with a loading apparatus to the lower dentition through the articulator placed upside down.

Loading and Calculation of Strains

A vertical load of 98 N was applied using the same method as in the authors' previous studies⁸⁻¹¹ (Fig 5). The strains on both implants and dentures were recorded for 10 seconds at 50-ms intervals, and all measurements were conducted five times for each condition.

To compare the implant strains, two directions of bending strain, mesiodistal and palatolabial (or palatobuccal), were calculated, and a composite strain on

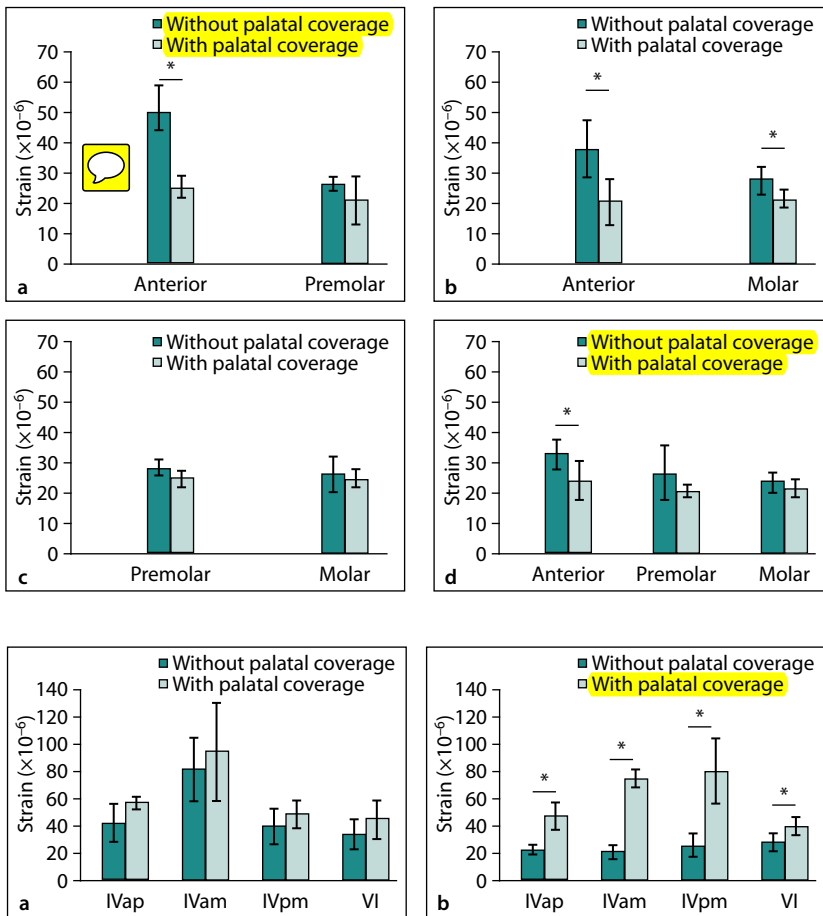


Fig 6 Graphs of the composite strain of the implants (± SD) comparing the denture with and without palatal coverage for each condition. (a) IVap. (b) IVam. (c) IVpm. (d) VI. Differences in mean values were analyzed using the *t* test. *Significant difference ($P < .05$). Key: anterior; anterior implant, premolar; premolar implant and molar; molar implant. X-axis = implant location; y-axis = implant strain. IVap = supported by two anterior and two premolar implants; IVam = supported by two anterior and two molar implants; IVpm = supported by a premolar and a molar implant on each side; VI = supported by six implants.

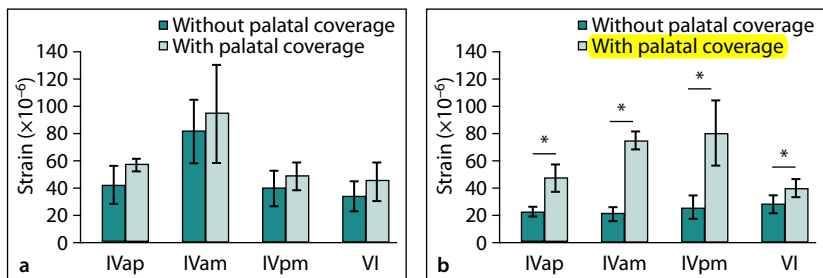


Fig 7 Graphs of the shear strain (± SD) in dentures with and without palatal coverage. Differences in mean values were analyzed using the *t* test. *Significant difference ($P < .05$). (a) Shear strain on labial side. (b) Shear strain on palatal side.

each implant was calculated from these two bending strains, as if the two vectors were combined as a composite vector.

To compare the denture strains, the strain at each axial gauge ($\epsilon_a, \epsilon_b, \epsilon_c$) was measured, and the shear strain (γ_{max}) was calculated from three strains using the following formula:

$$\gamma_{max} = \sqrt{2\{(\epsilon_a - \epsilon_b)^2 + (\epsilon_b - \epsilon_c)^2\}}$$

Statistical Analyses

The differences in composite strains of implants and shear strain of overdentures for each type of overdenture among the four implant configurations were compared by one-way analysis of variance (ANOVA) with a post hoc comparison by the Bonferroni method ($P = .05$). The differences in composite strains of implants and shear strain of overdentures between dentures and the presence and absence of palatal coverage for each implant distribution were compared using the *t* test ($P = .05$). The statistical analyses were performed using SPSS Statistics Ver.22 (IBM).

RESULTS

Effect of Palatal Coverage on Implant Strain

In anterior implants, the strain on implants under dentures without palatal coverage was significantly greater than that under those with palatal coverage in all implant configurations ($P < .05$). In premolar implants, there was no significant difference between the two types of overdentures in all implant distributions. In molar implants, there was a significant difference between the two types of overdentures in the case of IVam ($P < .05$), but no significant difference in IVpm and VI (Fig 6).

Effect of Palatal Coverage on Denture Strain

On the labial side, the strain for each implant configuration was similar for the two types of overdentures. The strain on the palateless dentures tended to be greater than that on the dentures with palatal coverage, but there was no significant difference between the two types of overdentures in any of the implant configurations (Fig 7).

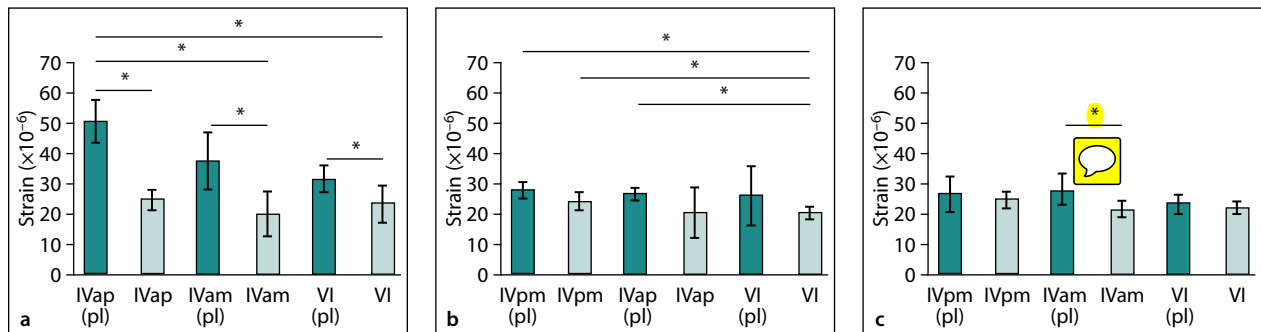
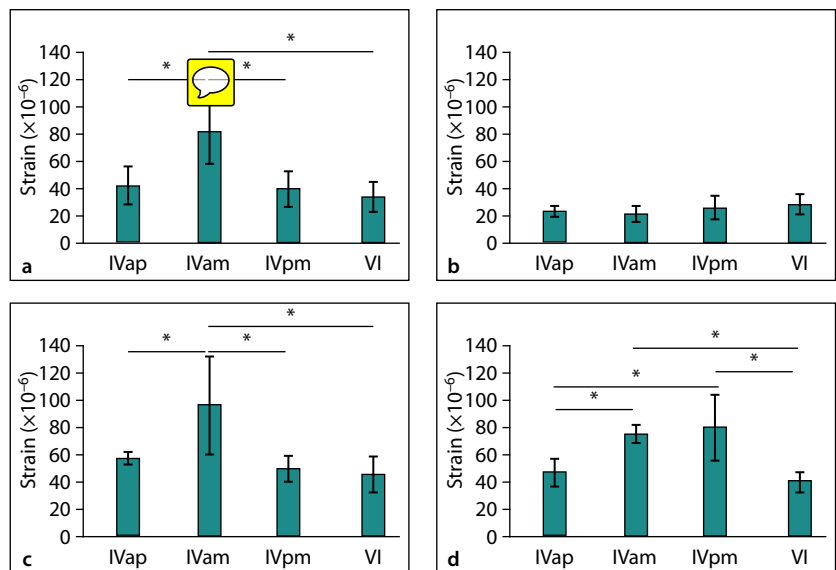


Fig 8 Graphs of the composite strain of the implant (\pm SD) compared with implant configuration. Differences in mean values were analyzed by the one-way ANOVA with a post hoc comparison using the Bonferroni method. (a) Anterior implant. (b) Premolar implant. (c) Molar implant. *Significant difference ($P < .05$). X-axis = implant distribution; y-axis = implant strain; (pl) = denture without palatal coverage.

Fig 9 Graphs of the shear strain (\pm SD) in dentures with different implant configurations. Differences in mean values were analyzed by the one-way ANOVA with a post hoc comparison using the Bonferroni method. *Significant difference ($P < .05$). (a) Shear strain on labial side of denture with palatal coverage. (b) Shear strain on palatal side of denture with palatal coverage. (c) Shear strain on labial side of denture without palatal coverage. (d) Shear strain on palatal side of denture without palatal coverage.



On the palatal side, the strain was greater on the dentures without palatal coverage than on those with palatal coverage, and these differences were significant for all the implant configurations except for VI ($P < .05$; Fig 9).

Effect of Implant Distribution on Implant Strain

In anterior implants, the strain on implants under palateless overdentures was greatest in IVap, and the strain under overdentures with palatal coverage was similar for all implant configurations. In premolar implants, there was no significant difference among the four implants regardless of the presence of palatal coverage, but the strain of overdentures with palatal coverage using six implants was the smallest. In molar implants, the strain on implants under palateless overdentures was greatest in IVam, and there was no significant difference among the other implant distributions (Fig 8).

Effect of Implant Configuration on Denture Strain

In dentures with palatal coverage, the strain was greatest for the IVam implant configuration, and there were



significant differences between IVam and the other three configurations on the labial side ($P < .05$). There was no significant difference among the four implant distributions on the palatal side (Fig 9).

In the palateless dentures, the strain was also the greatest for the IVam configuration, and there were significant differences between IVam and the other three configurations on the labial side ($P < .05$). On the palatal side, there were significant differences among IVam and IVap or VI, and among IVpm and IVap or VI ($P < .05$), but there was no significant difference between IVam and IVap (Fig 9).

DISCUSSION

When planning maxillary IOD treatment, there are many factors to be considered, including mechanical, economical, and patient comfort issues, and clinicians should balance these factors to create the best treatment plan for each patient. It is desirable to induce the least possible strain or stress on the implants and

overdentures, so the design should incorporate measures to decrease such forces. The literature about maxillary IODs has mainly focused on the underlying implants, and the few studies that are related to the overdenture are mainly concerned with functional aspects such as the patients' satisfaction or oral function.^{30,31} A previous systematic review of maxillary IOD treatment recommended that more than four widely distributed implants should be used or that all underlying implants should be connected.³⁰ However, the effectiveness of this recommendation is still unclear because there has been insufficient research into the mechanical aspects of the relationship between overdentures and implant configuration.

Therefore, this study focused on implant configurations and the presence of palatal coverage over splinted implants, and investigated the situation to decrease both implant and denture strains.

Bar Attachment



Bar attachments consist of two main types: resilient and rigid. The resilient type is egg-shaped and the female section can rotate; therefore, the overdenture also rotates slightly, and the load on the implant can be decreased. The rigid type is U-shaped and the female section is fixed, as used in this study; therefore, the overdenture cannot rotate and the load is directly transmitted to the implants. Previous studies indicate that the resilient type is used with a small number of implants, especially when two anterior implants are connected in a mandibular IOD,³² and the rigid type is used with more than four implants.³³ However, one review concluded that use of a resilient bar in a maxillary IOD may result in the transmission of extra force to the implants when the overdenture moves, and this bar should not be used in cases with less than four implants.²⁵ In this study, four or more implants were distributed on both the right and left sides so the overdenture could not rotate, so a rigid bar was used to splint the implants.



When comparing the implant strains of this study with those of previous studies using unsplinted attachments,^{13,14} they were smaller regardless of the implant configurations.

Another important point about the design of the bar attachment is the amount of clearance between the residual ridge and the bar. It has been reported that a clearance of more than 2 mm is necessary to maintain cleanliness around the implant and to achieve appropriate stress distribution.³⁴ Therefore, the present study used a clearance of 2 mm, and the denture base around the bar, especially in the anterior midline area, was consequently thinner, which may have influenced the shear strain. In fact, the strain values were also much greater than those of the present authors' previous studies using isolated attachments in the same experimental

model.⁸⁻¹⁰ It has been suggested that bar attachments may be less favorable for overdentures than isolated attachments, but they are effective in decreasing the implant stress from functional forces.

Comparing Presence or Absence of Palatal Coverage

In the present study, the shear strain on the palatal side of the palateless denture was significantly greater than that on the denture with palatal coverage, except when six implants were used. However, the strain values were smaller than those of the present authors' previous studies using unsplinted attachments, even in palateless dentures.^{8,9} On the labial side, the strain values followed a similar trend and did not differ significantly regardless of the denture type, but the strain values of the palateless denture were slightly higher than those of the denture with palatal coverage.

The present authors' previous study using unsplinted attachments^{13,14} found that the implant strain under palateless dentures was much greater than that under dentures with palatal coverage; this tendency has also been reported in other experimental models.^{20,35} Some studies even recommended that unsplinted attachments should not be used when using palateless dentures.⁵ In this study, significant differences were detected in the implant strain of anterior implants between two types of dentures in each implant distribution. In IVam, significant differences were detected in both anterior and molar implants. The strain on palateless dentures tended to be greater even if the difference between them was not significant. Therefore, palateless overdentures seemed to not be effective in decreasing the implant strain even when the implants were splinted.



Taking these points into consideration, splinting of the implants is thought to be necessary regardless of the palatal shape to reduce the risk of implant and overdenture complications, and palatal coverage should be considered in higher-risk cases, such as those involving short or mini implants or a small number of implants.⁵

Implant Configuration

In past model studies,^{36,37} the stress on implants when using four implants was greater than that when using six implants, but whether these differences are significant has not been clarified. Anterior, premolar, and molar implants are usually used in clinical practice, and combinations of these three positions are used when using four implants. It is not clear which combination is most effective in decreasing the implant strain, as this has not yet been examined in the same model.

Significant differences of strain were detected among implant configurations in the anterior implants: There were significant differences between four implants and

six implants, and only one significant difference in molar implants. In previous studies investigating maxillary IODs,^{23,24} the strain on anterior implants was found to be subject to the implant configuration because the direction of the implants was inclined against the occlusal plane and the strain was much greater than the strain on premolar and molar implants. In the case of IVap, all implants were located only in the anterior half of the maxilla, and there was a lack of posterior support. In the case of IVpm, four implants were used, but only two implants on each side were splinted. Therefore, in these two cases, the effect of the splinted implants was smaller than the other four implant configurations. These results suggest that six implants or a combination of anterior and molar implants is recommended.

In IODs, the implants are thought to assist in preventing denture deformation. In the present study, the strains of anterior implants on the IOD were smaller compared with the results of the present authors' previous studies that used unsplinted attachments^{8,9} in the case of IVap, IVam, and VI. The present study showed that the shear strain on the labial side was greatest in IVam in both types of dentures, and the shear strain values on the labial side were similar to each other in the other three configurations. This is because the bar attachment splinting the anterior and molar implants spanned the longest distance between the implants, and bent more easily than the bars in other configurations. In the other three configurations, the bars were splinted to nearby implants and provided more rigid anchorage; thus, denture deformation could be prevented.

The shear strain on the palatal side was almost equal for all implant configurations in the denture with palatal coverage. However, the shear strain in IVam and IVpm configurations was significantly greater than that for the other two configurations in the palateless denture. In the case of IVam, the same reasons seemed to apply as on the labial side. In the case of IVpm, the implants were located only in the posterior area, and deformation of the anterior area of the IOD could not be prevented. These results suggest that anterior implants are better when using splinted attachments.

Comparing the strain induced in the four implant configurations, the configuration with six implants recorded a smaller strain of implants and dentures in overdentures with and without palatal coverage, and the values were much smaller than those of the present authors' previous studies using unsplinted attachments.^{8,9}

When designing a maxillary IOD, clinicians should place equal importance on the design of both the

implants and the overdenture. Six implants and four implants are currently recommended and have been used appropriately according to the clinicians' judgment. The results of this study suggest that six implants is superior to four implants in reducing the risk of complications of both implants and overdentures from a mechanical point of view. However, some method for preventing denture fracture or deformation, such as reinforcement, should be incorporated into the design even when using splinted attachments. Also, when using four implants under maxillary IODs, anterior and molar implants should be combined, and premolar implants should be optional according to the patient's situation. In higher-risk cases, the overdenture should include palatal coverage.

These findings are based only on mechanical aspects revealed from a model study. Other factors, such as cost and surgical stress, are less optimal when using six splinted implants compared with using four implants.

CONCLUSIONS

In this study, it was revealed that the strain of splinted implants and overdentures was influenced by the implant distribution and the presence of palatal coverage of the overdenture. Within the limitations of this study, the following conclusions were revealed:

- The shear strain on overdentures using splinted attachments was lower when six or two anterior and two premolar implants were used, and the greatest strain was recorded when two anterior and two molar implants were used.
- The shear strain on the palatal side of the overdenture was significantly greater on palateless overdentures than on overdentures with palatal coverage when four implants were used, regardless of their configuration. However, the difference between the two overdenture types was not significant when six implants were used.
- The strain of anterior and premolar implants when using six implants was smaller than that when using four implants.
- The strain of implants was smaller when using an overdenture with palatal coverage than when using a palateless overdenture except for the use of two premolar and two molar implants.
- The strain of anterior implants was greater when using a palateless overdenture in all implant configurations compared with using an overdenture with palatal coverage.

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