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Effect of bone loss simulation and periodontal splinting on bone strain
Periodontal splints and bone strain

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ABSTRACT

Objectives: The influence of bone loss and periodontal splinting on strains in supporting bone is still not well understood. The aim of this study was to analyse the effect of bone loss and periodontal splints on strains in an anterior mandible structure.

Methods: Ten anterior mandible models were fabricated using polystyrene resin. Eighty human teeth were divided in 10 groups (right first premolar to left premolar) and embedded in simulated periodontal ligament. Strain gauges were attached to the buccal and lingual mandible surfaces. The models were sequentially tested for 7 conditions: no bone alterations and no splinting; 5 mm of bone loss between canine teeth; bone loss associated with resin splint between canine teeth; bone loss with wire splint; bone loss with wire/resin splint; bone loss with extracoronal fibre–glass/resin splint; and bone loss with intracoronal fibre–glass/resin splint. Oblique loads (50, 100, and 150 N) were applied on the teeth. Data were analysed using 3-way ANOVA and Scheffe's test ($\alpha = .05$).

Results: Strains on buccal surface were higher than on lingual surface. Bone loss resulted in strain increase at 100 and 150 N loading. Dental splinting with resin resulted in strain values similar to the control levels.

Conclusions: Bone loss increased strain mainly in the buccal region. Dental splints with adhesive system and composite resin produced lower bone strains irrespective of occlusal load.

1. Introduction

Periodontal disease is considered an infectious pathology caused by the interaction between a susceptible host and bacterial factors present in dental plaque.[1,2] As a result of the inflammatory process there is a disorganization of periodontal fibres, induction of bone resorption, and destruction of epithelial cell attachment.[1,3,4] Occlusal forces also play an

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important role because they may exacerbate a preexisting periodontal lesion when they exceed the resistance threshold of a compromised attachment apparatus.[1–5] In the presence of frequent loading, the time for bone remodelling may not be enough, and thus bone resorption takes place.[6] Reduced periodontal attachment can therefore result in tooth mobility and migration, causing misaligned occlusal forces that hinder the balance between bone resorption and bone remodeling[7] and the reorganization of periodontal fibres.[5] The relationship between occlusal trauma and tooth mobility therefore depends on the intensity and frequency of occlusal forces.[1–5,10,11] Periodontal disease and occlusal trauma are most prevalent in the mandibular anterior region. Although occlusal forces may be lower in this region compared to other regions,[8,9] stress levels might be higher due to less bone thickness.

Treatment of tooth mobility in periodontal disease is determined by the degree of damage to the bone support. For mobility caused by a widened periodontal space as a result of adaptation to functional demands,[1,5,10] the treatment is occlusal adjustments in combination with periodontal therapy.[1,10] In teeth affected by gingival inflammation and with higher mobility due to loss of bone tissue,[1,5] the treatment is a combination of periodontal therapy, occlusal adjustments, and tooth restraints for stability.[2,3,5,10,12] Stability is accomplished by periodontal splinting, which redistributes functional and parafunctional forces.[6] This helps the process of reorganization of the gingival tissues, periodontal fibres and alveolar bone,[3] and maintains patient comfort.[2–4] When periodontal splinting is used before surgical periodontal therapy,[2,6] it will promote tooth stabilization[2] and tissue healing by reducing inflammation.[2,6] Various techniques have been used to create periodontal splints, such as, composite resin in combination with adhesive systems,[6,10,13] orthodontic wire,[13,14] orthodontic wire in combination with composite resin, or preimpregnated fibre-reinforced composite in combination with composite resin.[6,10,15] An important aspect for the selection of a splint type is the mechanical interaction between splinting materials and tooth substrates.[12,16,17] However, the impact of bone loss and splint type on the biomechanical response has not been measured yet. Therefore, determining when to splint and selecting the most appropriate technique remains a difficult decision for clinicians.

The aim of this study was to assess the biomechanical response in the anterior region of a mandible to bone loss and to different types of periodontal splints by measuring strains. Strains represent deformation, and thus indicate the biomechanical response of the mandible. Strains have previously been measured using strain gauges to analyse the biomechanical response of mandibular bone and tooth structures[19] during masticatory loading in vivo[18] and in cadavers with natural teeth after implant insertion.[20] Bone deformation has also been estimated indirectly by measuring strains on mandible replicas made of epoxy resin[21] or autopolymerized acrylic resin.[19] In this study, it was hypothesized that bone loss and splint type affect the strains in the mandible, and that the strain values depend on mandible surface (buccal or lingual), region (central or lateral incisor), and load level.

2. Materials and methods

2.1. *Tooth selection*

Eighty mandibular human teeth (approved by the Federal University of Uberlândia Ethics Committee, protocol #112/06), extracted for periodontal or orthodontic treatment, were selected in this study: 20 central incisors, 20 lateral incisors, 20 canines and 20 first premolars (being half of the right side and half of the left side). Teeth of similar size were selected, where the buccolingual and mesiodistal widths had a maximum deviation of 10% from the mean. Soft tissue and calculus deposits were removed with a periodontal curette (Hu-Friedy, Chicago, IL, USA). The teeth were cleaned using a rubber cup and fine pumice water slurry and stored in 0.2% thymol solution (Pharmacia Biopharma Ltda, Uberlândia, Brazil). The teeth were randomly divided into 10 groups. The teeth were stored in distilled water at 4 °C.

2.2. *Mandible replica*

To reproduce the anatomy of the anterior mandible, an intact dentate human mandible was obtained from the Laboratory of Human Anatomy at Federal University of Uberlândia. A wax barrier (Wilson, Polidental Indústria e Comércio Ltda, Cotia, Brazil) was made around the anterior mandibular region up to the first molars (Fig. 1). A vinyl polysiloxane impression material (Aerojet, São Paulo, Brazil) was prepared according to the manufacturer's instructions and inserted into the wax barrier. After 24 h the mandible was removed, leaving its impression in the vinyl polysiloxane mould. Melted wax was inserted into this mould to create a wax model. From the wax model, all teeth were removed at the level of the alveolar bone crest. An impression was made from the wax model using vinyl polysiloxane material. After 24 h the wax model was removed, creating a mould of the external anatomy of the anterior mandible. Ten wax (Epoxiglass, Diadema, SP, Brazil) replicas were made. Eight alveoli were created in the wax models. Before the teeth were inserted in the created alveoli, their roots were dipped into melted wax up to 2.0 mm below the cementoenamel junction (CEJ), resulting in a 0.2–0.3 mm thick wax layer to accommodate the space for a periodontal ligament.[19,22–24] Petroleum jelly (Rioquímica, São José do Rio Preto, Brazil) was painted over the wax covered roots before the teeth were inserted into the alveoli that had first been filled with melted wax. Wax excess was carefully removed, avoiding damage to the external anatomy of the mandible model. Subsequently, the teeth were removed from artificial alveoli and the wax was removed from the root surface. A final vinyl polysiloxane impression was made of the wax model with the artificial alveoli, and the mandible anatomy was reproduced in polystyrene resin (Aerojet, São Paulo, Brazil). Polystyrene resin has an elastic modulus (13.5×10^3 MPa)[25,26] similar to cortical bone (14.4×10^3 MPa).[27] The periodontal ligament was simulated with polyether-based impression material (Impregum F, 3M ESPE, St. Paul, MN).[23,24] A vinyl polysiloxane adhesive (3M ESPE) was painted on the roots and into the artificial alveoli, and allowed to dry for 5 min before the polyether material was placed in the artificial alveoli. The

Fig. 1 – Human mandible with teeth and no bone support alteration. A wax barrier, limited to the first molars, was used to reproduce the mandibular anterior region.

teeth were re-inserted into artificial alveoli and excess polyether material was removed.[23,26]

2.3. *Strain gauges*

Four strain gauges (PA-06-060BG-350LEN, Excel Sensores, São Paulo, Brazil) were fixed parallel to the long axes of the teeth on the external surfaces of each plastic mandible in the central and lateral incisors regions, using cyanoacrylate adhesive (Super Bonder, Loctite, Sao Paulo, Brazil). The strain gauges were positioned 6 mm apically from the crest of the replicated bone. According to the manufacturer (Excel Sensores), the base material of these gauges consisted of a polyimide and metal constantan film, with temperature self-compensation for steel. The strain gauge grid had an area of 4.1 mm^2 and an electrical resistance of 350 Ω. The gauge factor, which expresses the linear relationship between electrical resistance variation and strain,[26] was 2.12. A Wheatstone quarter-bridge design was used for each strain gauge, in which temperature effects were compensated by a dummy gauge attached to another passive mandible model (Fig. 2D).[26] The strain gauge output was acquired using a data acquisition device (ADS0500IP, Lynx Tecnologia Eletronica Ltda, Sao Paulo, Brazil) (Fig. 2C).

2.4. *Mechanical loading*

Each plastic mandible was mounted in a metallic device with a 135° inclination (Fig. 2A and B) design to simulate the contact of the mandibular incisor edges with the lingual surfaces of maxillary teeth. The device was placed in a mechanical testing machine (EMIC DL 2000, EMIC Equipamentos e Sistemas de Ensaio Ltda, Sao Jose dos Pinhais, Brazil). The plastic mandible was subjected to compression loading of 50, 100, or 150 N, at a crosshead speed of 0.5 mm/min. To ensure that the load was applied to all incisors and canines, an acrylic medium that was adapted to their incisal edges was used between the teeth and the metal crosshead. During load application, the strain data was recorded at 3 Hz[24,25] by a computer with data analysis software (AqDados 7.02 and AqAnalisys, Lynx Tecnologia Eletronica Ltda, São Paulo, Brazil). The tests were repeated 3 times for each load. Between trials the strain gauges were allowed to recover. Gauges that did not recover to zero strain after 3 min were recalibrated (zeroed) in the software prior to the next experiment.

2.5. *Experimental groups*

All plastic mandibles ($n = 10$) were tested sequentially for seven conditions. The groups are identified as: Cont, B1, B1/SpCR, B1/SpW, B1/SpWCR, B1/SpFgExt, and B1/SpFgInt.

(1) The Cont group, with no bone loss and no splinting, represented the control group (Fig. 3A and B).
(2) The Bl group simulated the bone loss. The bone loss was achieved by removing 5 mm of the polystyrene resin in the mesial, distal, lingual and buccal regions of mandibular central and lateral incisors and in the mesial region of canines (Fig. 3C) using a diamond bur (#2135, KG Sorensen, Barueri, Brazil) in a high-speed handpiece (KaVo do Brasil Ltda, Joinville, SC, Brazil) under water spray. The strain-gauges were protected with adhesive tape (Fita Mágica®, 3M ESPE) during the preparation.
(3) In the Bl/SpCR group (Fig. 3D), extracoronal dental splints were made with a microhybrid composite resin (Shade A2, Filtek Z250, 3M ESPE) and a single bottle adhesive system (Adper Single Bond, 3M ESPE) from right canine to left canine. All lingual and accessible interproximal surfaces were etched for 30 s with 37% phosphoric acid (3M ESPE), rinsed with water for 15 s, and dried with absorbent paper (Santepel, Bragança Paulista, SP, Brazil). With a fully saturated brush tip, two consecutive coats of adhesive were applied to the tooth and polymerized with a halogen light-polymerization unit (XL 3000, 3M ESPE) for 20 s at an intensity of 650 mW/cm^2. The composite resin was applied in 2-mm increments over etched surfaces and then light polymerized for 40 s with the same halogen light unit. After this group was tested, the composite splints were completely removed with a finishing diamond bur (#2200 F, KG Sorensen, Barueri, Brazil) in a high-speed handpiece. No damage was caused to the teeth and plastic mandible.
(4) For the Bl/SpW group (Fig. 3E), a splint was made with dead-soft round stainless steel wires (0.25 mm; Morelli, Araraquara, Brazil). A 10 cm long wire was placed across

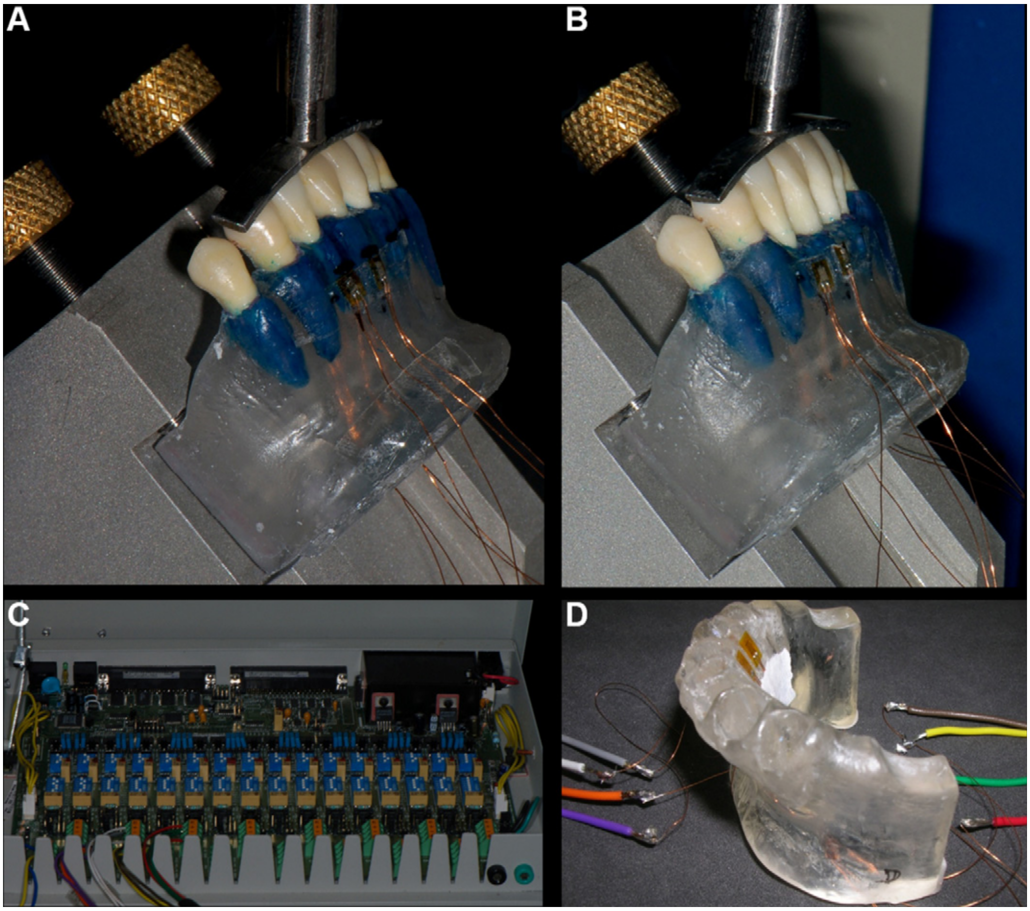

Fig. 2 – Strain gauge test. (A) Plastic mandible of Cont group (no bone loss) mounted for an occlusal loading at a 135° inclination in a mechanical testing machine. (B) Plastic mandible of Bl group (crestal bone loss) mounted in the testing machine. (C) Data acquisition device with the strain gauges connected to a plastic mandible and to a dummy model for temperature compensation. (D) The dummy mandible model with four strain gauges.

the anterior teeth, 0.5 mm apical to the proximal contacts on the buccal and on the lingual surface. Individual vertical wires were then placed between the teeth and tightened in a clockwise direction.[10,14] After finishing the load tests for this group, the wire splints were completely removed to prepare the mandible model for the next group.

(5) For the Bl/SpWCR group (Fig. 3F), the splints were made using a combination of wires and composite resin. Firstly, the wire splints were made the same as described in the Bl/SpW group. Then, the buccal surfaces around the wire splint were conditioned as described for group Bl/SpCR and the wires were covered with composite resin. After this group was subjected to the mechanical load testing, the wire-composite splints were again carefully and completely removed.

(6) For the next Bl/SpFgExt group (Fig. 3G), extracoronal dental splints were made with fibre-reinforced composite (FRC) and composite resin. The FRC consists of polymer-preimpregnated multi-directionally glass–fibres (Interlig, Ângelus, Londrina, Brazil). The FRC was cut into pieces that were 2.0 mm shorter than the distance between the distal edges of the left and right canines. The lingual and proximal surfaces were conditioned as described for group Bl/SpCR. First a 1 mm thick composite increment was applied and the FRC was placed on it. Then the composite was polymerized. The second increment was placed over the FRC, and was polymerized for 40 s at each tooth location. After the mechanical load tests with this group were completed, the FRC-composite splints were carefully and completely removed to prepare the mandible replicas for the final splint type.

(7) The Bl/SpFgInt group (Fig. 3H) received intracoronal dental splints with FRC and composite resin. A continuous cavity of approximately 2.0 mm in depth and 2.0 mm in width were prepared in the lingual surface of all teeth using a rounded diamond bur (#1014, KG Sorensen, Barueri, Brazil) in a high-speed handpiece. The splints were made following the same procedures described for the Bl/SpFgExt group. The second layer of composite resin restored the lingual anatomy of the teeth.

2.6. *Statistical analysis*

The collected strain data was subjected to a 3-way analysis of variance (ANOVA) to examine the effect of support tissue condition (with or without bone loss), tooth region, and

Fig. 3 – A plastic mandible for the seven experimental dental support conditions. (A) Buccal view in Cont group (no bone loss). (B) Lingual view in Cont group. (C) Bl group (bone loss). (D) Bl/SpCR group (bone loss, composite resin splint). (E) Bl/SpW group (bone loss, wire splint). (F) Bl/SpWCR group (bone loss, combination of wires and composite resin splint). (G) Bl/SpFgExt group (bone loss, extracoronal fibre-reinforced composite and composite resin splint). (H) Bl/SpFgInt group (bone loss, intracoronal fibre-reinforced composite and composite resin splint).

Table 1 – Results of 3-way ANOVA for data obtained with 50 N loading (dependent variable: strain).

Source of variation	*df*	Sum of squares	Mean square	Calculeted *F*	*P*
Bone condition	6	272 983.43	45 497.24	13.17	<.001
Tooth region	1	155 428.15	155 428.15	44.99	<.001
Mandible surface	1	413 683.59	413 683.59	119.74	<.001
Bone condition × tooth region	6	13 396.84	2232.81	.65	.69
Bone condition × mandible surface	6	26 298.50	4383.08	1.27	.27
Tooth region × mandible surface	1	14 896.39	14 896.39	4.31	.03
Bone condition × tooth region × mandible surface	6	4880.17	813.36	.24	.97
Error	252	870 612.28	3454.81		
Total	280	7 783 086.15			
Corrected total	279	1 772 179.34			

mandible surface, as well as the interaction between these 3 parameters on the strain under 50, 100, and 150 N loading. The Scheffe's test was performed to determine differences between factor levels. All tests were performed at a significance level of $\alpha = .05$. Statistical software (SPSS/PC, Version 10.0, SPSS, Chicago, IL) was used for statistical data analysis.

3. Results

The results of the 3-way ANOVA for the support tissue conditions, tooth regions, and mandible surfaces are presented in Table 1 for 50 N loading, in Table 2 for 100 N and in Table 3 for 150 N. The 3-way ANOVA indicated significant differences between the three factors (support tissue conditions, tooth regions, and mandibular surfaces; $P < .05$), irrespective of load level. Of the 2-factor interactions, only the interaction between tooth region and mandible surface at the 50 N load level was significant ($P = .03$).

The results of Scheffe's multiple comparison test are shown in Table 4 for each of the three different load levels. At each load level same letters indicate mean strain values that were not significantly different ($P > .05$). Irrespective of the load levels, the mean strain values measured on the buccal surfaces were significantly higher than on the lingual surfaces, indicated by the different number indices ($P < .001$). The mean strain values obtained at the central incisor region were significantly higher than for the lateral incisor region, irrespective of load level or mandible surface ($P < .001$). Strain values obtained at the 50 N loading on the buccal and lingual surface of the lateral incisor region and on the lingual surface of the central incisor region were not significantly different. However on the buccal surface of the central incisor region the strain values of the Bl group (bone loss) were similar to the

Table 2 – Results of 3-way ANOVA for data obtained with 100 N loading (dependent variable: strain).

Source of variation	*df*	Sum of squares	Mean square	Calculeted *F*	*P*
Bone condition	6	915 462.35	152 577.06	12.85	<.001
Tooth region	1	314 724.66	314 724.65	2545.27	<.001
Mandible surface	1	2 023 472.63	20 234 72.63	15.63	<.001
Bone condition × tooth region	6	7283.78	1213.96	32.23	.99
Bone condition × mandible surface	6	95 529.83	15 921.64	207.24	.14
Tooth region × mandible surface	1	23 075.55	23 075.55	.12	.13
Bone condition × tooth region × mandible surface	6	7286.43	1214.41	1.63	.99
Error	252	2 460 551.82	9764.09		
Total	280	30 699 682.77			
Corrected total	279	5 847 387.04			

Table 3 – Results of 3-way ANOVA for data obtained with a 150 N loading (dependent variable: strain).

Source of variation	*df*	Sum of squares	Mean square	Calculeted *F*	*P*
Bone condition	6	1 817 099.74	302 849.96	14.27	<.001
Tooth region	1	620 842.09	620 842.09	29.25	<.001
Mandible surface	1	5 278 514.98	5 278 514.98	248.68	<.001
Bone condition × tooth region	6	11 624.32	1937.38	.09	.99
Bone condition × mandible surface	6	148 919.68	24 819.95	1.17	.32
Tooth region × mandible surface	1	21 319.36	21 319.36	1.00	.32
Bone condition × tooth region × mandible surface	6	3505.94	584.32	.03	1.00
Error	252	5 349 021.22	21 226.28		
Total	280	68 289 770.56			
Corrected total	279	13 250 847.35			

Table 4 – Results of Scheffe's multiple comparisons test ($P < .05$) for strain values (μstrain) obtained at three load levels (50, 100, and 150 N).

Tissue condition	Mandible surface			
	Buccal		Lingual	
	Central incisor	Lateral incisor	Central incisor	Lateral incisor
50 N loading				
Cont	187.4 (83.3)^{A}	110.2 (57.7)^{A}	138.5 (64.2)^{A}	82.0 (44.0)^{A}
Bl	323.1 (106.2)^{A}	177.1 (74.9)^{A}	224.1 (72.4)^{A}	136.0 (76.0)^{A}
Bl/SpCR	211.7 (48.4)^{A}	124.8 (51.4)^{A}	149.7 (48.3)^{A}	87.9 (61.8)^{A}
Bl/SpW	248.8 (74.5)^{A}	135.1 (64.4)^{A}	163.8 (66.6)^{A}	98.5 (51.3)^{A}
Bl/SpWCR	206.8 (52.0)^{A}	118.4 (41.1)^{A}	142.6 (64.2)^{A}	83.6 (35.9)^{A}
Bl/SpFgExt	166.8 (52.7)^{A}	110.2 (37.3)^{A}	130.7 (61.3)^{A}	80.6 (37.8)^{A}
Bl/SpFgInt	164.4 (48.7)^{A}	94.6 (42.4)^{A}	129.3 (40.3)^{A}	74.1 (17.5)^{A}
General means – 50 N	215.6 (48.7)^{b}	124.3 (52.7)^{a}	154.1 (59.6)^{b}	91.8 (46.3)^{a}
100 N loading				
Cont	385.0 (144.6)^{A}	203.5 (79.8)^{A}	303.6 (107.9)^{A}	156.2 (65.2)^{A}
Bl	596.5 (146.5)^{C}	320.1 (77.0)^{C}	482.9 (153.2)^{C}	272.1 (106.5)^{C}
Bl/SpCR	411.3 (91.8)^{AB}	242.3 (84.7)^{AB}	313.9 (109.7)^{AB}	187.8 (89.8)^{AB}
Bl/SpW	484.2 (91.5)^{B}	253.5 (72.4)^{B}	395.8 (110.6)^{B}	218.2 (97.5)^{B}
Bl/SpWCR	407.9 (78.3)^{AB}	241.0 (81.8)^{AB}	311.2 (95.3)^{AB}	180.8 (77.7)^{AB}
Bl/SpFgExt	346.2 (94.2)^{A}	207.7 (66.3)^{A}	294.6 (96.4)^{A}	152.6 (66.8)^{A}
Bl/SpFgInt	347.5 (123.2)^{A}	193.4 (112.8)^{A}	270.4 (99.0)^{A}	151.6 (67.2)^{A}
General means – 100 N	425.5 (110.0)^{b}	237.4 (82.1)^{a}	338.9 (110.3)^{b}	188.5 (81.5)^{a}
150 N loading				
Cont	561.1 (191.0)^{A}	278.4 (114.2)^{A}	460.5 (163.5)^{A}	215.9 (92.6)^{A}
Bl	866.9 (209.8)^{C}	477.3 (167.8)^{C}	728.1 (246.4)^{C}	369.7 (139.9)^{C}
Bl/SpCR	607.7 (149.2)^{AB}	335.8 (123.4)^{AB}	491.4 (165.2)^{AB}	259.8 (105.9)^{AB}
Bl/SpW	706.0 (137.4)^{BC}	395.4 (132.3)^{BC}	610.0 (165.6)^{BC}	308.5 (125.9)^{BC}
Bl/SpWCR	602.3 (125.4)^{AB}	356.7 (112.4)^{AB}	493.6 (153.9)^{AB}	278.9 (107.3)^{AB}
Bl/SpFgExt	556.3 (150.4)^{A}	289.1 (109.4)^{A}	457.1 (166.8)^{A}	223.8 (99.3)^{A}
Bl/SpFgInt	554.9 (152.4)^{A}	278.3 (107.6)^{A}	433.2 (145.1)^{A}	217.4 (94.8)^{A}
General means – 150 N	636.5 (159.4)^{b}	344.4 (123.9)^{a}	524.8 (172.3)^{b}	267.7 (109.4)^{a}
General means mandible surface	357.2 (108.5)^{2}		209.0 (82.7)^{1}	

Upper-case letters represent comparisons within each column at each bone condition, within each load level; lower-case letters represent comparisons of values within each final row at load level within each mandible surface. Numbers represent comparisons of general values within last row at mandible surface. Means marked with the same letter and numbers were not significantly different ($\alpha = .05$).

values of the Bl/SpW group (bone loss, wire splint), and significantly higher than the other groups.

Strain values obtained at the 100 and 150 N load levels were not significantly affected by the tooth region or mandible surface. All groups showed significantly lower strains than the Bl group (bone loss), except the wire splint (Bl/SpW group), which did not produce a significant reduction in strain values at the 150 N load level. Strains obtained when splints were made with composite resin and adhesive systems (Bl/SpCR, Bl/SpWCR, Bl/SpFgInt, and Bl/SpFgExt) were not significantly different from the control group (Cont). The Bl/SpW group (wire splint) showed no significant differences when compared to the Bl/SpWCR and Bl/SpCR groups at any of the three load levels.

4. Discussion

Rehabilitation of masticatory ability in patients with reduced bone support is a complex challenge in dentistry.[12] Extraction of teeth and replacement with complete dentures or implant-supported prostheses may not always be the best treatment option for severely advanced periodontal destruction. Splinting and periodontal treatment may be a more appropriate method to regain good function in cases of reduced periodontal tissue support.[12] Based on the premise that tooth stabilization with splinting should restore original biomechanical conditions that allow rehabilitation, strain measurements were carried out in this study to first establish the effect of bone loss and subsequently assess recovery with splinting. The results of this study supported the hypotheses that bone loss in the anterior mandible increased the strains on the remaining bone support, whilst subsequent splinting reduced the strains. Furthermore, it was shown that the magnitude of the measured strain values was influenced by the tooth region, mandible surface, and load level.

The clinical significance of these strain values is that they characterize the biomechanical conditions in the bone tissue. Strains in the bone tissue represent the deformation response of the mandible to occlusal loading. Deformation response depends on the combined effect of shape, tissue properties, and loading. To yield relevant results in this in vitro study, it was therefore important that these three factors closely approximated a clinical situation.

The shape of the anterior human supporting alveolar bone was carefully replicated in the polystyrene model. Polystyrene was chosen because it has a similar elastic modulus as cortical bone,[26] which predominates in the anterior human mandible. Blood, humidity, and other tissue characteristics that may also affect strains in bone tissue[18] could not be simulated. However, the values obtained in this study were similar to values reported for cadaver bone where measurements were conducted on maxillary alveolar bone with natural teeth. The reported strain values varied between 94 and 139 μstrain for a 50 N loading on the central incisor, and 196 μstrain for 50 N and 239 μstrain for 100 N at the canine. These regions had similar bone thickness and density as the mandibular section simulated in this study.[20] Another important aspect in the approximation of a clinical situation was the simulation of the periodontal ligament, because this tissue plays an important role in the transfer and evenly distribution of occlusal loads to supporting bone tissue.[23,24] An elastomeric material was used in this study to simulate the role of the periodontal ligament in the load distribution.

Load levels of up to 150 N were selected because the maximum bite force at incisors has been reported to vary between 40 and 200 N.[8] The 50, 100 and 150 N load steps were used to test the influence of loads that are low, medium and near the limit of the reported physiological loading. It is important to consider a range of physiological loading. Although occlusal loads in the anterior region are usually considered to be relatively small,[11] the incidence of higher loads in the anterior region can arise, for example, due to loss of posterior tooth support that leads to concentration of the occlusal forces on anterior teeth. Strain measurements at the three loading conditions showed that strain values in the anterior mandible was proportional to the applied load level. High strains in supporting bone tissue may cause immediate damage to the bone or dental splint structure. Although lower loads lead to lower strains, low loads can still be clinically significant. If applied repetitively over a longer period of time, even low loads may lead to fatigue failure or interfere with the rehabilitation process. Furthermore, when the occlusal loads are transferred through supporting bone, which can be extremely thin in the anterior region, even low occlusal loads may induce high levels of strain. The higher strain values that were found on the buccal side may be attributed to the thinner support structure compared to the lingual side (Table 4). In an area with periodontal disease, bone support of the teeth is reduced, therefore also increasing strains in the support tissue, as shown in the Bl group (Table 4). The dense structure of cortical bone in the anterior mandible has a relatively low strain limit. If strains exceed the strain limit, microcracks will form in the supporting bone. Osteoclasts preferentially resorb bone tissue that contains microcrack spaces, thus this condition may lead to bone resorption.[7] It has been reported that if the loading amplitude and frequency exceed the damage repair rate, damage may accumulate and bone resorb due to the osteoclastic activity.[7] The healing rate of alveolar bone may thus be determined by the presence of microcracks, since formation of new bone must fill resorption spaces. Lowering the strain levels is likely to reduce the initiation of microcracks and induce the formation of new bone matrix by the action of osteoblasts, promoting the repair process.[7] The main objective of stabilizing teeth with a splint can thus be summarized as the reduction of biomechanical strains in the supporting bone structure. This study evaluated how various splint types affected the strain values.

This study found that at the lowest load level, the type of splint was not a significant factor in improving the strain conditions. Under the 50 N loading, the effect of bone loss on the increase of the strain values was only significant on the buccal side of the central incisor region (Table 4), which was the region with the thinnest bone layer. This observation implies the benefit of an integrated clinical approach that includes minimizing the occlusal loading and occlusal interference.

At the higher load levels, differences between the different splint types showed up. Splints made from composite resin with adhesive system recovered the strain levels in the mandible with bone loss. This may be attributed to a better transfer and distribution of the applied loads. Only the wire splint (Bl/SpW) failed to stabilize the teeth sufficiently, resulting in strain levels that were significantly higher than in the groups that used FRC (Bl/SpFgExt and Bl/SpFgInt). At the 150 N load level, the wire splint had no significant capacity to stabilize the teeth. According to these results, the use of the wire splint without support of composite resin and adhesive system should not be indicated for periodontal splinting.

The splints that used composite resin and the adhesive system had a similar biomechanical response in the supporting bone at the different load levels. However, this study only applied a nondestructive static loading condition, and only measured strains in the supporting bone structure. Although the bone strains obtained with this group of splint types may be similar, in practice there can be differences in the performance, for example in their fracture properties.[12] Fractured splints pose a clinical problem and need to be replaced.[12,15] Splints consisting of wire and composite resin (Bl/SpWCR) contain an interface of materials that have different elastic moduli (stainless steel and composite resin) and that do not bond. These interfaces may be more susceptible to fatigue failure initiation, and thus reduced life-expectancy.[12,15] Splints containing reinforcement materials with similar elastic properties (FRC and composite resin) and that accommodate bonding (Bl/SpFgExt and Bl/SpFgInt), more evenly transfer the occlusal loads and thus reduce areas of stress concentrations. This is likely to benefit the fracture strength and fatigue resistance.[12,16,17] Splints which are reinforced by FRC do not easily fracture. They have been reported to create an environment where tooth movement can be contained within physiological limits whilst restoring function.[6,10,12,13] Tokajuk et al. (2006)[15] reported a decrease in periodontal pocket depths and a considerable improvement of oral hygiene after 10 months in a clinical evaluation involving 52 patients with chronic periodontal diseases treated using FRC and composite resin splints. Of the two FRC reinforced composite splint types investigated in this study, the internal splint is more comfortable for the patient,[10,12] and provides good aesthetic and functional results. Considering these advantages and the good performance of recovering original strain levels in the mandible as shown in this study, this splint type may present the best option in periodontal treatment.

Finally, it is important to emphasize that the results should be interpreted within the study's limitations. The conclusions are based on an in vitro experiment. Therefore, the innervations of teeth and physical properties of the periodontal ligament and bone could only be partially simulated. Furthermore, the applied load did not simulate the dynamic loading behaviour in the oral cavity. Over longer periods of time in the oral cavity, strain distributions may be affected by viscoelastic and biological bone responses. Therefore, the results of this study should be considered as an approximation of the initial condition after a splint has been placed. Within the limitations of this in vitro study, in conclusion the loss of bone support and the increasing occlusal loading resulted in significantly greater strain in the remaining structure. The strain measured on the buccal surface of mandible was significantly higher than on the lingual surface; moreover, strains in the central incisor region were significantly higher than in the lateral incisor region. Finally, periodontal splints with adhesive systems were more effective in reducing the strain levels, which was significant at higher occlusal load levels. On the other hand, the wire splint was the least adequate splint type for restoring the original strain values, especially during high occlusal loading. Future research using experimental animal studies and clinical observations can further develop the understanding of biomechanical aspects in Periodontics, in which biological aspects have dominated diagnoses and therapies. This study showed how biomechanics can help to better understand the periodontal disease aetiology and design protocols to maintain teeth with periodontal problems.

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