Strain characteristics of Marburg double crown-retained implant overdentures compared with bar and ball-retained implant overdentures, with and without a rigid major connector

F. Şehnaz Kazokoğlu, DDS, PhD[a] and Funda Akaltan, DDS, PhD[b]
Faculty of Dentistry, Okan University, Istanbul, Turkey; Faculty of Dentistry, Ankara University, Ankara, Turkey

Statement of problem. It is hard to identify the most favorable retainer type and the denture design when considering strain levels around implants and in edentulous ridges for implant overdentures (IOVD).

Purpose. The purpose of this study was to evaluate the strain transmitted to the implants and edentulous ridges by Marburg double crown (MDC)-retained IOVD as opposed to bar and ball-retained IOVD and the efficiency of a rigid major connector in the maxilla.

Material and methods. An in vitro maxillary model was prepared with 4 implants, with strain gauges placed distally to each implant and also in the anterior and posterior edentulous ridges. Five overdentures were fabricated for each MDC and each ball and bar attachment retainers. Vertical loads of 280 N were applied bilaterally on the first molar region. Then the palatal bars of each IOVD were disconnected, and loading procedures were repeated for the prostheses.

Results. No significant difference was observed among the MDC and the bar and ball-retained IOVD, with and without a rigid bar according to the data taken from both the implants and edentulous ridges. However, when the strain values attained from each strain gauge separately were considered, a slight difference was observed around the implants of ball-retained overdentures and in the edentulous ridges of MDC-retained overdentures.

Conclusions. Within the limitations of this in vitro study, MDC-retained maxillary overdentures with 4 parallel and symmetrically placed implants can be used safely without a rigid major connector as with bar and ball-retained IOVD with regard to the strains generated in the edentulous ridge and around implants. (J Prosthet Dent 2014;112:1416-1424)

Clinical Implications

Maxillary IOVD-retained by Marburg double crowns (MDC) and ball and bar retainers can be used without a rigid major connector when supported by 4 implants placed symmetrically and parallel. In particular, patients with gagging may benefit.

Dental implants improve retention and stability, as well as the masticatory function of edentulous patients.[1] Because of extreme resorption, inappropriate maxillomandibular relations, financial restrictions, or the problems of advanced surgical techniques, implant overdentures (IOVD) are often preferred to implant-supported fixed dental prostheses.[2]

Because knowledge of functional loads on implants is essential to achieve long-term implant success, the correct qualification and quantification of forces on implants is important in understanding their biomechanical characteristics.[3-7] Strain gauge (SG) analysis is a commonly used method in dentistry for the biomechanical evaluation of stress distribution in vivo[8,9] and in vitro.[10-14] However, the validation of biomechanical strain measurements and calculated stress values is important in gaining reliable results. The

Supported by Astra Tech AB, Sweden, Reference D-2007-63; and Department of Scientific Research Projects of Ankara University, Project 20070802082.

[a]Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Okan University, Istanbul, Turkey.
[b]Professor, Department of Prosthodontics, Faculty of Dentistry, Ankara University, Ankara, Turkey.

information obtained from SG under differing experimental conditions should be regarded skeptically before clinical interpretation and prediction because these measurements are limited to the area where the gauge is bonded[11] or embedded in resin.[10,14]

Various retentive mechanisms are available for attaching an overdenture to implants.[3-5,15-18] Unfavorable load transfer from the attachment to the implant and thereby to the alveolar bone surrounding the implants can be detrimental to osseointegrated implants.[6,19,20] The choice of retention mechanism in planning the IOVD might be critical in providing equitable load transfer within the maxilla.[21] In addition, regarding load transfer, the effects of palatal support and the alignment of the implants for maxillary IOVDs have been shown to be important.[22,23] The increased coverage of palatal support and the use of a rigid major connector may improve the distribution of stress between implants and edentulous ridges. In contrast, some authors have suggested that IOVDs would be clinically acceptable without palatal coverage when at least 4 implants are used with successful placement and healing.[2,24] However, palatal coverage may not be preferred for patients with a hyperactive gag reflex, with psychological or emotional problems, or with a maxillary torus. Moreover, patients may seek dental implant treatment not only for better retention and support but also for improved comfort by the removal of palatal coverage necessary for conventional complete dentures.[25] The degree of prosthesis retention and stability is based on attachment type, design, alignment, and position.[26]

Major attachment retainers used in IOVDs are bar, stud, magnetic, and telescopic attachments.[27] The MDC system is one of the telescopic attachments providing retention with additional attachments. In this system, only the apical third of the coping is parallel to the outer crown. The outer crown is part of the cast framework and fits precisely onto the inner crown without any friction or wedging. To achieve retention, the TC-SNAP system is used. The inner crowns and framework of the denture are cast in a cobalt-chromium-molybdenum (Co-Cr-Mo) alloy. The framework, including the outer crowns, is cast in a single piece without any soldering or welding.[28,29] Minimal coverage of the palatal mucosa provides comfort for the patient.[30] Because of the high elastic modulus of the Co-Cr-Mo alloy and the resulting stiffness of the framework, major connectors can be avoided, and the outer crowns can serve as minor connectors.

Telescopic crowns are classified into 2 main groups: rigidly interlocked telescopic crowns and telescopic crowns with built-in resilience. Surface interactions between the primary coping and secondary crown are responsible for retaining rigidly interlocked telescopic crowns when they are engaged.[31] Telescopic crowns with built-in resilience exhibit no friction during insertion or removal; retention is achieved by using additional attachments or functional molded denture borders, and contrary to other telescopic crown systems, they can be used to retain both tooth-supported and mucosa-supported prosthesis.[28,29] Prostheses supported by 4 or more abutting teeth are considered tooth supported, whereas dentures supported by 3 or fewer abutting teeth are considered mucosa supported.[25,29]

To enable resilient support, the prosthesis is fabricated with an occlusal space of 0.3 to 0.5 mm between the inner and outer crowns.[28,29] The nonrigid telescope attachment is still relatively unknown, and few comparative studies with other attachment systems are available.[27] Limited information exists about the force transmission characteristics and patterns of telescopic-retained prostheses as related to their type and rigidity (rigid and/or resilient) and the number of abutting teeth supporting the telescopic dentures.[10]

Some clinical studies reveal the success of rigid telescopic designs.[32,33] Although the number of studies on MDC-retained tooth or implant overdentures are insufficient, satisfying results have been demonstrated with regard to their clinical success.[15,28,29,34,35] Studies comparing the strain levels and implant success between bar and ball-retained IOVDs are available. Some of these studies support using bar attachments,[18,36,37] and some support using ball attachments.[3,38-40] However, no important clinical difference between bar and ball-retained IOVDs is mentioned.[15,41-43] If the prosthesis is well designed, and under ideal conditions, no significant difference can be found between stud attachments and resilient bar-clip designs in terms of stress distribution to the implants. However, rigid designs and cantilever bars are more likely to increase the force transmitted to the implant fixtures;[44,45] most of these studies were done for mandibular IOVDs.

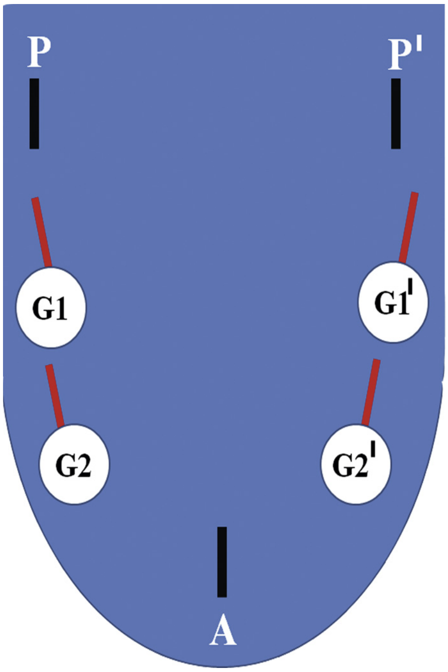
The aim of this study was to compare the strain around the implants and edentulous ridges supporting MDC-retained IOVDs with ball and bar-retained IOVDs and to investigate the efficiency of a rigid major connector by using a SG technique.

MATERIAL AND METHODS

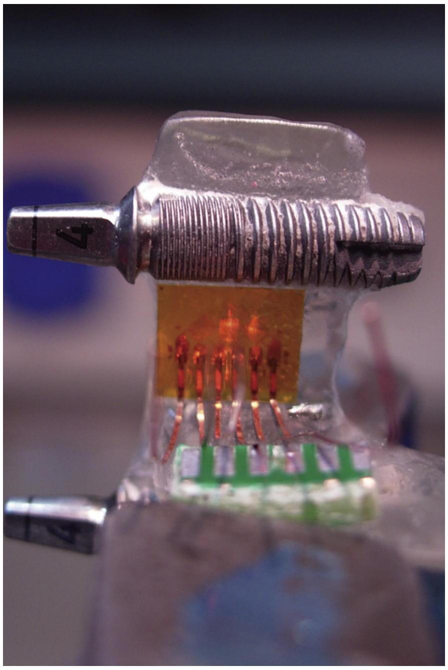
To form an in vitro maxillary model with 4 implants (Osseospeed, 3.5 S-11 mm; Astra Tech Dental), a plaster cast was obtained by using a standard maxillary template with teeth. Implants were placed symmetrically in the following positions: midline second premolar positions bilaterally and canine positions bilaterally. During implant placement, special attention was given to obtaining cervicoocclusal leveling of the implant shoulders. All the teeth except the canine and second premolar were engraved from the maxillary template to form a maxillary plaster model with 4 teeth that would stand for 4 implants. Afterward, an impression of the model was made with an elastomeric impression material (Zetaplus; Zhermack SpA). Autopolymerizing polymethylmethacrylate (PMMA) resin (Classic; Schütz-Dental GmbH) was poured in the negative space of the canine and second premolar. Before the polymerization process, implants and abutments (direct abutment, 3.5/4.0-4.4 mm; Astra Tech Dental) were joined and placed into the resin by using a parallelometer. Thus, interim crowns for the abutments were prepared to fix the implant and abutments in the model.

If the principal axis for a strain is known, single element SGs are used; otherwise, 3-element rosette SGs are recommended.[46] Three-element miniature rosette SGs (EA-05-031RB-120 Option LE; Vishay Measurements Group) were selected to determine the strain distal to the implants, and single-element SGs (EA-05-125BT-120 Option LE; Vishay Measurements Group) were selected to determine the strain on the anterior and posterior edentulous ridges. The positions of the SGs were determined from a previous study.[10] Acrylic resin frames were prepared to place 3 element, 45 degree rectangular rosette SGs distally to each implant and single element SG in the edentulous region inside autopolymerizing PMMA. After bonding of the SGs on the acrylic resin frames, the soldering processes of SGs were completed. These acrylic resin frames were placed in the impression, and autopolymerizing PMMA was poured. Because the polymerizing reaction is exothermic, the model was polymerized in a heat-pressure polymerization device (Ivomat IP3; Ivoclar Vivadent AG) for 6 minutes at 40°C under 0.3 MPa to prevent the SGs from being damaged because of the heat. Each SG was named as follows: G1, right second premolar; G1′, left second premolar; G2, right canine; G2′, left canine; A, anterior edentulous ridge; P, right posterior edentulous ridge; and P′, left posterior edentulous ridge (Fig. 1). The designated positions of the SGs were the distal axial surfaces of implants for the 3-element rosette SGs (Fig. 2). Single-element SGs were placed in the anterior edentulous ridge along with the left and right posterior edentulous ridges perpendicular to the horizontal plane. Subsequently, cables of the same length were soldered to terminals to connect the SGs to the strain indicator and recorder device (P3 Strain Indicator Recorder; Vishay Precision Group Micro-Measurements) (Fig. 3). The model was then covered with silicone impression material (Express XT Light Body Quick VPS; 3M ESPE) (2 mm on residual crests, 1 mm on palatal side) to simulate the oral mucosa (Fig. 4).

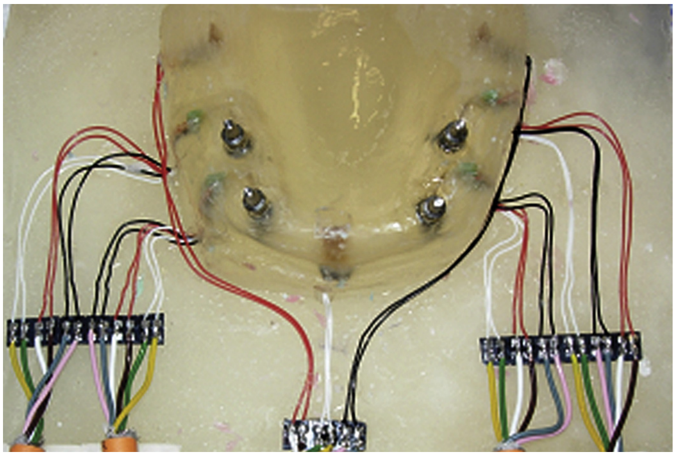
Direct abutments (3.5/4.0-4.4 mm; Astra Tech Dental) were used for MDC, ball abutments (3.5/4.0-4.0 mm; Astra Tech Dental), ball and 20 degree Uni Abutment (3.5/4.0-4 mm; Astra Tech Dental), and bar-retained IOVDs. For bar-retained IOVDs, OD Gold Cylinders 20 (Astra Tech Dental) were placed onto the abutments, and round bars were welded to join the 4 abutments. Copings were fabricated from Co-Cr-Mo alloy (Biosil F; DeguDent) with a resilient design for MDC-retained IOVDs. Primary TC-Snap-in parts (#0101L; Si-tec) were used to fabricate resilient primary copings as recommended by the manufacturer. After the casting of primary crowns for the MDC system, metal frameworks were cast from Co-Cr-Mo alloy (Biosil F; DeguDent). Clix Female and Insert Clix were placed for the ball-retained IOVDs and Rider Round Bar (Astratech Dental) for the bar IOVDs. After precisely locating TC-Snap-in with a titanium ball (TC-Snap-in; Si-tec GmbH), 5 each of the MDC ball and bar-retained IOVDs were prepared in a standard manner (Figs. 5, 6). The anteroposterior bar was planned as a major connector to enable the removal of the palatal bar and convert the major connectors to a less rigid character in a standard manner. Acrylic resin occlusion rims were fabricated over the frameworks parallel to the horizontal plane with an autopolymerizing PMMA. A steel plate was attached to both first molar sites to facilitate loading. The maxillary model was attached to the loading apparatus. SGs were connected to a static strain indicator and recorder device (Model P3; Vishay Measurements Group) in a half-bridge configuration with dummy gauges (EA-05-125BT-120 Option LE; Vishay Measurements Group) installed in a separate acrylic resin block to provide thermal



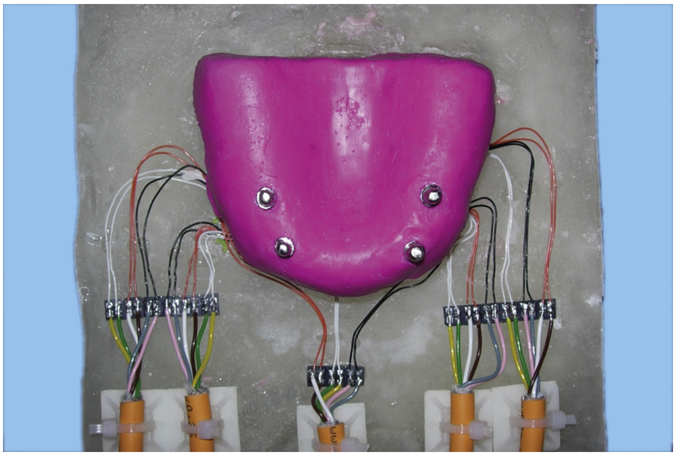
1 Location and abbreviation of SGs in model. G1, right second premolar; G1′, left second premolar; G2, right canine; G2′, left canine; A, anterior edentulous ridge; P, right posterior edentulous ridge; P′, left posterior edentulous ridge.



2 Position of 3-element SGs in PMMA resin.



3 After polymerization of maxillary model, required electrical connections were attached to SGs.



4 Model covered by silicone impression material.

5 TC-Snap-in system for MDC retainer.

compensation. A vertical static load of 140 N was applied bilaterally to obtain a total vertical static load of 280 N[47] for 60 seconds to ensure that the applied force reached a stable continuous level that could be recorded accurately with the help of a loading apparatus, and the strain values were recorded (Fig. 7). This procedure was repeated 3 times, and the averages of the 3 measurements were used for the calculations. The palatal bars were disconnected from the IOVDs (Fig. 8), and the same loading and measurement protocols were repeated for the prosthesis.

The strain data obtained from the 3-element rosette SGs were transformed to maximum and minimum principal strain values where negative strain values indicated compression strains. The biggest absolute principal strain values were used in the statistical analysis. The strain data obtained from the single element gauges were used directly.

The statistical analysis was carried out by SPSS for Windows 11.5 software (IBM) and repeated measures analysis of variance. After obtaining the results from the Greenhouse-Geisser test to determine the significant differences (α=.05) of data taken from each SG and IOVD with and without major connectors, the Bonferroni adjustment for all possible multiple comparison tests was used. The difference between the attachment types was evaluated with 1-way ANOVA. The post hoc Tukey HSD test was used if any significant difference was found.

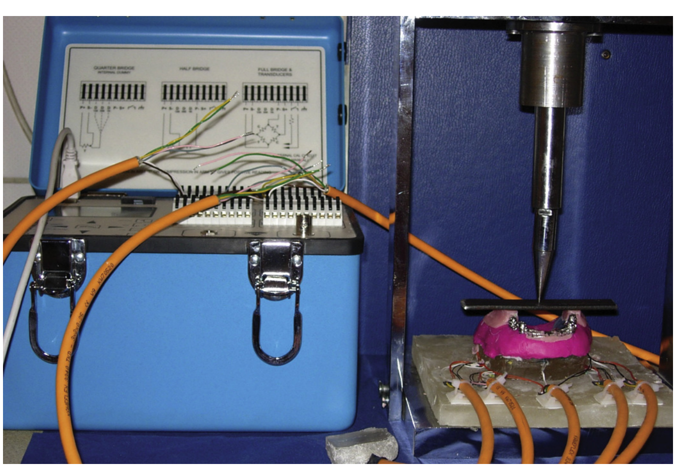
RESULTS

For each MDC ball and bar IOVD, the maximum and minimum principal strain values around the implants were calculated. The biggest absolute values were included in the statistical evaluation. The data obtained from the edentulous ridges were also included in the statistical evaluation as absolute values.

Strain patterns around implants

The descriptive statistics of measurements obtained from the 4 rosette SGs for the MDC ball and bar attachments with and without palatal bar are shown in Table I, and the statistical results for the repeated measures analysis are shown in Table II. The difference between the strain patterns around the implants produced by using MDC ball and bar attachments with and without the palatal bar was found to be statistically nonsignificant (*P*=.180), as was the difference between the strain patterns of the attachment types (*P*=.230). The mean strain values taken from each SG around the implants were statistically significant (*P*=.001). However, an interaction was noted between the SG and the attachment type (*P*=.022). The mean strain values of the G1 and G1′ SGs were not different among the attachment types; however, the difference between G2 (*P*=.001) and G2′ (*P*=.004) was found to be statistically significant. For G2, the mean strain values for ball attachments were significantly greater than the corresponding values of the MDC (*P*=.003) and bar (*P*=.004) attachments. For G2′, the mean strain values with ball attachments were lower than the corresponding mean values of the bar attachments (*P*=.003). Although the difference between the strain values of G1 and G2 for MDC attachments

6 IOVDs with palatal bars. A, MDC. B, Ball retainers. C, Bar retainers.



7 Axial loading apparatus and recording machine.

seemed to be significant (*P*=.037), after the Bonferroni correction, the difference was not found to be statistically significant. Again, although the difference between the strain values of G1′ and G2′ for ball attachments seemed to be significant (*P*=.045), after the Bonferroni correction, the difference was not found to be statistically significant. The difference among the strain values of SGs for bar attachments was nonsignificant (*P*=.128).

Strain patterns in edentulous ridges

The descriptive statistics of measurements taken from 3 single-element SGs for MDC ball and bar attachments with and without palatal bar are provided in Table III, and the statistical results for the repeated measures analysis are provided in Table IV. The difference among the strain patterns in the edentulous ridges produced by MDC ball and bar attachments with and without palatal bar was not found to be statistically significant (*P*=.099). Table IV shows that the differences among the mean strain values for each attachment type (*P*=.008) and the SGs (*P*=.001) were statistically significant.

An interaction was noted between the SG and the attachment type (*P*=.017). According to each attachment type, the mean strain values of A (*P*=.069) and P′ (*P*=.050) SGs were not different from each other; however, the mean strain values of P were found to be different from the corresponding values of others (*P*=.006). For P, the mean strain values for MDC were higher than the mean strain values

8 IOVDs after palatal bars disconnected. A, MDC. B, Ball retainers. C, Bar retainers.

Table I. Descriptive statistics of measurements obtained from strain gauges

Strain Gauge	Attachment	Palatal Bar		No Palatal Bar	
		Mean	SE	Mean	SE
G1	MDC	27.80	3.74	28.40	3.81
	Ball	19.60	4.91	21.20	5.58
	Bar	26.20	3.23	26.40	4.48
G2	MDC	9.40	0.81	11.80	1.20
	Ball	23.80	3.05	26.80	4.64
	Bar	11.00	1.34	11.40	1.75
G1′	MDC	34.80	4.09	34.40	5.55
	Ball	36.00	4.09	34.80	4.42
	Bar	23.00	4.35	21.80	4.27
G2′	MDC	13.20	0.97	15.40	1.86
	Ball	10.20	1.43	9.20	2.27
	Bar	17.80	0.86	18.00	0.89

MDC, Marburg double crown system; SE, standard error.

of bar attachments (P=.005). An interaction was found between the palatal bar and the SGs (P=.048); however, no interaction was noted among the palatal bar, the SGs, and the attachment type (P=.950).

DISCUSSION

The aim of this study was to draw the attention of clinicians to an IOVD design if the results showed similar strain characteristics; the clinical treatment modalities for maxillary IOVDs could be modified to define more comfortable and still safe solutions for patients. If the null hypothesis that MDC-retained IOVD with a less rigid major connector design but without a palatal bar would provide similar outcomes were supported, they might be preferable to less comfortable IOVD designs involving a major connector needing more palatal coverage.

The SGs used in the current study were embedded in an acrylic resin model[10,14] instead of being bonded to the surfaces[11] to obtain strain values directly from their intended positions. Sahin et al[10] tested the efficiency of such a configuration in a pilot study by comparing the strain obtained from

Table II. Statistical results of source of variance according to repeated measures analysis of variance around implants

Source of Variance	F	*P*
Palatal bar	2.023	.180
Attachment	1.663	.230
Palatal bar × Attachment	0.889	.437
Strain gauge	14.487	.001*
Strain gauge × Attachment	3.686	.022*
Palatal bar × Strain gauge	2.447	.101
Palatal bar × Strain gauge × Attachment	0.684	.624

α=.05.
*Statistically significant.

Table III. Descriptive statistics of measurements obtained from strain gauges regarding attachments with and without palatal bar in edentulous ridges (με)

Strain Gauge	Attachment	Palatal Bar		No Palatal Bar	
		Mean	SE	Mean	SE
A	MDC	6.58	0.52	6.28	0.53
	Ball	7.62	0.08	7.72	0.21
	Bar	7.04	0.30	6.80	0.30
P	MDC	52.64	2.53	52.56	2.49
	Ball	43.62	2.14	45.20	2.41
	Bar	39.14	2.53	39.14	2.76
P′	MDC	44.28	3.15	45.80	4.15
	Ball	32.62	2.93	35.00	3.18
	Bar	42.90	2.61	44.24	2.61

SE, standard error; MDC, Marburg double crown system.

Table IV. Statistical results of source of variance according to repeated measures analysis of variance in edentulous ridges

Source of Variance	F	*P*
Palatal bar	3.202	.099
Attachment	7.512	.008*
Palatal bar × Attachment	0.697	.517
Strain gauge	231.012	.001*
Strain gauge × Attachment	4.638	.017*
Palatal bar × Strain gauge	3.489	.048*
Palatal bar × Strain gauge × Attachment	0.170	.950

α=.05.
*Statistically significant.

single-element SGs, either bonded to or embedded in autopolymerizing acrylic resin specimens prepared according to the requirements of the American Society for Testing and Materials D 638 Type I and subjected to a tension test indicating a correlation coefficient of .998.

SGs are small, resistive devices capable of measuring surface strains. The rosette-type SGs used in the present study were placed on the distal aspects of implants where the stress transmitted from the overdentures is critical and where alveolar bone loss is possible because of the intensity and duration of the transmitted stress. These locations of the SGs were consistent with the bilateral loading protocol. However, if the effects of the unilateral loading protocols on the stress distribution of the buccal and palatal aspects of the dental implants were to be investigated, placing additional rosette type gauges perpendicular to the buccal and palatal surfaces of the dental implants would be required. The palatal and perpendicular positioning of a rosette type gauge is possible; however, the buccal and perpendicular positioning of such a gauge is not feasible because of the dimensions of the gauges, and any attempt to thicken the facial wall of the PMMA resin on the buccal aspects of the dental implants would lead to errors affecting the entire study. This phenomenon should be considered as a technical limitation of the present stress analysis technique.

This study investigated the strain within the bone around the implants and edentulous ridges produced by MDC-retained IOVDs compared to ball and bar attachments and the efficiency of the rigid major connector. The strain levels among the 3 attachment types were not found to be different either with a rigid or less rigid major connector.

Ochiai et al[25] suggested that removing the palatal support from a maxillary IOVD produced a greater load transfer effect and more concentrated stress difference around the supporting implants than the specific selection of the attachment designs used. Other authors have also emphasized the effects of palatal coverage on reducing stress on implants, thereby improving retention and stability.[23] In the present study, an anteroposterior bar was used to provide adequate rigidity and easy cutting to evaluate the effect of a rigid major connector on the strain. The study showed that removal of the palatal bar from anteroposterior bar major connector did not cause any change in the strain levels of implants and the edentulous ridges for MDC bar and ball-retained maxillary IOVDs supported by 4 implants. This result of the present study supported the concept of IOVDs without palatal coverage when at least 4 implants were used with successful placement and healing.[2,24] However, palatal coverage that covers the palatal mucosa fully, unlike the anteroposterior bar, may reduce the stress around implants and should be reconsidered for implants of reduced width or length, unfavorable implant positions, immediate or progressive implant loading protocols, or implants of questionable prognosis.

Some studies support using bar attachments for better force distribution. Cekic et al[36] showed that the strain levels around implants supporting ball-retained IOVDs were higher than those supporting bar-retained and distal cantilevered bar-retained IOVDs in the mandible. In another study, the splinting of 2 interforaminal dental implants reduced the strain compared to unsplinted implants.[37] Again, bar-retained maxillary IOVDs were found to be more successful than ball-retained IOVDs regarding the survival of implants and IOVDs.[18]

Some studies have shown that lower stress levels were observed with ball-retained mandibular implant IOVDs.[3,38-40] However, the results of various studies indicate that the attachment system does not influence the clinical parameters for implants.[15,41-43] Although further investigation is necessary, if the prosthesis is well designed and placed under ideal conditions such as good bone quality and quantity, arch morphology, and implant length, no significant difference can be found between ball attachments and resilient bar clip designs in terms of stress distribution to the implants. Rigid designs and cantilever bars are more likely to increase the force transmitted to the implant fixtures.[44,45] A resilient retention mechanism is recommended for an IOVD to provide equal tissue and implant support. In the present study, regarding the mean strain values around the implants and in the edentulous ridges, no significant difference was observed in all 3 attachments: MDC and round bar and ball-retained IOVDs with and without a rigid major connector.

When the strain values attained from each SG separately are considered, the difference in strain values of G2 and G2′ for ball-retained IOVDs can be attributed to the characteristics of the model. However, ball attachments may have different biomechanical characteristics from bar and MDC attachments. The slight occlusal resiliency in the matrix part of the ball attachment may especially create some difference.[27] In the edentulous ridge, only the strain level of P (SG in the right posterior edentulous ridge) for MDC-retained IOVDs was higher than bar-retained IOVDs. This result seems consistent with a study in which the highest-bearing area-loading values were attained with a resilient telescope attachment; this can be explained by the built-in occlusal space, which compensates for oral mucosa resiliency or model characteristics.[27] However, claiming that the MDC system shows higher strain levels in the edentulous ridges would be inaccurate because the difference mentioned earlier is not the same for both posterior SGs.

Until future scientific studies provide insight into the biologic effects of interfacial stress transfer, one goal of the clinician should be to provide the most favorable delivery of forces to the implant through proper prosthesis design.[21] The results of the present study, however, focused only on forces arising during axial bilateral loading, and the implants had been placed symmetrically and in a parallel manner. In addition, the results were derived from in vitro experiments and should be tested in clinical follow-up studies.

CONCLUSIONS

The strain patterns produced by the MDC and the ball and bar attachments with and without a rigid major connector on edentulous ridges and around implants were not found to be significant. However, the stress distributions of ball attachments were different from those of the MDC and the bar attachments around the implants. Relying on the results of the present in vitro study, and only considering the stress distribution in the maxilla, IOVDs retained by the MDC ball and bar retainers can be used without rigid major connector when supported by 4 implants placed symmetrically and in a parallel manner. These are in vitro results, which are qualitative in nature, and their clinical significance should be tested in clinical follow-up studies.

REFERENCES

1. Fueki K, Kimoto K, Ogawa T, Garrett NR. Effect of implant-supported or retained dentures on masticatory performance: a systematic review. J Prosthet Dent 2007; 98:470-7.
2. Sadowsky SJ. The implant-supported prosthesis for edentulous arch: design considerations. J Prosthet Dent 1997;78:28-33.
3. Barão VA, Assunção WG, Tabata LF, Delben JA, Gomes EA, de Sousa EA, et al. Finite element analysis to compare complete denture and implant-retained overdentures with different attachment systems. J Craniofac Surg 2009 Jul;20:1066-71.
4. Prakash V, D'Souza M, Adhikari R. A comparison of stress distribution and flexion among various designs of bar attachments for implant overdentures: a three dimensional finite element analysis. Indian J Dent Res 2009;20:31-6.
5. Cehreli MC, Karasoy D, Kökat AM, Akça K, Eckert S. A systematic review of marginal bone loss around implants retaining of supporting overdentures. Int J Oral Maxillofac Implants 2010;25:266-77.
6. Porter JA, Petropoulos VC, Brunski JB. Comparison of load distribution for implant overdenture attachments. Int J Maxillofac Implants 2002;17:651-62.
7. Tiossi R, De Torres EM, Rodrigues RCS, Conrad HJ, De Mattos MD, Fok AS. Comparison of the correlation of photoelasticity and digital imaging to characterize the load transfer of implant supported restorations. J Prosthet Dent 2014;112:276-84.
8. Mericske-Stern R, Venetz E, Fahrländer F, Bürgin W. In vivo force measurements on maxillary implants supporting a fixed prosthesis or an overdenture: a pilot study. J Prosthet Dent 2000;84:535-47.
9. Jemt T, Carlsson L, Boss A, Jörneús L. In vivo load measurements on osseointegrated implants supporting fixed or removable prostheses: a comparative pilot study. Int J Oral Maxillofac Implants 1991;6:413-7.

10. Sahin V, Akaltan F, Parnas L. Effects of the type and rigidity of the retainer and the number of abutting teeth on stress distribution of telescopic-retained removable partial dentures. J Dent Sci 2012;7:7-13.
11. Arat Bilhan S, Bilhan H, Kutay O, Bozdag E, Sunbuloglu E, Baykasoglu C. The influence of the attachment type and implant number supporting mandibular overdentures on stress distribution: an in vitro study, part I. Imp Dent 2013;22:39-48.
12. Chu CM, Hsu JT, Fuh LJ, Huang HL. Biomechanical evaluation of subcrestal placement of dental implants: in vitro and numerical analyses. J Periodontol 2011;82:302-10.
13. Karl M, Dickinson A, Holst S, Holst A. Biomechanical methods applied in dentistry: a comparative overview of photoelastic examinations, strain gauge measurements, finite element analysis and three-dimensional deformation analysis. Eur J Prosthodont Restor Dent 2009;17:50-7.
14. Clelland N, Gilat A, McGlumphy EA, Brantley WA. A photoelastic and strain gauge analysis of angled abutments for an implant system. Int J Oral Maxillofac Implants 1993;8:541-8.
15. Krennmair G, Weinlander M, Krainhöfner M, Piehslinger E. Implant-supported mandibular overdentures retained with ball or telescopic crown attachments: a 3-year prospective study. Int J Prosthodont 2006;19:164-70.
16. Ellis JS, Burawi G, Walls A, Thomason JM. Patient satisfaction with two designs of implant supported removable overdentures; ball attachment and magnets. Clin Oral Implants Res 2009;20:1293-8.
17. Bueno-Samper A, Hernández-Aliaga M, Calvo-Guirado JL. The implant-supported milled bar overdenture: a literature review. Med Oral Patol Oral Cir Bucal 2010;15:375-8.
18. Slot W, Raghoebar GM, Vissink A, Huddleston S, Meijer HJA. A systematic review of implant-supported maxillary overdentures after a mean observation period of at least 1 year. J Clin Periodontol 2010;37:98-110.
19. Lavelle CL. Biomechanical considerations of prosthodontic therapy: the urgency of research into alveolar bone responses. Int J Oral Maxillofac Implants 1993;8:179-85.
20. Sato T, Hara T, Mori S, Shirai H, Minagi S. Threshold for bone resorption induced by continuous and intermittent pressure in the rat hard palate. J Dent Res 1998;77:387-92.
21. Fanuscu MI, Caputo AA. Influence of attachment systems on load transfer of an implant-assisted maxillary overdenture. J Prosthodont 2004;13:214-20.
22. Lewis S, Sharma A, Nishimura R. Treatment of edentulous maxillae with osseointegrated implants. J Prosthet Dent 1992;68:503-8.
23. Bergendal T, Engquist B. Implant-supported overdentures: a longitudinal prospective study. Int J Oral Maxillofac Implants 1998;13:253-62.
24. Mericske-Stern R. Treatment outcomes with implant-supported overdentures: clinical considerations. J Prosthet Dent 1998;79:66-73.
25. Ochiai KT, Williams BH, Hojo S, Nishimura R, Caputo AA. Photoelastic analysis of the effect of palatal support on various implant-supported overdenture designs. J Prosthet Dent 2004;91:421-7.
26. Williams BH, Ochiai KT, Hojo S, Nishimura R, Caputo AA. Retention of maxillary implant overdenture bars of different designs. J Prosthet Dent 2001;86:603-7.
27. Heckmann SM, Winter W, Meyer M, Weber HP, Wichmann MG. Overdenture attachment selection and the loading of implant and denture-bearing area. Part II. A methodical study using five types of attachment. Clin Oral Impl Res 2001;12:640-7.
28. Wenz HJ, Lehmann KM. A telescopic crown concept for the restoration of the partially edentulous arch: the Marburg double crown concept. Int J Prosthodont 1998;11:541-50.
29. Wenz HJ, Hertramph K, Lehmann KM. Clinical longevity of removable dentures retained by telescopic crowns: outcome of the double crown with clearance fit. Int J Prosthodont 2001;14:207-13.
30. Straioto FG, De Azevedo AM, Do Prado CJ, Das Neves FD, Neto AJ. Rehabilitation of maxillary edentulism with implant-supported milled-bar prostheses. Implant Dent 2006;15:366-71.
31. Langer A. Telescope retainers and their clinical application. J Prosthet Dent 1980;44:516-22.
32. Krennmair G, Sütö D, Seemann R, Piehslinger E. Removable four implant-supported mandibular overdentures rigidly retained with telescopic crowns or milled bars: a 3-year prospective study. Clin Oral Implants Res 2012;23:481-8.
33. Szentpetery V, Lautenschlager C, Setz JM. Longevity of frictional telescopic crowns in the severely reduced dentition: 3-year results of a longitudinal prospective clinical study. Quintessence Int 2010;41:749-58.
34. Zou D, Wu Y, Huang W, Wang F, Wang S, Zhang Z, et al. A 3 year prospective clinical study of telescopic crown, bar and locator attachments for removable four implant-supported maxillary overdentures. Int J Prosthodont 2013;26:566-73.
35. Frisch E, Ziebolz D, Rinke S. Long-term results of implant-supported over-dentures retained by double crowns: a practice-based retrospective study after minimally 10 years follow-up. Clin Oral Imp Res 2013;24:1281-7.
36. Cekic C, Akça K, Cehreli MC. Effects of attachment design on strains around implants supporting overdentures. Quintessence Int 2007;38:291-7.
37. Akça K, Cehreli MC, Uysal S. Marginal bone loss and prosthetic maintenance of bar-retained implant-supported overdentures: a prospective study. Int J Oral Maxillofac Implants 2010;25:137-45.
38. Kenney R, Richards MW. Photoelastic stress patterns produced by implant-retained overdentures. J Prosthet Dent 1998;80:559-64.
39. Menicucci G, Lorenzetti M, Pera P, Preti G. Mandibular implant-retained overdenture: finite element analysis of two anchorage systems. Int J Oral Maxillofac Implants 1998;13:369-76.
40. Tokuhisa M, Matsushita Y, Koyano K. In vitro study of a mandibular implant overdenture retained with ball, magnet or bar attachments: comparison of load transfer and denture stability. Int J Prosthodont 2003;16:128-34.
41. Cune MS, De Putter C, Hoogstraten J. Treatment outcome with implant-retained overdentures. Part I. Clinical findings and predictability of clinical treatment outcome. J Prosthet Dent 1994;72:144-51.
42. Gotfredsen K, Holm B. Implant-supported mandibular overdentures retained with ball or bar attachments: a randomised prospective 5-year study. Int J Prosthodont 2000;13:125-30.
43. Narhi TO, Hevinga M, Voorsmit RACA, Kalk W. Maxillary overdentures retained by splinted and unsplinted implants: a retrospective study. Int J Oral Maxillofac Implants 2001;16:259-66.
44. Trakas T, Michalakis K, Kang K, Hirayama H. Attachment systems for implant retained overdentures: a literature review. Implant Dent 2006;15:24-34.
45. Itoh H, Caputo AA, Wylie R, Berg T. Effects of periodontal support and fixed splinting on load transfer by removable partial dentures. J Prosthet Dent 1998;79:465-71.
46. Padmanabhan TR. Industrial instrumentation: principles and design. London: Springer; 2000. p. 393-4.
47. Miyaura K, Morita M, Matsuka Y, Yamashita A, Watanabe T. Rehabilitation of biting abilities in patients with different types of dental prosthesis. J Oral Rehabil 2000;27:1073-6.

Corresponding author:
Dr F. Sehnaz Kazokoglu
Okan University
Faculty of Dentistry
Tuzla Kampüsü 34959 Tuzla
TURKEY
E-mail: sehnazkazok@yahoo.com