

RESEARCH AND EDUCATION

In vitro variation measurement of mandibular denture displacement resistance involving 1 to 3 implants



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The McGill consensus statement declared that an overdenture retained by 2 implants should be the first choice of treatment for an edentulous patient because the implants provide sufficient retention and stabilization for the overdenture and economic benefit for the patient.^{1,2} An overdenture supported by 3 implants displays better retention and less prosthesis movement than a 2-IOD.³ Recently, in consideration of cost-effectiveness and the increased operative invasiveness of additional implants, rehabilitation with a single-implant overdenture has been proposed as a valid treatment option to eliminate the functional difficulties and discomfort associated with conventional mandibular dentures.^{4,5}

Conventional dentures are hard and nonresilient, with no capacity to assimilate or dissipate pressure. Flaws, cracks, and weaknesses in the denture

ABSTRACT

Statement of problem. Single-implant-retained mandibular overdentures (1-IODs) may be an alternative to 2-IOD for maladaptive denture patients giving comparable satisfaction, lower cost, and shorter treatment times. However, studies evaluating the effect of the number of implants on the strain exerted around the implants of IODs using strain-gauge analysis are lacking.

Purpose. The purpose of this in vitro study was to evaluate the effect of the number of implants on the strain in an IOD under various loading and dislodging conditions.

Material and methods. A mandibular IOD with the Locator attachment system (pink nylon inserts) was fabricated on artificial mucosa. Three implant positions recorded the loading: 1-IOD (mid-anterior), 2-IOD (bilateral lateral incisor), and 3-IOD (mid-anterior and bilateral canine) were prepared. Strain gauges attached to the mid-anterior implant replica for the 1-IOD, the left lateral incisor replica for the 2-IOD, and the anterior and left canine replicas for the 3-IOD. Vertical loads of 50 N were applied to the experimental overdenture in the mid-anterior and right molar and left molar regions. Three dislodging tests were performed in 3 different areas: mid-anterior, posterior, and mid-anterior and bilateral molar. Six measurements were made under each loading and dislodging condition for each IOD (N=6). During the calibration test, the resultant strain measured by strain gauge was converted into a lateral force (F) value by using linear regression: $F_{\text{anterior-posterior}}(N)=1.08 \times \text{strain} (\mu\epsilon)$, $F_{\text{posterior-anterior}}(N)=0.192 \times \text{strain} (\mu\epsilon)$, $F_{\text{left-right}}(N)=0.590 \times \text{strain} (\mu\epsilon)$, $F_{\text{right-left}}(N)=0.560 \times \text{strain} (\mu\epsilon)$. Statistical analysis was performed by using 1-way ANOVA and the Tukey honestly significant difference test ($\alpha=.05$).

Results. The 3-IOD demonstrated the significantly highest strain under loading and dislodging conditions ($P<.05$). The 1-IOD demonstrated the significantly highest strain during right-side loading ($P<.05$). Upon anterior and left-side loading, no significant difference was noted in strain between the 1-IOD and 2-IOD ($P=.413$, $P=.272$). Under dislodging conditions, the 1-IOD exhibited the significantly lowest strain ($P<.05$).

Conclusions. Within the limitations of this study, the 3-IOD demonstrated the highest lateral resistance force during load and dislodge testing, whereas the 1-IOD exhibited the lowest. (J Prosthet Dent 2019;121:492-7)

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Clinical Implications

The number of implants used to secure mandibular IODs influences the amount of strain around the implants. The use of a single implant may exert the lowest amount of strain, making it an option for maladaptive denture patients.

base can eventually propagate through the denture, resulting in bone deformation, resorption, and fatigue fracture. In 1-IODs, most of the force is loaded on the mucosa of the dental bearing area. By increasing the number of implants, loading force can be shared by the implants, resulting in increased strain values in the bone around the implant.⁶ Biomechanical behavior analyses of IODs can help clinicians to understand stress distribution in the implants. The stress distribution of the IOD under the occlusal load has been investigated, with focus on the strain and stress analysis of the IOD with different attachment systems^{7,8} and number of implants.^{9,10} Maeda et al¹¹ examined the lateral forces of 1-IOD and 2-IOD systems using dome-type magnet and ball attachments and reported no difference between the 2 systems. Arat Bilhan et al¹² calculated the stress distribution in the bone tissue supporting 2 to 4 implants with ball and bar attachments, using 3-dimensional finite element analysis; they reported that an increase in implant number can lead to reduced stress around the implants, and a 2-IOD appeared to be the safest treatment option. Liu et al⁶ evaluated strain distribution in the implant bone with mandibular overdentures supported by 1 to 4 implants under 3 different types of load. They reported that the stress in the abutments of the 2-IOD was highest and that no damaging strain was found in the implant bone for the 1-IOD.

However, the authors are unaware of a study evaluating the effect of implant number on the strain around the implants of IODs using strain-gauge analysis. Therefore, in this *in vitro* study, the strain effect on the implants of 1-IOD, 2-IODs, and 3-IODs was measured and recorded using strain-gauge analysis under 3 different loading and dislodging conditions; the results were then compared after converting the strain measurements to lateral force values. The null hypothesis was that the number of implants would have no influence on the strain around the Locator abutments of mandibular IODs under the different loading and dislodging conditions.

MATERIAL AND METHODS

Strain gauges were used to measure the dimensional change of the Locator abutment when the overdenture

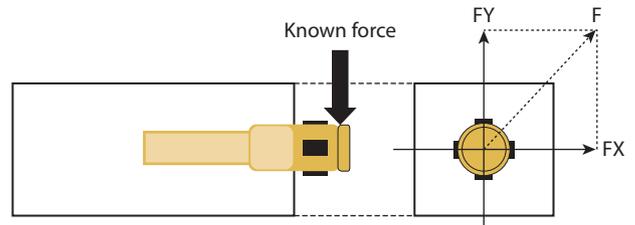


Figure 1. Experimental design. Implant replica inserted into acrylic resin block and Locator abutment placed onto implant replica. Four uniaxial strain gauges glued to anterior, posterior, left, and right surfaces of Locator abutment. Resultant strain measurements recorded by 2 pairs of strain gauges facing each other and lateral forces in 2 mutually orthogonal directions (FX and FY) obtained.

was under force. As the strain gauges could not directly evaluate the force borne by the abutments, calibration of the strain-force relationship was required.

An acrylic resin block was prepared for calibration. An implant replica (Implant Replica NobelReplace RP; Nobel Biocare) was placed into the calibration block, and a stud abutment (Locator Abutment NobelReplace RP 4 mm; Nobel Biocare) was installed onto the implant replica. Four uniaxial strain gauges (KFRS-02-120-C1-13; Kyowa Electronic Instruments Co Ltd) were glued to the anterior, posterior, left, and right surfaces of the Locator abutment using cyanoacrylate adhesive (Aron Alpha; Toagosei Co Ltd), parallel to the abutment's long axis (Fig. 1). The block was held so that the axis of the abutment was horizontal. Known forces (5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 N) were applied to the Locator abutment perpendicular to its long axis in 4 directions (anterior-posterior; posterior-anterior; left-right; and right-left) by using a universal testing machine (Instron Model 5544; Instron Corp). When the block was rotated on the axis of abutment, the output from the x-axis strain gauge was maximum, and the output from the y-axis strain gauge was minimum. The x-axis strain gauge was the calibrated value from the known force. Six measurements were made for each of the 4 directions under the 10 known forces.

The relationships between the known forces and resultant strains from each strain gauge were approximately linear, and the resultant strain for each strain gauge was converted into a lateral force (F) value using linear regression: $F_{\text{anterior-posterior}}(\text{N})=1.08 \times \text{strain} (\mu\epsilon)$ ($R^2=0.9817$), $F_{\text{posterior-anterior}}(\text{N})=0.192 \times \text{strain} (\mu\epsilon)$ ($R^2=0.9650$), $F_{\text{left-right}}(\text{N})=0.590 \times \text{strain} (\mu\epsilon)$ ($R^2=0.9991$), $F_{\text{right-left}}(\text{N})=0.560 \times \text{strain} (\mu\epsilon)$ ($R^2=0.9996$). The calibration of the strain gauges was then converted from strain to lateral force. The resultant strain measurements were recorded by 2 pairs of strain gauges facing one another, and the lateral forces in 2 mutually orthogonal directions (FX and FY) were obtained (Fig. 1). The 2 directions were X=right-left and Y=anterior-posterior. However, the



Figure 2. Three implant overdenture configurations used: 1-IOD (mid-anterior), 2-IOD (bilateral lateral incisor regions), and 3-IOD (mid-anterior and bilateral canine regions). IOD, implant overdenture.

lateral forces (F) were calculated by using the following formula: $F = (FX^2 + FY^2)^{1/2}$.

One experimental edentulous mandibular model was fabricated using a heat-polymerizing acrylic resin (Acron Clear; GC Corp). The elastic behavior of the acrylic resin is similar to the spongy bone of the anterior region of the mandible.¹³ A 3-mm-thick layer of silicone impression material (Exahiflex Cartridge; GC Corp) was used to simulate the mucosa. The elastic modulus of silicone material was in the same range as oral mucosa.¹⁴ Five implant replicas were placed parallel to one another in the anterior midline, bilateral lateral incisor, and bilateral canine regions of the mandibular cast. Three implant positions were modified on the mandibular cast by changing the location of the stud abutments: 1-IOD (mid-anterior), 2-IOD (bilateral lateral incisor regions), and 3-IOD (mid-anterior and bilateral canine regions; Fig. 2).¹⁵ The 4 strain gauges were glued to the buccal, lingual, mesial, and distal sides of the stud abutment on the mandibular model. The stud abutment, with the attached strain gauges, was placed onto the mid-anterior implant replica for the 1-IOD, the left lateral incisor replica for the 2-IOD, and the anterior and left canine replicas for the 3-IOD. All tests were conducted using this model.

An experimental overdenture was fabricated from autopolymerizing resin (Procast DSP; GC Corp). Five metal caps (Locator Male Processing Pkg; Nobel Biocare) with pink nylon inserts (Extra Light Retention Replacement Male 3Lbs/1360g [pink]; Nobel Biocare)¹⁶ were incorporated into the anterior midline, bilateral lateral incisor, and bilateral canine regions of the intaglio surface of the experimental overdenture. Three metal hooks were installed at the mid-anterior and bilateral molar regions of the buccal surface of the experimental overdenture for the dislodging tests (Fig. 3).



Figure 3. Experimental mandibular overdenture with 5 pink nylon inserts and 3 hooks in different dislodging areas.

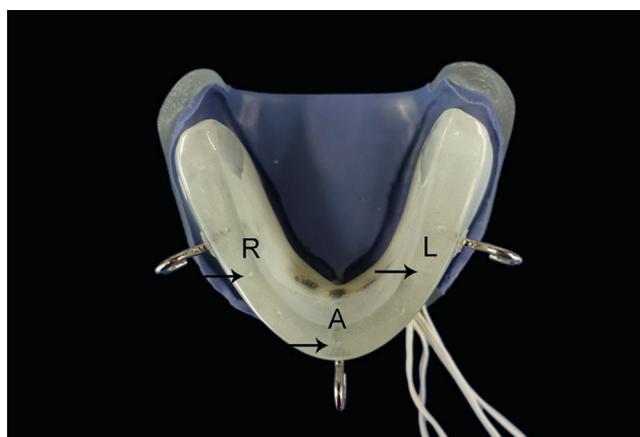


Figure 4. Three loading points on experimental overdenture: mid-anterior (A), right molar (R), and left molar (L) regions.

Loading tests were performed using a universal testing machine with a 5-mm-diameter acrylic resin ball. Vertical loads of 50 N were applied to the occlusal plane of the experimental overdenture in the mid-anterior, right molar, and left molar regions with a crosshead speed of 10 mm/min (Fig. 4). The loading force was equivalent to the average occlusal force of edentulous patients.¹⁷ The lateral force was obtained from the resultant strain measurements. Six measurements were made for each of the 3 different loading points (N=6).

Three chains were attached to the experimental overdenture in 3 different areas for the 3 dislodging tests: anterior dislodgement (mid-anterior area), posterior dislodgement (bilateral molar areas), and anterior-posterior dislodgement (mid-anterior and bilateral molar areas; Fig. 5).¹⁰ Six consecutive pull-separation measurements for each group were made in the vertical direction by using the universal testing machine with a crosshead speed of 50 mm/min; this speed has been reported as that at which a patient's denture moves away from the edentulous ridge.¹⁸ The resultant strain

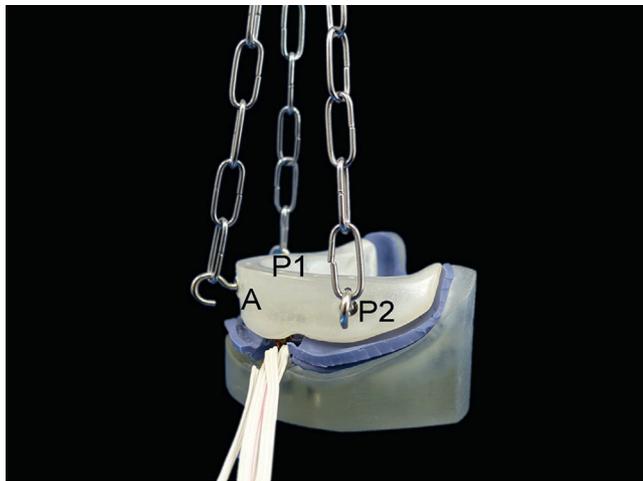


Figure 5. Three types of dislodging tests. Anterior dislodging test with 1 chain (chain A), posterior dislodging test with 2 chains (chains P1 and P2), and anterior-posterior dislodging test with 3 chains (chains A, P1, and P2).

was measured and then converted to a lateral force value.

The lateral force values were analyzed using 1-way ANOVA and the post hoc Tukey honestly significant difference test to identify statistically significant differences among the number of implants. All statistical analyses were performed using statistical analysis software (SPSS Statistics v17.0; SPSS Inc) ($\alpha=.05$).

RESULTS

With anterior loading, the anterior and canine implants of the 3-IOD exhibited significantly higher strain than the implants of the 1-IOD and 2-IODs ($P<.05$). With left-side loading, the anterior and canine implants of the 3-IOD had the significantly lowest and significantly highest strain ($P<.05$), respectively. With right-side loading, the strain in the implant of the 1-IOD was significantly higher than that in both the 2-IODs and 3-IODs ($P<.05$) (Table 1).

During all types of dislodging conditions, the 3-IOD demonstrated the highest strain ($P<.05$). During posterior pull, the canine implants of the 3-IOD exhibited higher strain than the others ($P<.05$). During anterior-posterior pull, the strain of the anterior implant of the 3-IOD was the highest ($P<.05$). The 1-IOD exhibited the lowest strain during all dislodging conditions ($P<.05$) (Table 2).

DISCUSSION

In this study, overdentures anchored to an edentulous cast with implants of varying number and position were subjected to various forces. The results suggest that the number of implants used to retain a mandibular overdenture has a significant influence on the lateral force

Table 1. Mean \pm standard deviation lateral force (N) of 3 types of implant-maintained mandibular overdentures (IOD) under various loading conditions

Loading Region	Type of IOD				(Comparison) P
	1-IOD	2-IOD	3-IOD		
			Anterior	Left Canine	
A	8.9 \pm 1.8	11.3 \pm 0.4	19.5 \pm 4.4	16.4 \pm 2.3	(1-IOD versus 2-IOD)=.413
					(1-IOD versus 3-IOD A)<.05
					(1-IOD versus 3-IOD C)<.05
					(2-IOD versus 3-IOD A)<.05
					(2-IOD versus 3-IOD C)<.05
					(3-IOD A versus 3-IOD C)=.219
L	10.4 \pm 0.4	9.6 \pm 0.8	2.3 \pm 0.7	16.4 \pm 0.7	(1-IOD versus 2-IOD)=.272
					(1-IOD versus 3-IOD A)<.05
					(1-IOD versus 3-IOD C)<.05
					(2-IOD versus 3-IOD A)<.05
					(2-IOD versus 3-IOD C)<.05
					(3-IOD A versus 3-IOD C)<.05
R	10.2 \pm 0.3	5.4 \pm 0.6	5.5 \pm 0.5	3.9 \pm 0.4	(1-IOD versus 2-IOD)<.05
					(1-IOD versus 3-IOD A)<.05
					(1-IOD versus 3-IOD C)<.05
					(2-IOD versus 3-IOD A)=.989
					(2-IOD versus 3-IOD C)<.05
					(3-IOD A versus 3-IOD C)<.05

P<.05 Tukey honestly significant difference test. 3-IOD A: Strain gauges located on 3-IOD anterior abutment. 3-IOD C: Strain gauges located on 3-IOD canine abutment.

around the implant abutments during loading and dislodging conditions. Therefore, the null hypothesis was rejected.

On mid-anterior loading, the 3-IOD had the significantly highest lateral force around the implants. This result may have occurred because the 3 implants prevented rotation of the overdenture. The absence of a fulcrum line with the 3-IOD provides good denture stability. However, higher stability can lead to the implants bearing more stress. A previous study determined that the vertical displacement of a 3-IOD was significantly smaller than that of a 2-IOD¹⁷ and that the implant abutments of a 3-IOD had the highest lateral force.

With left-side loading, the canine implant of the 3-IOD demonstrated the highest lateral force because the

Table 2. Mean \pm standard deviation lateral force (N) of 3 types of implant-maintained mandibular overdentures (IOD) under various dislodging conditions

Dislodging Region	Type of IOD				(Comparison) <i>cx P</i> value
	1-IOD		3-IOD		
	1-IOD	2-IOD	Anterior	Left Canine	
A	4.9 \pm 1.4	11.9 \pm 1.0	17.6 \pm 0.8	16.4 \pm 1.2	(1-IOD versus 2-IOD) <.05 (1-IOD versus 3-IOD A) <.05 (1-IOD versus 3-IOD C) <.05 (2-IOD versus 3-IOD A) <.05 (2-IOD versus 3-IOD C) <.05 (3-IOD A versus 3-IOD C) = .388
P1 and P2	3.6 \pm 0.3	8.1 \pm 0.6	16.6 \pm 0.8	19.1 \pm 2.2	(1-IOD versus 2-IOD) <.05 (1-IOD versus 3-IOD A) <.05 (1-IOD versus 3-IOD C) <.05 (2-IOD versus 3-IOD A) <.05 (2-IOD versus 3-IOD C) <.05 (3-IOD A versus 3-IOD C) = .013
A, P1, and P2	3.5 \pm 0.7	11.3 \pm 0.8	19.5 \pm 1.1	18.0 \pm 0.8	(1-IOD versus 2-IOD) <.05 (1-IOD versus 3-IOD A) <.05 (1-IOD versus 3-IOD C) <.05 (2-IOD versus 3-IOD A) <.05 (2-IOD versus 3-IOD C) <.05 (3-IOD A versus 3-IOD C) = .049

Data presented as mean (SD) unless otherwise indicated. *P* < .05 Tukey honestly significant difference test. 3-IOD A: Strain gauges located on 3-IOD anterior abutment. 3-IOD C: Strain gauges located on 3-IOD canine abutment.

loading point was close to the strain gauge on the canine abutment and the canine implant acted as the fulcrum for the loading force. Meanwhile, the anterior implant of the 3-IOD had the lowest lateral force because the lateral force was sustained by the canine implant. These results support a previous report that a 3-IOD does not experience high strain in the middle implant and that maximum strain is experienced on the same side of loading.⁶

With right-side loading, the 2-IOD and 3-IOD demonstrated lower lateral forces than the 1-IOD, owing to the position of the load being applied. The lateral force of the 1-IOD was approximately the same as that of the 2-IOD and 3-IOD during anterior and left-side loading. By comparing the lateral forces, the 1-IOD was found to be the most acceptable option under

the loading conditions. Overall, the implants did not experience high lateral forces during right-side loading.

During the dislodging tests, regardless of the position in which the dislodging force was applied, the 3-IOD exhibited the highest lateral force, followed by the 2-IOD, then the 1-IOD. This result indicates that the 1-IOD separated from the abutments under dislodging forces from various directions, whereas the 2-IODs and 3-IODs exhibited limited separation. These results agree with those of a previous study that also indicated that increasing implant numbers leads to increased retention.⁹

During posterior pull, the canine implants of the 3-IOD exhibited higher lateral force than the others; owing to a dislodging position close to the strain gauge on the canine abutment, the anterior abutment became the fulcrum leading to the highest lateral force in the canine abutment. During anterior-posterior pull, the lateral force of the anterior implant of the 3-IOD was the highest; because the distance between the anterior abutment and anterior dislodging position was shorter than the distance between the canine abutment and posterior dislodging position, the canine abutments became the fulcrum. This led to a higher lateral force on the anterior abutment than on the canine abutment. Moreover, higher retention led to higher lateral forces on the implants during dislodgment. Because the 3-IOD applied the highest lateral force to the implants during dislodgment, this force is important in overdenture. As the authors are unaware of other studies that compared the effect of different implant numbers on the lateral force during dislodging conditions, the results of the dislodging tests in this study should be considered in choosing the number of implants to anchor an overdenture.

In clinical situations, the number of implants affects the treatment outcomes of mandibular IODs. Considering the influence of stress on bone tissue and the implant abutments, strain analysis could improve the clinical success rate of IODs. The high lateral force exerted at the implant abutments generated by 3-IODs appears to suggest a continued cautious approach to the clinical selection of the number of implants used. As fewer implants resulted in less lateral force, the 1-IOD could be the optimal choice in clinical treatment because of the lowest lateral force exerted on the implant abutments. These results are consistent with previous studies.^{5,10}

Retention and strain gauge position are important factors affecting strain values; therefore, the ranking of the results in a clinical situation would be similar to the ranking in this *in vitro* study. However, to obtain more accurate strain predictions, different factors should be considered, including the fabrication of the denture model, bone implant interface, boundary conditions, and properties of the materials in wet conditions. The retention of Locator attachments in water at body

temperature (37°C) has been reported not to be significantly different from that in dry conditions.¹⁶ However, the elastic modulus of denture resin is different under actual oral conditions; the amount and direction of the force required to remove an overdenture and the denture-bearing mucosa in this study differed from an actual clinical situation. Therefore, strain was analyzed using a simplified model that could not simulate clinical situations such as the properties of occlusal load. In future research, the strain on the implants should be assessed intraorally in both the vertical and oblique directions. The effect of type of implant attachment, denture base materials, saliva, location of strain gauge, reinforcement of denture base material with metal, and coverage of the mucosa-bearing area should also be evaluated.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. The number of implants used to anchor a mandibular overdenture had a significant influence on the strain in the Locator abutments.
2. The 3-IOD demonstrated the highest strain in the implant abutments under the load and dislodging conditions.
3. The 1-IOD exhibited the lowest strain under each type of dislodging condition.

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