

Effect of Implant Position and Attachment Type on the Biomechanical Behavior of Mandibular Single Implant Prostheses

Keywords

Strain Gauge
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Attachment Type
Prosthesis Displacement

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ABSTRACT

This study aimed at evaluating different implant positions and attachment systems for mandibular single implant prostheses (MSIP) with respect to loading of bone and prosthesis displacement. A model with three interforaminal implants served as a basis. Four prostheses differing in the attachment type used (ball anchor, locator, rigid telescopic crown, non-rigid telescopic crown) were fabricated. During occlusal loading, the prostheses were either supported by a midline implant, the left canine implant or the two canine implants. Strain and displacement measurements conducted during loading were quantitatively compared. In general, molar loading led to high levels of prosthesis displacement while loading in the incisor area caused higher strains at the supporting implants and unilateral loading led to an unequal distribution of strains. Using the canine implant instead of the midline implant for support resulted in greater magnitude and disparity of loading while the use of two implants had no clear advantage. The use of telescopic crowns led to inconsistent results. None of the attachments seems to be ideal as they all transferred strain to the supporting implant. In particular, the unequal distribution of strain indicative of moment loading is of concern. An alternative attachment system with a consistent cushioning effect seems desirable.

INTRODUCTION

The use of two implants for retaining a mandibular complete denture is a classic treatment option¹ which is still relevant today. Numerous articles have focused on the use of different attachment systems for such prostheses often resulting in contradictory findings with respect to maintenance and peri-implant conditions.²⁻⁴ There seems to be consensus however, that non-homogeneous implant loading should be avoided,^{1,5} that non-parallel implants result in greater wear of the attachments⁶ and that higher retention of the attachments also causes greater stress.⁷

Despite the higher laboratory fees associated with individually fabricated attachments as compared to prefabricated components,⁸ different types of telescopic crowns¹ have also been applied with good long-term results.^{9,10} Other than with prefabricated attachments for which inserts with different levels of retention are available, adjusting an equilibrated retention of telescopic crowns has been shown to be difficult.¹¹

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Additional factors influencing the performance of removable restorations which can hardly be controlled by the treating clinician include the cross-sectional shape of the alveolar process, the outer form of the mandible and mandibular deformation during function.¹² Also, the presence or absence of contact between the denture base and the supporting tissue¹³ as well as the varying thickness and resiliency of the mucosa¹⁴ may be relevant factors partially causing the contradictory findings mentioned above.

In comparison with the use of two interforaminal implants, utilizing one single implant in the mandibular midline for retaining a complete denture represents a rather novel treatment modality. While high levels of implant survival over ten years have recently been reported,¹⁵ prosthetic maintenance¹⁶ seems to be high with fractures of the prostheses representing a frequent incident.¹⁷ With respect to overall behavior and clinical performance, mandibular single implant prostheses (MSIP) have been claimed not to differ from restorations supported by two implants.^{18,19} Several authors have pointed out that the presence of the mandibular lingual vascular canal may be a risk factor associated with MSIP.²⁰⁻²²

It was the goal of this *in vitro* study to compare different attachment types and implant positions for the MSIP concept with respect to implant loading and prosthesis displacement under simulated masticatory loading. A mandibular overdenture supported by two implants served as control. The null hypothesis tested was that neither implant position and implant number nor attachment type had an effect on peri-implant strain and prosthesis displacement.

MATERIALS AND METHOD

A mandibular acrylic resin model (ProBase Cold) received three bone level implants (SCIP1042) in the midline and canine regions (*Figure 1*). Unidirectional strain gauges (LY11-0.6/120, 120 Ω reference resistance) were attached mesially and distally adjacent to each implant.^{1,19,23,24} Posteriorly, the alveolar process was horizontally split and metal rods were incorporated in the model material allowing for extensometers (Extensometer) to be attached.²⁵ A soft tissue mask made from polyether material (Vestogum) completed the model.²⁶ Transfer copings for open-tray impressions (AGM-302-C), a custom tray (PalatrayXL) and polyether impression material (Impregum) were subsequently used for transferring the model situation onto a master cast (Fujirock EP).

Four identical prostheses (*Figure 2*) incorporating different attachments for all three implants were fabricated on the master cast. Besides prefabricated locator-type attachments with medium-type matrices (AGM-106-2) and ball anchors (AGM-105-2C), rigid and non-rigid telescopic crowns¹ were used (*Figure 3*). To this end, the primary telescopic crowns were fabricated on the basis of screw-retained abutments (AGM-207-2H) using dental training alloy (Phantom-Metall NF) and employing standard casting and milling procedures. While for the rigid telescopic crowns a tight fit between primary and secondary crown was achieved, an occlusal space of 0.3mm and a circular space of 0.03mm was introduced in the non-rigid telescopic crowns. No further instructions were provided to the laboratory technician who adjusted the retention of the telescopic crowns as would be done for a clinical case.

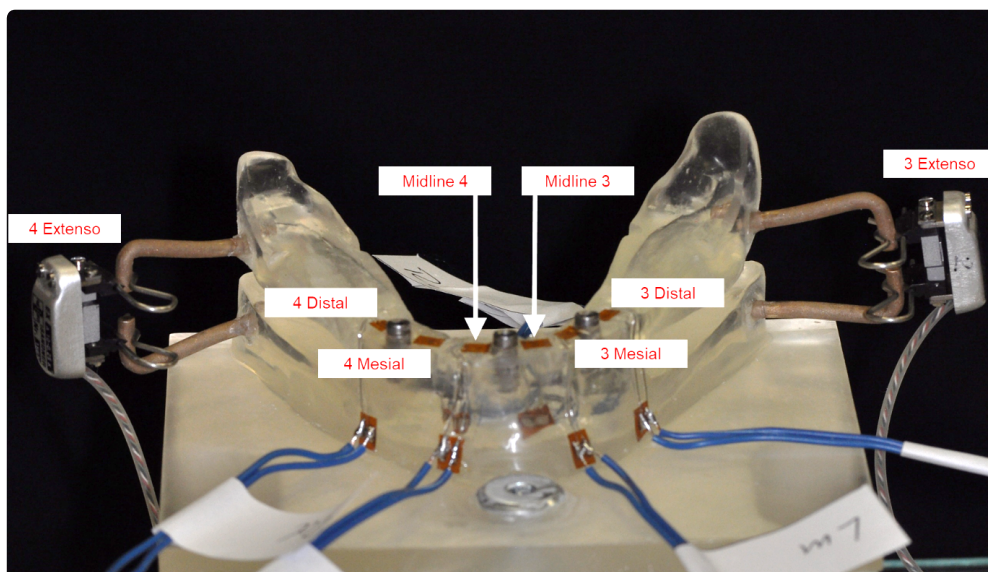


Figure 1: Mandibular acrylic resin model with three bone level implants placed in the midline and in the canine positions. Strain gauges were added to the model material mesially and distally adjacent to the implants and extensometers were attached in the posterior region for measuring prosthesis displacement.



Figure 2: Four identical mandibular complete dentures were fabricated and subsequently used to incorporate different attachment systems

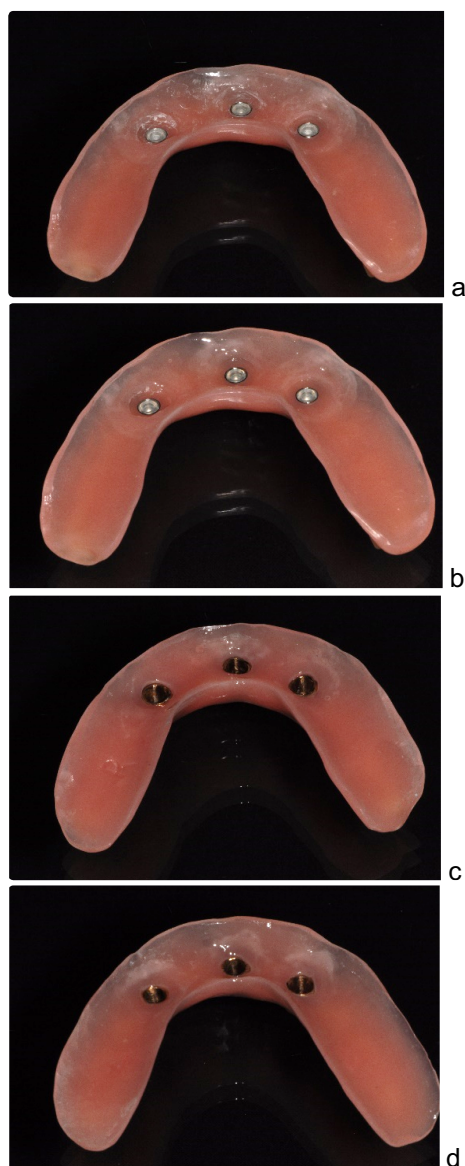


Figure 3: Basal aspects of the four prostheses showing the matrices of the attachment systems used: Locator (a), Ball anchor (b), Rigid telescopic crown (c), Non-rigid telescopic crown (d)

All prostheses could be positioned on the acrylic resin model either employing only the midline implant or the left canine implant (position 33 FDI) or both canine implants (positions 33 and 43 FDI) while the remaining implants were left without an abutment. Following positioning in a universal testing machine (Z20), a force of 100N was applied in the second premolar / first molar area or in the left canine area or in the anterior midline region.²⁷ A measurement amplifier (Quantum X) and analyzing software (jBEAM) were used for recording maximum strains at the supporting implants and maximum displacement at the extensometers during loading.

Statistical analysis was based on the absolute values of both strain and displacement data. Mean values for the two parameters periimplant strain and prosthesis displacement were calculated for each prosthesis type under each loading condition. These were statistically analysed applying the Welch test for equal means and the Games-Howell test for pairwise differences with the level of significance set at $\alpha=0.05$.

RESULTS

MIDLINE IMPLANT

Molar loading led to high levels of prosthesis displacement while the strains measured at the supporting implant were low. On the contrary, loading in the incisor area caused higher strains at the implants and less prosthesis displacement. Unilateral loading led to increased strains at the contralateral side of the supporting implant and to an unequal distribution of strains (Figure 4a, Table 1).

Considering molar loading, using the rigid telescopic crown led to greater prosthesis displacement as compared to all other attachment systems ($p \leq 0.003$). The lowest strains were measured when the ball anchor was used leading to a significant difference as compared to the rigid ($p=0.000$) and non-rigid ($p=0.005$) telescopic crown. During left canine loading as well as during incisor loading, no statistically significant differences could be observed for pairwise comparisons between attachment types. When the right canine was loaded, the rigid telescopic crown showed strains significantly greater as compared to the locator attachment ($p=0.001$) while the ball anchor showed significantly higher strain levels as compared to the non-rigid telescopic crown ($p=0.001$).

IMPLANT 33

Changing the position of the supporting implant to the left canine further pronounced the situation observed with the midline implant i.e. molar loading led to even greater prosthesis displacement, incisor loading led to greater strains at the supporting implant and unilateral loading led to an even greater strain disparity (Figure 4b, Table 1). No significant differences between the attachment systems used could be observed with respect to the strains measured at the supporting implant regardless of the loading situation

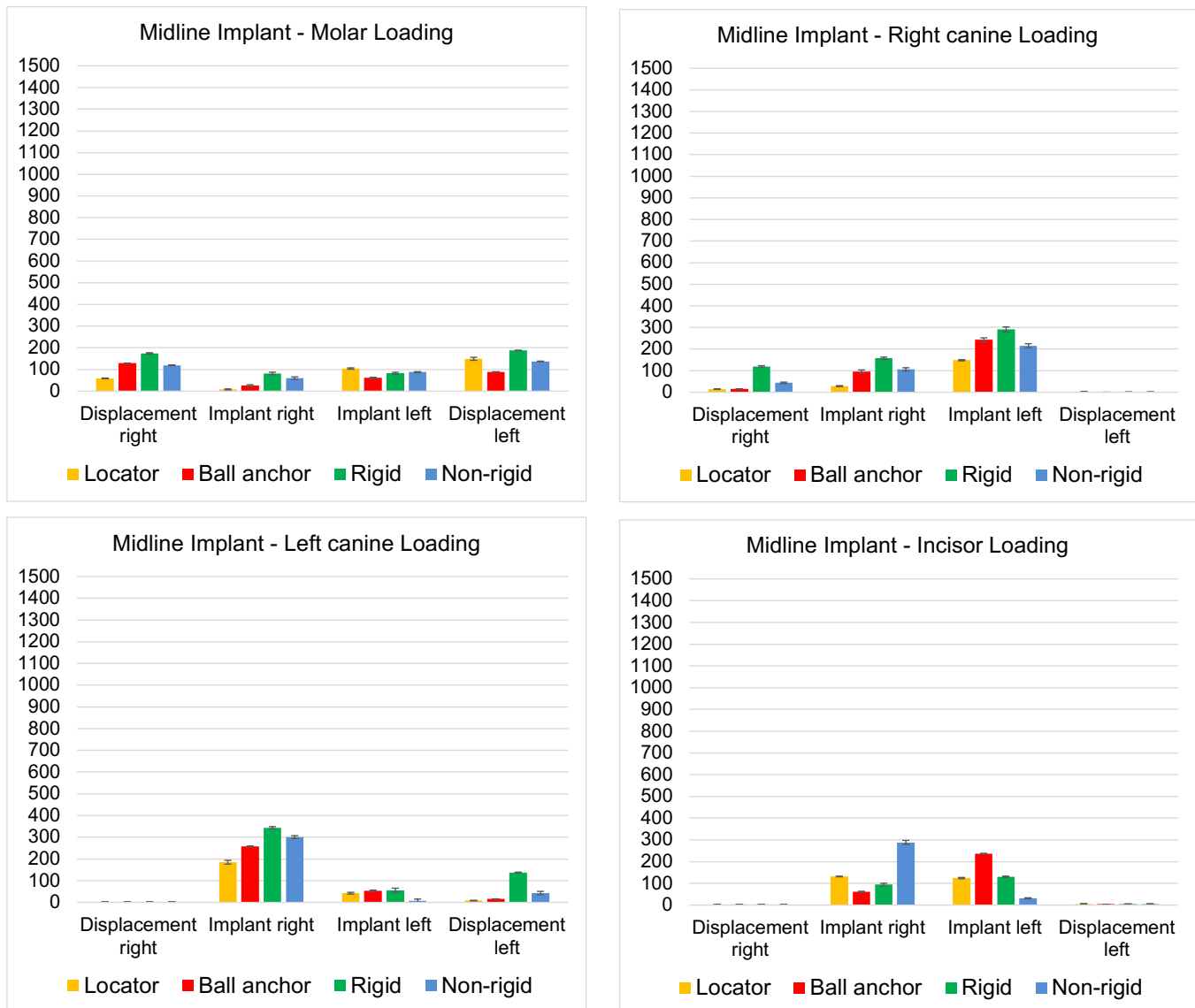


Figure 4a: Strain and displacement data measured during loading in different locations when using the midline implant for supporting the mandibular prosthesis

simulated. Similarly, no differences in prosthesis displacement were observed when loading in the molar area or in the area of the left or right canine was simulated. Under incisor loading, maximum prosthesis displacement was seen with the use of the non-rigid telescopic crown which was significant as compared to ball anchor ($p=0.028$) and rigid telescopic crown ($p=0.021$). Significantly less prosthesis displacement was recorded with the use of the rigid telescopic crown as compared to the use of the locator ($p=0.034$).

IMPLANTS 33 AND 43

As observed with the use of one single supporting implant, molar loading caused greater values for prosthesis displacement than incisor loading while unilateral loading resulted in non-homogeneous strain distribution (Figure 4c, Table 1). Under molar loading, significant differences between the attachment systems were only recorded with respect to prosthesis displacement where the non-rigid telescopic crowns

showed significantly greater values as compared to ball anchors ($p=0.028$) and rigid telescopic crowns ($p=0.026$). During left canine loading, the non-rigid telescopic crowns showed the highest level of periimplant strain which was significant as compared to rigid telescopic crowns and locators ($p=0.000$). On the other hand, ball anchors showed significantly greater strain development as compared to rigid telescopic crowns ($p=0.027$). In terms of prosthesis displacement, the non-rigid telescopic crowns showed significantly greater values as compared to locators ($p=0.029$). When loading was exerted in the area of the right canine, the non-rigid telescopic crowns caused both maximum prosthesis displacement and periimplant strain. With respect to periimplant strain, differences as compared to locator ($p=0.011$) and rigid telescopic crown ($p=0.019$) reached the level of significance. In terms of prosthesis displacement, significant differences were observed between non-rigid telescopic crowns and both, locators ($p=0.029$) and ball anchors ($p=0.018$) as well as between

Table 1. Results of comparisons within specific prosthesis and loading groups based on Welch test for equal means and the Games-Howell test for pairwise differences of implant strain and prosthesis displacement. Significant differences (p<0.05) are written in bold.

	Midline Implant			Implant 33			Implants 33 & 43		
	Welch test	Games-Howell	Prosthesis displacement Welch test	Welch test	Games-Howell	Prosthesis displacement Welch test	Games-Howell	Welch test	Prosthesis displacement
Molar Loading		Rigid vs. Ball anchor 0.000	Rigid vs. Locator 0.003						Non-rigid vs. Ball anchor 0.028
	0.000	Non-rigid vs. Ball anchor 0.005	Rigid vs. Ball anchor 0.000	0.117		0.038	0.648	0.002	Non-rigid vs. Rigid 0.026
Left canine Loading	0.432		0.014	0.213	0.006				
							Non-rigid vs. Locator 0.000	0.005	Non-rigid vs. Locator 0.029
Right canine Loading	0.003	Rigid vs. Locator 0.001	0.041	0.368	0.005		Non-rigid vs. Locator 0.011	0.000	Non-rigid vs. Locator 0.029
		Non-rigid vs. Ball anchor 0.001					Non-rigid vs. Rigid 0.019	0.000	Rigid vs. Ball anchor 0.000
Incisor Loading	0.134		0.074	0.063	0.001		Non-rigid vs. Ball anchor 0.028	0.004	Non-rigid vs. Ball anchor 0.000
							Non-rigid vs. Rigid 0.021	0.000	Rigid vs. Ball anchor 0.012

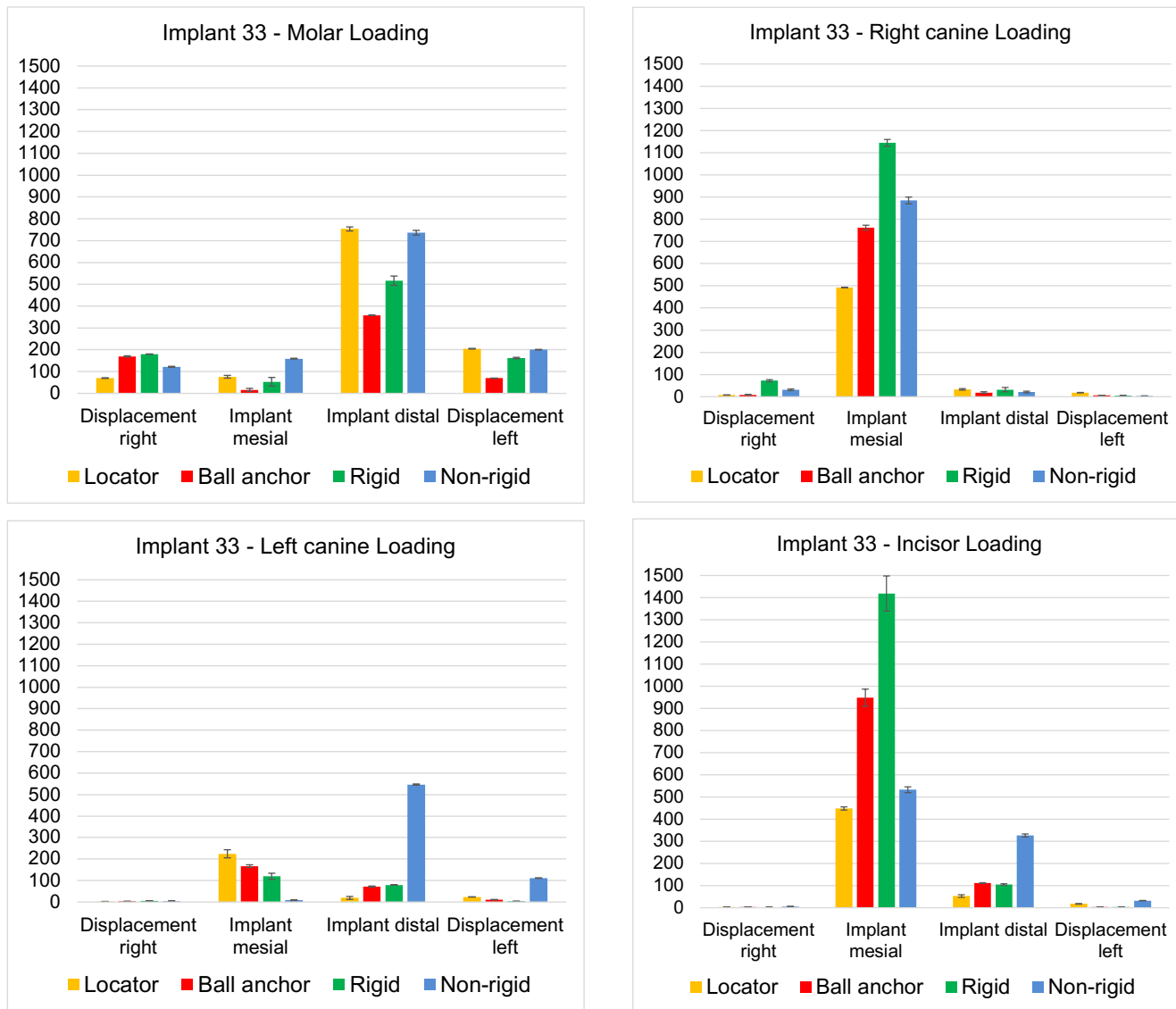


Figure 4b: Strain and displacement data measured during loading in different locations when using the left canine implant for supporting the mandibular prosthesis

rigid telescopic crowns and ball anchors ($p=0.000$). Under incisor loading, greatest periimplant strain was again seen with non-rigid telescopic crowns reaching a significant difference as compared to the use of locator attachments ($p=0.015$). Significantly lower prosthesis displacement was seen when ball anchors were used as compared to non-rigid ($p=0.000$) and rigid ($p=0.012$) telescopic crowns.

DISCUSSION

Applying measurements of peri-implant strain and prosthesis displacement, this *in vitro* study evaluated the loading situation of implants and denture bearing area of mandibular complete dentures supported by either one or two implants using four different attachment types. The differences in prosthesis displacement among the three implant configurations seemed to be only minor and consequently, the use of two implants in conjunction with single standing attachment systems seems not to bear advantages. The null hypothesis had to be

rejected as distinct differences were observed with respect to peri-implant strain and prosthesis displacement depending on the number and distribution of supporting implants and attachment type. Given the inconsistent behavior of non-rigid and rigid telescopic crowns seen here, it has obviously not been possible to properly adjust the level of resiliency and retention. This seems to be consistent with a clinical report claiming that adjusting an equilibrated retention of telescopic crowns is difficult when several implants are utilized.¹¹ In the light of the higher laboratory costs associated with the use of individually fabricated attachments,⁸ their use should be questioned. While it is still under debate whether or not mechanical load can have a detrimental effect on implant performance, a combined *in vivo* and *in vitro* study pointed out that non-homogeneous loading should be avoided in overdenture restorations.¹⁵ The bad performance of two rigid telescopic crowns supporting maxillary overdentures²⁸ as well as the greater need for maintenance in prostheses supported by ball anchors² may be seen as a result of local load concentrations.

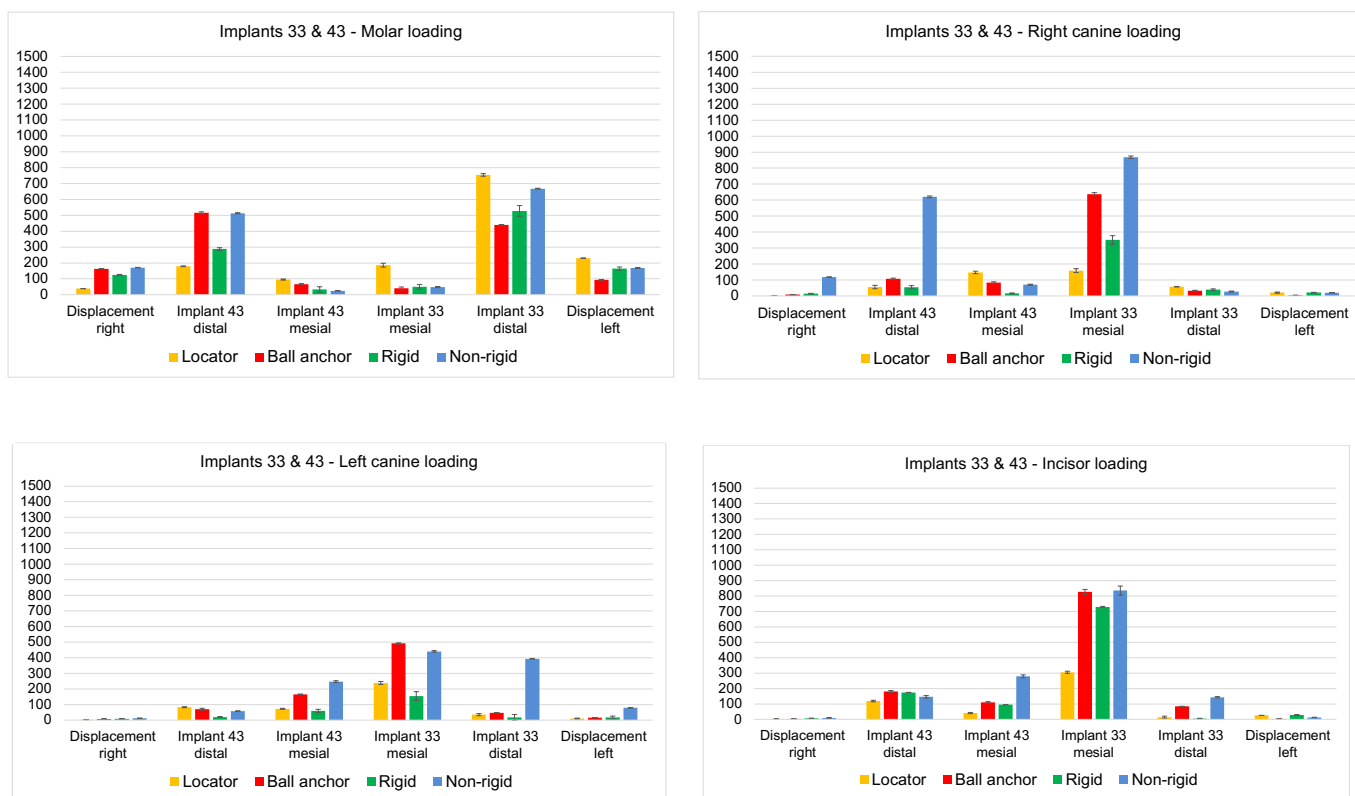


Figure 4c: Strain and displacement data measured during loading in different locations when using both canine implants for supporting the mandibular prosthesis

In this context, care should be taken to achieve equilibrated static and dynamic occlusion regardless of the number of implants and attachment type used in a specific situation.

As with every *in vitro* study, the model situation chosen cannot simulate representative clinical situations. However, the model used here seemed to react consistently allowing for relative comparisons among the attachment systems used. A variety of additional parameters affecting load transfer in implant-supported removable prostheses have been identified, which could not be addressed in this study. Among these are the cross-sectional shape of the alveolar process, the outer form of the mandible, mandibular deformation during function,¹² presence or absence of contact between the denture and the supporting hard and soft tissue,¹³ varying thickness and resiliency of the mucosa¹⁴ as well as load types occurring during function.²⁹ Although placed freehanded, the position and angulation of the implants in this *in vitro* setting have potentially been more favorable as compared to clinical settings where a negative effect of implant disparallelism on retention has been shown with respect to wear phenomena in particular.⁶ The use of strain gauges has to be seen as an additional limiting factor as only superficial deformations can be captured while strains at the implant-bone interface which may also depend on implant diameter and length, cannot be recorded. Consequently, the measurement results obtained can only be used for relative comparisons as done here.

Within the obvious limitations of this *in vitro* study, it may be concluded from a biomechanical point of view that the use of a single implant for retaining a mandibular prosthesis is not inferior to the use of two interforaminal implants. This seems to be in line with a biomechanical study showing that, depending on the attachment type used, MSIP behave comparably to two-implant supported prostheses.¹⁹ As already done clinically, the supporting implant should be positioned in the midline for achieving homogeneous implant loading and prosthesis displacement. However, the presence of the mandibular lingual vascular canal has to be taken into account.²⁰⁻²²

CONCLUSIONS

None of the attachment systems tested is ideal as they all transfer strain to the supporting implant. In particular the unequal distribution of strain indicative of moment loading is of concern. Individually fabricated attachments i.e. telescopic crowns seem to bear a minor and less consistent cushioning effect as compared to prefabricated components employing plastic inserts for retention. An alternative prefabricated attachment system with a consistent level of resilience seems desirable.

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MANUFACTURERS' DETAILS

- ProBase Cold: Ivoclar Vivadent, Schaan, Liechtenstein
- SCIP1042: AlfaGate, KfarQara, Israel
- AGM-302-C: AlfaGate, KfarQara, Israel
- AGM-106-2: AlfaGate, KfarQara, Israel
- AGM-105-2C: AlfaGate, KfarQara, Israel
- AGM-207-2H: AlfaGate, KfarQara, Israel
- LY11-0.6/120: Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany
- Quantum X: Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany
- Extensometer: Sandner Messtechnik GmbH, Biebesheim, Germany
- Vestogum: 3M Espe, Seefeld, Germany
- Impregum: 3M Espe, Seefeld, Germany
- PalatrayXL: Kulzer GmbH, Hanau, Germany
- Fujirock EP: GC Europe N.V., Leuven, Belgium
- Phantom-Metall NF: Dentsply Sirona Deutschland GmbH, Bensheim, Germany
- Z020: Zwick/Roell, Ulm, Germany
- jBEAM: AMS GmbH, Chemnitz, Germany

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