Bone Strains Around Immediately Loaded Implants Supporting Mandibular Overdentures in Human Cadavers

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Purpose: *To compare the biomechanical effect of splinted versus unsplinted mandibular implants supporting overdentures subjected to experimental static immediate load on bone tissue deformation using strain gauge analysis.* ***Materials and Methods:*** *Strain gauges were bonded on the labial cortical bone adjacent to 2 Straumann dental implants placed in the mandibular interforaminal region of 4 completely edentulous mandibles of fresh human cadavers. The installation torque value (ITV) of each implant was measured using a custom-made torque wrench, and implant stability quotients (ISQs) were also obtained using resonance frequency analysis. Three overdentures (ODs), 2 splinted (bar- and cantilevered bar-retained) and 1 unsplinted (ball-retained), were fabricated for each edentulous mandible. Two experimental loads were applied subsequently via 2 miniature load cells that were placed bilaterally 10 mm (anterior loading) and 15 mm (posterior loading) from the implant. Strain measurements were performed at a sample rate of 10 KHz and under a maximum experimental static load of 100 N; they were simultaneously monitored from a computer connected to a data acquisition system. Finally, the removal torque values (RTV) of the implants were measured.* ***Results:*** *Strains on the labial cortical bone around implants supporting mandibular ODs under anterior loading were significantly higher than measured under posterior loading for all attachment types (P < .05). All strain values were compressive in nature, and the minimum strain (−19 με) was recorded for bar-retained ODs under 25 N posterior loading, while the maximum strain (−797 με) was for recorded for retentive anchor-retained ODs under 100 N anterior loading. Nonparametric correlations between ISQs, ITVs, and RTVs identified significant correlations only for ITVs and RTVs (P < .05).* ***Conclusion:*** *Splinting of 2 interforaminal dental implants, regardless of attachment type, to support mandibular ODs subjected to immediate load significantly reduced initial bone tissue strains experienced on the labial cortical bone in comparison with the use of unsplinted implants.* INT J ORAL MAXILLOFAC IMPLANTS 2007;22:101–109

Key words: *biomechanics, dental implants, immediate loading, mandibular overdentures, micromovement, resonance frequency analysis, strain gauges*

Following the introduction of osseointegration, completely edentulous mandibular arches, especially those of elderly patients, received primary concern regarding the rehabilitation of oral function with implant-supported prostheses. Two treatment concepts presenting fundamental differences in support, retention, and design have been scientifically approved contingent on long-term successful outcomes[1,2]: the use of dental implants to support either fixed prostheses with bilateral cantilever extensions or removable prostheses.[3,4] Extensive clinical experience recently resulted in a revolutionary consensus on implant-supported overdentures (ODs) as the first treatment option for the rehabilitation of complete mandibular edentulism.[5] Indeed, comparative clinical studies have demonstrated that implant-supported ODs provide physiologic and psychologic satisfaction to patients.[6,7]

It has been claimed that forces acting on implants supporting ODs increase the magnitude of the bending moment compared with those acting on implant

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supporting fixed prostheses.[8] Interest, therefore, has been focused on exploring the influence of different attachment types on stress/strain magnitudes around implants supporting ODs. Several studies relevant to the biomechanical effects of various attachment types on implants and peri-implant tissues supporting ODs were inherently limited to in vitro testing conditions.[9–11] In vivo studies[12,13] were insufficient to derive data concerning the biomechanical environment of bone tissue around implants. Not only were measurements carried out above bone level, they were carried out on prosthetic abutments, which do not represent the biomechanical characterization of living bone. Controversy and lack of consensus remain regarding intraosseous stress/strain levels around splinted and unsplinted osseointegrated implants supporting mandibular ODs. Nevertheless, high success rates of implants supporting mandibular ODs[14–16] suggest that high bone quantity and quality in the mandibular anterior region[17] and decreased occlusal bite forces in completely edentulous elderly patients[18] allow force distribution around osseointegrated implants to remain within physiologically viable levels.

Because micromotion of loaded implants may partly contribute to the bone formation process,[19] the use of an unloaded healing phase,[20] the necessity of which was empirically asserted,[20] is no longer considered an absolute prerequisite[21] to achieve successful osseointegration, at least under certain conditions. Indeed, promising early results of preliminary studies[22,23] have been recently coupled with successful long-term clinical outcomes regarding immediate loading of splinted[24–26] and early loading of unsplinted[27,28] interforaminal implants supporting mandibular ODs. Assuming a preference for immediate and early loading of implants with ODs, the biomechanical impact of attachment type on bone tissues around implants becomes more crucial than it would be for conventionally loaded implants. Unfortunately, experience based on clinical applications of immediate loading of implants supporting mandibular ODs seriously suffers from a lack of fundamental scientific evidence considering the effects of attachment type. The inability to simulate real-life immediate-loading conditions with in vitro experimental models and the impracticality and invasive nature of the procedures required for in vivo trials led the present researchers to propose the validity of animal models and the placement of implants in fresh human ex vivo bone tissue to examine the biomechanical characterization of immediately loaded implants. In the present study, it was hypothesized that splinting of 2 implants supporting mandibular ODs would reduce initial (early) bone tissue deformation around implants under immediate loading. The purpose of this study was, therefore, to compare strains in ex vivo bone tissue around splinted and unsplinted implants supporting mandibular ODs subjected to experimental static immediate load.

MATERIALS AND METHODS

Fabrication of a Working Model and Guide-Bar Retainer

The purpose of using a working model prior to the cadaver experiments was to create a guide-bar retainer for standard placement of implants in all cadavers. Because the anterior mandibles of the cadavers were similar in shape and dimensions, implant placement using the guide-bar retainer did not lead to problems in fabrication of the prosthesis and strain-gauge experiments. To fabricate a working model, an edentulous human mandible fixed in formaldehyde was duplicated using a vinyl polysiloxane impression material (Panasil; Kettenbach Dental, Eschenburg, Germany) and autopolymerized methylmethacrylate resin (Technovit 4004; Heraeus Kulzer, Wehrheim, Germany). On this cast, an anterior teeth arrangement was completed according to the guidelines established for fabricating complete dentures[29] to determine implant locations. Indicator marks representing 2 interforaminal implants[30] 20 mm apart were placed between the canine and lateral incisors bilaterally. Following removal of the artificial teeth, the working model was placed on the surveying table of a milling machine (Bego Paraskop, Bremen, Germany) to prepare implant sockets perpendicular to the horizontal base plane using 2.2- and 2.8-mm-wide pilot drills, a 3.5-mm-wide twist drill, and a 4.1-mm-wide tapping drill (Straumann, Basel, Switzerland). Before tightening the 4.1 × 10 mm Straumann solid-screw implants into the sockets using a ratchet (Straumann), implants were dipped once into a fresh mixture of methylmethacrylate to secure positional implant stability (Fig 1). Upon polymerization, synOcta abutments for transocclusal screw-retained prostheses (Straumann) were connected to the implants to fabricate a guide-bar retainer. Plastic copings (Straumann) were placed over the abutments and connected using a custom-made 1.25 × 2.5-mm acrylic resin plate (GC Pattern Resin, GC Europe, Leuven, Belgium). The plastic superstructure was cast with gold alloy (Degudent; Degussa Dental, Hanau-Wolfgang, Germany) following the manufacturer's instructions. The fit of the guide-bar retainer was verified visually using finger pressure and one-screw and screw resistance tests in conjunction with a brand-new explorer.[31,32]

Fig 1 Acrylic resin working cast of an edentulous mandibular arch hosting 4.1 × 10-mm Straumann dental implants placed 20 mm apart in the interforaminal region.

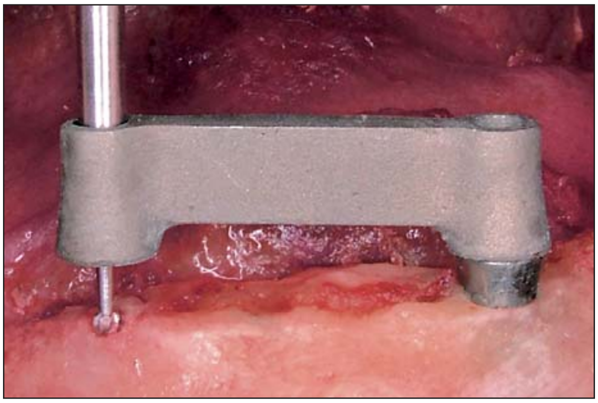

Fig 2 Marking the companion implant location with a round bur through the guide-bar retainer screwed onto the placed implant.

Surgical Procedures and Experimental Parameters

Completely edentulous mandibular arches of 4 freshly frozen human cadavers (2 women and 2 men who had bequeathed their bodies for medical/scientific research purposes) were obtained. These cadaveric mandibles were used to determine *(1)* implant insertion and removal torque values (ITV and RTV, respectively), *(2)* implant stability quotient (ISQ), and *(3)* the amount of strain developed on the labial cortical bone around implants.

Cadavers were left in room temperature for 24 hours prior to the experiments. Full-thickness flaps were reflected in the mandible between the premolar regions. Each cadaver received 2 implants; thus, a total of 8 implants were studied. To determine the aperture of each implant location, the guide-bar retainer was positioned over the edentulous anterior residual ridge; the genial tubercles were used as the anatomic midline reference. After marking the implant locations on the cortical bone by passing a round bur (Straumann) through the guide-bar retainer, preparation of the recipient bone site of the first implant was completed without the guide-bar retainer according to defined principles.[33] Then, the first implant was placed in the socket using the manual ratchet. Quantification of ITV was performed as defined by Akkocaoglu and associates[34] using a custom-made manual torque wrench.[35] Resonance frequency analysis (RFA) was then performed to ascertain the ISQ.

Prior to bone preparation of the second implant, an abutment was connected to the placed implant. The guide-bar retainer was positioned along the ridge and secured in place with an occlusal screw (Fig 2). Then, initial implant orientation was created using a 2.2-mm-wide pilot drill through the retainer spare of the guide bar. The guide-bar retainer was removed to complete bone preparation following the guidelines.[33] During implant placement, particular attention was given visually to appropriate cervico-occlusal leveling of the implant shoulder to the margin of corresponding guide-bar retainer. The ITV and ISQ of the second implant were then recorded.

Fabrication of ODs

Implant-level impressions were made of the transmucosal parts of the implants using impression caps (Straumann) and positioning cylinders (Straumann) and a stock tray with a vinyl polysiloxane impression material (Panasil). Upon removal of the impressions, implant analogs (Straumann) were placed and poured with type IV dental stone (Giludur; BK Giulini Chemie, Ludwigshafen/Rh, Germany) to obtain working casts of each edentulous mandible.

For each cadaver, 3 sets (2 splinted, 1 unsplinted) of ODs without integration of metal reinforcement were fabricated on working casts. To fabricate splinted implant-supported ODs, synOcta abutments for transocclusal screw-retained prostheses were connected to the implant analogs. Burnout plastic copings for the cast bar (Straumann) were screwed into place, and a 3-mm-high plastic bar (Straumann) with an egg-shaped cross-section was attached to the copings using pattern resin (GC Pattern Resin). Another bar retainer design was obtained by including bilateral 7-mm-long distal cantilever bar extensions. Both types of bar retainer superstructures were cast using a gold alloy (Degudent G) following the instructions of the manufacturer. Upon verification of the fit of bar retainer superstructures to implant analogs on working casts, ODs were fabricated and processed according to the principles and guidelines established for removable dentures.[30] To fabricate unsplinted implant-supported ODs, retentive anchors (Straumann) were connected to implant

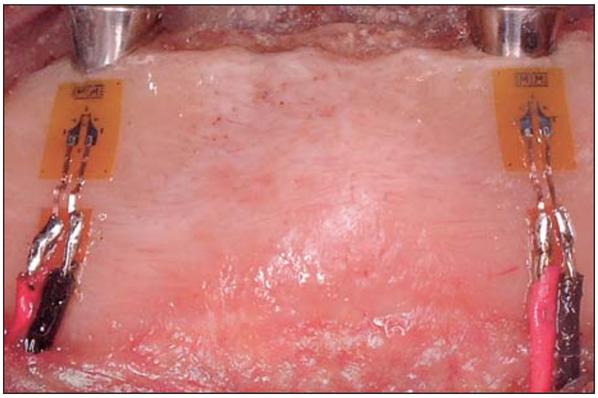

Fig 3 The linear strain gauges bonded on the labial cortical bone adjacent to the implants.

Fig 4 The ODs prior to placement over *(a)* a bar retainer, *(b)* a cantilevered bar retainer, and *(c)* a retentive anchor retainer.

analogs, followed by gold matrices (Straumann). Unsplinted implant-supported ODs were completed by following the defined guidelines.[30] Occlusal slots were prepared bilaterally in each OD 10 and 15 mm distal to the implants to house miniature load cells (EL Entran Sensors & Electronics, Fairfield, NJ) for controlled experimental anterior and posterior immediate static loading.

Quantification of Bone Tissue Strain

A linear strain gauge (EA-06-015CK-120; Micromeasurements Group, Raleigh, NC; resistance 120.0% ± 0.3 ohms; gauge factor, 2.04% ± 2.0%) was bonded to the labial cortical bone adjacent to the implants, approximately 2 mm from the alveolar crest.[36–38] The lead foils of the gauges were soldered to connecting terminals (Micromeasurements Group), and each gauge was wired separately into a Wheatstone bridge (Fig 3). The wires of the gauges were waterproofed by application of an air-drying polyurethane (M Coat A; Micromeasurements Group).[39] For each OD (Fig 4), 2 separate experimental occlusal loadings were performed by applying a maximum static load of 100 N over load cells placed bilaterally into anterior and posterior occlusal slots separately. Because an intimate contact was achieved between the ODs and casts during polymerization of polymethylmethacrylate, the distal section of the prosthesis was in contact with the supporting tissues when the loading experiments were undertaken. During the experiments, the load cells and strain-gauge signals were digitalized by the data acquisition system (ESAM Traveller 1; Vishay Micromeasurements Group, Raleigh, NC), and corresponding software (ESAM; ESA Messtechnik, Olching, Germany) at a sample rate of 10 KHz. Before experimental loading sequences, strain gauges were balanced to 0 using the software (ESAM) to exclude the strains likely to result from nonpassive fit of the bar superstructures and OD placement. Upon completion of the strain-gauge experiments, RTVs of the implants were measured using the custom-made manual torque wrench.

Statistical Analysis

The Student *t* test was used to evaluate the difference between the strain values of the left and right implants; once it was determined that the difference was not significant ($P > .05$), strain data for the right and left implants were combined for each applied load (25 to 100 N) and prosthesis design.

For within-group evaluations, the Friedman test was used to compare the strain values on the cortical bone around implants under 25-N, 50-N, 75-N, and 100-N loads. The Mann-Whitney test was performed to compare the strain values under anterior loading and posterior loading. For between-group comparisons, the Kruskal-Wallis test was used to assess the differences between the strain data under anterior and posterior loading of 25 to 100 N. ISQs, ITVs, and RTVs were subjected to Spearman's rho test for a nonparametric correlation assessment. $P < .05$ was considered statistically significant.

Table 1 Microstrains in the Bone Labial to Implants Supporting Mandibular ODs Under a 25-N Experimental Static Load

	n	Max	Min	Mean	SD	SEM
Bar-retained OD						
Anterior	8	−160	−116	−132.00	17.25	6.10
Posterior	8	−53	−19	−33.25	12.87	4.55
Cantilevered bar-retained OD						
Anterior	8	−183	−153	−169.38	10.61	3.75
Posterior	8	−64	−29	−43.38	13.32	4.71
Retentive anchor-retained OD						
Anterior	8	−598	−571	−580.88	9.63	3.40
Posterior	8	−231	−192	−207.25	14.68	5.19

SEM = standard error of the mean.

Table 2 Microstrains in the Bone Labial to Implants Supporting Mandibular ODs Under a 50-N Experimental Static Load

	n	Max	Min	Mean	SD	SEM
Bar-retained OD						
Anterior	8	−167	−121	−139.50	17.16	6.07
Posterior	8	−66	−25	−41.25	15.26	5.39
Cantilevered bar-retained OD						
Anterior	8	−245	−198	−219.75	17.09	6.04
Posterior	8	−72	−39	−51.00	13.11	4.64
Retentive anchor-retained OD						
Anterior	8	−637	−612	−626.75	9.57	3.38
Posterior	8	−253	−221	−236.25	12.36	4.37

Table 3 Microstrains in the Bone Labial to Implants Supporting Mandibular ODs Under a 75-N Experimental Static Load

	n	Max	Min	Mean	SD	SEM
Bar-retained OD						
Anterior	8	−181	−127	−146.75	20.99	7.42
Posterior	8	−79	−40	−52.88	15.83	5.60
Cantilevered bar-retained OD						
Anterior	8	−277	−222	−241.00	22.40	7.92
Posterior	8	−88	−48	−63.37	14.77	5.22
Retentive anchor-retained OD						
Anterior	8	−692	−672	−681.88	6.90	2.44
Posterior	8	−302	−275	−286.63	11.48	4.06

RESULTS

Strain values around the splinted and unsplinted implants supporting ODs under anterior and posterior loads of 25 to 100 N were compressive for all attachment types and are presented in Tables 1 to 4.

Within-group comparisons revealed that strain values increased as the applied load increased from 25 N to 100 N, and the differences in strain values between 2 consecutive loadings were significant for each prosthesis under anterior and posterior loading ($P < .05$). Strain values were higher under anterior loading than under posterior loading for each prosthesis ($P < .05$). Between-group comparisons showed that the highest strain values were recorded under anterior loading of retentive anchor–retained ODs under 100 N of load, while the lowest strain values were obtained for the bar-retained OD under posterior loading at 25 N of load (Fig 5).

The ITVs, ISQs, and RTVs of the implants placed in all cadavers are presented in Table 5. Nonparametric correlations between ISQs, ITVs, and RTVs are described in Table 6. While 91.6% correlation between ITVs and RTVs was significant ($P < .05$), neither the correlation between ISQ and ITV (52.8%) nor the correlation between ISQ and RTV was significant at the 95% confidence level.

Table 4 Microstrains in the Bone Labial to Implants Supporting Mandibular ODs Under a 100-N Experimental Static Load

	n	Max	Min	Mean	SD	SEM
Bar-retained OD						
Anterior	8	−192	−143	−160.87	19.31	6.83
Posterior	8	−94	−57	−69.88	14.99	5.30
Cantilevered bar-retained OD						
Anterior	8	−294	−248	−270.13	16.56	5.85
Posterior	8	−106	−65	−79.88	15.62	5.52
Retentive anchor-retained OD						
Anterior	8	−797	−752	−777.00	15.13	5.35
Posterior	8	−463	−345	−422.00	47.53	16.81

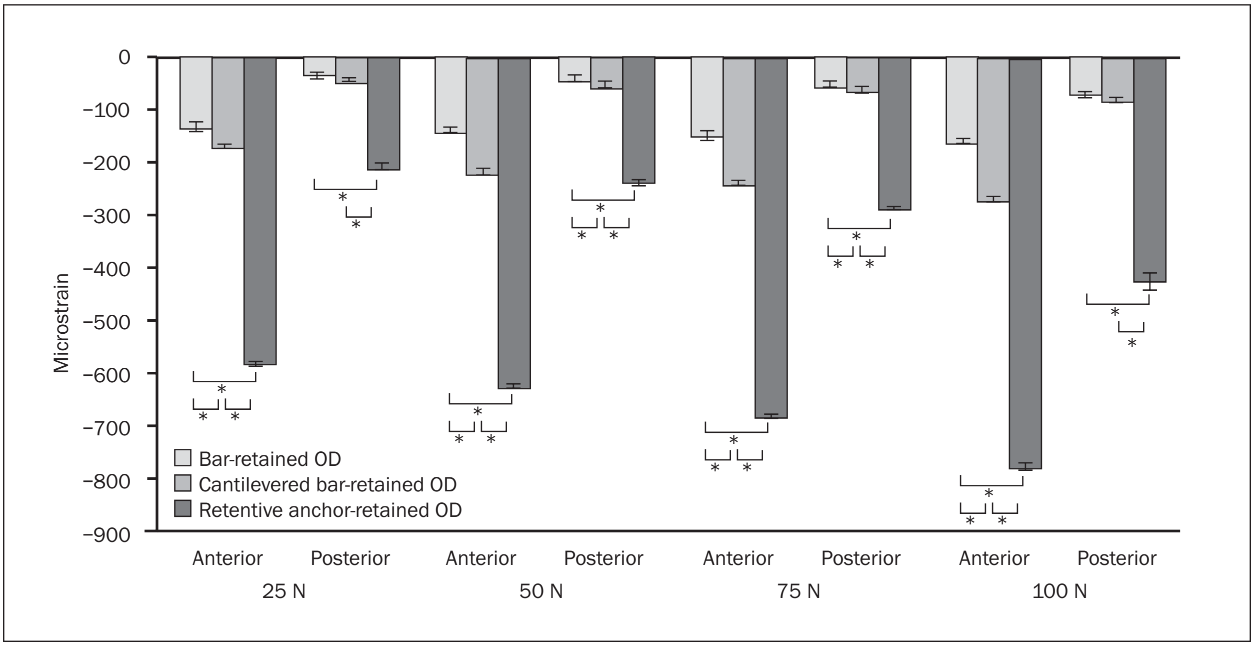

Fig 5 Mean microstrains on the labial cortical bone of implants supporting bar-retained, cantilevered bar-retained, and retentive anchor-retained ODs under anterior and posterior experimental loading static loads of 25 to 100 N. *indicates $P < .05$.

DISCUSSION

Current knowledge regarding immediate or early loading of dental implants is based mainly on clinical studies,[24–28] which have certain limitations.

In contrast to immediate loading, early loading is the loading of implants more than 3 days following surgical placement.[21] Because the biomechanics of immediately loaded implants in humans in the beginning of treatment are unknown, the present human cadaver study was designed to shed light on this issue. Indeed, the fresh-frozen cadaver bone is probably the best experimental model to measure bone tissue strains for immediately loaded implants.

Nevertheless, this study was limited to quantification of the strains on cortical bone in the implant collar region with linear strain gauges and under static load, as it is not possible to quantify bone implant-interface strains with this technique. However, in the future it may be possible to measure bone implant-interface strains using biosensors. Due to the limited number of fresh-frozen cadaver models, the number of parameters examined was minimized for optimum evaluation of ex vivo bone behavior. Furthermore, a unique guide-bar retainer was fabricated for the placement of all implants to minimize the effect of 3-dimensional implant placement variability within and between edentulous mandibular arches.

Table 5 ISQ Values, ITVs, and RTVs of All Placed Implants in 4 Cadaveric Mandibles

	ISQ		ITV (N/cm)		RTV (N/cm)	
Cadaver	Right	Left	Right	Left	Right	Left
1	70	72	67	67	64	62
2	68	64	52	58	49	56
3	70	70	52	54	48	41
4	66	68	22	24	19	22

Experimental loads up to a maximum of 100 N, which is slightly lower than the maximal occlusal forces determined for mandibular ODs supported by osseointegrated implants,[18] were applied to compare the bone tissue strains experienced under anterior and posterior loading. For each OD, loading sequence was controlled via miniature load cells bilaterally placed over the slots prepared on the occlusal surfaces. In all ODs, labial cortical bone strains under anterior loads of 25 to 100 N were significantly higher than those measured under posterior loads. In an in vitro experimental acrylic resin mandibular model, higher force and moment were demonstrated using strain gauges on custom abutments connected to implants supporting mandibular ODs when the load was applied directly over the implant or interimplant region in comparison to the distal loading condition.[16] However, another in vitro experimental acrylic resin mandibular model with interferometric optical holography presented unfavorable implant displacement regardless of the attachment type when the OD was loaded distal to the first molar area.[40] The inconsistency between these 2 studies could be due to differences in the methods used to simulate clinical conditions; such inconsistency can make it difficult to correctly interpret the results for application in a clinical setting.[41] The results of the present cadaver models showed that labial cortical bone around implants supporting mandibular ODs subjected to immediate loading experienced higher deformation under anterior than posterior loading. This indicates the importance of the load-bearing capacity of edentulous ridge, which probably reduces the moments acting on implants under posterior loading.

Although similar strain values have been obtained at abutment level for conventionally loaded implants supporting mandibular ODs with bar and cantilevered bar attachments,[12,13] it was essential to explore the validity of these data for immediately loaded implants. The current study presented comparable outcomes for both attachment types in the splinted group. The successful outcomes might be attributed to high primary stability of implants in the mandibular anterior region, the splinting of the implants, effective load participation of the residual ridges, and the short distal cantilever extensions. However, the labial cortical bone around the unsplinted implants experienced higher strain values in comparison with the splinted implants. Nonetheless, clinical studies have indicated high survival rates for 2 unsplinted implants supporting early-loaded mandibular ODs.[27,28,42,43] In these clinical trials, unsplinted pairs of implants were functionally loaded with ODs either 2 weeks[42,43] or 6 weeks[27,28] after surgery; they were studies of early loading rather than immediate loading.[21] *Immediate loading* refers to immediate bearing of functional load (ie, a prosthesis) on the day of implant placement, whereas *early loading* refers to implant loading within a couple of weeks. Placing 2 unsplinted mandibular implants under functional loading during the early healing phase might contribute to osseointegration. However, when functional loading within 2 to 3 days, namely immediate loading,[21] is considered, increased strain values on bone tissue around unsplinted 2 implants reach the pathologic level. Additionally, Berglundh and colleagues[44] studied alveolar bone formation adjacent to implants in

Table 6 Nonparametric Correlations Between ISQ Values, ITVs, and RTVs Determined by Spearman's rho Test

	ISQ	ITV	RTV
ISQ			
Correlation coefficient	1.000	0.528	0.405
Significance (2-tailed)	0	.179	.319
N	8	8	8
ITV			
Correlation coefficient	0.528	1.000	0.916**
Significance (2-tailed)	.179	0	.001
N	8	8	8
RTV			
Correlation coefficient	0.405	0.916**	1.000
Significance (2-tailed)	.319	.001	0
N	8	8	8

**Correlation is significant at the .01 level (2-tailed).

dogs and demonstrated ongoing bone remodeling, resorption, and apposition at 2 weeks at pitch regions of the implants, which provide primary implant stability in the early healing stages of bone-implant interface. A study by Sennerby and associates[45] also showed extensive remodeling in the rabbit cortical bone relevant to a healing reaction to surgical wounding, which likely caused a decrease in the stiffness of the bone-implant interface. Glauser and colleagues[46] clinically presented a decrease in initial implant stability within the first 3 months following implant placement using RFAs. These authors concluded that the decrease in primary implant stability may have been related to microfractures in the peri-implant bone induced by immediate loading. Similar decrease in primary implant stability following implant placement in the early stages was also observed only for implants that displayed high ISQs.[47]

CONCLUSION

Taking the results of the present study into account, it might be suggested that the early mechanical environment in bone around implants as well as the achieved primary stability[29] might impair the initial healing when 2 unsplinted implants are planned to support immediately loaded mandibular overdentures. Because the primary stability of implants may decrease within the first 3 months of placement, splinted implants may be advantageous over unsplinted implants in the anterior mandible when immediate function is desired for overdentures.

ACKNOWLEDGMENTS

This study was partly supported by the State Planning Organization, Prime Ministry, Republic of Turkey (project no. 01 K 120 650).

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