Comparison of Retention and Stability of Implant-Retained Overdentures Based upon Implant Number and Distribution

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Purpose: *The purpose of this investigation was to evaluate the effects of number and distribution of implants upon in vitro dislodging forces to a simulated implant-supported overdenture and to examine differences between several different attachment systems.* ***Materials and Methods:*** *An experiment was undertaken utilizing a model simulating a mandibular edentulous ridge with dental implants in positions on the model approximating tooth positions in the natural dentition. A cobalt-chromium–cast testing framework was used to measure the peak load required to disconnect an attachment. Four different types of commercially available attachments were used in various positions on the model in sequence to evaluate the effects of retention and stability of overdentures based on implant number and distribution: (1) ERA, (2) O-Ring, (3) Locator, and (4) Ball. For each group, 10 measurements were made of peak dislodging forces. Means were calculated and differences among the systems, directions, and groups were identified using a repeated measured analysis of variance ($\alpha = .05$).* ***Results:*** *The interactions between the attachment system, direction of force, and implant number and distribution were statistically significant. Vertical dislodging forces of the simulated overdenture prosthesis increased with additional widely spaced implants. Oblique dislodging forces of the simulated prosthesis increased with additional widely spaced implants except in the two-implant model with all attachments, and in the four-implant groups with Locator attachments. Anteroposterior dislodging forces of a simulated overdenture prosthesis increased with additional widely spaced implants except in the four-implant groups with Ball and Locator attachments. Ball attachments reported the highest levels of retention and stability followed by Locator, O-Ring, and ERA.* ***Conclusions:*** *Within the limitations of this study, retention and stability of an implant overdenture prosthesis are significantly affected by implant number, implant distribution, and abutment type.* Int J Oral Maxillofac Implants 2013;28:xxx–xxx. doi: 10.11607/jomi.3067

Key words: *denture, overdenture retention, implant distribution, stability, number*

Treatment options for dental implant therapy in conjunction with removable prostheses have become increasingly more complex throughout the past two decades. The use of implants in the mandible to retain a fixed or removable prosthesis is rapidly becoming the first choice in treatment planning for edentulous patients.[1] Three main factors are involved in optimal overdenture treatment: retention, support, and stability.[2–4] While difficult to isolate from each other, the combination of these factors contributes to overall acceptance and satisfaction of a removable prosthesis.

Retention of commercially available stud attachment systems has been the subject of many in vitro studies.[5–14] Most of these studies assumed a two-implant model approximating the location of the mandibular canines, and evaluation of in vitro retention of prostheses outside of these areas is limited. Retention and stability have been measured comparing the number of implants for implant-retained and -supported overdentures[15–19]; however, these studies have focused their attention on evaluating retention, release, and stability between types and forms of attachments.

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Fig 1   Acrylic resin test model and 3-mm gingival analog with 11 dental implants placed approximating tooth arrangements (central incisor, lateral incisor, canine, first premolar, second premolar, molar).

Fig 2   Attachments evaluated from left to right: ERA, Saturno O-Ring, Locator, Ball.

The impact of the location of implants and attachment systems of overdentures has been alluded to in several studies.[20–33] Many of these authors justified the use of well-distributed teeth and implants based upon empirical information, but few studies have accurately evaluated the effect of implant distribution and number upon the retention and stability of overdenture prostheses. One study designed several models for testing magnetic retention of overdentures including one two-implant model, two four-implant models, and one six-implant model.[27] The authors were able to determine that retention and stability of overdentures could be improved by altering implant location and distribution. Another study investigated distribution of implants according to two main designs: triangular versus quadrangular support.[33] The authors determined after cyclic loading and wear analysis that wide, even distribution of attachments provided the highest level of retention and stability.

In consideration of the currently available studies, limited information exists regarding implant position, distribution, and number and the effect upon the retention and stability of mandibular implant overdentures. The purpose of this investigation was to provide an in vitro analysis of the effect of implant distribution and number upon the magnitude of force required to dislodge implant overdenture prostheses.

MATERIALS AND METHODS

A model simulating a mandibular edentulous ridge (Zimmer Institute) was selected and 11 tapered screw vent implants (Zimmer Dental) were placed in the following positions based upon tooth arrangements: central incisor, lateral incisor, canine, first premolar, second premolar, and molar (Fig 1). Implants were placed with a surveyor (Ney Surveyor, Dentsply) and a drill press (Paraskop M, BEGO) to ensure parallelism between components and remained the same throughout the experiment.

Four commercially available attachment designs were evaluated: (1) a one-piece extracoronal resilient attachment composed of a titanium zero-degree female coated with titanium nitride and a nylon male (ERA, Sterngold; 8 N manufacturer-reported retention); (2) a one-piece extracoronal resilient attachment composed of a titanium ball anchored to the implant and a nylon female O-Ring housed within a two-piece pivoting titanium-alloy cap/race (Saturno Standard, Zest Anchors; manufacturer-reported retention not available); (3) a one-piece extracoronal semiresilient attachment composed of a titanium zero-degree female coated with titanium nitride and a nylon male (Locator, Zest Anchors; 13.34 N manufacturer-reported retention); and (4) a one-piece extracoronal nonresilient attachment composed of a titanium ball anchored to the implant and a nylon female cap housed within a one-piece titanium cap (Ball, Zimmer; manufacturer-reported retention not available) (Fig 2).

Patrix portions of the attachment system were placed into areas designed as group numbers that approximate natural tooth positions: group I-CI (one implant, central incisor), group II-CA (two implants, canines), group II-P2 (two implants, second premolars), group III-CI/CA (three implants, one central incisor, two canines), group III-CI/P2 (three implants, one central incisor, two second premolars), group IV-LI/CA (four implants, two lateral incisors, two canines), and group IV-CA/P2 (four implants, two canines, two second premolars) (Fig 3). Matrix housing portions of the attachment system were attached to the prosthesis following manufacturer guidelines with a bisacryl material (ERA PickUp, Sterngold).
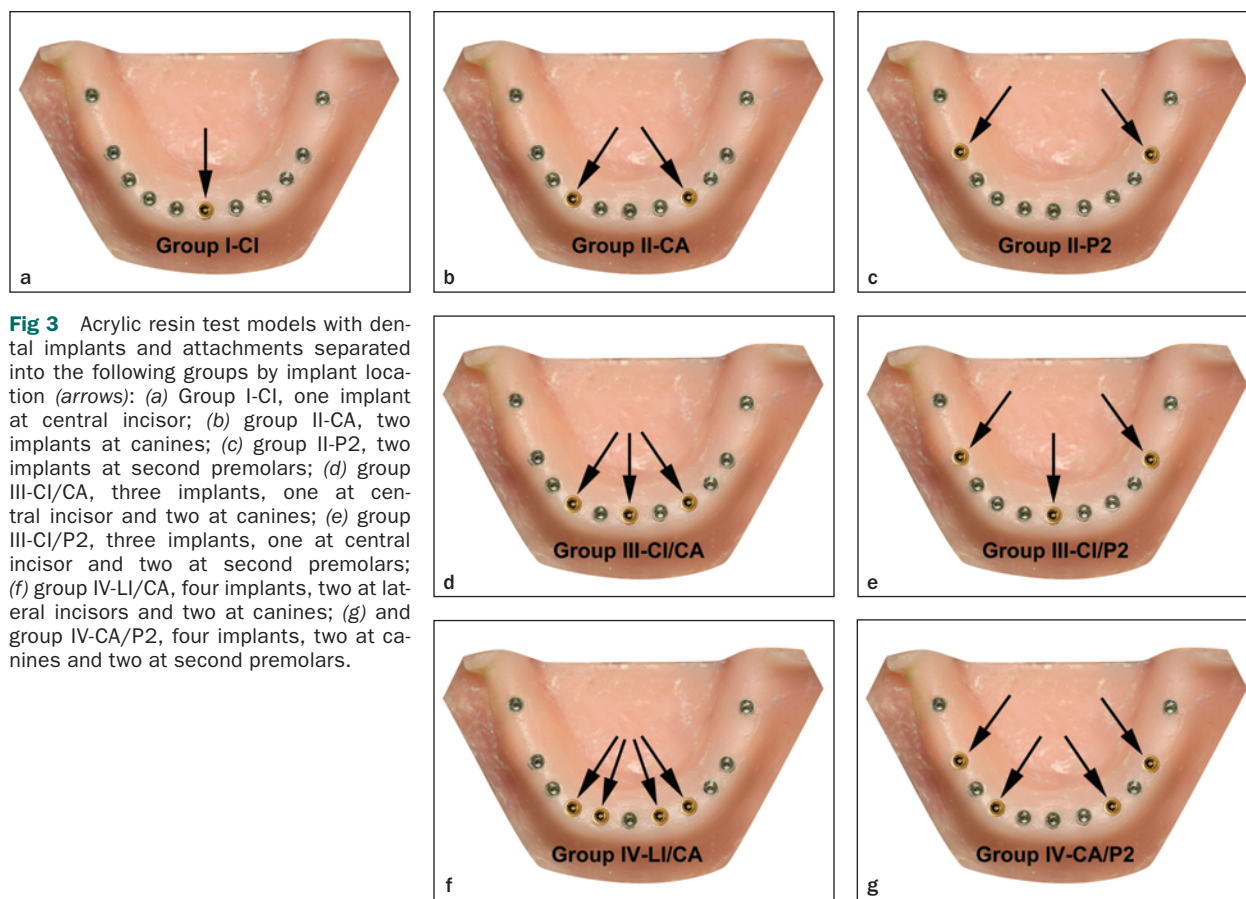
Fig 3 Acrylic resin test models with dental implants and attachments separated into the following groups by implant location (arrows): (a) Group I-CI, one implant at central incisor; (b) group II-CA, two implants at canines; (c) group II-P2, two implants at second premolars; (d) group III-CI/CA, three implants, one at central incisor and two at canines; (e) group III-CI/P2, three implants, one at central incisor and two at second premolars; (f) group IV-LI/CA, four implants, two at lateral incisors and two at canines; (g) and group IV-CA/P2, four implants, two at canines and two at second premolars.

A cast cobalt-chromium framework (NobilStar, Nobilium) was fabricated to act as a denture base throughout treatment. Three withdrawal loops were incorporated into the framework, with one approximating the incisor region and the other two approximating the first molar regions (Fig 4). Autopolymerizing polymethyl methacrylate (PMMA) acrylic resin (Dentsply) was incorporated in the intaglio and facial/lingual surfaces of the framework to allow for attachment of the matrix portions. The metal framework remained constant throughout testing.

The occlusal plane of the test model was set even with the horizontal plane of a metal plate (150 × 75 × 4) and three #8–32 bolts were placed to affix the model to the metal plate. The incorporation of the plate allows precise reproduction of the position of the model clamped to the testing apparatus when testing the different attachment systems. A universal testing machine (Model 5500R, Instron) was applied to the test forces required to dislodge the prosthesis in various directions as previously described.[6–8,19,27,33] Three 6.2 cm metal chains were attached to an 8.0 mm washer with three #8-32 × 41 mm eye bolts in a triangular orientation with #8-32 machine screw nuts.[7] The washer was attached in the center with a 6.35 mm bolt and nut to a ball/socket pivoting joint assembly incorporated into the universal testing machine (Fig 5). The use of the eye bolts and pivoting joint allowed for precise adjustment of the chains and ensured that all chains were pulling evenly throughout the experiment.

The testing machine instrumentation was calibrated and balanced using a computer algorithm to account for the weight of the simulated prosthesis and chains. Three chains were attached to the prosthesis and a three-point vertical pull was used to determine retention against a vertically directed dislodging force parallel to the path of insertion. A two-point oblique/posterior pull was used to determine stability and resistance against para-axial, oblique dislodging forces. Two chains were attached: one in the incisor region and alternating chains either on the right or left side molar region. To test posterior dislodging forces, the incisor chain was removed and the remaining two chains were attached in the molar regions. In vitro posterior dislodging forces using two chains have been used previously to simulate a lifting force of the prosthesis' distal extension base.[7,19,34] This lifting force also has been reported as an indirect measurement of the incisor function of a mandibular overdenture.[19,35]

Fig 4 Cobalt-chromium cast framework with three loops approximating incisor and molar regions.
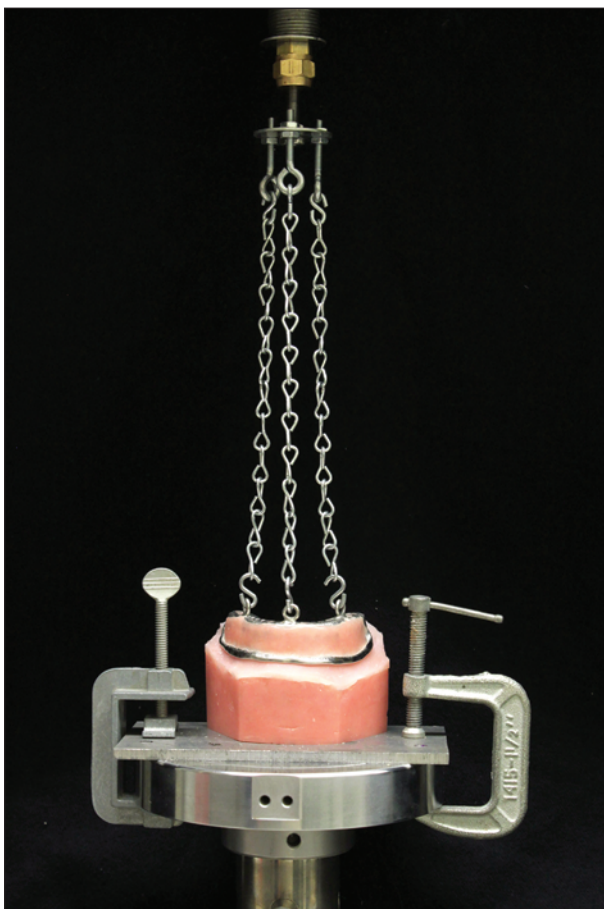

Fig 5 Experimental test model attached to universal testing machine base with clamps. The washer, eye bolts, and pivoting joint assembly allowed for adjustment of the slack in the chains and for correction of pivoting throughout the experiment.

Table 1 Summary of Mean Dislodgment Forces (N) of Attachments at Peak Load for Experimental Groups

Attach-ment	Group	Peak vertical load (N)	Peak oblique load (N)	Peak antero-posterior load (N)
ERA	I-CI	3.98	3.32	2.70
	II-CA	9.31	5.17	6.61
	II-P2	11.78	6.84	9.87
	III-CI/CA	10.41	6.17	7.49
	III-CI/P2	12.00	7.82	7.96
	IV-LI/CA	12.86	9.01	9.39
	IV-CA/P2	23.23	13.85	10.60
O-Ring	I-CI	5.55	5.21	5.63
	II-CA	13.04	11.14	8.48
	II-P2	15.26	5.65	11.40
	III-CI/CA	16.25	13.47	12.49
	III-CI/P2	13.72	10.79	9.91
	IV-LI/CA	20.37	15.29	14.68
	IV-CA/P2	21.62	15.60	14.81
Locator	I-CI	9.34	8.32	5.51
	II-CA	26.61	16.85	18.58
	II-P2	27.30	14.99	19.13
	III-CI/CA	31.29	20.45	15.54
	III-CI/P2	34.54	23.84	28.80
	IV-LI/CA	64.22	49.21	35.35
	IV-CA/P2	61.91	37.40	30.09
Ball	I-CI	18.05	15.89	14.35
	II-CA	35.15	20.23	26.67
	II-P2	37.17	20.20	31.28
	III-CI/CA	39.59	20.12	22.71
	III-CI/P2	51.79	32.08	30.39
	IV-LI/CA	65.17	42.15	45.20
	IV-CA/P2	71.20	44.60	35.39

Means linked by vertical bars are not statistically different (P > .05, repeated measures ANOVA with Bonferroni post hoc correction).

The chains were adjusted to reduce slack and force was applied until separation of the prosthesis occurred. The dislodging force applied resulted in a peak load measurement (in N) that was graphically recorded on a computer with analytical software (Partner, Instron). The horizontal load frame and load cell was set at a constant crosshead speed of 50.8 mm per minute, previously described as the approximate speed of movement of a denture from the ridge during mastication.[6–8,19,36]

For each system/group, 10 measurements were made of peak dislodging forces according to similar parameters established previously.[6,36] The same male/female attachments were reused for each of the 10 measurements and were replaced in between groups to ensure wear was minimized. Means were calculated and differences among the systems, directions, and groups were identified using a repeated measured analysis of variance (α = .05). Power analysis was performed and the smallest differences between means were determined. The oblique dislodging forces between alternating right and left sides were averaged to report a single oblique dislodging force mean value (N). For differences observed between measurements, the Bonferroni post hoc method at the 5% level of significance was used to determine the location and magnitude of significant differences (SAS version 9.2).
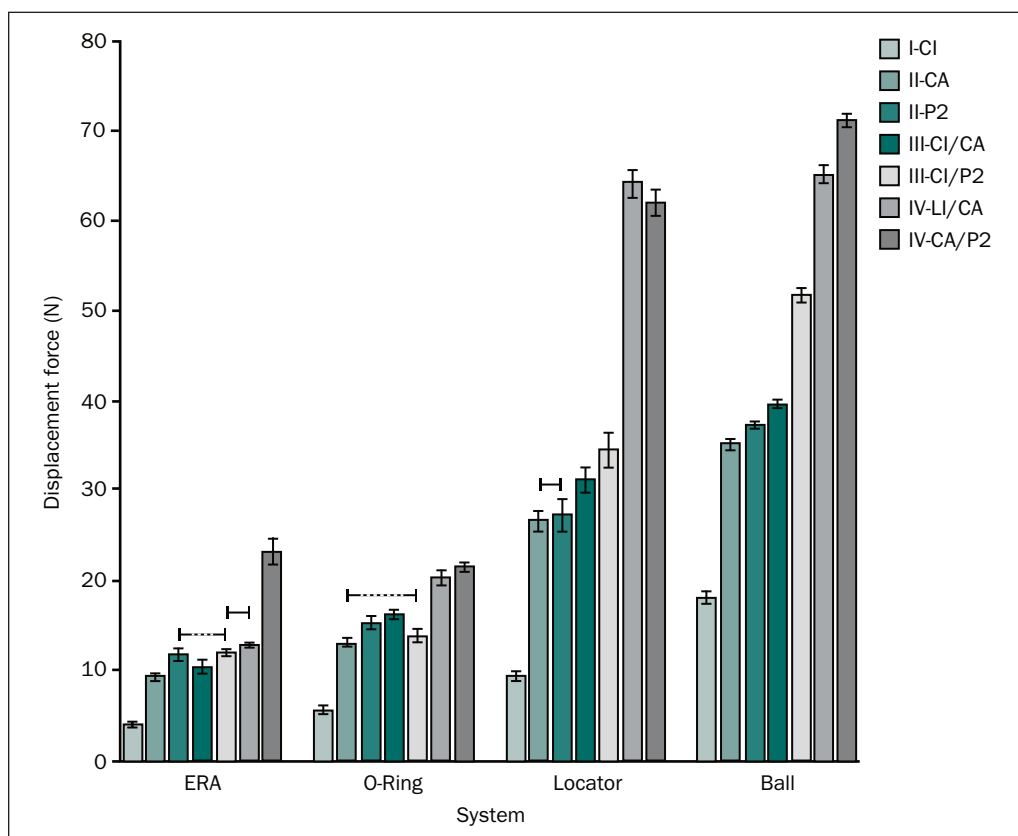
Fig 6 Mean values of vertical dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different ($P > .05$).

RESULTS

Results are presented in Table 1 and Figs 6 to 8. Peak load to dislodgment values for all groups ranged from 2.70 to 71.20 N (Table 1). Statistically significant differences were found between systems, directions, and groups.

In the vertically directed test, peak load means ranged from 3.98 to 71.20 N (Fig 6). Samples tested in group IV-CA/P2 reported the highest average forces to dislodgment while groups IV-LI/CA to I-CI reported progressively lower average forces to dislodgment, with group I-CI reporting the lowest value. The means between groups were statistically significant for all groups. When comparing attachments, the Locator attachment was unique compared to the other systems in that group IV-LI/CA had a statistically higher retentive value than group IV-CA/P2. Statistically significant differences were found between systems; Ball attachments had the highest mean retentive value, followed by Locator and O-Ring, with ERA having the lowest mean retentive value. Statistically significant differences were found

between attachment systems for all groups except the following comparisons: ERA group I-CI vs O-Ring group I-CI, ERA group IV-LI/CA vs O-Ring group IV-LI/CA.

In the obliquely directed test, peak load means ranged from 3.32 to 49.21 N (Fig. 7). Samples tested in group IV-CA/P2 reported the highest average forces to dislodgment while groups IV-LI/CA to I-CI reported progressively lower average forces to dislodgment, with group I-CI reporting the lowest value. Similar to the vertical test, the obliquely directed test also showed that the Locator group IV-LI/CA system had higher dislodging forces than group IV-CA/P2. The O-Ring group IV-CA/P2 mean values were higher; however, it was not statistically different from group IV-LI/CA. The means between groups were statistically significant for all groups. Ball attachments had the highest mean retentive value, followed by Locator and O-Ring, and ERA had the lowest mean retentive value (Ball > Locator > O-Ring > ERA). Statistically significant differences were found between attachment systems at all groups except for the comparison of Ball group III-CI/CA vs Locator group III-CI/CA.
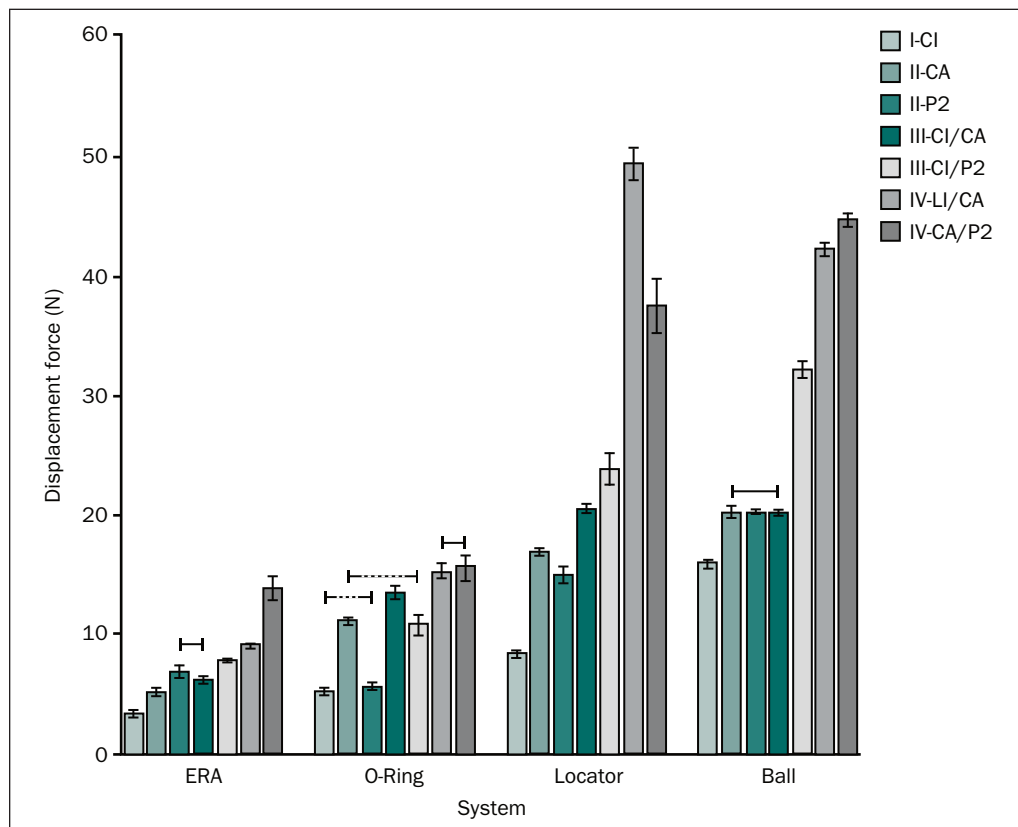
Fig 7 Mean values of oblique dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different (*P* > .05).

In the anteroposteriorly directed test, peak load means ranged from 2.70 to 45.20 N (Fig 8). Samples tested in group IV-LI/CA reported the highest force to dislodgment, followed by groups IV-CA/P2, III-CI/P2, II-P2, II-CA, III-CI/CA, and group I-CI, which reported the lowest force to dislodgment. The anteroposterior dislodging forces were slightly higher in group IV-CA/P2 than in group IV-LI/CA with O-Ring and ERA attachments; however, the differences are statistically similar. Significant differences were found between systems; Ball attachments had the highest mean retentive value, followed by Locator and O-Ring, with ERA demonstrating the lowest mean retentive value. Significant differences were found between attachment systems at all groups except for the comparison of O-Ring group I-CI vs Locator group I-CI.

DISCUSSION

The present in vitro study investigated the effect of implant distribution and number on the retention and stability of a simulated prosthesis. The results of this study indicate that implant distribution and number affect in vitro retention and stability of an implant overdenture.

Retention is a major concern to patients, and one of the greatest challenges facing clinicians is providing prosthetic treatment with the retention that patients desire.[37–40] While retention and its effect upon overdenture prosthetic factors are related, studies have not established a consensus regarding what is considered sufficient retention. An in vitro study evaluated several different types of attachments and reported that retention strengths between 5 and 8 N may be sufficient for implant-retained overdentures during long-term function.[41] A prospective crossover clinical study evaluated the correlation of patient satisfaction with force values and determined that approximately 10 N of retention was effective.[42] The aforementioned measured clinical factors related to prosthetic success and acceptance by the patients at several time points throughout treatment, and patients preferred the attachment that provided greater retention. Based upon these two established studies, it can be established that an effective retentive force may be between 8 and 10 N. Mandibular implant overdentures, when in place in the oral environment, move in complex ways. Movement of overdentures typically occurs in six directions: occlusal, gingival, mesial, distal, facial, and lingual. While true unidirectional dislodging forces rarely occur in
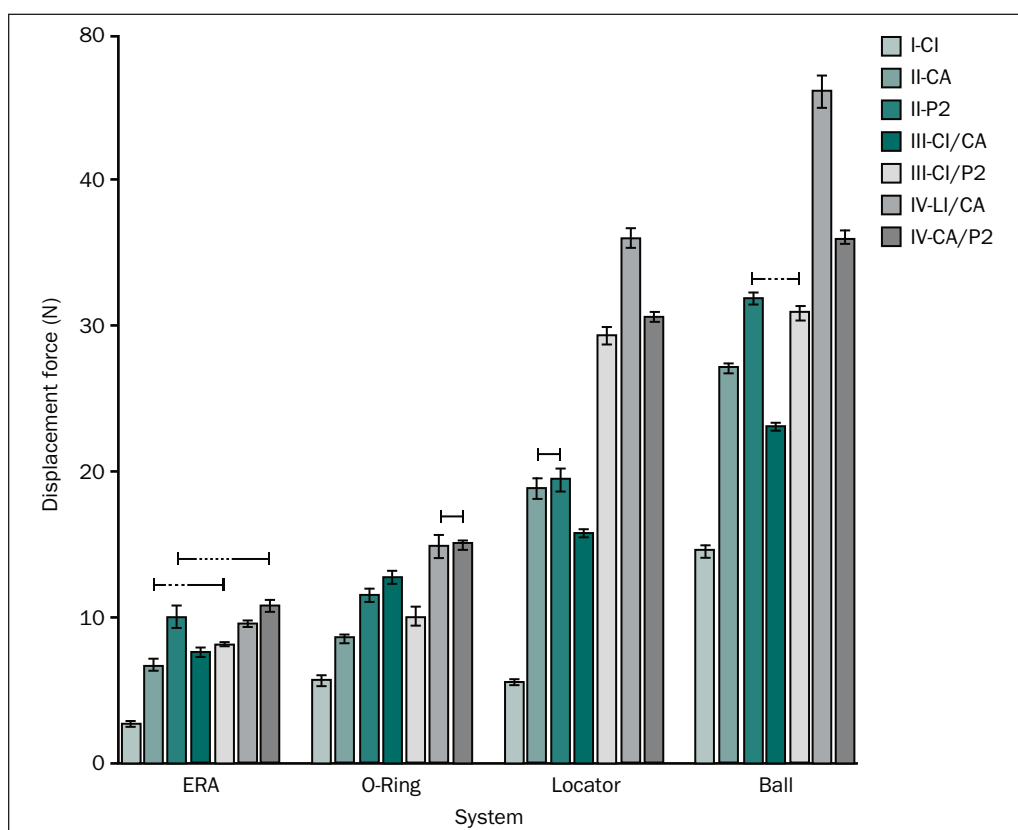
Fig 8 Mean values of anteroposterior dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different ($P > .05$).

clinical scenarios, directional pull-testing is an effective way of estimating retention and stability of a prosthesis using an in vitro laboratory evaluation.[6–8,13–20,33–36]

The current in vitro study reveals that retention increases with increasing implant number and distribution. The vertical dislodging tests performed in this study simulate retentive force of a mandibular overdenture analog when pulling on three chains simultaneously. In the vertical pull tests, the single implant reported the lowest mean retentive values and steadily increased as the implant number was increased. The greatest increase occurred when comparing single implants versus two; retention doubled for most systems. This increase in retention was statistically significant and could potentially be clinically significant as well. The lowest mean values were reported in the single implant groups and increased at the two- and three-implant groups, with the highest reported in the four-implant groups. The type of attachment influenced the effect of vertically applied forces; Locator and Ball attachments showed similar trends when compared with each other. In these attachment types, the highest level of force was required to dislodge the four-implant group and the lowest was recorded in the one-implant group. Locator attachments showed no statistical difference

in vertical dislodging forces between canine and second premolar sites in the two-implant experimental groups, and Ball attachments only showed a moderate statistical difference between these two groups. Both systems also saw statistically significant increases between narrowly and widely spaced implants in the three-implant model. This effect was not clearly shown in the ERA and O-Ring groups, indicating that the resilient design of the attachment may affect its retentive behavior. O-Ring groups, furthermore, showed a decrease in retention in the widely spaced three-implant group versus the narrowly spaced three-implant group. ERA groups showed no significant difference between two widely spaced implants and three widely spaced implants in regards to retention. With the four-implant groups, wide distribution had a significant effect upon values except with the Locator attachment, where forces were statistically higher in narrow distribution. When comparing attachment systems within the single-implant groups and based upon the aforementioned acceptable clinical vertical dislodging force estimates, only Locator and Ball attachments had values that may be sufficient for patient satisfaction. Further, all two, three, and four attachment systems tested would be sufficient for patient satisfaction.

Oblique dislodgment forces increased with increasing implant number and distribution except in the two-implant model. The oblique dislodging tests performed in this study simulated lateral or horizontal stability of a mandibular overdenture analog when pulling on two alternating chains. The single implant reported the lowest mean force to dislodgment and steadily increased as implant number was increased. In the oblique pull tests, the results varied tremendously depending on the type of attachment utilized. The ERA attachments showed only moderate increases in forces when comparing one-, two-, and three-implant groups. A nonsignificant decrease in forces occurred when three narrowly spaced implants were compared to two widely spaced implants. The O-Ring attachments saw a significant and substantial increase in dislodging forces in two implants at the canine locations compared to a single, midline implant. The two widely spaced implants, however, showed no statistical difference compared to the single implant. This trend was repeated when comparisons were made between three narrowly spaced versus widely spaced implants. In the O-Ring system, three narrowly spaced implants gave higher dislodging forces than three widely spaced implants. The Locator and Ball attachment systems were similar, except in the Locator attachment where four narrowly spaced implants showed higher dislodging forces than the widely spaced implants. Both systems showed significant increases in values when additional implants were added; however, in the Ball attachments, no statistical difference was found between two and three narrowly spaced implants. Similar to the vertical dislodging forces experiment, the Locator attachment was unique in that the four-implant group with narrow distribution reported higher values than the widely distributed group.

The current in vitro study reveals that anteroposterior dislodging forces increase with increasing implant number, but the results are mixed for the effect of distribution. The anteroposterior dislodging tests performed in this study simulated a posterior dislodging force of a mandibular overdenture's distal extension base lifting off the tissues.[7,19,34] This lifting force also has been reported as an indirect measurement of incisor function of a mandibular overdenture.[19,35] Similar to the vertical and oblique dislodgment tests, in the anteroposterior test, the single implant reported the lowest mean force to dislodgment and steadily increased as implant number was increased. Increased resistance to dislodgment occurred with increasing implant number and distribution except with all of the attachments in the three-implant groups and with Locator and Ball attachments in the four-implant groups. A steady increase was noted between groups I-CI and IV-LI/CA with the exception of groups III-CI/P2, the

widely spaced three-implant model, and a sudden increase in dislodging forces in Locator and Ball group IV-LI/CA followed by a sharp decrease in group IV-CA/P2. This trend was also seen with the Locator attachment in the vertical and oblique tests. The Locator and Ball attachment systems were similar in their trends for anteroposterior stability values. Both systems showed significant increases in stability when additional implants were added; however, large decreases in resistance occurred between two widely spaced implants and three narrowly spaced implants. The results of this study illustrate that attachment systems respond in different ways depending on their number and distribution in the edentulous arch. Therefore, if 8 to 10 N of force are considered appropriate for retention of a prosthesis, only Locator and Ball attachments would provide sufficient vertical retention in the single-implant model. Furthermore, when considering posterior dislodging forces, only Ball attachments would provide enough resistance to posterior dislodgment in the single-implant model. This finding may help illustrate the rationale for reports in the literature of successful treatment with a single ball overdenture.[43–45] Results of this study in regards to implant distribution and number are in agreement with previous studies.[27,33]

The high values obtained for the Locator and Ball attachments with variations in distribution of the four-implant groups also illustrate a unique phenomenon. Group IV-LI/CA force values were found to be higher than group IV-CA/P2 values in anteroposterior dislodging forces for both Locator and Ball attachments, and only with Locator in vertical and oblique forces. One potential reason for this finding is related to the behavior of the actual attachments. The difference in resiliency of attachment systems may have had an effect upon dislodging forces of the simulated overdenture prosthesis. The design of ERA and O-Ring attachments allows greater flexibility in their matrix/patrix interface and thus greater rotation; a finding has been illustrated previously.[6,46] As a result, the findings illustrate that the rotational property increases the resiliency of the attachment, which subsequently affects the reported peak load retentive values. While not evaluated directly, the O-Ring and ERA attachments had longer release periods of the attachments as compared to Locator and Ball attachments. This property may help illustrate the ability of the simulated prosthesis to rotate more freely[6,46] and could be a potential explanation for why the O-Ring system did not experience a sudden drop in anteroposterior peak load values between groups 3 (narrowly spaced three-implants) and four (widely spaced four-implants) as seen with the other systems. Furthermore, while Locator can be considered a moderately resilient attachment and Ball attachments a nonresilient attachment, both behaved similarly in the

anteroposterior experiments. The substantial decrease in resistance to posterior dislodging forces was evident in the three-implant model; when implants were widely spaced, greater stability resulted. While this effect was also seen in the two-implant model, it was especially evident in the three-implant model. The proximity of the two canine implants to the midline implant creates an unstable pivoting effect that causes the posterior implant attachments to rotate more freely and disengage quickly. In regards to the four-implant groups, it is logical to assume that the four narrowly spaced implants with Locator and Ball attachments in group IV-LI/CA behaved as a single unit giving significantly higher dislodging force values than in group IV-CA/P2, where they functioned as two separate units. Narrow implant spacing may preclude the use of high resiliency attachments such as ERA and O-Ring if optimum physical properties are desired. When implants are narrowly spaced, moderate or nonresilient attachments such as Locator and Ball would be preferable.

Caution must be emphasized, however, that these findings do not take into consideration the clinical reality of management of edentulous patients. The results of this study indicate that one, two, three, or four implants may produce effective in vitro retention and stability of an overdenture prosthesis. The testing performed is limited with specific conditions and methods and does not completely replicate clinical situations as the implant overdenture clinical reality is much more complex than a laboratory setting can replicate. Furthermore, the findings of this study also do not account for attachment wear, resiliency, and tissue effects. The test model assumes an intimately adapted prosthesis to the soft tissue underlying support. In vivo, alveolar ridge resorption, soft tissue changes, and attachment wear occurs over time. As these changes occur, the prosthesis may no longer be intimately adapted to the soft tissue and rotation around the implants may occur. This resultant change could change the biomechanical situation from a class 2 to a class 1 lever, and the implant may become the fulcrum point as opposed to the anterior residual ridge as seen in this study. Further studies should help evaluate whether this phenomenon is clinically significant. While this in vitro–based analysis shows a statistical difference between groups, long-term comparative prospective controlled studies are needed to reach agreement on an accepted treatment concept. Factors such as the type and location of implants placed, quality and quantity of bone, and type of superstructure should be part of these studies.

Clinicians often base their selection of implant location and attachment system empirically on expected retentive qualities. Scientifically evaluating these factors allows the clinician to formulate a comparison of implant location to retention and stability of an implant-retained overdenture prosthesis. The results of this in vitro study indicate that single ball attachments, and two, three, or four widely spaced implants may be an effective therapeutic protocol for use in implant-retained overdenture therapy. Widely spaced implants may be more effective in improving physical properties of overdentures than narrowly spaced implants. Additionally, four narrowly spaced Locator or Ball attachments may provide higher retention than four widely spaced implants.

CONCLUSIONS

Within the limitations of this in vitro laboratory study, the following conclusions were made.

- The interactions between attachment system, direction of force, and implant number and distribution were statistically significant.
- Resistance to vertical dislodging forces of a simulated overdenture prosthesis increased with additional widely distributed implants.
- Resistance to oblique dislodging forces of a simulated overdenture prosthesis increased with additional widely distributed implants except in all the two-implant attachment groups and the four-implant Locator groups.
- Resistance to anteroposterior dislodging forces of a simulated overdenture prosthesis increased with additional widely distributed implants except in the four-implant groups. Four narrowly distributed implants with Locator and Ball attachments had higher mean dislodging forces than widely spaced implants.
- Attachment type affects retention and stability differently by location. Ball attachments reported the highest levels of retention and stability.
- A single implant and ball attachment may provide adequate retention for implant overdenture treatment. Two widely spaced implants may be as effective as three narrowly spaced implants. Four parallel implants may provide the most retention and stability.
- Retention and stability of a simulated prosthesis is significantly affected by implant number, distribution, and position.

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