



Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an *in vitro* study

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Abstract (J Korean Assoc Oral Maxillofac Surg 2019;45:199-206)

Objectives: In mandibular edentulism, the treatment option with a two-interforaminal implant-retained bridge and a removable partial denture is rarely evaluated in literature. The aim of this *in vitro* study was to evaluate the stress distribution of this treatment option by comparing it with traditional treatment options with interforaminal implants in the edentulous mandible.

Materials and Methods: Two interforaminal implants were placed in a formalin-fixed cadaver mandible, and overdentures with three different types of attachments were fabricated: (1) two ball attachments and an overdenture, (2) a Dolder bar and an overdenture, and (3) screw-retained two-implant inter-canine porcelain fused to a metal bridge and an implant-assisted removable denture (IARD) with precision attachments. Three biting conditions were generated for each denture type, and the strains were documented under vertical loading of 100 N.

Results: The calculated strain values from measured strains in all measurement sites and loading conditions for the screw-retained two-implant inter-canine porcelain fused to a metal bridge and a cast framework partial denture with precision attachments situation were lower than in the other scenarios ($P < 0.05$).

Conclusion: Within the limitations of the present study, it can be concluded that an IARD may be a reasonable and valuable alternative to ball attachments or a bar in two interforaminal implants, especially when the patients prefer to be able to show their teeth even when they take out their removable dentures.

Key words: Implant, Strain gauge, Removable denture, Overdenture, Dental

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I. Introduction

Two implants are considered the minimum necessity to retain a mandibular denture in edentulous patients^{1,2}. Previous studies have shown that mandibular two-implant-supported overdentures (ISRDs) provide significant enhancement in stability, retention, patient satisfaction, and quality of life³⁻⁶.

ISRDs may be used either with single attachments or attachments splinted together using a cast metal bar and clips⁷. Several types of single attachments are available for ISRDs such as ball attachments, locators, magnets, and rigid or non-rigid telescopic copings^{8,9}.

The indications for different attachment systems for ISRDs are well-documented in literature, but some controversial opinions exist¹⁰⁻¹². However, no significant difference in satisfaction level¹³⁻¹⁶ and quality of life^{17,18} were reported by patients receiving various attachment types of overdentures except for a few studies concerning magnetic attachments^{19,20}. The results of several clinical studies indicate that the retention mechanisms have similar effects on marginal bone levels²¹⁻²³. Still, there is no consensus opinion^{24,25} about the influence of attachment systems on patient satisfaction or marginal bone level maintenance²⁶ around supporting im-

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plants. Since overloading of ISRDs may lead to bone loss at the implant-bone interface^{27,28}, it is important to evaluate the influence of possible variables on load distribution in bone and around implants. In a recent clinical study, no statistically significant differences were found between single and bar attachment types, although the bone loss rate observed in those with single attachments tended to be lower²⁹. On the other hand, as splinted implants act together as a group, less bone loss due to distribution of the loads by splinting of the implants can be expected³⁰.

Although it is not a common type of implant superstructure, an implant-assisted removable denture (IARD) can be fabricated instead of an ISRD in cases with few anterior implants. In most IARDs, implants are placed under conventional removable partial dentures (RPDs) with abutment teeth to optimize stability and retention of the prosthesis³¹. This solution has shown a more helpful effect on oral health compared to conventional RPDs^{32,33}. While these advantages advocated for IARD treatment in the early 2000s^{31,34}, clinical studies evaluating its technical features and performance are scarce. A recent literature review reported that treatment with IARDs is a simple and cost-effective approach, but the absence of robust publications related to IARDs has limited significant conclusions³¹. Likewise, offering IARDs to edentulous patients as an alternative to ISRDs has been published only in case studies³⁴⁻³⁷. The consensus that had been reached in these reports³⁴⁻³⁷ was increased satisfaction due to the resolved need to remove anterior teeth during sleep or oral hygiene maintenance as with ISRDs. With this solution, patients reported increased confidence since the anterior part of the prosthesis is fixed and more comfortable due to reduced denture volume^{34,35}. Furthermore, this treatment option fulfills patient desire to show their teeth even after removal of the mandibular denture³⁶. Therefore, this *in vitro* study was conducted to observe if the stress distribution in the mandible is advantageous for this type of prosthetic alternative or if it has a detrimental effect on force distribution.

Whether this kind of superstructure will reduce or increase maintenance requirements will be the subject of another clinical study. This *in vitro* study was performed to test different scenarios in terms of the influence of types of attachment and superstructure on stress distribution in the edentulous mandible. The null hypothesis of the study was that IARD and ISRD would not have a significant difference on stress distribution in the edentulous mandible.

II. Materials and Methods

An edentulous mandible from a formalin-fixed human cadaver was selected from the Department of Anatomy, Faculty of Medicine, Istanbul University to use in this *in vitro* strain gauge (SG) measurement study. After removal of the mandible from the cadaver, locations where the SG rosettes (CEA 125UR, 350 Ω ; Vishay Precision Group Inc., Malvern, PA, USA) would be applied were cleaned using pure alcohol. Surface smoothing was accomplished through the two-stage application of sandpaper. Six SG rosettes were applied at the following locations:

- 1) Right mylohyoid ridge (MRR)
- 2) Left mylohyoid ridge (MRL)
- 3) Symphysis midline (SM)
- 4) Right retromolar pad (RP)
- 5) Buccal shelf left (BP)
- 6) Right canine region (C)

The SGs were adapted, bonding material (M-Bond; Vishay Micro-Measurements, Raleigh, NC, USA) was applied to the bone, and the gauges were fastened to the bone to finger pressure. All connections were soldered afterward. After this process was complete, all single elements of the rosettes were circuit balanced and shunt calibrated electronically *in situ*. (Fig. 1)

A 2-mm-thick polyvinylsiloxane impression material (Afinis light body, Coltene/Whaledent AG, Altstätten, Switzerland) was adapted to the mandible to mimic soft tissue.(Fig. 2) An impression was fabricated from the equipped mandible

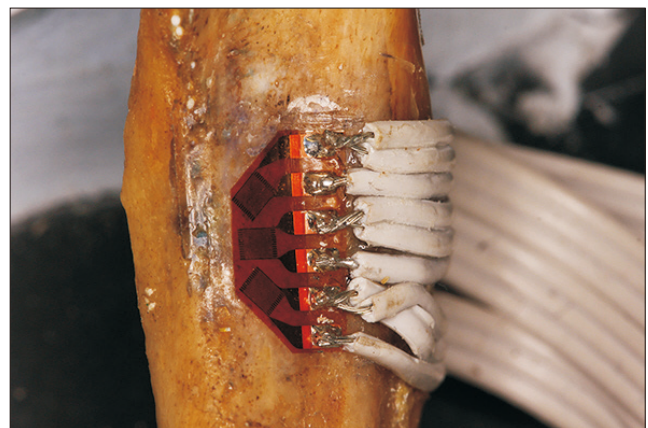


Fig. 1. Following the assembly process, all single elements of the rosettes were circuit balanced and shunt calibrated electronically *in situ*.

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an *in vitro* study. J Korean Assoc Oral Maxillofac Surg 2019

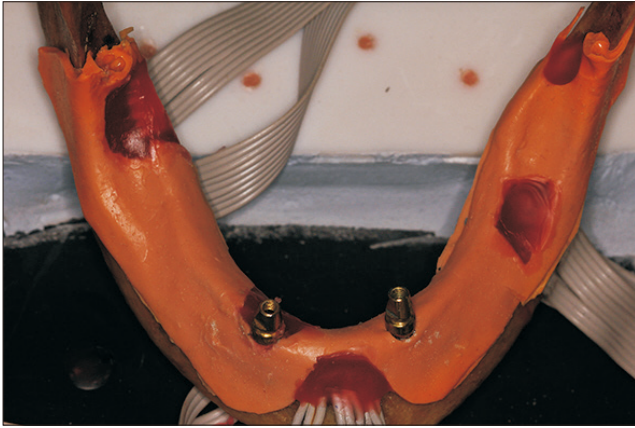


Fig. 2. A 2-mm-thick polyvinylsiloxane impression material was adapted to the mandible to mimic soft tissue.

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

with soft tissue using a reversible hydrocolloid impression material (Kromopan 100; Lascod, Florence, Italy) and was then filled with dental stone to obtain a working cast. A matching maxillary edentulous cast was selected from those used for pre-clinical education of dental students. Record bases and occlusion rims were prepared on the casts with average height and width values as described previously, and the maxillary cast with the mandible was mounted to a modified semi-adjustable articulator (Artex CT Articulator; Amann Girrbach AG, Koblach, Austria). Anatomically shaped acrylic resin artificial teeth (Trend GD Dent, Sakarya, Turkey) were arranged, and a pair of maxillary and mandibular complete dentures (MCDs) was processed and finished using heatpolymerized polymethylmethacrylate (Meliodent; Bayer UK Ltd., Newbury, UK). One MCD was duplicated from the original with a previously described method²³ to create two identical dentures—one to use for the bar attachment situation and one with ball attachments. For fabrication of a surgical template, the mandibular denture was additionally duplicated using a clear heat-cured acrylic resin (Rodex, Rodent, Italy).

1. Surgical procedures

Two 3.8-mm-wide, 11-mm-long dental implants (Xive; Dentsply Sirona, York, PA, USA) were placed in the canine positions with the aid of a template prepared by an experienced oral and maxillofacial surgeon according to the guidelines determined by the manufacturer. During implant placement, special attention was given to obtain successful apico-



Fig. 3. The anterior bridge and the bilateral distal extension removable partial denture.

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

coronal leveling of implant shoulders.

2. Prosthetic procedures

An implant-level impression was created using the closed impression technique with polyvinylsiloxane impression material (Affinis light body; Coltene/Whaledent AG). Upon removal of the impression, 2 implant analogues (Xive) were placed into the replicas in the impression, and the impression was filled with type IV dental stone (GC Fujirock EP; GC Dental, Tokyo, Japan) to obtain a working cast.

Three attachment types were used to retain the mandibular prosthesis.

1) Screw-retained abutments (Xive) were screwed to the analogues; and a two-implant retained bar was fabricated, screwed to the implants, and attached to the 3 MCDs with autopolymerizing acrylic resin (Meliodent; Kulzer GmbH, Hanau, Germany) after removal of adequate acrylic using a round bur (#140. 277. 040; Acurata Imperial, Thurmansbang, Germany).

2) Ball abutments (Xive) were screwed to the implants and attached to the remaining 3 MCDs with auto polymerizing acrylic resin (Meliodent; Kulzer GmbH) after removal of adequate acrylic using a round bur (#140. 277. 040).

3) A new set of screw-retained abutments (Xive) was added to the implants, and a 6-unit, anterior, metal fused to porcelain fixed bridge with extra coronal precision attachments and a bilateral distal extension RPD (Fig. 3) were fabricated³⁸. Bilateral extracoronal precision attachments were used (Vario Soft 3; Bredent GmbH & Co.KG, Senden, Germany).

3. Experimental procedures

The modified semi-adjustable articulator together with the mandible that had been provided with SGs was placed under a universal testing machine (MTS Bionix-II Axial/Torsional Test System; MTS, Eden Prairie, MN, USA), and occlusal forces were applied through the center of the maxillary model. For strain data acquisition, a multichannel, multipurpose, universal data acquisition system (Model 8048, 128 Channel Configuration; Prosig, Fareham, UK) was used. The strains were collected in synchronization with the axial force values obtained from the MTS Controller Unit. A 40-kg load cell (ESIT, Istanbul, Turkey) was used for optimum force measurement accuracy during the tests. Quasi static tests were subsequently conducted 10 times for each implant, and attachment configurations were performed at each of the replicated “biting” conditions: centric occlusion and left and right chewing positions. The loading and unloading rates were both 7 N/s. To exclude possible minor misalignment errors due to assembly and production tolerances, a preload of 5 N was placed on the system as the reference state. Each member of the strain rosette represented a one-quarter bridge. Accordingly, a total of 18 channels of data were gathered. Thermal drift was not observed during any tests.

4. Statistical analyses

For statistical analysis of the results, IBM SPSS Statistics (ver. 21; IBM Corp., Armonk, NY, USA) was used to analyze the measured strains from 6 SGs at 3 different loading conditions. Comparison of quantitative data was accomplished with the Mann–Whitney U test for groups without normal distribution. For comparison of the 3 denture types, the Kruskal–Wallis test was used. The results were assessed at a 95%

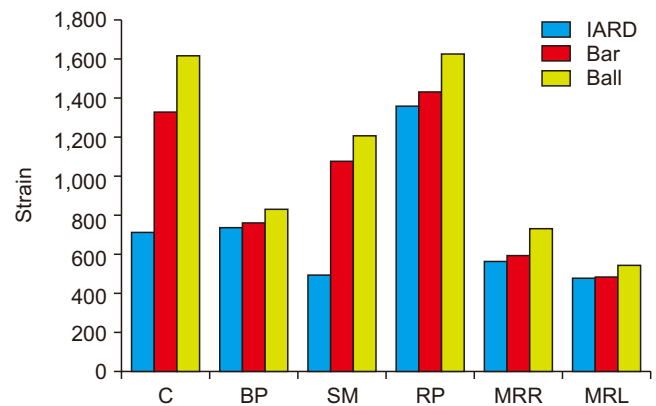


Fig. 4. Strain distribution under centric loading measured on all strain gauges. (IARD: implant-assisted removable denture, C: right canine region, BP: buccal shelf left, SM: symphysis midline, RP: right retromolar pad, MRR: right mylohyoid ridge, MRL: left mylohyoid ridge)

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

Table 1. Mean micro-strain values of different loading situations measured at all gauges

		IARD	Bar	Ball	P-value
C	Centric loading	739.70±15.78	1,354.20±91.78	1,641.05±20.73	0.002
	Loading on left side	717.60±14.44	858.85±38.99	987.60±20.89	0.002
	Loading on right side	1,692.05±45.83	2,122.60±130.20	2,659.50±27.24	0.004
BP	Centric loading	764.95±17.06	785.90±15.61	854.25±52.95	0.002
	Loading on left side	1,283.00±38.18	1,414.70±50.28	1,486.00±72.71	0.001
	Loading on right side	1,063.55±26.94	1,326.65±44.09	1,144.75±36.30	0.045
SM	Centric loading	523.80±19.44	1,104.95±44.87	1,235.30±38.88	0.001
	Loading on left side	863.95±47.14	1,019.45±54.47	1,142.65±15.72	0.001
	Loading on right side	1,240.50±49.66	1,525.70±48.84	1,620.30±53.58	0.003
RP	Centric loading	1,384.70±32.68	1,450.05±22.17	1,656.65±50.19	0.001
	Loading on left side	1,147.15±29.43	1,187.15±27.46	1,240.50±16.11	0.007
	Loading on right side	1,964.25±23.42	2,071.35±38.83	2,477.60±30.56	0.001
MRR	Centric loading	593.30±13.17	617.30±40.99	756.35±39.23	0.002
	Loading on left side	582.65±18.88	586.90±35.81	668.00±36.64	0.013
	Loading on right side	867.90±32.05	906.40±48.98	866.40±81.78	0.289
MRL	Centric loading	501.60±28.43	511.60±41.38	570.55±73.53	0.004
	Loading on left side	812.00±14.91	793.90±28.44	856.00±36.64	0.002
	Loading on right side	525.20±16.34	564.10±20.20	516.35±23.39	0.008

(IARD: implant-assisted removable denture, C: right canine region, BP: buccal shelf left, SM: symphysis midline, RP: right retromolar pad, MRR: right mylohyoid ridge, MRL: left mylohyoid ridge)

P-values by Kruskal–Wallis analysis.

Values are presented as mean±standard deviation.

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

confidence interval for a significance level of 0.05.

III. Results

Results for loading in the centric occlusion position are presented in Table 1 and Fig. 4.

The lowest strain values were measured in the IARD. The only exception was the MRL region for the ball attachment situation (136.55), whereas the highest value was observed in the C region for the ball attachment situation (1,941.05).

Results for unilateral loading on the left side are presented in Table 1 and Fig. 5.

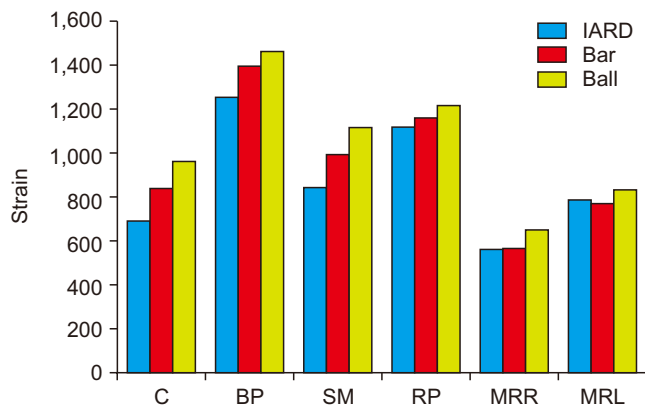


Fig. 5. Strain distribution under left side loading measured on all strain gauges. (IARD: implant-assisted removable denture, C: right canine region, BP: buccal shelf left, SM: symphysis midline, RP: right retromolar pad, MRR: right mylohyoid ridge, MRL: left mylohyoid ridge)

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

The lowest strain values were measured in the IARD, except for the MRL region for the ball attachment situation (586). The highest value was observed in the C region for the bar attachment situation (1,857.6).

Results for unilateral loading on the right side are presented in Table 1 and Fig. 6.

The lowest strain values were measured in the IARD. The highest value was observed in the C region for the ball attachment situation (1,192.05).

All P-values comparing attachment types are presented in Table 2.

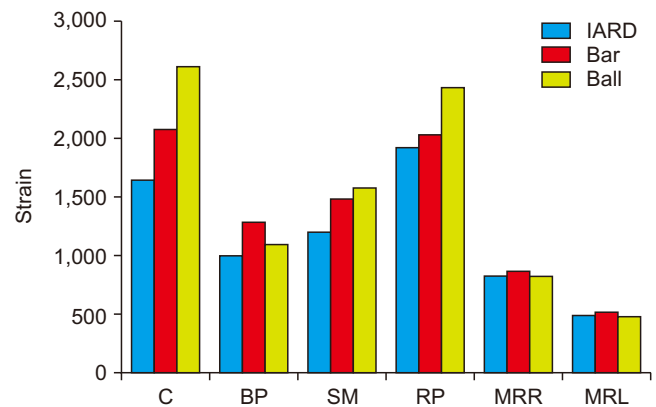


Fig. 6. Strain distribution under right side loading measured on all strain gauges. (IARD: implant-assisted removable denture, C: right canine region, BP: buccal shelf left, SM: symphysis midline, RP: right retromolar pad, MRR: right mylohyoid ridge, MRL: left mylohyoid ridge)

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

Table 2. P-values when comparing treatment types

	C	BP	SM	RP	MRR	MRL
Centric loading						
Ball-bar	0.003*	0.335	0.001*	0.000*	0.365	0.000*
Ball-IARD	0.000*	0.000*	0.000*	0.000*	0.000*	0.001*
Bar-IARD	0.001*	0.756	0.001*	0.554	0.110	0.365
Unilateral loading left side						
Ball-bar	0.001*	0.335	0.000*	1	0.001*	0.000*
Ball-IARD	0.001*	0.000*	0.000*	0.001*	1.000	0.335
Bar-IARD	0.000*	0.001*	1	0.050	0.084	0.084
Unilateral loading right side						
Ball-bar	0.000*	0.000*	0.000*	0.001*	0.212	0.212
Ball-IARD	0.000*	0.015	0.335	0.000*	1	0.088
Bar-IARD	0.001*	0.000*	0.001*	0.335	0.050	1

(C: right canine region, BP: buccal shelf left, SM: symphysis midline, RP: right retromolar pad, MRR: right mylohyoid ridge, MRL: left mylohyoid ridge, IARD: implant-assisted removable denture)

*P<0.01.

P-values by Mann-Whitney U test.

Selda Arat Bilhan et al: Evaluation of two interforaminal implants and implant-assisted removable dentures on stress distribution: an in vitro study. J Korean Assoc Oral Maxillofac Surg 2019

IV. Discussion

The aim of this study was to explain the use of the presented new attachment system. If the results exhibited similar strain and/or stress distributions, the clinical treatment modalities for mandibular ISRDs could be modified to provide more economic, patient friendly, and safe solutions³⁸. The null hypothesis of the study that IARD and ISRD would not differ on stress distribution in the edentulous mandible was rejected. The lower stress patterns observed in the IARDs show that this treatment option may be preferred for clinical use in some situations. Since information about functional loads on implants and the bone is essential to achieve long-term implant success, correct qualification and quantification of forces on implants are crucial^{10,11,39,40}. Studies evaluating the IARD treatment option in two interforaminal implant situations are limited to a few case series³⁴⁻³⁷. The present study is the first report evaluating this type of IARDs.

Patients who can afford dental implants often have more esthetic demands and expectations of more rigid prosthetic solutions. Therefore, extracoronary precision attachments in IARDs were selected instead of conventional clasp-retained removable dentures in the present study. For biomechanical assessment of stress distribution *in vitro*, SG analysis is one of the most common methods used in dentistry³⁸. The info gathered from SGs under differing experimental conditions should be regarded skeptically before clinical use because these measurements are limited to the bonded area of the gauge. The measured force levels in the present study are comparable to those measured in recent *in vivo* studies with SG abutments on implants^{41,42}.

When patients use ISRDs, loads are transferred to the alveolar bone surrounding the implants as well as to residual alveolar ridges and abutments. Therefore, ISRDs depend on both implant and mucosal support⁴⁰. It is important not to create negative forces on implant abutments to avoid implant damage.

The thickness of the mucosa surrounding the alveolar ridge of the mandible was 2 mm in the present study, in agreement with previous studies^{38,43}. The effect of attachment type on stress distribution was studied in numerous investigations⁴³⁻⁴⁵, and controversies could not be eliminated. The results of a recent systematic review showed no difference in marginal bone levels around implants supporting mandibular ISRDs when different attachment systems were used²⁶. This suggests that, even if there are differences in the forces, they are not critical to bone loss.

The results of this *in vitro* study indicate that, compared to retentive anchors or bar attachments, the lowest strains occurred in the new tested denture system.

Strains in the posterior mandible, such as at the retromolar pad, buccal shelf, and mylohyoid ridge, were lower with the tested attachment system for ISRDs in the present study. This result is in agreement with another investigation that reported an inverse relationship between implant strain and bearing area loading value¹¹. Our results showed that ISRDs had the lowest denture-bearing area loading, whereas single-attachment situations exhibited relatively low implant strain and high bearing area load. The results of the present study should only be considered for forces arising during vertical occlusal loading.

The anterior fixed bridge with the precision attachment partial denture eliminates two problems of conventional attachment systems tested in the present study. First, the stability of an overdenture is hard to achieve with single attachments especially in severely resorbed alveolar ridges¹¹, and bar types of attachments generally require more space in the denture base and are more difficult to clean³. The proposed prosthetic solution eliminates the issues of stability and increased volume of the denture as a result of the bar system, especially in the anterior region. Second, the fixed part of the denture may increase the self-confidence of the patient. As shown in a recent study, wear of the matrices of single attachments are more noticeable when implants are divergently inserted⁴, requiring more maintenance over a shorter period of service. It was determined that the ideal solution in cases of divergent implants are splinted attachment types⁸. Therefore, the IARD solution is suitable for this kind of situation.

With the use of the described technique, it was not possible to quantify bone-implant interface strains, a limitation of the present study. Therefore, the results of the present study should be considered with caution. Although the *in vivo* situation was mimicked as ideally as possible, the results obtained from the *in vitro* experiments should be tested and confirmed in clinical follow-up studies before strict conclusions are drawn. However, the results encourage clinical use of the suggested fixed anterior bridge with precision attachments and RPD, since its esthetic and functional advantages are accompanied by favorable force distribution in the mandible. Use of IARDs is a good alternative to other attachment designs when 2 implants are inserted in the anterior region of the mandible.

V. Conclusion

Within the limitations of the present study, it can be concluded that an IARD may be a reasonable and valuable alternative to ball attachments or a bar in two interforaminal implants situations, especially when the patients prefer to have their teeth as fixed prosthesis even when they remove their dentures. The *in vitro* results are qualitative in nature, and their clinical significance should be tested and confirmed in clinical studies.

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Authors' Contributions

S.A.B. contributed experimental procedures, and data collection. O.G. contributed drafting article, critical revision of article, and approval of article. A.C. contributed data analysis and interpretation. E.B. contributed experimental procedures. H.B. contributed critical revision of article.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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