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Effects of Adjacent Tooth Type and Occlusal Fatigue on Proximal Contact Force of Posterior Bulk Fill and Incremental Resin Composite Restoration

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Clinical Relevance

Proximal contact effectiveness tends to decrease with occlusal fatigue loading. This effect was not detected visually using digital radiography. The bulk fill and incremental filling techniques have similar proximal contact forces.

SUMMARY

Objectives: To measure the proximal contact force in newtons (N) between incremental and bulk fill class II resin composite restorations and implant molar teeth or adjacent premolar teeth with simulated periodontal ligament.

Methods: The model used was created with a typodont first molar tooth with two bilateral occlusal-proximal class II cavities, an adjacent tooth simulating an implanted molar tooth (Titamax CM, Neodent, Curtiba, PR, Brazil) and a premolar with simulated periodontal ligament. Two resin composite restorative techniques were

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used: Inc-Z350XT, (Filtek Z350, 3M Oral Care, St. Paul, MN, USA) inserted incrementally and Bulk-OPUS, (Opus Bulk Fill APS, FGM, Joinville, SC, Brazil) high viscosity bulk fill resin composite (n=10). As a control, a typodont having intact teeth without restorations was used. After the restorative procedure, each specimen was radiographed using a digital system (Dürr Dental, Bietigheim-Bissingen, Germany). The proximal contact force (N) was measured using dental floss with a microtensile machine (Microtensile ODEME, Luzerna, SC, Brazil). The specimens were then subjected to mechanical fatigue cycling to simulate 5 years of aging. All the parameters were measured after aging. The X-rays were blindly qualitatively analyzed by two operators to identify the loss of proximal contact. One-way ANOVA was used for comparing the initial contact force between restored and intact teeth. Two-way ANOVA followed by Tukey testing was performed for contact area data and for the contact force/contact area ratio. The proximal contact force data were analyzed using one-way repeated measurement ANOVA followed by Tukey testing (α=0.05). The X-ray proximal contact analyses were described by the frequency.

Results: The initial proximal contact force was similar for intact and restored teeth. The contact force and contact area with the molar were significantly higher than with the premolar; however the contact force/contact area ratio was similar for all tested groups. The bulk fill technique showed a contact force similar to the incremental filling technique. Fatigue resulted in a significant reduction in the proximal contact force (p<0.001), irrespective of the region analyzed or restorative material used. The digital X-rays detected no alteration in the proximal contact after occlusal fatigue.

Conclusions: Larger contact area resulted in higher proximal contact force. Proximal contact force decreased with 5 years of simulated occlusal fatigue. The bulk fill technique showed a proximal contact force similar to that of the incremental filling technique.

INTRODUCTION

Resin composites have been successfully used for restoring posterior teeth, showing acceptable longevity in clinical studies.[1] More than 500 million direct dental restorations are carried out each year around the world, including approximately 261 million direct resin composite restorations.[1,2] Characteristics such as secondary caries, fracture resistance, retention, marginal adaptation and discoloration, and proximal contact of posterior restorations are the most important factors determining the clinical success of posterior restorations.[3,4]

Proximal contact occurs when the tooth or restoration contour on the distal or mesial surface remains in close contact with the adjacent tooth.[5] An adequate posterior proximal contact between adjacent teeth is related to the clinical success of restorations due to the maintenance and stabilization of the dental positions in the arches.[6] An adequate proximal contact point means that there is a space for the passage of dental floss between adjacent teeth with little resistance. The dental floss does not pass without resistance but also is not so tight as to prevent the passage of the floss or to tear it.[7] A contact point that is slightly open may cause food accumulation, gingival inflammation, carious lesions, bone loss in proximal areas, and tooth migration.[6,8,9] Likewise, very tight contact may cause periodontal complications, tooth migration, and difficulty with flossing.[7] Inadequate contact points (tight, open, or loose), can be associated with proximal caries formation.[10] Clinically, the adequacy of the contact point is assessed by the dentist by passing a wire with a slight resistance.[5,11,12] This is a simple method but does not allow evaluation of proximal contact force variations if proximal contact force is considered a physiological entity of multifactorial origin.[5,13,14] Nylon and Teflon floss materials tested in clinical studies of natural teeth found that contact forces ranged from 2 to 10 N.[15] An *in vitro* study using intact extracted permanent first premolars and measuring the contact point using waxed nylon dental floss found that the proximal contact forces ranged from 10 to 50 N.[16] Greater contact forces were described when dry surfaces were tested, and the magnitude of the forces tended to be unrelated to the contact angulation area during sliding of dental floss.[16] Thus, many studies using different devices and methodologies have tried to measure the force of the proximal contact.[17-24]

Reconstruction of a satisfactory resin composite proximal contact with correct anatomical contour and appropriate proximal contact tightness is essential but remains difficult in the placement of direct posterior restorations.[25,26] Resin composite and amalgam restoration techniques differ in proximal contact creation because of several factors, including that resin composites cannot be "condensed."[27,28] Bulk fill resin composites are gaining popularity because they reduce the number of layers during the restorative procedure and thus the curing time.[1] Bulk fill and conventional resin composites inserted incrementally in posterior teeth have shown similar clinical performance.[29] However, proximal contact is an important clinical parameter that has not often been investigated for bulk fill resin composites. In addition, proximal contact between natural dentition and implant restorations needs to be better understood in order to facilitate faithful reproduction in posterior proximal restorations.[8]

Insufficient adaptation of the matrix to the adjacent tooth, shrinkage of material during polymerization, and position of the tooth can influence the initial proximal contact.[30,31] A clinical study of posterior resin composite restorations has already shown that contact forces do not always remain stable over time and that proximal contacts tend to diminish after a period of six months.[20] Proximal contact loss is already considered to be a complication in implant prostheses; a 7-year clinical study evaluated the effects of proximal contact loss with implants and adjacent teeth, showing that periodontal ligament displacement can occur when performing resin composite restorations.[11]

To the best of our knowledge, no study has compared the influence of simulated mechanical cycling on the proximal contact force of bulk fill resin composites. Therefore, the purpose of this *in vitro* study was to analyze the proximal contact force (N) in incremental and bulk fill class II resin composite restorations with implant molar teeth and premolars with simulated periodontal ligaments. The null hypotheses were as follows: 1) restorations created with two different resin composites have similar proximal contact force; 2) tooth condition and contact location do not influence the contact force/contact area ratio; and 3) occlusal fatigue does not reduce the proximal contact force between resin composite restorations and adjacent teeth.

METHODS AND MATERIALS

Study Design

Twenty models were made using the artificial tooth Tech Pro (IM do Brazil Ltda, São Paulo, Brazil) (protected and registered with the National Institute of Intellectual Property under P11001631-7), which was used as a base for making the replica specimens with bilateral class II occlusal-proximal (OM, occlusal-medial; and OD, occlusal-distal) standardized cavity preparations. As a control, a group without cavity preparation and without restoration was used. The specimens were restored with two protocols, bulk filling and incremental filling techniques. The number of specimens was based on the coefficient of variability and the sample calculation. The designated power of the test was 80%, with a minimum detectable difference of 20%. There was a residual standard deviation of 15% and a significance level of 0.05; these calculations resulted in the decision to use 10 specimens per group. The compositions of the resin composites, provided by the manufacturers, are listed in Table 1. The proximal contact openings of the specimens were determined by digital radiographic examination; the proximal contact

Table 1: *Resin Composites Used in this Study*

Material	Code	Resin Composite Type	Organic Matrix[a]	Filler[a]	Filler % Wt/Vol[a]	Manufacturer	Batch Number
Filtek Z350XT	Inc-Z350XT	Nanofilled	Bis-GMA, Bis-EMA, UDMA, TEGDMA	Silica and zirconia nanofillers, agglomerated zirconia silica nanoclusters	79/63	3M Oral Care (St Paul, MN, USA)	N652583
OPUS Bulk Fill APS	Bulk-OPUS	High-viscosity bulk fill	TEGDMA, Bis- EMA, UDMA	Silica with urethane dimethacrylate, salinized silica dioxide, salinized barium glass, YbF3	68	FGM (Joinville, Brazil)	N251017

Abbreviations: Bis-EMA, bisphenol A polyethylene glycol diether dimethacrylate; Bis-GMA, bisphenol A diglycidylmethacrylate; TEGDMA, triethyleneglycoldimethacrylate; UDMA, urethane dimethacrylate; YbF3, ytterbium fluoride.

[a] *Composition as given by manufacturers.*

areas were calculated (mm^2); the proximal contact force (N) was measured by microtensile tests; and the ratio between the proximal contact force (N) and proximal contact area (mm^2) was calculated.

Model Development

A model with metallic teeth was designed for testing the proximal contact of posterior restorations (Figure 1). The mandibular posterior arch of a mannequin (MOM, Manequins Odontológicos Marília, Marília, SP, Brazil), composed of the 2nd molar, 1st molar and 2nd premolar, was used. The alveolus was adapted to the root of the first molar, and the second premolar was sculpted with Vipflash acrylic resin (VIP, Pirassununga, SP, Brazil). A Morse taper 3.5 mm x 7.0 mm dental implant (Neodent, Curitiba, PR, Brazil) was placed as a substitute for the second molar. The matrix model was then duplicated using silicone rubber (Redelease, Barueri, SP, Brazil), and 20 models made of polystyrene resin (Cristal, Piracicaba, SP, Brazil) were replicated. A polystyrene resin cylindrical base 2.5 mm in diameter was added to the base of all the models to fit the cycling machine and the microtensile testing machine. Metal crowns were replicated from an individual wax pattern applied to the reference model and adapted for each model from a standard silicone matrix. Premolars were replicated in wax from an artificial-tooth rubber silicone mold and cast completely with nickel chrome alloy (Kromalit, Knebel Produtos Dentários, Porto Alegre, RS, Brazil) to ensure that wear only occurred on the specimen of interest. The implant crowns were cemented using dual cure resin cement (Allcem Core, F) light cured for 40s on each surface using a VALO Cordless LED light curing unit (Ultradent, Salt Lake City, USA) with an irradiance of 1400 mW/cm^2, which was verified using a MARC Resin Calibrator (BlueLight, Halifax, NS, Canada). The typodont first molar and the second metallic premolars were inserted in the alveoli with polyether impression material (Impregum, 3M Oral Care), simulating the periodontal ligament.[32]

Specimen Development and Preparation

One artificial first molar tooth (TechPro) received two, standard proximal occlusal cavity preparations (MO and OD) using a preparation machine.[33] A trained operator used a high-speed diamond bur (N.3198 bur, KG Sorensen, Barueri, SP, Brazil) under constant irrigation to prepare class II cavities 4 mm mesial/distal, 4 mm deep in the occlusal surface and 5.0 mm in the gingival box. This single tooth was duplicated after cavity preparation to create twenty replica teeth of polystyrene pigmented resin (Cristal, Piracicaba, SP, Brazil) with standardized preparations. For the control group, the replica of the artificial typodont tooth was used without cavity preparation, simulating an intact tooth and standardizing the position of the adjacent teeth.

Restorative Procedure

The cavities in the specimens were then cleaned with 0.12% chlorhexidine, the well was dried, and the

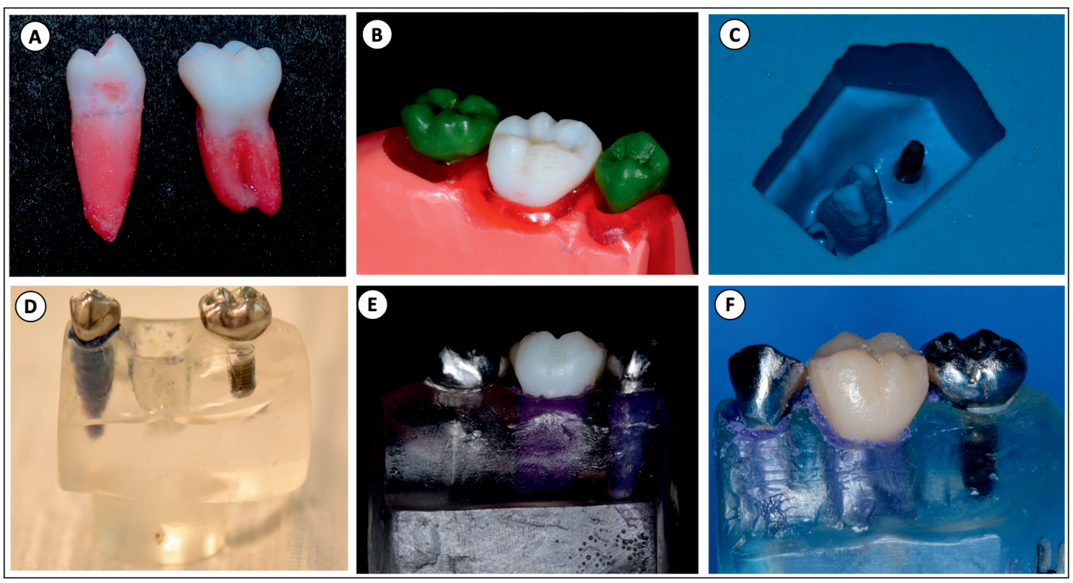

Figure 1. *Device developed for proximal contact test: (A): Artificial teeth with the periodontal ligament space simulation. (B): Artificial teeth fitted in the base model after alveoli relined with red acrylic resin shaping the roots of artificial teeth with periodontal ligament space simulation. (C): Mold base made with rubber silicone and implant position. (D): Aspect of the model with metal teeth and metal crown in position. (E): Final aspect of the model with restored specimen. (F): Final aspect of the model with intact specimen.*

adhesive system Âmbar APS (FGM) was applied. The adhesive system was photoactivated for 10 seconds. The partial preshaped metal matrix (Unimatrix, TDV Dental, Pomerode, SC, Brazil) was inserted and burnished to better define the proximal contact, and wood wedges (Cunhas anatômicas, TDV Dental) were inserted. The specimens were randomized (random.org.) and divided into two groups (n=10) according to the restorative techniques used (since the control group did not receive restorative intervention): In the Inc-Z350XT group, the proximal boxes were restored in two increments using nanofilled resin composite, Filtek Z350 XT (3M Oral Care).[34] The OPUS group was restored with a single increment of a bulk fill high viscosity resin composite, Opus Bulk Fill APS (FGM). The resin composites were photoactivated for 40 seconds. All the restorative procedures were performed by the same operator. The finishing was performed with intermittent water spray, using diamond burs (2135F and 2135FF, KG Sorensen) to remove the excess. The polishing was performed using Sof-Lex Pop-On discs (3M Oral Care).

Proximal Contact Force Calculation—Initial

The specimens were tested in a microtensile test machine (Microtensile ODEME) using a 1 mm/min crosshead speed to calculate the proximal contact force of the molar and premolar teeth. For the test, two metallic accessories were created for the microtensile machine, one for positioning the model during the tests and the other for stabilizing the dental floss during the tensile tests (Figure 2). Waxed texturized nylon dental floss with 0.09 mm diameter (Hillo, Aperibé, RJ, Brazil),[16] was inserted below the proximal contact area and was attached to the accessory stem fixed on the microtensile machine. The initial proximal contact tensile force values in newtons (N) were measured 6 times for each specimen, with 3 measurements at each proximal contact, and the average of the maximum tensile force was calculated for each proximal contact surface. The dental floss used was changed after each test, eliminating possible influence of dental floss wear on the measured proximal contact forces.[16]

Digital Radiographic Examination—Initial

Digital phosphor plate sensor radiography (Dürr Dental) was obtained within 20 cm of the source of a Timex 70 E X-ray machine (Gnatus, Ribeirão Preto, SP, Brazil). Interproximal radiography was performed, and the images were transferred from the phosphor plate to the computer by means of a scanner (VistaScan Mini View, Dürr Dental). When the specimens did not present contact between the adjacent teeth in the initial radiographic analysis, ie, when they presented visible gaps between adjacent teeth, the restored specimens were replaced because it was necessary and mandatory to start from the existing contact point to assess the contact force.[15]

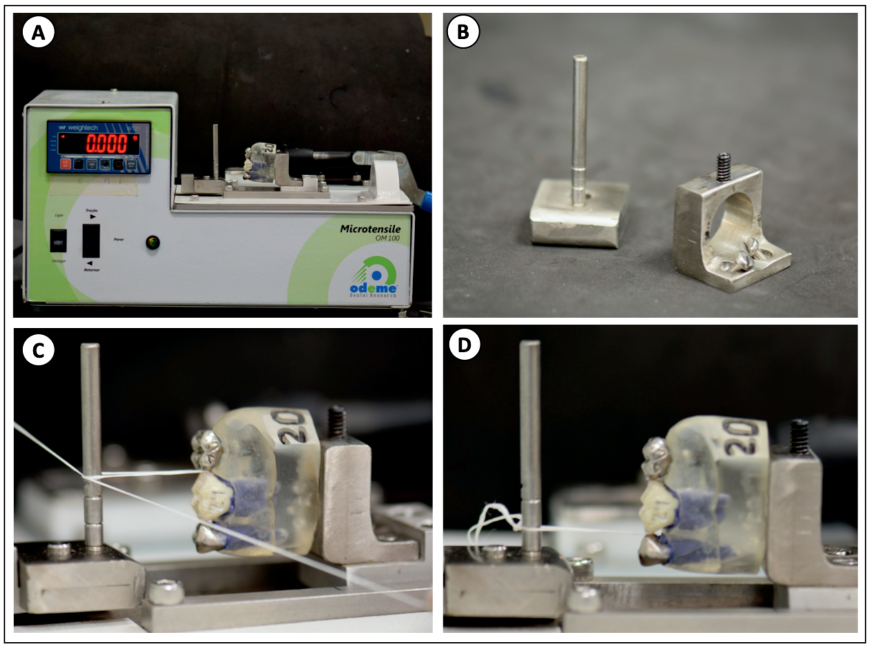

Figure 2. *Microtensile method used for contact force measurement: (A): Microtensile machine with specimen and devices positioned for measurements. (B): Devices developed to standardize the specimen position during test. (C): Clinical dental floss passed parallel around the contact point and pulled by the equipment in molar contact. (D): Dental floss passed in premolar contact.*

Mechanical Cycling Tests

The restored specimens were submitted to occlusal mechanical fatigue simulating 5 years of oral aging. The specimens were submerged in water at approximately 37°C, simulating chewing and mouth temperature and cycled 1,200,000 times from 0 to 50 N axial compressive loading with 8.0 mm diameter stainless steel spheres on the occlusal cusps with a 2 Hz frequency (Biocycle, Biopdi, São Paulo, SP, Brazil).[35,36]

Post Mechanical Fatigue Tests

After mechanical aging, the proximal contact tensile force values (N) were measured three times for each contact and six times for each specimen, and the average of the maximum tensile force was calculated as described above. The difference between the proximal contact forces was calculated: ΔPCforce = Final PCforce – Initial PCforce.

Contact Area Measurement and Calculation of Contact Force by Contact Area

The proximal contact mesio-distal and occlusal-cervical dimensions were measured using a digital caliper (Mitutoyo, Tokyo, Japan) for all restored and intact groups. The ratio between force (N) divided by area (mm^2) was calculated for all specimens in order to correlate the contact force between premolar and molar teeth.

Final Digital Radiographic Examination

Final X-ray images were taken of all the specimens, following the initial method. The initial and final X-ray images were displayed in PowerPoint (Microsoft Office, Microsoft, Washington, USA) on a screen without any manipulation or adjustment of the images. The X-ray images were blindly evaluated by two experienced and calibrated professionals, and these professionals analyzed the proximal contact using the following scores: (1) perfect proximal contact—no visible gap between restoration and adjacent tooth; (2) acceptable proximal contact—minimal areas of gapping that do not compromise the contact with the adjacent tooth; (3), unacceptable proximal contact—visible gapping between restoration and adjacent tooth that compromises the function of proximal contact (Figure 3).

Statistical Analysis

The contact force and the contact area data were tested for normal distribution (Shapiro-Wilk test) and equality of variances (Levene test), followed by parametric statistical tests. One-way ANOVA was used for comparing the initial contact force between restored and intact teeth. Two-way ANOVA followed by Tukey test was performed for contact area data and also for the contact force/contact area ratio with molar and premolar teeth. One-way repeated measurement ANOVA followed by Tukey test was performed for contact force for each tooth contact location. All the tests used $\alpha = 0.05$ as the significance level, and all the analyses were carried out with the statistical package Sigma Plot version 13.1 (Systat Software Inc, San Jose, CA, USA). The X-ray analyses were described by the frequency.

RESULTS

Proximal Contact Force

The initial proximal contact forces (N) between the restored molars and intact typodont teeth with adjacent molars and premolars measured by microtensile tests are shown in Figure 4. One-way ANOVA revealed no significant difference between intact tooth and restored teeth using incremental (p=0.101) and bulk fill filling (p=0.198) techniques.

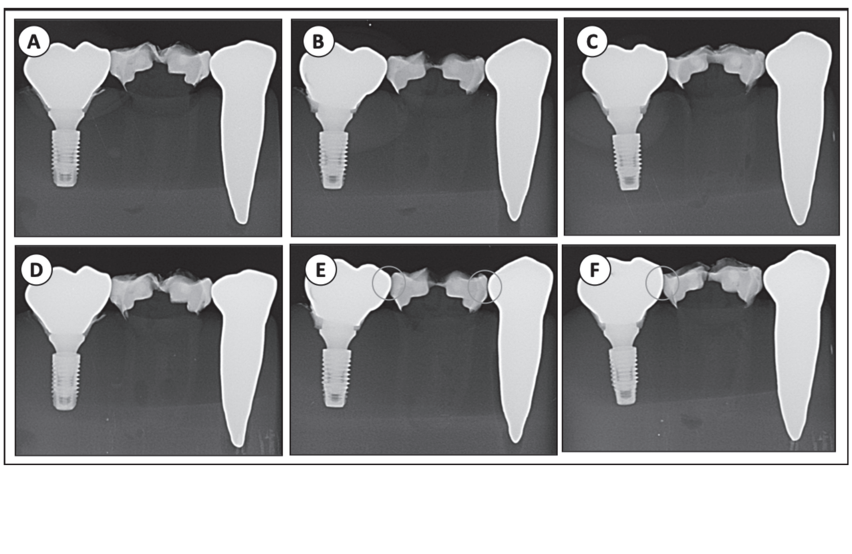

Figure 3. *Digital radiography examination: (A) and (D): Bulk-OPUS specimen score 0, with no difference at both proximal contacts comparing pre- and post-fatigue. (B) and (E): Inc-Z350XT specimen score 1, difference without continuity in both proximal contact points. (C) and (F): Bulk-OPUS specimen score 2 at the mesial and score 0 at distal, representing no difference.*

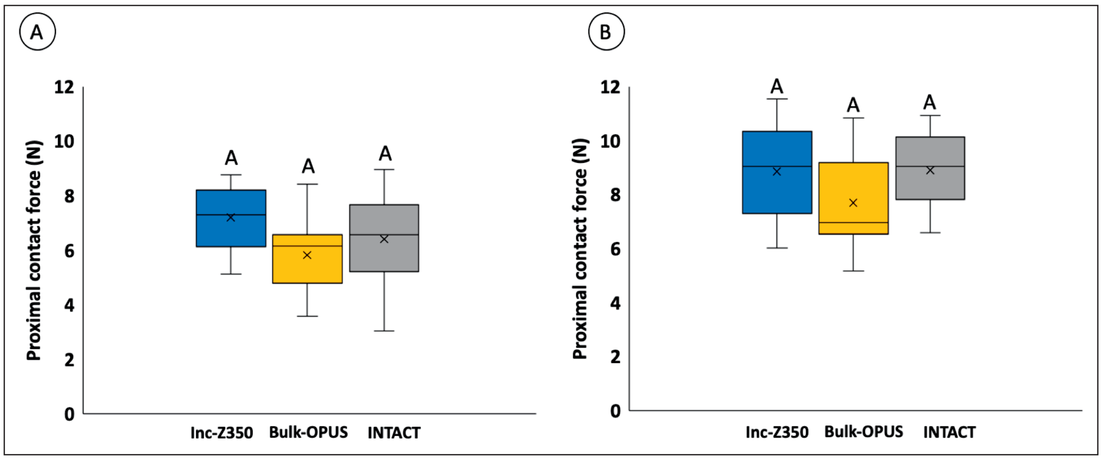

Figure 4. *The initial proximal contact forces (N) measured by microtensile tests between the restored molars and intact typodont teeth: (A): Adjacent molars. (B): Adjacent premolars. Same uppercase letters indicate no significant difference between restored and intact teeth for molar and premolar contact location, calculated using Tukey test (α=0.05).*

The proximal contact forces (N) between the restored molars (incremental and bulk fill filling technique groups) with adjacent molars and premolars, before and after the aging process are shown in Table 2. One-way repeated ANOVA revealed no significant influence for the resin composite type (p=0.102). Fatigue resulted in a significant reduction in the proximal contact force (p<0.001) irrespective of restorative material tested for both molar and premolar contact locations.

Contact Area Measurement and Calculation of Contact Force by Contact Area

The proximal contact area (mm^2) between the intact and restored molars using incremental and bulk fill filling techniques with adjacent molars and premolars are shown in Figure 5A. Two-way ANOVA revealed that the contact area was significantly influenced by contact region (p<0.001); however, no significant influence was observed for the tooth condition type (p=0.198) or for the interaction between the contact region and the tooth condition (p=0.219). The contact area measured in the molar contact region was significantly higher than the area measured in the premolar contact, irrespective of the tooth condition.

The ratios between proximal contact forces (N) and proximal contact area (mm^2) for intact and restored molars using incremental and bulk fill filling techniques with adjacent molars and premolars are shown in Figure 5B. Two-way ANOVA revealed no significant influence of contact region (p=0.248), of the tooth condition (p=0.265), or of the interaction between the contact region and tooth condition (p=0.652). The proximal contact force/proximal contact area ratio values were similar for all tested groups.

Proximal Contours— Digital Radiographic Examination

The results of the digital radiographic examination analysis are shown in Table 3. Perfect proximal contact (score 1) was predominant for the proximal contour after the fatigue mechanical cycling tests, regardless of the region analyzed (molar or premolar) or resin composite tested. The Inc-Z350XT group had three molar specimens and four premolar specimens with a

Table 2: *Means and Standard Deviations of Proximal Contact Force (N) Measured Using Microtensile Test*[a]

Restorative Material	Molar		Premolar	
	Initial	Post-fatigue	Initial	Post-fatigue
Incremental – Filtek Z350XT	7.7 ± 1.9 Aa	5.7 ± 2.4 Ba	5.8 ± 2.5 Aa	4.1 ± 1.8 Ba
Bulk fill – Opus Bulk Fill APS	8.9 ± 2.3 Aa	7.3 ± 1.9 Ba	6.1 ± 2.2 Aa	4.5 ± 2.1 Ba

Abbreviation: N, newton.

[a] *Different letters indicate a significant difference calculated using Tukey test (p<0.05); uppercase letters were used for comparing fatigue effect (pre- and post-fatigue); lowercase letters were used for comparing restorative material (Z350XT or OPUS).*

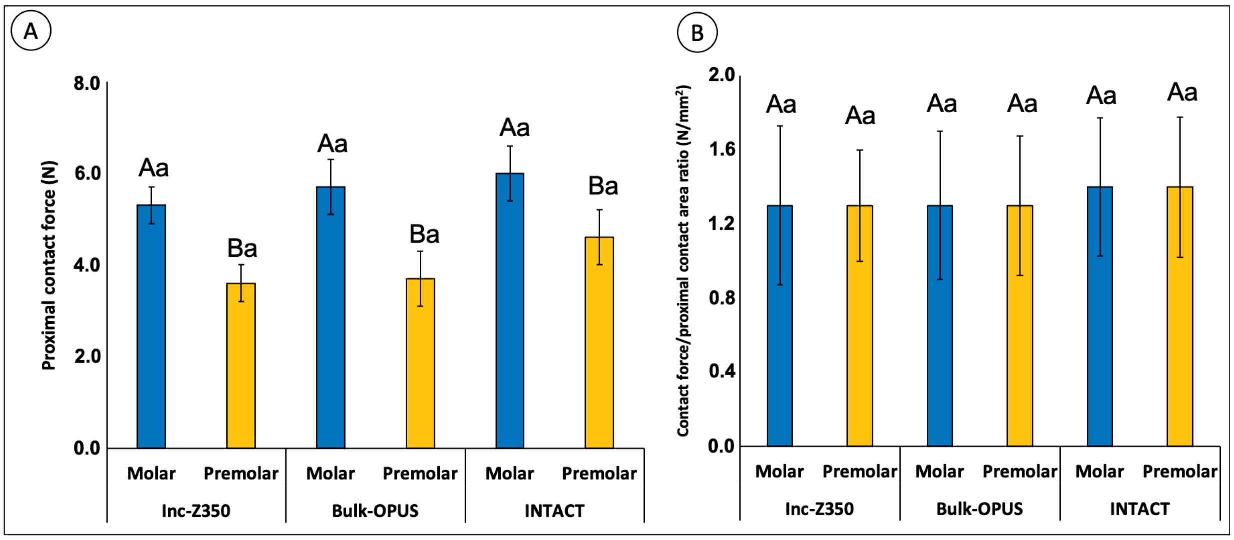

Figure 5. *(A): The proximal contact area (mm^2) between the intact and restored molars using incremental and bulk fill filling techniques with adjacent molars and premolars. (B): The ratio between proximal contact forces (N) and proximal contact area (mm^2) for intact and restored molars using incremental and bulk fill techniques with adjacent molars and premolars. Different letters indicate a significant difference calculated using Tukey test (α=0.05); uppercase letters were used for comparing fatigue effect (molar and premolar); and lowercase letters were used for comparing tooth condition (Inc-Z350XT, Bulk-OPUS or INTACT).*

score of 2, and no specimen had unacceptable proximal contact. The OPUS group had four molar specimens and three premolar specimens with a score of 2 and one molar specimen and one premolar specimen with a proximal contact score of 3.

DISCUSSION

The posterior restorations created using the incremental and bulk fill techniques had similar proximal contact forces; therefore, the first null hypothesis was accepted. Similar contact force/contact area ratios were verified for intact or restored teeth using the incremental and bulk fill techniques and also for implant retained molar teeth or premolar teeth with simulation of the periodontal ligament; therefore, the second null hypothesis was accepted. However, occlusal fatigue simulating five years of aging significantly decreased the proximal contact force irrespective of the region of contact with the implant retained tooth or the tooth with periodontal ligament simulation; therefore, the third null hypothesis was rejected.

Assessing proximal contact force in *in vitro* studies offers the possibility of standardizing the study conditions. Among the studies addressing proximal contact that report wear or force, many use pre-fabricated mannequin models or prepared typodonts but lack a simulation of the periodontal ligament for tests.[8,18-20,37] For this reason, in the present study we developed a model to approximate oral physiological conditions and performed a simulation of the periodontal ligament using polyether impression material.[32] The model in this study showed that proximal contact wear tends to occur only on the resin composite because both the crown on the implant retained tooth and the simulation of the natural tooth were made with metal.[8,37] To evaluate the influence of the absence of flexibility on proximal contact with adjacent teeth,

Table 3: *Proximal Contour Scorea Analysis with Digital Radiography Examination After Fatigue Mechanical Cycling*

Restorative Material	**Number of Teeth with each Criterion Evaluated[a]**					
	Molar (D)			**Premolar (M)**		
	1	**2**	**3**	**1**	**2**	**3**
Incremental – Filtek Z350XT	7	3	0	6	4	0
Bulk fill – Opus Bulk Fill APS	5	4	1	6	3	1

Abbreviations: D, distal; M, mesial.
[a] *1, perfect proximal contact; 2, proximal contact acceptable; 3, unacceptable proximal contact.*

the implant retained-tooth was included in the model, simulating a frequent clinical condition.

In one study, only the initial pre-restoration and post-restoration proximal forces were clinically measured, and there was no further clinical follow-up.[22] A 7-year clinical follow-up study observed natural tooth wear associated with a dental implant but with no quantification of the proximal contact force.[11] In this study, the use of a specimen replica of the intact typodont tooth without preparation or restoration attempted to simulate the pre-restorative condition. All groups had similar contact forces, demonstrating the standardization of the specimen preparation and the effectiveness of both restorative techniques. In a similar way, the use of the single prepared tooth replica allowed us to standardize the restorative procedure among groups. It was possible to compare the proximal contact forces on different materials, with implant retained teeth and teeth with simulated periodontal ligament, and also before and after mechanical cycling.[18] This is different from *in vivo* studies where the variability of anatomical characteristics of the proximal contact between individuals challenges the evaluation interpretation before and after the restorative procedure.[14,19]

The proximal contact force device developed at the University of Technology Delft in the Netherlands used a 0.05 mm thick metal strip inserted interdentally from the occlusal surface, quantifying the proximal contact force (N) when the strip was slowly removed in the occlusal direction.[19,21-24] The methodology for measuring the proximal contact force was modified in the present study. Dental floss was used to eliminate the influence of the strip on adjacent teeth without changing the physiological conditions.[14] Additionally, the method with dental floss used in this study is similar to a method used in clinical studies.[12,15] The use of dental floss in the *in vitro* tests approximates the clinical situation, and the measured force without pre-loading can be easily translated to clinical recommendations. A clinical study using nylon and Teflon floss materials in natural teeth showed contact forces ranging from 2 to 10 N.[15] The contact-point force values found in this study, measured with waxed nylon dental floss showed similar values, ranging from 4.1 to 8.9 N, including in the control group.

In vivo studies have shown that the loss of proximal contact structure tends to be greater in the mesial area due to mesial displacement of natural teeth by the anterior component of the occlusal force.[11] Using a model that simulates the clinical situation by positioning specimens according to the natural *in vivo* position, the application of occlusal loads during the mechanical fatigue tests led to a reproduction of these forces. It might initially be expected that the higher proximal contact force between implant retained molar teeth compared with premolar teeth simulating the periodontal ligament could be explained by the lack of mobility of the implant. However, after measuring the proximal contact area, which is significantly higher in the molar-molar than in molar-premolar proximal contact, and correlating these data with the proximal contact force, the ratio values were similar for all groups, demonstrating that higher contact area generates higher contact force regardless of whether teeth are restored or intact.[38]

Occlusal fatigue resulted in a significant reduction in proximal contact force irrespective of region analyzed or restorative material tested. The reduction in the proximal contact force can be attributed to wear resulting from the restored molar intrusion process during occlusal fatigue. The tooth moved up and down, generating friction with the adjacent metallic teeth, resulting in resin composite wear. The standardization of the load application is important in order to isolate the effect generated from that of additional factors and contribute to the possible reproducibility of this methodology. The fact that the load was applied only to the restored tooth can be considered a limitation of this study but can also be considered as the worst-case scenario of proximal contact restoration. Future studies analyzing proximal wear caused by occlusal loading in all posterior teeth are necessary to complement the results of this study. However, the occlusal fatigue reduction of the proximal contact force can be correlated with the observations extracted from clinical studies, since to the best of the authors' knowledge, no *in vitro* studies have evaluated the wear of the contact point after simulation of years of aging. Clinical studies have shown that proximal contact loss occurs over time, from short follow-ups of 3 months to longer periods of up to 5 years, under different clinical conditions.[11,12,21,39]

The initial proximal contact forces were similar for intact typodont teeth and restored teeth with both restorative techniques; this finding confirmed that the restorations performed using this experimental model were effective. The incremental filling technique using Inc-Z350XT presented a contact force similar to that of the bulk filling technique using OPUS. These results occurred because Opus Bulk Fill APS and Filtek Z350XT have similar compositions for both the organic and the inorganic matrix and thus similar mechanical properties and wear resistance.[40,41] Although a resin composite is conventionally inserted in oblique increments of up to 2 mm and bulk fill is inserted in a single application, both have high viscosity and similar inorganic filler content (Table 1). The wear of resin composite is highly dependent on the size, volume, and quantity of charged particles.[42] A previous study demonstrated that high-viscosity bulk fill resin composites had Knoop hardness number values similar to those of conventional resin composites.[43]

The results of the present study corroborate those of another study that found that proximal contact force is related to the consistency of the restorative material and the restorative technique used,[17] reaffirming that high viscosity resins produce strong proximal contact.[8] Previous studies had affirmed that conventional resin composite inserted in bulk filling did not improve proximal contact force values.[17,44,45] The X-ray image analysis showed differences before and after cycling, but similar behavior was maintained between the two groups tested, reinforcing the similarity between incremental and bulk filling techniques. The use of only one bulk resin composite should be considered as another limitation of this study. Different materials that present different filler content and mechanical properties can perform differently. [34,37,44]

Food impaction caused by the lack of proximal contact between adjacent teeth can lead to problems such as tooth movement and biofilm formation, increasing the risk of secondary caries and periodontal disease.[8,46] In contrast, very tight contact points can cause patient discomfort, make it difficult to floss, and cause periodontal injuries because the teeth are probably invading the interdental papilla space.[9] Clinical studies have shown that contact loss occurs over time at different intensities for restorations.[11,12,21,39] An annual failure rate of 2.8% has been observed for resin composite restorations in a study in which one factor evaluated was the lack of contact points and overhang.[47] For this reason, the generation of a proximal contact with adequate form and function with respect to physiological characteristics is essential for the longevity of resin composite restorations, as is expected for natural teeth[20] and implant prostheses.[11,12] The use of bulk fill resin composite provided good performance in this regard; however, future clinical studies should be performed.

As observed with the new methodology tested, occlusal fatigue was supported only by the central tooth, and the effect of fatigue may have been influenced by the adjacent tooth type, in turn influencing the results. Future studies varying the viscosity of resin composites, using a larger number and different compositions of bulk fill resin composites; and using specimens with greater resistance to the effects of cycling are needed to complement the current findings, leading to *in vitro* analysis of contact-point strength closer to clinical conditions.

CONCLUSIONS

Within the limitations of this *in vitro* study design and considering the restorative materials tested, the following conclusions can be drawn:

- Occlusal fatigue simulating an aging process of 5 years decreased the proximal contact force between the implant and adjacent teeth with simulated periodontal ligaments.
- The proximal contact forces before occlusal fatigue were similar for both restorative techniques compared with the intact-tooth control group.
- The proximal contact area was significantly larger for the molar-molar than for the molar-premolar location; however the ratio of proximal contact force/contact area were similar for all tested groups.
- Bulk filling using high viscosity Opus bulk fill APS resin composite showed similar proximal contact forces before and after occlusal fatigue to the incremental filling technique performed with Filtek Z350.

Conflict of Interest

The authors have no financial interest in any of the companies or products mentioned in this article.

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