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Tese

Influência do tipo de material e protocolo restaurador no desempenho físico-mecânico de restaurações *endocrown*

José Augusto Sedrez Porto

Pelotas, 2017

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“Mantenha seus pensamentos positivos, porque seus pensamentos tornam-se suas palavras. Mantenha suas palavras positivas, porque suas palavras tornam-se suas atitudes. Mantenha suas atitudes positivas, porque suas atitudes tornam-se seus hábitos. Mantenha seus hábitos positivos, porque seus hábitos tornam-se seus valores. Mantenha seus valores positivos, porque seus valores…. Tornam-se seu destino. “

(Mahatma Gandhi)

Notas Preliminares

A presente tese foi redigida segundo o Manual de Normas para trabalhos acadêmicos da UFPel, adotando o nível de descrição em capítulos não convencionais. Disponível no endereço eletrônico:
http://sisbi.ufpel.edu.br/arquivos/PDF/Manual_Normas_UFPel_trabalhos_acad%C3%AAmicos.pdf

O projeto de pesquisa referente a esta Tese, foi aprovado em 29 de janeiro de 2016, pela Banca Examinadora composta pelos Professores Doutores Eliseu Aldrighi Münchow, Giana da Silveira Lima, Mateus Bertolini Fernandes dos Santos e Rafael Ratto de Moraes (suplente).

Resumo

SEDREZ-PORTO, José Augusto. **Influência do tipo de material e protocolo restaurador no desempenho físico-mecânico de restaurações *endocrown*.** 2017. 139f. Tese (Doutorado em Odontologia) – Programa de Pós-Graduação em Odontologia. Universidade Federal de Pelotas, Pelotas, 2017.

O objetivo deste trabalho foi verificar a influência do tipo de material restaurador (resina composta convencional ou de preenchimento único/*bulk-fill*) e da técnica restauradora (aplicação ou não de líquido modelador entre camadas de resina composta e utilização ou não de pinos de fibra de vidro para aumentar a retenção do material restaurador) no desempenho físico-mecânico de restaurações do tipo *endocrown*. O trabalho foi dividido em quatro estudos: (1) uma revisão sistemática e meta-análise da literatura com o objetivo de averiguar se a posição dentária e o tipo da técnica restauradora (*endocrown* ou com pino de fibra de vidro) influenciariam na resistência à fratura das restaurações; (2 e 3) estudos *in vitro* que avaliaram se a presença de um material resinoso fluido (líquido modelador) entre as camadas de resina composta melhorariam o desempenho físico-mecânico e estabilidade de cor/translucidez de restaurações de resina composta; e (4) um estudo *in vitro* que determinou a resistência à fadiga e à fratura de restaurações *endocrown*, avaliando-se a influência do tipo da técnica restauradora (direta ou indireta) e dos sistemas restauradores utilizados. O primeiro estudo foi descrito de acordo com o PRISMA buscando responder se há diferença na resistência à fratura de dentes restaurados com *endocrown* e pino de fibra de vidro. O segundo e terceiro estudos envolveram metodologias de caracterização físico-mecânica e ópticas dos grupos experimentais. Já o quarto estudo simulou o desempenho de restaurações *endocrown* em cerâmica, resina composta de preenchimento único ou convencional, contendo ou não líquido modelador; ainda, as restaurações foram confeccionadas usando-se técnica direta ou indireta, e posteriormente submetidas à fadiga mecânica. Para análise estatística dos dados quantitativos, foi utilizado um nível de significância de 5%. Os resultados da meta-análise mostraram que as endocrowns apresentaram resistência à fratura semelhante as restaurações com resina composta. Os resultados dos estudos in vitro indicaram que o líquido modelador (resina adesiva) entre as camadas de resina composta melhorou o desempenho físico-mecânico do material quando comparado à não utilização, sendo mais evidente quando utilizado o adesivo hidrófobo. Com a conclusão deste trabalho, constatou-se que restaurações *endocrown* podem ser favoravelmente utilizados na rotina clínica para restabelecer a função e estética de dentes tratados endodonticamente e que apresentem grande destruição coronária. Ainda, foi possível compreender o comportamento físico e mecânico de resinas compostas modelados com resinas adesivas (líquido modelador), contribuindo asism para a seleção do melhor sistema restaurador e técnica restauradora para a confecção de restaurações do tipo *endocrown*.

Palavras-chave: *endocrown*; cerâmica; resina composta; adesivos dentinários; cimentos resinosos.

Abstract

SEDREZ-PORTO, José Augusto. **Influence of the restorative material and restorative protocol on the physic-mechanical performance of endocrown restorations.** 2017. 139f. Thesis (PhD in Dentistry). Graduate Program in Dentistry. Federal University of Pelotas, Pelotas, 2017.

The aim of this study was to investigate the influence of the type of restorative material (conventional resin composite or bulk-fill) and of the restorative technique (application or not of modeler liquid in-between the layers of resin composite, or the use or not of fiber-reinforced glass posts to increase the retention of the restorative material) on the physic-mechanical performance of endocrown restorations. The work was divided in four studies: (1) a systematic review and meta-analysis of literature aiming to investigate whether the dental position and the type of restorative technique (endocrown or with fiber-reinforced glass posts) would influence the fracture resistance of the restorations; (2 and 3) in vitro studies that evaluated whether the presence of a fluid resin material (modeler liquid) in between the layers of resin composite would improve the physic-mechanical performance and color/translucency stability of resin composite restorations; and (4) an in vitro study that evaluated the fatigue and fracture resistance of endocrown restorations, evaluating the influence of the type of restorative technique (direct or indirect) and of the restorative materials used. The first study was described according to the PRISMA Statement in order to verify the existence of differences concerning the fracture strength of teeth restored with endocrowns or glass fiber posts. The second study used methodologies of physic-mechanical and optical characterization of the experimental groups. Lastly, the fourth study simulated the performance of endocrown restorations prepared with ceramic, resin composites (conventional or bulk-fill) with or without modeler liquid; moreover, the restorations were prepared using direct or indirect techniques, which were submitted to mechanical fatigue testing. For statistical analysis, the data were analyzed with a 5% level of significance. The results of the meta-analysis showed that endocrowns had fracture strength similar to resin composite restorations. The results of the in vitro studies demonstrated that the presence of modeler liquid (resin adhesive) in-between the layers of resin composite improved the physic-mechanical performance of the material, with this effect being more pronounced for the modeler lquid with a hydrophobic composition. In conclusion, endocrown restorations can be satisfactorily used in the daily routine to reestablish the function and aesthetics of severely damaged non-vital teeth. Furthermore, it was possible to understand the physical and mechanical behavior of resin composites modeled using resin adhesives (modeler liquid), thereby contributing for the selection of the best restorative system and restorative technique for preparing endocrown restorations.

Key-words: endocrown; ceramic; resin composite; dental adhesives; resin cements.

Sumário

1 Introdução

A reabilitação de dentes com diferentes níveis de destruição coronária exige do profissional um entendimento sobre as diversas técnicas restauradoras disponíveis no mercado, diferenciando os métodos de escolha de acordo com o nível de remanescente dentário, presença ou não de tratamento endodôntico, bem como fatores oclusais e expectativa do paciente (ROSCOE et al., 2013). Dentre as diversas opções existentes, a escolha por procedimentos minimamente invasivos tornou-se uma constante na odontologia atual. Geralmente, nos casos em que há um bom nível de remanescente dentário, o tratamento pode ser solucionado através de restaurações diretas em resina composta. Por outro lado, nos casos de média a grande destruição coronária, as restaurações indiretas, seja com resina composta ou materiais cerâmicos, tornam-se uma escolha mais apropriada, podendo ou não envolver o uso de retentores intrarradiculares (HAMBURGER et al., 2014, RAGAUSKA et al., 2008).

O principal fator relacionado à reabilitação dentária de casos complexos envolvendo ampla destruição coronária é a devolução, o mais próxima possível, das características biomecânicas naturais do elemento dental. No entanto, a devolução destas características nunca é total, visto que a maioria dos materiais restauradores disponíveis no mercado apresenta características diferentes da dentina, especialmente relacionadas à rigidez (CHUN; LEE, 2014). Enquanto uns materiais são mais rígidos que a dentina, como no caso das cerâmicas e/ou metais, outros, apesar de apresentarem semelhança quanto às características de rigidez, são menos resistentes; exemplos destes últimos são os materiais poliméricos, como as resinas compostas e os pinos de fibra de vidro. Inicialmente, o tratamento reabilitador de dentes tratados endodonticamente era realizado a partir do uso de pinos/núcleos metálicos fundidos e posterior confecção de coroas cerâmicas (GUNCU et al., 2015). Esta modalidade de tratamento, conhecida pela sua natureza indireta já que envolve etapas laboratoriais adicionais, demonstra sucesso clínico comprovado. Contudo, quando o tratamento falha, uma das consequências mais prevalentes é a fratura corono-radicular, principalmente devido a elevada rigidez do sistema. Infelizmente, a complexidade do tratamento aumenta, resultando na maioria das vezes em perda do elemento dental (SOARES et al., 2012). Em virtude disso, materiais menos rígidos têm sido atualmente utilizados na reabilitação destes casos, e resultados clínico-laboratoriais têm demonstrado menor taxa de fraturas corono-radiculares, o que torna esta técnica mais vantajosa no quesito de conservação do remanescente dentário (GORACCI; FERRARI, 2011). Ainda, a utilização de materiais resinosos possibilita a realização do tratamento de maneira direta, não necessitando de etapas laboratoriais já que o próprio profissional pode confeccionar a restauração final do dente.

Atualmente, o tratamento reabilitador direto de dentes tratados endodonticamente e que apresentem moderada a ampla destruição coronária geralmente envolve em preenchimento do conduto radicular com um pino de fibra de vidro e posterior confecção de núcleo ou restauração final com resina composta (GORACCI; FERRARI, 2011). Uma modalidade de tratamento alternativa e que não envolve a colocação de retentores intrarradiculares é a restauração *endocrown*, caracterizada pela inserção única do material em um dente despolpado, o qual é ancorado na porção interna da câmara pulpar e nas margens da cavidade, obtendo-se assim retenção macro-mecânica (através das paredes pulpares circundantes) e micro-mecânica (pela utilização da cimentação adesiva), simultaneamente (LANDER; DIETSCHI, 2008, BINDL; MORMANN, 1999). Restaurações *endocrown* foram inicialmente preparadas com materiais cerâmicos, porém a maior rigidez desse sistema geralmente resulta em fraturas corono-radiculares (YEH, 1997, ZARONE et al., 2006). Considerando-se que restaurações *endocrown* podem transmitir a carga mastigatória de maneira mais homogênea quando comparadas às técnicas envolvendo retentores intrarradiculares, a utilização de materiais menos rígidos, como as resinas compostas, tem se mostrado uma alternativa interessante (ROCCA; KREJCI, 2013). Contudo, falhas na coesão do material podem ocorrer, bem como o desenvolvimento de tensão de polimerização devido à natureza polimérica desse material. Assim, alternativas que resultem em aumento das propriedades físico-mecânicas do complexo restaurador, bem como que reduzam o desenvolvimento dos efeitos negativos da tensão de polimerização, são extremamente necessárias para impulsionar a utilização de materiais resinosos para confecção de restaurações *endocrown* (AVERSA et al., 2009).

Dentre as possíveis alternativas que poderiam ser utilizadas para sanar esta limitação das restaurações *endocrown* confeccionadas com resina composta, tem-se a utilização de resinas do tipo *bulk-fill*, isto é, aquelas que podem ser inseridas em maiores espessuras para cada incremento e que resultam em menor desenvolvimento de tensão de polimerização (EL-DAMANHOURY; PLATT, 2014, KIM et al., 2015). Estas resinas foram lançadas recentemente no mercado odontológico, e dependendo do seu tipo e composição química, demonstram resultados positivos quanto à redução da tensão de polimerização (KIM; KIM; CHOI; LEE, 2015). No entanto, ainda não existem relatos acerca da utilização de resinas *bulk-fill* para a confecção de restaurações *endocrown*. Além dessa alternativa, dados preliminares (em fase de publicação) demonstraram que a aplicação de resinas adesivas como líquido modelador de resinas compostas aumentou significativamente a coesão do material, além de aumentar a resistência à degradação hidrolítica e aumentar a estabilidade de cor do material após armazenagem em água/vinho tinto. A presença de líquido modelador no interior de restaurações do tipo *endocrown* poderia, dentre outras vantagens, aumentar a resistência do sistema restaurador, bem como diminuir o desenvolvimento de tensão de polimerização, visto que este material de menor viscosidade poderia funcionar como zonas de liberação de tensão, influenciando positivamente o resultado final da restauração *endocrown*. No entanto, não existem relatos na literatura sobre a influência de líquido modelador nas características de restaurações *endocrown*.

Dessa forma, esta tese teve o objetivo geral de investigar o efeito de resinas compostas do tipo *bulk-fill* ou da presença de líquido modelador no comportamento biomecânico de restaurações *endocrown* em dentes posteriores. Os objetivos específicos da presente tese foram:

1. revisar sistematicamente a literatura acerca do desempenho biomecânico (resistência a fratura) de restaurações do tipo *endocrown* (independente do material) quando comparado a técnica convencional com pinos intrarradiculares;
2. caracterizar o desempenho físico-mecânico e estabilidade de cor/translucidez de resinas compostas contendo líquido modelador; e
3. avaliar o efeito das variáveis "tipo de resina" e "presença de líquido modelador" no comportamento biomecânico de restaurações *endocrown*.

2 Capítulo 1

Endocrown restorations: a systematic review and meta-analysis[1].

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Abstract

Objectives: A systematic review was conducted to evaluate clinical (survival) and in vitro (fracture strength) studies of endocrown restorations compared to conventional treatments (intraradicular posts, direct composite resin, inlay/onlay).

Data: This report followed the PRISMA Statement. A total of 8 studies were included in this review.

Sources: Two reviewers performed a literature search up to February 2016 in seven databases: PubMed, Web of Science, Scopus, BBO, SciELO, LILACS and IBECS.

Study selection: Only clinical trials and in vitro studies that evaluated endocrowns were included. Case reports, case series, pilot studies, reviews and in vitro studies that evaluated properties other than fracture strength of endocrowns were excluded. From the 103 eligible articles, 8 remained in the qualitative analysis (3 clinical trials and 5 in vitro studies), and 5 in vitro studies in the meta-analysis. A global comparison was performed with random-effects models at a significance level of $p < 0.05$. *Results*: Clinical trials showed a success rate of endocrowns varying from 94 to 100%. The global analysis in posterior and anterior teeth demonstrated that endocrowns had higher fracture strength than conventional treatments (p=0.03). However, when comparing endocrowns to conventional treatments only in posterior teeth (subgroup analyses), no statistically significant differences were found between treatments (p=0.07; I^2=62%).

Conclusion: The literature suggests that endocrowns may perform similarly or better than the conventional treatments using intraradicular posts, direct composite resin or inlay/onlay restorations.

Clinical significance: Although further studies are still necessary to confirm the present findings, endocrowns show potential application for the rehabilitation of severely compromised, endodontically treated teeth.

Keywords: monoblock restoration; endodontically treated teeth; intraradicular posts.

1. Introduction

Rehabilitation of endodontically treated teeth with large coronal destruction is still a clinical challenge, especially due to the loss of strength characteristics associated to the removal of pulp and surrounding dentin tissues [1]. Coronal retention of the restoration is usually compromised, thus intraradicular posts combined or not with core materials may be required [2]. Despite all clinical success achieved with the use of intraradicular posts, one disadvantage of this system is the additional removal of sound tissue needed for fitting the post into the root canal [3]; additionally, this procedure was revealed to affect the overall biomechanical behavior of the restored teeth [4]. Alternatively, other restorative approaches have been suggested, including but not limited to the well-known endocrown restorations.

Endocrowns assemble the intraradicular post, the core, and the crown in one component [5, 6], thus representing monoblock restorations [7]. Different from conventional approaches using intraradicular posts, endocrown restorations are anchored to the internal portion of the pulp chamber and on the cavity margins, thereby resulting in both macro- and micro-mechanical retention, provided by the pulpal walls and adhesive cementation, respectively [8-10]. In addition, endocrowns have the advantage of removing lower amounts of sound tissue compared to other techniques, and with much lower chair time needed. Also, the masticatory stresses received at the tooth/restoration interface are more properly dissipated along the overall restored tooth structure when endocrowns are placed [11]. Depending on the material chosen, i.e., ceramic or resin composites, the system may become more rigid than the dental structure (in case of ceramics) or biomechanically similar to the tooth (in case of resin composites). Consequently, the type of material may also have influence on the performance of endocrowns [12].

Despite the increased popularity of endocrown restorations, the question that remains is whether clinicians should consider using endocrowns instead of conventional treatments with intraradicular posts. In fact, and from the best of our knowledge, there is still scarce clinical evidence available in the literature, and the existing ones have short follow-up periods, e.g., from 6 to 36 months [5, 9, 13]. Nevertheless, in vitro evaluations reporting on the fracture strength of endocrowns are fairly available [8, 12]; thereby a review of literature taking into account this subject is needed.

Thus, the aim of this study was to systematically review the literature to evaluate clinical and in vitro studies that evaluated endocrown restorations compared to conventional treatments (intraradicular posts, direct composite resin, inlays/onlays). The hypothesis tested was that endocrowns would perform similarly to conventional treatments.

2. Materials and methods

This systematic review is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA Statement) [14].

2.1. Search strategies

Two independent reviewers carried out the literature search until February 2016. The following databases were screened: Pubmed (MedLine), Lilacs, Ibecs, Web of Science, BBO, Scielo and Scopus - using the search strategy described in Table 1. The references cited in the included papers were also checked to identify other potentially relevant articles. After the identification of articles in the databases, the articles were imported into Endnote X7 software (Thompson Reuters, Philadelphia, PA, USA) to remove duplicates.

2.2. Study selection

Two review authors independently assessed the titles and abstracts of all documents. The studies were analyzed according to the following selection criteria: clinical trials that evaluated endocrown restorations or in vitro studies that evaluated fracture strength of endocrowns compared to conventional treatments (intraradicular posts, direct composite resin, inlay/onlay). Case reports, case series, pilot studies, reviews and in vitro studies that evaluated other properties rather than fracture strength of endocrowns and language other than English were excluded. Full copies of all of the potentially relevant studies were identified; those appearing to meet the inclusion criteria or for which there were insufficient data in the title and abstract to make a clear decision were selected for full analysis. The full-text papers were assessed independently and in duplicate by two review authors. Any disagreement regarding the eligibility of included studies was resolved through discussion and consensus or by a third reviewer. Only papers that fulfilled all of the eligibility criteria were included.

2.3. Data extraction

The data were extracted using a standardized form in Microsoft Office Excel 2016 software (Microsoft Corporation, Redmond, WA, USA). If there was any information missing, the authors of the included papers were contacted via e-mail to retrieve any missing data. The reviewers tabulated data of interest for the composition of a spreadsheet in Excel format, with all included studies containing the following: authors, year, number of teeth, type of teeth (anterior or posterior), outcomes, type of cement, groups evaluated, and fracture strength.

2.4. Quality assessment

Two reviewers independently assessed the methodological quality of each included study. Clinical trials were evaluated and classified according to Cochrane guidelines [15] to the following items: selection bias (sequence generation, allocation concealment), performance and detection bias (blinding of operators or participants and personnel), bias due to incomplete data, reporting bias (selective reporting, unclear withdrawals, missing outcomes), and other bias (including industry sponsorship bias). Evidence for each outcome was graded according to the GRADE working group of evidence using Grade Profiler 3.6 [16].

The methodological quality of in vitro studies was assessed as previously described [17, 18]. Thus, the quality assessment was performed according to the articles' description of the following parameters: teeth randomization, presence of control group, teeth with similar morphology, data of fracture strength with coefficient of variation lower than 50%, sample size calculation, blinding of the examiner. If the studies presented the parameter, the article had a ''Yes'' on that specific parameter; if it was not possible to find the information, the article received a ''No.'' Articles that reported on one or two items were classified as having a high risk of bias, three items as a medium risk of bias, and four or five items as a low risk of bias.

2.5. Statistical analysis

The analyses were performed using Review Manager Software version 5.2 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark).

The first global analysis was carried out using a random-effect model, and pooled-effect estimates were obtained by comparing the standardized mean difference of each endocrown group compared with conventional treatments. A p value < 0.05 was considered statistically significant. Multiple groups from the same study were analyzed according to Cochrane guidelines formula for combining groups [15]. Additionally, subgroup analyses were performed to analyze the fracture strength of endocrowns only in posterior teeth compared to conventional treatments. Endocrown restorations were also compared to intraradicular posts restorations. Statistical heterogeneity of the treatment effect among studies was assessed using the Cochran's Q test and the inconsistency I^2 test, in which values greater than 50% were considered as indicative of substantial heterogeneity [15].

3. Results

3.1. Search strategy

A total of 103 potentially relevant records were identified. No additional studies were identified as relevant after search of the reference lists. Fig. 1 summarizes the article selection process according to the PRISMA Statement [14]. After the title and abstract examination, 40 studies were excluded because they did not meet the eligibility criteria. Of the 17 studies retained for detailed review, 9 studies could not be able to be included in the qualitative analysis: 3 studies with finite element analysis [19-21]; 2 studies analyzed only marginal adaptation [22, 23]; 2 studies analyzed only cements [24, 25]; and 2 studies did not compare endocrowns to conventional treatments [26, 27]. A total of 8 studies were included in the qualitative analysis: 3 clinical trials and 5 in vitro studies. In the quantitative analysis, 3 clinical studies were excluded because they did not present a control group [9, 13] or did not evaluate fracture strength [5]. Thus, 5 in vitro studies were included in the meta-analysis [11, 12, 28-30].

3.2. Descriptive analysis

Three clinical trials were included in the qualitative analysis and were published between 1999 and 2014 (Table 2). Follow-up periods were up to 6 months [13], 15 months [5] or 36 months [9] showing a success rate of endocrowns varying from 94 to 100%. Of a total of 55 posterior teeth evaluated in three clinical studies, only two endocrown failures were reported due to secondary caries.

Five in vitro studies investigating fracture strength of endocrowns were published between 2008 and 2015 (Table 2). The sample size ranged from 20 to 48 teeth by study. A total of 102 teeth were evaluated in this review, considering all included studies. Four studies analyzed endocrowns in posterior teeth, and only one in anterior teeth. All studies evaluated ceramic endocrowns, and only one study also included resin composite endocrowns, although no comparison regarding fracture strength between these two manufacturing methods was performed. The included studies evaluated fracture strength, failure modes, marginal continuity, Weibull analysis and finite element method. Table 3 describes the groups evaluated with fracture strength (in N) and standard deviation (SD).

Concerning the quality assessment of clinical studies (Fig. 2b), they scored particularly poor on random sequence generation, allocation concealment, blinding of participants and personnel, and blinding of outcome assessment. The strength of evidence was subsequently downgraded to very low due to risk of bias being very serious in study limitations, imprecision and inconsistency. Regarding in vitro studies, all studies showed a low risk of bias (Fig. 2a), while they scored particularly poor on sample size calculation.

3.3. Meta-analysis

A meta-analysis was performed with 5 in vitro studies. The global analysis of endocrowns fracture strength considering posterior and anterior teeth showed statistically significant differences (p=0.03) compared to conventional treatments (intraradicular posts, direct composite resin, inlay/onlay), favoring the former group treatment (Fig. 3). The value of the I^2 test was 52%. However, in the subgroup analysis considering only endocrowns in posterior teeth, four studies were included (Fig. 4a), with no statistically significant difference between endocrowns and conventional treatments (p=0.07; I^2 = 62%). Also, fracture strength of endocrowns in posterior teeth compared only with intraradicular posts (Fig. 4b) showed no statistically significant difference (p=0.12; I^2 = 75%).

4. Discussion

According to the present systematic review with meta-analysis, and concerning fracture strength outcome, endocrown restorations seemed to perform better when compared to conventional restorations. Several factors may be associated to this positive outcome, including but not limited to differences in configuration/design, thickness, and elastic moduli that endocrowns have compared to conventional systems. First, the ferrule, which is typically found in conventional crowns and can be described as a ‘bracing mechanism’ of the restoration around the cervical tooth structure [31] may cause the loss of sound enamel and dentin tissues that would be important for proper bonding of the restoration [32]; in contrast, endocrowns are usually prepared without ferrule. Second, thickness of the occlusal portion of endocrowns varies from 3 to 7 mm, differently from conventional crowns that varies from 1.5 to 2 mm only [33]; taking into consideration that the greater the occlusal thickness of the restoration the higher the fracture resistance of the system, endocrowns are more prone to resist occlusal loading than conventional crowns. Lastly, conventional restorations are usually prepared using materials with different elastic moduli, i.e. metals or glass-reinforced fibers for the post portion and resin composites or ceramics for the core/crown portion. Considering that the stiffness mismatch between dentin, luting cement, and the restorative system may influence stress distribution, with the higher the number of interfaces between distinct materials the lower the stress distribution, the monoblock nature of endocrowns would support more stress loading than the multi-interfacial nature of conventional restorations [7].

Something important to consider is that four of the included studies were performed on posterior teeth, with premolars summing approximately 58% of the total teeth samples analyzed here (Table 2). Although premolars might be easier to obtain and to restore as compared to molars, thus explaining their preferable use in in vitro studies, endocrowns were revealed to fail more when fixed to premolars in a clinical trial [9], probably due to their smaller adhesion area and greater crown height compared to molars. In addition, premolars receive more horizontally (non-axial) directed forces than molars, which may also influence fracture resistance [32]. Concerning anterior teeth, only one study was included in the review, thus highlighting the need for more studies evaluating the performance of endocrowns when placed in anterior teeth. Although there is no previous report comparing the performance of anterior and posterior endocrowns in the same standardized study, one could expect that endocrowns would fail more when placed in anterior teeth than in posterior ones. Indeed, and similarly to premolars, incisors and/or canines receive higher non-axial forces when compared to the more axially directed forces that posterior teeth face during oral function [34]; consequently, the former would receive greater stresses than the latter, increasing the chance for restoration failure. This fact may explain the lack of clinical and in vitro studies on anterior teeth, thus reinforcing the need for well-designed studies on this subject.

According to the present findings, endocrown restorations seemed to perform better than conventional restorations only when the five studies were grouped together (Fig. 3). As stated before, the most reasonable explanations are related to the distinctive configuration/design, thickness, and elastic moduli characteristics that endocrowns have compared to conventional systems. Conversely, when sub-analyses were performed without adding the study of Ramírez-Sebastià et al. [12], i.e., the only study testing anterior teeth, endocrowns exhibited similar fracture strength to conventional crowns (Fig. 4a). Although some inherent factors related exclusively to posterior teeth may be responsible for the obtained data, it is also important to highlight that the absence of more studies testing anterior teeth makes it difficult to explain this dual result. One could speculate that data became less heterogeneous with the sub-analysis, thereby contributing for the similar results obtained; however, heterogeneity was not significantly modified by removing the data of Ramírez-Sebastià et al. [12]. Also, considering that the p-value was very near the cut-off of 0.05 for this finding (subgroup analysis p=0.07), the low number of samples in the included studies and the lack of power calculations could be the reason why there was no statistically significant difference. Another aspect to consider is the influence of cement type used to fix the restorations to the tooth structure. While endocrowns cemented with Variolink (Ivoclar) demonstrated similar fracture strength to the control groups (also cemented with the same luting material), endocrowns cemented with All-Bond 1 and C & B (Bisco) or RelyX ARC (3M ESPE) resulted in higher fracture strength than the controls (Table 3). It must be considered that the adhesion of the restoration is dependent on the type of cement used [35]; moreover, it can be expected that the greater the adhesion of the restoration, the better the stress distribution within the system, thus resulting in higher fracture strength. Not less important, premolars and molars may receive similar forces during oral function, contributing for the similar results when considering only posterior teeth.

Different from the sub-analysis shown in Fig. 4a, another sub-analysis was also conducted in order to compare the performance of posterior endocrowns to groups that were restored using intraradicular posts (Fig. 4b). This sub-analysis was performed because intraradicular posts have been commonly preferred for the rehabilitation of endodontically treated teeth [2]. Although intraradicular posts may truly help with the retention of restoration, they may also contribute to the occurrence of root fracture and catastrophic failures when metal posts are used, or post/restoration debonding when glass fiber posts are used [2]. In the former situation, fracture is prone to occur due to the greater rigidity of metal posts compared to dentin, thereby increasing stress concentration within the post and/or at the tooth/post interface [36]; in the latter circumstance, the similar elastic properties between glass fiber posts and dentin prevents fracture to occur, demonstrating an advantage over metal posts [2]. Here, endocrowns performed similarly to restorations built-up using intraradicular posts, regardless of the nature of the post. For instance, in the study of Forberger et al. [29], endocrowns resulted in similar fracture strength when compared to groups restored with posts based on ceramic (zirconia), gold or glass fiber (Table 3). In the other studies, i.e., Biacchi et al. [28] and Chang et al. [11], endocrowns resulted in statistically higher fracture strength than control groups restored using glass fiber posts. Despite these divergent results, the present meta-analysis did not demonstrate significant differences between endocrowns and groups restored with intraradicular posts. This finding is clinically relevant because it shows that endocrowns may work similar to restorations made with intraradicular posts, at least concerning fracture resistance of posterior teeth.

Taken together these findings show that endocrown restorations performed similarly or better than conventional restorations prepared with intraradicular posts and/or core materials, thereby partially accepting the study hypothesis. Nevertheless, this result should be considered with caution since eight studies were included. Few clinical trials are available in the literature [5, 9, 13] although they presented high clinical success rates (94 to 100% up to 36 months). Furthermore, the reason of failure was secondary caries, and no study reported fracture or retention loss of endocrown. However, these studies presented small sample sizes and high risk of bias, and their results should be interpreted with caution. Further studies and especially clinical trials with long follow-up periods are of utmost importance to clarify the usage of endocrown restorations for rehabilitation of severely compromised, endodontically treated teeth. Studies evaluating the effect of endocrowns in anterior teeth should be also conducted. Lastly, and considering that endocrowns may be more cost effective (e.g., faster/simpler to prepare and cheaper) when compared to other treatment modalities, they bring potential application for oral rehabilitation purposes.

5. Conclusion

The available literature found suggests that endocrowns may perform similarly or better than the conventional treatments using intraradicular posts, direct composite resin or inlay/onlay restorations. However, caution must be taken when interpreting the results of in vitro studies. Further studies are needed to confirm that endocrown restorations for endodontically treated teeth are a feasible option.

References

1. Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of Post Placement on the Restoration of Endodontically Treated Teeth: A Systematic Review. The International Journal of Prosthodontics 2015;**28**(5):475-83.
2. Sarkis-Onofre R, Jacinto Rde C, Boscato N, Cenci MS, Pereira-Cenci T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. Journal of Dentistry 2014;**42**(5):582-7.
3. Lazari PC, Oliveira RC, Anchieta RB, Almeida EO, Freitas Junior AC, Kina S, et al. Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite element analysis based on micro-CT data. Journal of Applied Oral Science 2013;**21**(6):511-7.
4. Roscoe MG, Noritomi PY, Novais VR, Soares CJ. Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. The Journal of Prosthetic Dentistry 2013;**110**(2):116-26.
5. Otto T. Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. International Journal of Periodontics and Restorative Dentistry 2004;**24**(5):446-55.
6. Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. Dental Materials 2006;**22**(11):1035-44.
7. Tay FR, Pashley DH. Monoblocks in root canals: a hypothetical or a tangible goal. Journal of Endodontics 2007;**33**(4):391-8.
8. Biacchi GR, Mello B, Basting RT. The endocrown: an alternative approach for restoring extensively damaged molars. Journal of Esthetic and Restorative Dentistry 2013;**25**(6):383-90.

9. Bindl A, Mormann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. The Journal of Adhesive Dentistry 1999;**1**(3):255-65.

10. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. Operative Dentistry 2015;**40**(2):201-10.

11. Chang C, Kuo J, Lin Y, Chang Y. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. Journal of Dental Science 2009;**4**(3):110-7.

12. Ramirez-Sebastia A, Bortolotto T, Cattani-Lorente M, Giner L, Roig M, Krejci I. Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength. Clinical Oral Investigations 2014;**18**(2):545-54.

13. Decerle N, Bessadet M, Munoz-Sanchez ML, Eschevins C, Veyrune J, Nicolas E. Evaluation of Cerec endocrowns: a preliminary cohort study. European Journal of Prosthodontics and Restorative Dentistry 2014;**22**(2):89-95.

14. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Journal of Clinical Epidemiology 2009;**62**(10):1006-12.

15. Higgins JPT, Green S. Cochrane handbook for systematic reviews of interventions. Wiley-Blackwell 2008;**1**:673.

16. Andrews, J., G. Guyatt, A. D. Oxman, P. Alderson, P. Dahm, Y. Falck-Ytter, M. Nasser, J. Meerpohl, P. N. Post, R. Kunz, J. Brozek, G. Vist, D. Rind, E. A. Akl and H. J. Schunemann GRADE guidelines: 14. Going from evidence to recommendations: the significance and presentation of recommendations. Journal Clinical Epidemiology 2013;66(**7**):719-725.

17. Rosa WLO, Piva E, Silva AF. Bond strength of universal adhesives: A systematic review and meta-analysis. Journal of Dentistry 2015;**43**(7):765-76.

18. Sarkis-Onofre R, Skupien JA, Cenci MS, Moraes RR, Pereira-Cenci T. The role of resin cement on bond strength of glass-fiber posts luted into root canals: a systematic review and meta-analysis of in vitro studies. Operative Dentistry 2014;**39**(1):E31-44.

19. Lin CL, Chang YH, Hsieh SK, Chang WJ. Estimation of the failure risk of a maxillary premolar with different crack depths with endodontic treatment by

computer-aided design/computer-aided manufacturing ceramic restorations. Journal of Endodontics 2013;**39**(3):375-9.

20. Lin CL, Chang YH, Pa CA. Estimation of the risk of failure for an endodontically treated maxillary premolar with MODP preparation and CAD/CAM ceramic restorations. Journal of Endodontics 2009;**35**(10):1391-5.

21. Schmidlin PR, Stawarczyk B, DeAbreu D, Bindl A, Ender A, Ichim IP. Fracture resistance of endodontically treated teeth without ferrule using a novel H-shaped short post. Quintessence International 2015;**46**(2):97-108.

22. Ramirez-Sebastia A, Bortolotto T, Roig M, Krejci I. Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation. Operative Dentistry 2013;**38**(6):663-73.

23. Rocca GT, Saratti CM, Poncet A, Feilzer AJ, Krejci I. The influence of FRCs reinforcement on marginal adaptation of CAD/CAM composite resin endocrowns after simulated fatigue loading. *Odontology* 2015. *(Approved for publication)*

24. Gregor L, Bouillaguet S, Onisor I, Ardu S, Krejci I, Rocca GT. Microhardness of light- and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns. The Journal of Prosthetic Dentistry 2014;**112**(4):942-8.

25. Borges Junior HF, Sábio S, Bender KRF, Costa YM, Sábio SS, Mondelli J. Endocrown - Avaliação da resistência dos cimentos dentários. Revista de Odontologia de Araçatuba 2013;**34**(2):23-26.

26. Gresnigt MM, Ozcan M, van den Houten ML, Schipper L, Cune MS. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. Dental Materials 2016. *(Approved for publication)*

27. Magne P, Carvalho AO, Bruzi G, Anderson RE, Maia HP, Giannini M. Influence of no-ferrule and no-post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns. Operative Dentistry 2014;**39**(6):595-602.

28. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Operative Dentistry 2012;**37**(2):130-6.

29. Forberger N, Gohring TN. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. The Journal of Prosthetic Dentistry 2008;**100**(4):264-73.

30. Lin CL, Chang YH, Pai CA. Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. Dental Materials 2011;**27**(5):431-8.

31. Jotkowitz A, Samet N. Rethinking ferrule--a new approach to an old dilemma. British Dental Journal 2010;**209**(1):25-33.

32. Skupien JA, Luz MS, Pereira-Cenci T. Ferrule effect: a meta-analysis. Journal of Dental Research 2016. *(Approved for publication)*

33. Motta AB, Pereira LC, Duda FP, Anusavice KJ. Influence of substructure design and occlusal reduction on the stress distribution in metal ceramic complete crowns: 3D finite element analysis. Journal of Prosthodontics 2014;**23**(5):381-9.

34. Silva GR, Santos-Filho PC, Simamoto-Junior PC, Martins LR, Mota AS, Soares CJ. Effect of post type and restorative techniques on the strain and fracture resistance of flared incisor roots. Brazilian Dental Journal 2011;**22**(3):230-7.

35. De Souza G, Braga RR, Cesar PF, Lopes GC. Correlation between clinical performance and degree of conversion of resin cements: a literature review. Journal of Applied Oral Sciences 2015;**23**(4):358-68.

36. Coelho CS, Biffi JC, Silva GR, Abrahao A, Campos RE, Soares CJ. Finite element analysis of weakened roots restored with composite resin and posts. Dental Materials Journal 2009;**28**(6):671-8.

Figures

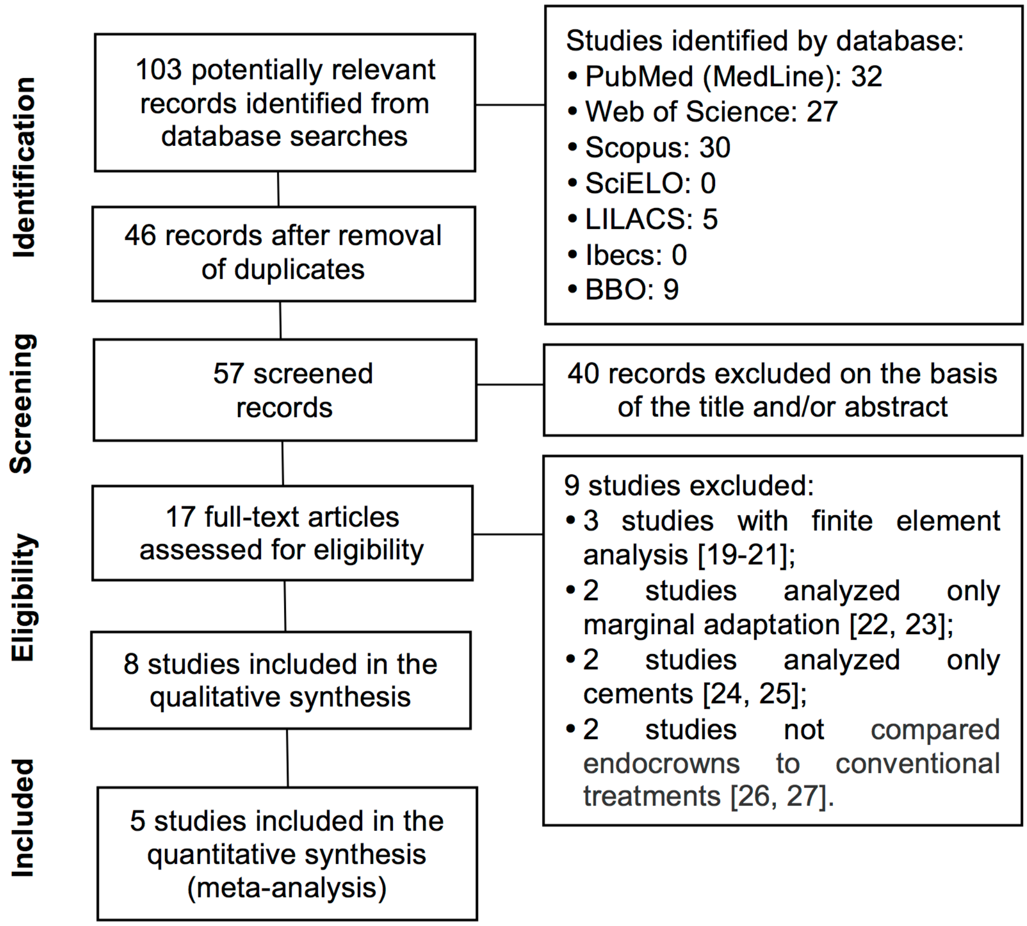

Fig. 1 - Search flow (as described in the PRISMA statement).

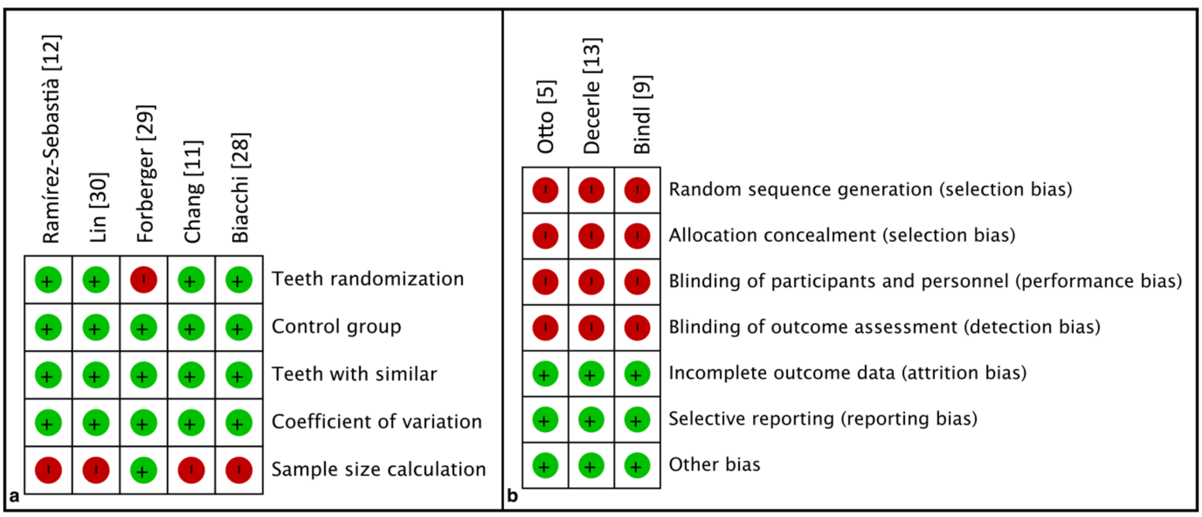

Fig. 2 - Review authors' judgments about each risk of bias item for each included in vitro study (a) and clinical trial (b).

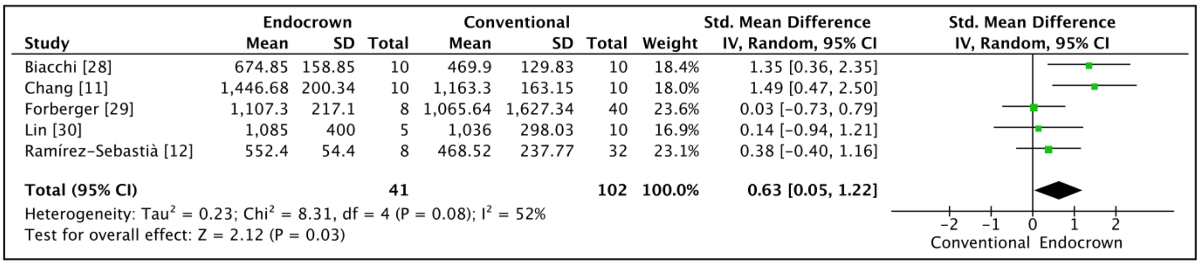

Fig. 3 - Results for the global analysis of the fracture strength of endocrowns compared to conventional treatments using random-effects models. Statistically significant differences between groups (p=0.03) were observed.

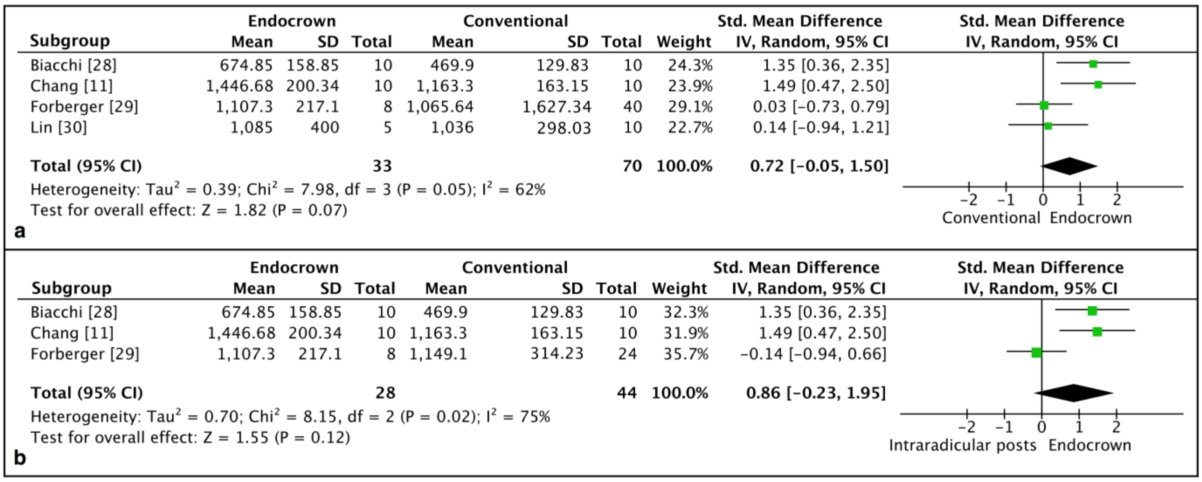

Fig. 4 - Results for the subgroup analysis of fracture strength of endocrowns in posterior teeth compared to conventional treatments (a) and intraradicular posts (b). No statistically significant differences between groups in both analyses (p=0.07).

Table 1 – Search strategy used in eletronic databases (Web of Science, PubMed (MEDLINE), Scopus, Scielo, Lilacs and Ibecs).

Search Terms
Web of Science “Endocrown” OR “Endocrowns” OR “depulped restoration” OR “no buildup crown” OR “no build-up crown” OR “no-post buildup” OR “no-post build-up” OR “endo crowns” OR “endo crown” OR “endodontic crown” OR “endodontic crowns” OR “adhesive endodontic crown” OR “adhesive endodontic crowns”
PubMed (MEDLINE) “Endocrown” OR “Endocrowns” OR “depulped restoration” OR “no buildup crown” OR “no build-up crown” OR “no-post buildup” OR “no-post build-up” OR “endo crowns” OR “endo crown” OR “endodontic crown” OR “endodontic crowns” OR “adhesive endodontic crown” OR “adhesive endodontic crowns”
Scopus (Endocrown) OR (Endocrowns) OR (depulped restoration) OR (no buildup crown) OR (no build-up crown) OR (no-post buildup) OR (no-post build-up) OR (endo crowns) OR (endo crown) OR (endodontic crown) OR (endodontic crowns) OR (adhesive endodontic crown) OR (adhesive endodontic crowns)
Scielo, Lilacs and Ibecs (Endocrown) OR (Endocrowns) OR (depulped restoration) OR (no buildup crown) OR (no build-up crown) OR (no-post buildup) OR (no-post build-up) OR (endo crowns) OR (endo crown) OR (endodontic crown) OR (endodontic crowns) OR (adhesive endodontic crown) OR (adhesive endodontic crowns) OR (coroa endodôntica adesiva) OR (coroa endodôntica) OR (corona de endodoncia)

Table 2 - Demographic data of the included studies.

Author	Year	Type of Study	Country	Number of teeth (per group)	Type of teeth*	Outcomes
Forberger [29]	2008	In vitro	Switzerland	48 (8)	PM (Posterior)	Marginal continuity, fracture strength and failure modes with thermal cycling
Chang [11]	2009	In vitro	Taiwan	20 (10)	PM (Posterior)	Fracture strength and failure modes with thermal cycling
Lin [30]	2011	In vitro	Taiwan	15 (5)	PM (Posterior)	Fracture strength, weibull analysis and finite element method
Biacchi [28]	2012	In vitro	Brazil	20 (10)	M (Posterior)	Fracture strength and failure modes
Ramírez-Sebastià [12]	2014	In vitro	Switzerland	40 (8)	CI (Anterior)	Fracture strength and failure modes
Bindl [9]	1999	Retrospective clinical trial	Switzerland	19 (**)	M and PM (Posterior)	Retention, fracture, marginal adaptation, anatomic form, secondary caries, surface texture, color match
Decerle [13]	2004	Retrospective clinical trial	France	16 (**)	M and PM (Posterior)	Retention, fracture, marginal adaptation, anatomic form, secondary caries, surface texture, color match
Otto [5]	2014	Prospective clinical trial	Switzerland	20 (10)	M and PM (Posterior)	Retention, fracture, marginal adaptation, anatomic form, secondary caries, surface texture, color match

* PM: premolars; M: molars; CI: central incisor; ** Only one group reported

Table 3 – Groups evaluated with fracture strength (N) and standard deviation (SD)

Study	Testing methods of fracture strength*	Laboratory procedures			Fracture strength (N) Mean (±SD)
		Groups	Number of teeth	Type of cement	
Forbeger [29]	Universal testing machine with a 5mm steel sphere at 30° and a cross-head speed of 0.5mm/min.	Endocrown (ceramic crowns)	8	Variolink (Ivoclar Vivadent, Liechtenstein)	1107.3 (±217.1)
		Untreated	8	No	849.0 (±94.0)
		Composite	8	No	1031.9 (±266.7)
		Glass Fiber-Reinforced Composite Posts	8	Variolink (Ivoclar Vivadent, Liechtenstein)	1092.4 (±307.8)
		Zirconia Ceramic-Post	8	Variolink (Ivoclar Vivadent, Liechtenstein)	1253.7 (±226.5)
		Gold-Post	8	Ketac Cem (3M ESPE, United States)	1101.2 (±182.9)
Chang [11]	Universal testing machine with a 5mm steel sphere at 90° and a cross-head speed of 0.5mm/s.	Endocrown (ceramic crowns)	10	All-Bond 1 and C & B Cement (Bisco, United States)	1446.7 (±200.3)
		Glass Fiber-Reinforced Composite Posts	10	All- Bond 1 and C & B Cement (Bisco, United States)	1163.3 (±163.2)
Lin [30]	Universal testing machine with a 5mm steel sphere at 90° and a cross-head speed of 0.05mm/s.	Endocrown (ceramic crowns)	5	Variolink II luting composite resin cement (Ivoclar Vivadent, Liechtenstein)	1085.0 (±400.0)
		Inlay	5	Variolink II luting composite resin cement (Ivoclar Vivadent,	946.0 (±404.0)

				Liechtenstein)	
		Crown	5	Variolink II luting composite resin cement (Ivoclar Vivadent, Liechtenstein)	1126.0 (±128.0)
Biacchi [28]	Universal testing machine with a 6 mm steel sphere at 135° and a cross-head speed of 1mm/min.	Endocrown (ceramic crowns)	10	Dual resin cement (RelyX ARC, 3M ESPE, United States)	674.8 (±158.9)
		Glass-fiber posts	10	Dual resin cement (RelyX ARC, 3M ESPE, United States)	469.9 (±129.8)
Ramírez-Sebastià [12]	Universal testing machine with stainless steel rod at 45° and a cross-head speed of 1mm/min.	Endocrown (ceramic/composite crowns)	8	Dual-cured luting cement (Clearfil Esthetic Cement, Kuraray, Japan)	552.4 (±54.4)
		Short glass-fiber post	8	Dual-cured luting cement (Clearfil Esthetic Cement, Kuraray, Japan)	470.9 (±55.2)
		Long glass-fiber post	8	Dual-cured luting cement (Clearfil Esthetic Cement, Kuraray, Japan)	432.6 (±55.3)
		Ceramic	8	Dual-cured luting cement (Clearfil Esthetic Cement, Kuraray)	483.1 (±46.2)
		Composite	8	-	487.5 (±42.4)

* Angle of incidence along the long axis of the specimen

3 Capítulo 2

Title. Use of dental adhesives as modeler liquid of resin composites[2].

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Abstract

Objectives. Resin adhesives (RA) have been applied between resin composite (RC) increments, but there is no consensus on the impact of this technique on the properties of the final restoration. This study evaluated the effect of the presence of RA between RC layers on physical properties, translucency and long-term color stability of the restorative material.

Methods. Scotchbond™ Multi-Purpose (bond, 3M ESPE) and Adper™ Single Bond 2 (3M ESPE) were used as RA, and Filtek™ Z350 (3M ESPE) as RC. Specimens containing RA were prepared by applying 3 layers of the adhesive between 4 increments of RC; adhesive-free specimens were also used (control). Tests of water sorption and solubility, mechanical performance (microtensile cohesive strength, flexural strength, and flexural modulus, after immediate and long-term water storage), and translucency and color stability (after immediate and 1, 7, 90, and 180 days of water or wine storage) were performed. Scanning electron microscopy (SEM) images were also taken from the fractured specimens (flexural strength test). Data were analyzed using ANOVA and Tukey test ($p<0.05$).

Results. Scotchbond (SBMP) showed lower water sorption and solubility than the control ($p<0.001$), and an overall similar ($p\geq0.198$, immediate tests) or higher ($p\leq0.019$, long-term tests) mechanical performance. SBMP exhibited a rougher cross-sectional surface compared to the other groups. Translucency remained unaltered after 180 days of storage ($p\geq0.313$), except for Single Bond that had increased translucency with wine storage ($p<0.045$). After 180 days, all groups changed color ($p\leq0.002$), although more intensively when immersed in wine.

Significance. The presence of RA within RC increments increased the physical stability of the material, being this effect more evident by using the hydrophobic unfilled adhesive resin (SBMP). This study is the first to show positive results from the use of adhesive resins as modeler liquid of resin composite, which is common in clinical practice.

Keywords: FTIR; water sorption and solubility; flexural strength; flexural modulus; translucency; color stability

Highlights

Resin adhesives may be used as modeler liquids of resin composites

Modeler liquids applied within increments of composite may improve its strength

Hydrophobic resins are more appropriate to serve as modeler liquids of composites

1. Introduction

Dental resin composites have been widely used as direct/indirect restoratives mainly due to their excellent esthetic properties [1]. However, despite of all satisfactory properties expected when using current composites [2-4], some materials are comprised of viscous resin monomers that make it difficult to sculpt and to model the composite in the anatomical shape of the tooth. Consequently, some continuous education courses on restorative dentistry as well as some dental practitioners/dentists are advocating the use of low viscous materials (e.g., resin adhesives) as 'modeler liquids' of resin composites. This approach would be able to reduce the surface tension improving the handling/placement of the restorative material in the cavity or dental preparation. Indeed, the 'build-up' process of dental ceramic restorations uses modeler liquids to mix the powder, which reduces the surface tension produced between the material and the spatula/instruments, making the layer-by-layer placement of material easier [5].

As aforementioned, resin adhesives have been used as modeler liquids of resin composites, although manufacturers do not report this technique. The technique consists of applying the adhesive on the surface of the first composite increments before light curing, and/or on the spatula/instrument, enabling the easy modeling of the next increment. This technique may be also useful for reducing air entrapment and porosity/defects into the restoration body since the low viscous resin may easily penetrate through these spaces [6]. However, to the best of our knowledge, there is no report in the literature investigating if the presence of modeler liquid into the composite structure may affect the final quality/properties of the restoration/composite. Moreover, it is unknown whether the different compositions of adhesives/modeler liquids may affect the translucency and color stability of composite over time.

Hence, the aim of this *in vitro* study was to investigate the effect of the presence of resin adhesive between layers of resin composites on the physical properties, translucency and long-term color stability of the restorative material. Three hypotheses were tested: (1) the presence of adhesive into the composite structure would not reduce its mechanical strength; (2) the presence of adhesive into the composite structure would alter the translucency and the color shade of the composite after storage when compared to a bulk adhesive-free composite; and (3) the type of adhesive applied would influence on the long-term translucency and color stability of the composite.

2. Materials and Methods

2.1. Study design

This *in vitro* study used resin composite specimens (Filtek™ Z350 XT, 3M ESPE, St. Paul, MN, USA) with or without modeler liquid (adhesive resin) in order to investigate the effect of the latter on long term physical properties, translucency, and color stability of the composite. For that, two different adhesive resins were used as modeler liquids: SBMP (the bond component of Adper™ Scotchbond™ Multi-Purpose Adhesive, 3M ESPE) as a more hydrophobic composition, and SB (Adper™ Single Bond 2 Adhesive, 3M ESPE) as a more hydrophilic material. All specimens were prepared by placing four increments of resin composite. Specimens containing modeler liquid were prepared as it follows: after the placement of the first composite increment, the respective adhesive resin was applied on the composite surface with a disposable brush (Microbrush® International, Grafton, WI, USA); next, a new increment of composite was placed, modeled, and coated with another layer/pellicle of the modeler liquid, until the fourth increment was placed. The modeler liquid was not directly light-activated since it was mixed and entrapped within the composite's increments, which were light-activated separately (for specimens thicker than 2 mm) or only after placement of the fourth increment (for specimens with 2 mm of thickness). Specimens without adhesive were prepared as control group. Each set of specimens was prepared varying the format and thickness of the specimen, in accordance with each test performed, aiming the simulation of a restoration in clinical practice with additional/intermediate layers of adhesive resin; the thickness of each composite increment has never exceeded 2 mm.

2.2. Microtensile cohesive strength (μTCS) test

Six cylinder-shaped specimens (6 mm diameter × 6 mm thickness) of each group were prepared. Each increment of composite (around 1.5 mm-thick) was light-activated for 20 s using a light-emitting diode (LED, Radii®, Bayswater, VIC, Australia – 900 mW/cm^2 of irradiance) curing unit. The samples were stored in distilled water for 24 h at 37 °C, and then transversally and longitudinally sectioned using a water-cooled diamond saw at low speed (Isomet 1000, Buheler Ltd, Lake Bluff, IL, USA) to obtain specimens with approximately 0.8 mm^2 of transverse-sectional area. All specimens were randomly allocated in two subgroups according to the period of storage in distilled water (37 °C): immediate (24 h) or long-term (6 months). After that, each specimen was fixed to a custom-made testing jig using cyanoacrylate glue (Super Bonder Gel, Loctite, Brazil) and its μTCS was tested in a universal testing machine (DL500, Emic, São José dos Pinhais, Brazil) at a crosshead speed of 1 mm/min. The μTCS results were expressed in MPa.

2.3. *Flexural strength, flexural modulus, and scanning electron microscopy (SEM) analyses*

Ten bar-shaped specimens (25 mm length × 2 mm width × 2 mm thickness) of each group were prepared, and light-activation for 20 s was performed in four consecutive points of both top and bottom surfaces of each specimen. Next, the specimens were randomly allocated into two subgroups according to the period of storage in distilled water at 37 °C (n = 5): 24 h or seven days. All specimens were then submitted to three-point bend test in the DL500 universal testing machine at a crosshead speed of 1 mm/min. The flexural strength (*σ*) and the flexural modulus (*E*) results were calculated using the following formulas:

$$\sigma = \frac{3Fl}{2bh^2} \qquad E = \frac{F1l^3}{4bh^3d}$$

where *F* is the peak load (N); *l* is the span length (mm); *b* and *h* are, respectively, the width and the thickness of the specimen (mm), and *d* is the deflection of the specimen at load *F1* during the straight line portion of the load-displacement trace. The *σ* and the *E* data were expressed in MPa and GPa, respectively.

Two distinct fractured specimens of each group (those tested after 24 h of water storage) were randomly selected, mounted on aluminum stubs with the cross-sectional surfaces faced up, sputter-coated with gold/palladium, and then analyzed under a scanning electron microscope (SSX-550, Shimadzu, Tokyo, Japan).

2.4. *Water sorption and solubility tests*

Ten cylinder-shaped specimens (6 mm diameter × 4 mm thickness) of each group were prepared and then placed into a desiccator containing freshly dried silica gel and calcium chloride, and after 24 h they were removed, stored in a desiccator at 23 ºC for 1 h and weighed on a precision balance with 0.01 mg readability (AUW 220D, Shimadzu Corp. Nakagyo-ku, Kyoto, Japan). This cycle was repeated until a constant mass (m_1) was obtained. Thickness and diameter were randomly measured to calculate each specimen volume (V, in mm^3). The specimens were immersed in distilled water at 37 ºC for seven days, then removed, blotted dry, and weighed (m_2). Next, they were dried inside the desiccators and their weight was recorded daily in order to obtain a third constant mass (m_3), as previously described. For each sample, data of water sorption (WS) and solubility (SL) were calculated (in μg/mm^3) using the following formulas:

$$WS = \frac{m_2 - m_3}{V} \qquad SL = \frac{m_1 - m_3}{V}$$

2.5. Translucency test

Fourteen disk-shaped specimens (6 mm diameter × 2 mm thickness) of each group were prepared and then polished with medium, fine, and extra-fine aluminum oxide abrasive disks (Sof-Lex Pop On Orange series, 3M ESPE) for 15 s per disk, and also with felt disk containing extra-fine (2-4 μm) diamond paste (Diamond AC II, FGM, Joinville, SC, Brazil) [7]. After polishing, the specimens were randomly allocated into two subgroups according to the storage media: distilled water (pH 5.9) or red wine (Cabernet Sauvignon 2007, Concha y Toro, Las Condes, Chile – pH 3.6 and 14.5% in volume of alcohol), which were renewed weekly and kept at 37 °C. Translucency of specimens was measured using the translucency parameter (TP) method, where the color parameters of each specimen were recorded according to the CIE$L^*a^*b^*$ system against white (L^*_W = 94.44, a^*_W = 0.26, b^*_W = 1.69) and black (L^*_B = 1.38, a^*_B = 0.00, b^*_B = 0.06) backgrounds using a digital spectrophotometer

(Vita Easyshade, Vita Zahnfabrik, Bad Sackingen, Germany). The TP was calculated using the following formula:

$$TP = \sqrt{(L_W^* - L_B^*)^2 + (a_W^* - a_B^*)^2 + (b_W^* - b_B^*)^2}$$

where L^*_W, a^*_W, and b^*_W were measured over white background, and L^*_B, a^*_B, and b^*_B were measured over black background.

The TP of all specimens was evaluated at different periods of time: immediately after the polishing of specimens (baseline) and after 24 h, 7, 90, and 180 days of storage in each medium.

2.6. Color stability test

The color parameters measured over the white background in the translucency test were used to calculate the color change (ΔE^*) of specimens after storage in water and red wine for the same storage periods aforementioned. The ΔE^* was calculated using the following formula:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^*, Δa^*, and Δb^* were the difference between the final and initial L^*, a^*, and b^* color parameters, respectively.

2.7. Statistical analysis

All data were analyzed with the statistical program SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA) using analysis of variance (ANOVA) and the Tukey test for multiple comparisons (α = 5 %). Depending on the variables analyzed, different tests were used: One Way ANOVA for water sorption and solubility data;

Two Way ANOVA for μTCS, *σ*, and *E* data; and Two Way Repeated Measures ANOVA for translucency and color change data after each storage period evaluated.

3. Results

3.1. Microtensile cohesive strength (μTCS)

Results for μTCS are shown in Table 1. The factors 'material' ($p \leq 0.001$) and 'period of storage' ($p \leq 0.001$) were both significant, whereas their interaction was not significant ($p = 0.062$). Groups presented similar μTCS mean after 24 h of storage ($p \geq 0.198$). By contrast, the control demonstrated lower strength than SBMP and SB after the six-month storage ($p \leq 0.002$), although all groups significantly decreased the μTCS ($p \leq 0.001$).

3.2. Flexural strength (σ), flexural modulus (E), and SEM results

Data for *σ* and *E* are shown in Table 1. There was a significant interaction between factors 'material' and 'period of storage' ($p \leq 0.001$) for *σ*, but not for *E* ($p = 0.110$). After 24 h of storage all groups presented similar *σ* and *E* results ($p \geq 0.828$), except SB that demonstrated lower *σ* compared to SBMP and control ($p \leq 0.001$). After seven days of water storage, *σ* and *E* were significantly reduced, except for SB ($p = 0.155$) and SBMP ($p = 0.173$) that maintained, respectively, the *σ* and the *E* mean values similar to the immediate results. The control showed the lowest *σ* and *E* results after storage ($p < 0.001$).

According to the SEM micrographs obtained from the fractured surfaces, which are shown in Figure 1, the presence of modeler liquid between composite increments did not change the inner structure and morphology of specimens when compared to the control group. Although the presence of voids/cracks could not be generally detected on the analyzed specimens, one defect was observed in the control group (black arrows).

3.3. Water sorption and solubility

There was a statistically significant difference among the groups investigated for both analyzes ($p \leq 0.001$), which results are presented in Table 1. SBMP showed lower water sorption (16.8 $\mu g/mm^3$) than the control and SB groups (25.4 and 21.5 $\mu g/mm^3$, respectively; $p \leq 0.035$), which have not differed between each other ($p = 0.079$). With regard to the solubility data, SBMP and SB (2.9 and 3.0 $\mu g/mm^3$, respectively) resulted in lower solubility than the control (4.5 $\mu g/mm^3$; $p \leq 0.001$).

3.4. Translucency parameter

The TP results are shown in Figure 2. The factors ‘material’ and ‘period of storage’ were significant within the water storage group ($p \leq 0.003$) but not within the red wine group ($p > 0.05$). Specimens stored in water for 90 days increased translucency when compared to the baseline measurements ($p \leq 0.045$), although SBMP and SB took longer time (180 days) than the control to change the TP. The control group showed lower TP than SBMP and SB after one day of water storage ($p \leq 0.038$). Immersion in the red wine medium maintained the translucency of the control and SBMP groups stable after 180 days of storage ($p \geq 0.171$). However, SB group became more translucent after 90 days of storage ($p \geq 0.010$), showing higher TP than the control and SBMP groups ($p \leq 0.044$).

3.5. Color change (ΔE^*)

The ΔE^* results are displayed in Figure 3. The factors 'material' and 'period of storage' were not significant for both storage media ($p > 0.05$), although the interaction between factors was significant ($p \leq 0.009$). For all groups and storage periods evaluated, wine storage resulted in higher color change compared to water storage ($p < 0.05$). Within the water storage condition, SB and SBMP showed, respectively, higher ΔE^* than the control after one day and 180 days of storage ($p = 0.041$ and $p = 0.038$). SBMP and SB took 180 days to present a significant color change ($p \leq 0.044$), whereas the control changed color after 90 days of storage ($p \leq 0.043$). With regards to the wine storage condition, all groups progressively increased ΔE^* with up to 90 days of storage ($p < 0.001$); after this period, the color of specimens was maintained ($p \geq 0.359$). After 180 days of storage, SBMP resulted in lower color change compared to the SB and control groups ($p \leq 0.001$).

4. Discussion

This is the first study to show the positive effects that are added when modeler liquids (i.e., in this study represented by dental adhesive resins) are used in between layers of resin composite. This technique is reported as a way of achieving good clinical results with an adequate insertion and especially modeling of resin composite increments, but scientific evidence that supports this use is lacking. The findings of this study showed favorable results when compared with the conventional technique (without the use of modeler liquid), showing similar or superior physical and mechanical properties and color variations.

During the build-up process of resin composites some defects (e.g., air voids, un-packed zones) may remain in the bulk of the material [8], leading to accelerated hydrolytic degradation of the resin matrix [9] or crack initiation/propagation while the material is undergoing a stress event [10]. These foregoing consequences corroborate the significant and fast reduction in all the mechanical properties observed with the control group, which resulted in reduction of almost 64%, 80%, and 40%, respectively, of the μTCS, *σ*, and *E* after water storage (Table 1). Although these foregoing values can be considered somewhat higher than the percentage reductions usually reported by previous studies in the literature, which ranged from 5.9 to 55% [11-13], crack initiation increases during the first few days of water storage, leading to fatigue of the composite [14], explaining the fast degradation observed for the control group. Surprisingly, the groups containing modeler liquid within the composite showed lower mechanical degradation compared with the control, which was approximately 33% (μTCS), 35% (*σ*), and 12% (*E*) of reduction for SBMP, and almost 36% (μTCS), 18% (*σ*), and 21% (*E*) of reduction for SB (Table 1). It can be suggested that the low viscous adhesive resin applied within the composite increments avoided the occurrence of defects/voids during the modeling of the material, making the composite more cohesive and densely-packed and more resistant to degradation [15]. Despite no clear structural and morphological differences could be detected among specimens prepared with or without modeler liquid (Figure 1), specimens prepared with SBMP exhibited considerably higher mechanical stability when compared to the other groups (Table 1). Firstly, it is important to note that the incremental technique used here was carefully performed, playing a crucial role on the preparation of defect-free specimens; in fact, a proper incremental technique is expected to result in a well-packed structure, preventing the occurrence of internal defects and fast degradation of composite restorations. However, it can be speculated that the higher mechanical performance of specimens prepared with SBMP is due to the improvement in the cross-link nature of these specimens, since the moderately hydrophobic composition of SBMP may have enhanced the entanglement and cohesive strength between the composite increments. Taking all these results together, the first hypothesis of the study was only partially accepted.

According to a recent review study about the factors involved in the mechanical fatigue of dental resin composites [10], the organic phase and the matrix/filler interface were considered the two main zones that contribute to the degradation of composites. Indeed, both the resin matrix and the silane coupling agent covering the fillers are susceptible to undergo chemical degradation (hydrolysis), making the polymer network weak [9]. Moreover, depending on the hydrophilicity of the system, the water uptake can become more or less intense [12, 16]. As shown in Table 1, SBMP demonstrated lower water sorption than the other groups, which is easily explained by its hydrophobic chemical composition, which have probably acted as a protective barrier against the water uptake, decreasing the internal areas of the composite (i.e., resin matrix, matrix/filler interface) able to undergo hydrolysis [17]. On the other hand, SB is constituted of a mixture of hydrophilic/hydrophobic monomers and solvents, so its presence within the composite made the material hydrophilic and physically unstable, explaining the similar water sorption results compared to the control. Interestingly, the solubility results were lower for the composites containing the adhesives in comparison with the control group (Table 1), which once again reaffirm the possible absence of voids/defects into the bulk of the former, limiting the entrance of water, and consequently, reducing the occurrence of the hygroscopic and hydrolytic phenomena of degradation [9].

Considering that dental adhesives have been mainly used as modeler liquid of resin composites during the build-up process of anterior aesthetic restorations, it would be interesting to verify if this technique would affect negatively the optical properties of the composite. Thus, translucency and color change (ΔE^*) characteristics were also investigated in the study. According to Figure 2, the specimens became more translucent after 180 days of water storage and irrespective of the presence or absence of adhesive within the material. With regard to the storage in red wine, only SB group became more translucent. The translucency of resin composites is influenced by two main factors: the resin matrix [18] and the content of fillers [19]. While the former is more responsible for the absorption and reflection of light, the latter is responsible for the scattering effect that may occur within the structure of composite restorations [20]. Therefore, the way how light is absorbed, reflected and scattered determines the translucency property. Consequently, any changes occurring on these optical phenomena may alter the translucency of composites.

After one day of water storage, SB group demonstrated a fast increase in translucency, differently from the other groups which maintained it similar (Figure 2a). It is believed that the solvent molecules (e.g., ethanol, water) present in SB were entrapped between the increments of the composite during polymerization. Nevertheless, after one day of storage in water the solvent was somewhat eliminated from the bulk of the composite, leading to free spaces that were then filled with water, that consequently modified the absorption/reflection phenomena of light. Considering these sequence of events, light propagation within the composite was facilitated, thus increasing translucency [21]. Indeed, several studies have already demonstrated that storage in water or staining solutions can alter the translucency of composites mainly due to degradation of resin monomers and fillers lixiviation [7, 22]. In the present study, water storage resulted in increased translucency for all groups evaluated, and surprisingly, wine storage increased translucency only within SB group (Figure 2b). This difference may be due to the hydrophilic composition of SB, which had probably increased the uptake of staining molecules into the composite [7]. Worth mentioning, the absence of solvent/hydrophilic molecules into the control and SBMP groups allowed a higher resistance of the composite to the dyeing phenomena, and consequently, to the absence of significant change in translucency.

Differently from the translucency results, storage in red wine significantly changed the color of all specimens compared to those immersed in water (Figure 3). This is probably due to the staining nature of red wine compared to water [23], increasing the optical density of composite. Furthermore, the wine used in this study has low pH (3.6) and high alcoholic composition (14.5%), which have probably potentially increased the staining/pigmentation of the composite [24]. In addition, considering that specimens were uninterruptedly kept in direct contact with the solution, an intense pigmentation was indeed expected. The color of specimens changed after every consecutive storage period evaluated, although after 90 days of storage the color of specimens became stable. Storage in water had also modified the color of the composite, although less intensively than red wine (Fig. 3). Notwithstanding, a significant color change occurred only around 90 days of storage for the control group and 180 days for the adhesive-containing groups. Here, it can be suggested that hydrolysis occurred slowly within the latter, demonstrating once again that the presence of resin adhesive between layers of composite protected the system against fast degradation. Despite of the differences obtained after storage in red wine or water, it was demonstrated that the type and composition of the resin adhesive used as modeler liquid may influence on the color change of the composite. Indeed, hydrophilic materials may impact more negatively on the color stability of the restorative.

Taking together the findings of translucency and color shade stability, the second hypothesis of the study that the presence of adhesive into the composite structure would alter the translucency and the color shade of the composite after storage when compared to a bulk adhesive-free composite can be partially accepted. Lastly, the third hypothesis that the type of adhesive applied would influence on the long-term translucency and color stability of the composite can be also partially accepted.

Once again, the present study aimed to investigate for the first time the potential impact of the presence of unfilled resin adhesives into resin composite restorations, knowing that resin adhesives were used here because there is no specific material for the modeling of composites. This fact highlights the limitation about using this restorative technique without proper scientific support, although it has been performed by different dental practitioners. Therefore, more studies should be performed using different resin composites and/or modeler liquids, evaluating their effect on the properties and performance of the restorative material. Moreover, further studies should investigate the optimal amount of modeling liquid that can be used without impairing negative effects to the material. Lastly, studies on fatigue stress would be interesting to understand the mechanical behavior of composite restorations containing modeling liquid.

5. Conclusion

Modeler liquids can be used to increase resin composite modeling without jeopardizing important properties of the material, probably due to improved cohesiveness between the composite increments. Furthermore, the use of a hydrophobic unfilled resin was the only one capable of truly enhancing mechanical properties and the material's stability over time.

References

[1] da Costa J, Vargas M, Swift EJ, Jr., Anderson E, Ritter S. Color and contrast ratio of resin composites for whitened teeth. J Dent, 2009; 37 Suppl 1:e27-33.

[2] Chen MH. Update on dental nanocomposites. J Dent Res, 2010; 89:549-560.

[3] de Andrade A, Duarte R, Silva FM, Batista A, Lima K, Monteiro G, et al. Resin Composite Class I Restorations: A 54-month Randomized Clinical Trial. Oper Dent, 2014; 39:588-594.

[4] Ferracane JL. Resin composite--state of the art. Dent Mater, 2011; 27:29-38.

[5] Ivoclar Vivadent. IPS InLine® Instructions for Use. 2012. p. 20-23. Retrieved online on November 29, 2014 from: http://www.ivoclarvivadent.us/en/products/metalceramics/ips-inline-system/ips-inline

[6] Li X, Liu W, Sun L, Aifantis KE, Yu B, Fan Y, et al. Resin composites reinforced by nanoscaled fibers or tubes for dental regeneration. BioMed Res Int 2014; 2014:542958.

[7] Kaizer Mda R, Diesel PG, Mallmann A, Jacques LB. Ageing of silorane-based and methacrylate-based composite resins: effects on translucency. J Dent, 2012; 40 Suppl 1:e64-71.

[8] Kwon SR, Oyoyo U, Li Y. Influence of application techniques on contact formation and voids in anterior resin composite restorations. Oper Dent, 2014; 39:213-220.

[9] Ferracane JL. Hygroscopic and hydrolytic effects in dental polymer networks. Dent Mater, 2006; 22:211-222.

[10] Lohbauer U, Belli R, Ferracane JL. Factors involved in mechanical fatigue degradation of dental resin composites. J Dent Res, 2013; 92:584-591.

[11] Fonseca AS, Gerhardt KM, Pereira GD, Sinhoreti MA, Schneider LF. Do new matrix formulations improve resin composite resistance to degradation processes? Braz Oral Res, 2013; 27:410-416.

[12] Munchow EA, Zanchi CH, Ogliari FA, Silva MG, de Oliveira IR, Piva E. Replacing HEMA with alternative dimethacrylates in dental adhesive systems: evaluation of polymerization kinetics and physicochemical properties. J Adhes Dent, 2014; 16:221-228.

[13] Rodrigues Filho LE, Burger LA, Kenshima S, Bauer JR, Medeiros IS, Muench A. Effect of light-activation methods and water storage on the flexural strength of two composite resins and a compomer. Braz Oral Res, 2006; 20:143-147.

[14] Takeshige F, Kawakami Y, Hayashi M, Ebisu S. Fatigue behavior of resin composites in aqueous environments. Dent Mater, 2007; 23:893-899.

[15] Ye Q, Spencer P, Wang Y, Misra A. Relationship of solvent to the photopolymerization process, properties, and structure in model dentin adhesives. J Biomed Mater Res A, 2007; 80:342-350.

[16] Sideridou ID, Karabela MM, Vouvoudi E. Physical properties of current dental nanohybrid and nanofill light-cured resin composites. Dent Mater, 2011; 27:598-607.

[17] Karabela MM, Sideridou ID. Effect of the structure of silane coupling agent on sorption characteristics of solvents by dental resin-nanocomposites. Dent Mater, 2008; 24:1631-1639.

[18] Azzopardi N, Moharamzadeh K, Wood DJ, Martin N, van Noort R. Effect of resin matrix composition on the translucency of experimental dental composite resins. Dent Mater, 2009; 25:1564-1568.

[19] Lee YK. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. Dent Mater, 2008; 24:1243-1247.

[20] Kim DH, Park SH. Evaluation of resin composite translucency by two different methods. Oper Dent, 2013; 38:E1-15.

[21] Ikeda T, Sidhu SK, Omata Y, Fujita M, Sano H. Colour and translucency of opaque-shades and body-shades of resin composites. Eur J Oral Sci, 2005; 113:170-173.

[22] Ozakar Ilday N, Celik N, Bayindir YZ, Seven N. Effect of water storage on the translucency of silorane-based and dimethacrylate-based composite resins with fibres. J Dent, 2014; 42:746-752.

[23] Tan B, Yap A, Ma H, Chew J, Tan W. Effect of Beverages on Color and Translucency of New Tooth-Colored Restoratives. Oper Dent, 2015; 40:E56-65.

[24] Barutcigil C, Yildiz M. Intrinsic and extrinsic discoloration of dimethacrylate and silorane based composites. J Dent, 2012; 40 Suppl 1:e57-63.

Figures

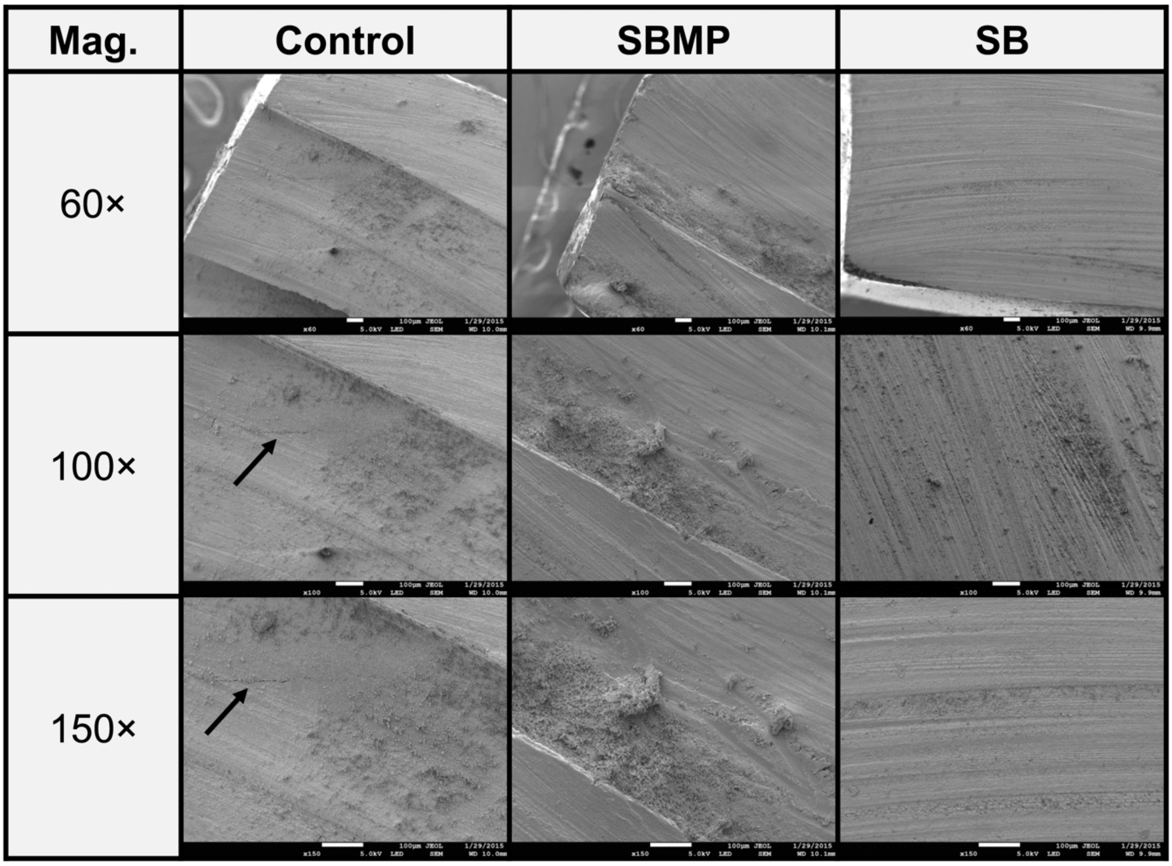
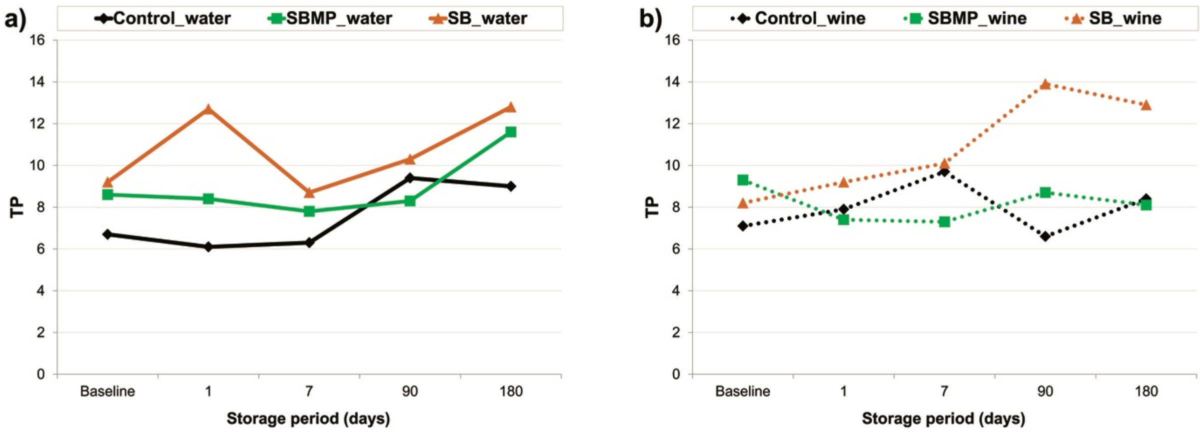


Figure 1. SEM micrographs showing the cross-sectional surface of the fractured specimens (from flexural strength test) for the control, SBMP, and SB groups. Images were reported with magnifications (Mag.) of 60×, 100×, and 150×. Black arrows indicate the presence of a defect.



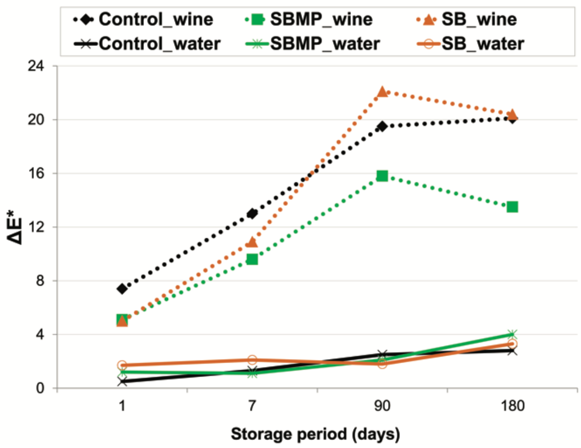
Groups	WATER storage (period, in days)				
	Baseline	1	7	90	180
Control	A 6.7 (±1.5) b	B 6.1 (±0.8) b	A 6.3 (±1.4) b	A 9.4 (±1.0) a	A 9.0 (±1.1) a
SBMP	A 8.6 (±1.6) b	A 8.4 (±1.8) b	A 7.8 (±1.7) b	A 8.3 (±1.8) b	A 11.6 (±1.5) a
SB	A 9.2 (±1.4) b	A 12.7 (±0.5) a	A 8.7 (±1.5) b	A 10.4 (±1.9) ab	A 12.8 (±1.0) a

Distinct uppercase letters before means and lowercase letters after standard deviations (±SD) represent, respectively, statistical significant differences among groups (same column) and storage periods (same row) ($p < 0.05$).

Groups	RED WINE storage (period, in days)				
	Baseline	1	7	90	180
Control	A 7.1 (±1.1) ab	A 7.9 (±1.6) ab	A 9.7 (±1.2) a	B 6.6 (±0.7) b	B 8.4 (±1.9) ab
SBMP	A 9.3 (±1.5) a	A 7.4 (±1.8) a	A 7.3 (±2.0) a	B 8.7 (±1.7) a	B 8.1 (±1.0) a
SB	A 8.2 (±1.8) b	A 9.2 (±3.1) b	A 10.1 (±1.8) ab	A 13.9 (±1.0) a	A 12.9 (±1.3) a

Distinct uppercase letters before means and lowercase letters after standard deviations (±SD) represent, respectively, statistical significant differences among groups (same column) and storage periods (same row) ($p < 0.05$).

Figure 2. Translucency parameter (TP) of groups stored in water (a) and red wine (b) after different periods of time.



Groups	WATER storage (in days)			
	1	7	90	180
Control	B 0.5 (±0.2) b	A 1.3 (±1.0) b	A 2.5 (±1.0) a	B 2.8 (±1.0) a
SBMP	AB 1.2 (±0.4) b	A 1.1 (±0.3) b	A 2.1 (±1.0) b	A 4.0 (±2.0) a
SB	A 1.7 (±0.6) b	A 2.1 (±0.7) b	A 1.8 (±0.7) b	AB 3.3 (±0.6) a

Distinct uppercase letters before means and lowercase letters after standard deviations (±SD) represent, respectively, statistical significant differences among groups (column) and storage periods (row) ($p < 0.05$).

Groups	RED WINE storage (in days)			
	1	7	90	180
Control	A 7.4 (±2.1) c	A 13.0 (±2.8) b	AB 19.5 (±5.0) a	A 20.1 (±5.9) a
SBMP	A 5.1 (±2.0) c	A 9.6 (±3.3) b	B 15.8 (±4.9) a	B 13.5 (±5.6) a
SB	A 5.0 (±1.2) c	A 10.9 (±2.4) b	A 22.1 (±6.7) a	A 20.4 (±4.3) a

Figure 3. Color change (ΔE^*) of groups stored in water and red wine after different periods of time.

Table 1. Means and standard deviations (±SD) of the physical properties evaluated in the study.

Groups	µTCS (MPa)		*σ* (MPa)		*E* (GPa)		WS	SL
	24 h	6 months	24 h	7 days	24 h	7 days	(µg/mm^3)	(µg/mm^3)
Control	A 44.8 a (±10.9)	B 16.4 b (±6.6)	A 109.4 a (±24.1)	B 22.0 b (±7.5)	A 10.6 a (±1.5)	B 6.4 b (±2.1)	A 25.4 (±4.2)	A 4.5 (±0.5)
SBMP	A 50.4 a (±13.2)	A 33.7 b (±8.3)	A 114.6 a (±12.8)	A 74.4 b (±11.0)	A 10.5 a (±1.3)	A 9.2 a (±1.3)	B 16.8 (±2.0)	B 2.9 (±0.6)
SB	A 49.6 a (±8.6)	A 31.7 b (±10.0)	B 73.6 a (±14.0)	A 60.6 a (±7.3)	A 10.5 a (±1.7)	AB 8.3 b (±0.6)	A 21.5 (±5.0)	B 3.0 (±0.9)

Distinct uppercase letters before means and in a same column (factor ‘material’) and distinct lowercase letters after means and in a same row (factor ‘period of storage’) indicate statistically significant differences among groups ($p < 0.05$).

SBMP: Scotchbond™ Multi-Purpose; SB: Adper™ Single Bond 2; µTCS: microtensile cohesive strength; *σ*: flexural strength; *E*: flexural modulus; WS: water sorption; and SL: solubility.

4 Capítulo 3
Translucency and color stability of resin composite and dental adhesives as modeling liquids – one-year evaluation[3]

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Abstract

Objectives. The aim of this study was to evaluate the influence of modeling liquid on translucency and color shade of resin composites (RC) after one year of storage.

Materials and methods. RC specimens were prepared using a conventional insertion technique (control; without modeling liquid) or a Restorative Dental Modeling Insertion Technique (RDMIT) with dental adhesives as modeling liquids (Scotchbond™ Multi-Purpose [SBMP; 3M ESPE] or Adper™ Single Bond 2 [SB; 3M ESPE]). Initial colors of the specimens were obtained with a digital spectrophotometer and the CIE$L^*a^*b^*$ color system. The specimens were stored (37°C) in distilled water or red wine for 12 months, and the color measurements reassessed after 6 and 12 months of storage. Scanning electron microscopy (SEM) analysis was performed after 12 months. Translucency and color changes were calculated and analyzed using ANOVA and Tukey's test (α = 5%).

Results. RC prepared with the RDMIT showed similar translucency compared to the control, whereas color change was less intense for RC containing SBMP. Specimens stored in wine showed a clear pattern of degradation, especially in the control group. Surface degradation seemed to be less intense for specimens prepared with SBMP and SB. Specimens stored in water did not show clear evidence of surface degradation.

Clinical relevance. The RDMIT may be an interesting approach to reduce color change of RC over time without negative effects on translucency of the material. However, the modeling liquid should present a hydrophobic composition, similar to that used in the SBMP group.

Keywords

Aging; Dental Materials; Restorative Dental Modeling Insertion Technique; Scanning Electron Microscopy; Modeler Resins.

Introduction

The Restorative Dental Modeling Insertion Technique (RDMIT) in esthetic restorations is arising growing interest by dental practitioners. This technique consists of using low viscosity, resin-based solutions to facilitate resin composite sculpture and manipulation, especially in the case of large restorations, which usually require combination of composites with different optical characteristics (e.g., translucency, shade, chrome, value) in an attempt to mimic the effect of natural teeth.[1,2] The modeling resins may be applied directly to the composite increments by using a brush or used as lubricants in the insertion instruments; both strategies make the process of sculpting esthetic restorations easier than using the conventional technique, i.e., without modeling liquids. Nevertheless, concerns regarding the effects of RDMIT in the mechanical behavior and physical stability of composite restorations have grown equally, making researchers to focus on the evaluation of resin composites prepared with the RDMIT.

Barcellos et al.[2] investigated the influence of different modeling liquids, such as composite wetting resins or dental adhesives, on the cohesive strength of composites. Indeed, the authors showed that the RDMIT contributed to improve the cohesive bond strength at the composite interfaces as compared to specimens prepared without modeling liquid. In addition, the modeling liquid that resulted in the highest cohesive strength was the solvent free, Scotch Bond Multi-Purpose Adhesive (SBMP; 3M ESPE); other compositions containing solvent in their formulation resulted in significantly lower cohesiveness. In a different study,[3] the use of SBMP, which is a hydrophobic unfilled resin, as modeling liquid also enhanced mechanical properties and stability of composites; the same trend was not observed for specimens prepared using a more hydrophilic composition. Thus, RDMIT may truly contribute to improve composites' characteristics, but on the other hand it may depend on the type of modeling liquid used.

It is also of utmost importance that the RDMIT do not alter the optical appearance of composite restorations over time. In a study by Tuncer et al.,[4] color stability of resin composites covered with a superficial layer of modeling resin was negatively affected. However, when present between layers of resin composite, modeling liquids were capable to reduce or delay staining of the material.[3,5] It is already expected that the optical properties of resin composites would not remain stable over time, especially due to degradation phenomena that composites may undergo after placement into the oral environment.[6,7,8] Among these properties, color shade and translucency are the main characteristics susceptible to modification, and special attention must be given for restorations prepared using modeling liquids, since they may influence on color and translucency after aging.

Despite any effect the RDMIT technique may produce on color/translucency of resin composite restorations, the analysis of color and its perception is another fundamental point for the clinical success of the restorative procedure. According to some studies,[9,10] the professional may suffer bias during color evaluations, since his/her perception of color may alter over time, due to both external variables (e.g., light throughout the day) or individual variables (e.g., color sense in different moments of life). In light of this, color evaluation using mechanical instruments may allow the analysis of color with reduced risk of bias or human fatigue, contributing for a standardized method of evaluating color parameters, thus increasing the chances of success for the restorative treatment.

Hence, the purpose of this study was to investigate the influence of modeling liquid on translucency and color shade of resin composites after one year of storage.

The null hypothesis tested was that composites prepared following the RDMIT would present similar translucency and color alteration as compared to composites prepared using the conventional insertion technique after aging.

Materials and methods

This in vitro 3 × 2 × 2 factorial study (n=5) evaluated three distinct factors: presence of modeling liquid, storage solution, and storage period. In total, thirty resin composite specimens (Filtek™ Z350 XT, 3M ESPE, St. Paul, MN, USA) with or without modeling liquid (resin adhesive, i.e., SBMP [the bond component of Adper™ Scotchbond™ Multi-Purpose Adhesive, 3M ESPE] or SB [Adper™ Single Bond 2 Adhesive, 3M ESPE]) were prepared in order to investigate their translucency and color stability over time.

Specimen preparation and groups allocation

Each specimen was prepared by placing four increments of resin composite into a silicone mold (6 mm diameter × 2 mm thickness), as described elsewhere.[3] For specimens prepared without modeling liquid (control), four composite increments (approximately 0.5 mm-thick) were packed into the mold and covered with a mylar strip; light-activation was then performed for 20 s on both top and bottom surfaces using a light-emitting diode (LED, Radii®, Bayswater, VIC, Australia – 900 mW/cm^2 of irradiance) curing unit; any excess material was gently removed using a scalpel. For specimens prepared with modeling liquid, after the placement of the first composite increment, SBMP or SB was applied on the composite surface with a disposable brush (Microbrush® International, Grafton, WI, USA); a new increment was then placed, modeled, and coated with another pellicle of the modeling liquid, until the fourth increment was placed and modeled too. Next, mylar strips were placed over the surface of specimens and light-activation was performed as aforementioned with the LED. Any excess was also gently removed using a scalpel. After light-activation, all specimens were polished with medium, fine, and extra-fine aluminum oxide abrasive disks (Sof-Lex Pop On Orange series, 3M ESPE) for 15 s per each disk, and also with felt disk containing extra-fine (2-4 µm) diamond paste (Diamond AC II, FGM, Joinville, SC, Brazil).[3]

After polishing, the specimens were randomly allocated into two groups (n=5) according to the storage media: distilled water (pH 5.9) or red wine (Cabernet Sauvignon 2007, Concha y Toro, Las Condes, Chile – pH 3.6 and 14.5% in volume of alcohol). The media were renewed weekly and specimens were kept immersed at 37°C for twelve months.

Translucency and color stability tests

Translucency and color tests were performed following the ISO/TR 28642:2016. From the first measurement until the last measuring procedure, specimens were tested under the same environmental condition, i.e., similar light and humidity circumstances.

Translucency of specimens was measured using the translucency parameter (TP) method,[11] in which the color parameters of each specimen were recorded according to the CIE $L^*a^*b^*$ system (L^*: white/black; a^*: red/green; b^*: yellow/blue)[12] against white (L^*_W = 94.44, a^*_W = 0.26, b^*_W = 1.69) and black (L^*_B = 1.38, a^*_B = 0.00, b^*_B = 0.06) Munsell-like neutral value scale sheet background (AG-5330, BYK Gardner, USA). The measurements were obtained using a digital spectrophotometer (Vita Easyshade, Vita Zahnfabrik, Bad Sackingen, Germany). The TP of all specimens was evaluated at different periods of time: immediately after polishing (baseline) and after six and twelve months of storage in each medium. The TP was then calculated using the following formula:[12]

$$TP = \sqrt{(L^*_W - L^*_B)^2 + (a^*_W - a^*_B)^2 + (b^*_W - b^*_B)^2}$$

where L^*_W, a^*_W, and b^*_W were measured over white background, and L^*_B, a^*_B, and b^*_B were measured over black background.

The color stability of specimens was evaluated using the color parameters measured over the white background in the translucency test, which were used to calculate color change (ΔE^*) according to the following formula:[12]

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where ΔL^*, Δa^*, and Δb^* were the difference between the final and initial L^*, a^*, and b^* color parameters, respectively. Color change was measured after six and twelve months of storage in the respective medium.

Scanning electron microscopy (SEM) analysis

After twelve months of storage, specimens from each group were randomly selected for surface evaluation under SEM analysis. Specimens were dried into a desiccator at 37°C, sputter-coated with gold/palladium, and then evaluated under a scanning electron microscope (SSX-550, Shimadzu, Tokyo, Japan). The obtained images were qualitatively analyzed.

Statistical analysis

All data were analyzed with the statistical program SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA). Two-way repeated measures analysis of variance and the Tukey test (α=5%) were used to analyze the effect of factors "presence of modeling liquid" and "storage period" on the TP and ΔE^* of groups investigated. Specimens stored in water were not statistically compared to their counterparts stored in wine.

Results

Regarding translucency parameter (TP) results, which are shown in Table 1 and Figure 1, while the presence of modeling liquid was a significant factor only for specimens stored in distilled water (p=0.012), the storage period was a significant factor regardless of the storage solution tested (p=0.007). Factors did not statistically interact between each other (p=0.573). For specimens stored in distilled water, SBMP and SB showed higher TP than the control at baseline (p=0.036), but similar values after six and twelve months of storage (p=0.065). TP increased for the control and SB groups after six months (p=0.049), but no further increase was observed after twelve months of water storage (p=0.959). SBMP presented stable TP over time. For specimens stored in red wine, groups did not differ from each other (p=0.060), except for SB at twelve months of storage, which showed higher TP value when compared to baseline (p=0.037).

Concerning color change (ΔE^*) results, which are shown in Table 2 and Figure 1, the presence of modeling liquid was a significant factor only for specimens stored in red wine (p=0.002), whereas the period of storage was a significant factor for specimens stored in distilled water (p=0.008). Statistically significant interactions were not observed between the factors tested, regardless of storage solution (p=0.085). For specimens stored in distilled water, color change was greater after twelve months for the control (p=0.004); by contrast, specimens containing modeling liquid showed color stability over time (p=0.079). For specimens stored in red wine, while SBMP presented lower ΔE^* than the control, at both six and twelve months of storage (p=0.007), SB showed similar color change as compared to the control (p=0.071). Comparing SBMP and SB groups between each other, SB resulted in greater ΔE^* than SBMP at six months (p=0.004), but similar results at twelve months (p=0.161).

Figure 2 shows the SEM images of specimens prepared with or without modeling liquid and stored in distilled water or red wine after twelve months. Specimens stored in wine presented a clear pattern of degradation, especially for the control group. Surface degradation seemed to be less intense for specimens prepared with SBMP and SB, although the presence of the latter was associated to a more generalized rougher topography. Specimens stored in water did not show clear evidence of surface degradation.

Discussion

Color is one of the major characteristics desired for resin composite restorations, especially when involving anterior teeth. However, composites commonly suffer from degradation due to their polymeric nature, thus compromising color appearance over time. According to recent studies,[3,5] the use of modeling liquids (e.g., unfilled adhesive resins) between layers of resin composite may be a useful strategy to reduce or delay composite staining, thus the purpose of the present study was to investigate whether translucency and color shade of resin composites prepared with modeling liquids would change after one year of storage. In the overall analysis, translucency and color changes depended on the type of modeling liquid used.

Translucency and color shade are two optical properties that vary according to the composition of materials. In the present circumstance, one could expect that the refractive index mismatch between modeling liquid (unfilled resin) and composite (highly filled resin) would affect the way light is transmitted within materials containing the former,[13,14,15] thereby changing translucency and opacity characteristics of composites. This was indeed observed at baseline, in which specimens containing SBMP or SB showed higher TP than control, ranging from 29 to 60% of increase (Figure 1a,b). This may be explained because light scattering was probably reduced for specimens prepared with modeling liquid, since unfilled resins would facilitate light transmission within the material,[14] thus increasing translucency. However, TP was stable over time for SBMP, regardless of the storage medium; on the other hand, TP increased for SB after 6 months of water storage and 12 months of wine storage compared to baseline. This dual finding shows that the type of modeling liquid played an important role on translucency, probably due to compositional characteristics. While SBMP exhibits a moderately hydrophobic composition, SB is comprised of high content of solvents, making the latter hydrophilic. In the study of Münchow et al.,[3] specimens containing SB showed increased translucency after one day of water storage, and the authors proposed a series of events to explain this result: first, solvent molecules of SB were entrapped between the increments of the composite during polymerization; after some period of water immersion, the solvent was eliminated from the bulk of the material, leading to free spaces that were then filled with water; light propagation was then facilitated, increasing translucency.

Similarly to specimens prepared with SB, control specimens demonstrated increased TP after 6 months of water storage, which may be explained by hydrolysis that is prone to occur within polymer-based materials.[8] Indeed, water is a potent solvent capable of degrading intermolecular bonds of resin composites.[16] Notwithstanding, the presence of SBMP within the composite kept TP stable over time, even after one year of water or wine storage, probably due to a protective effect against hydrolysis. This finding is corroborated by recent studies.[3,5] It can be suggested that specimens prepared with SBMP were stronger and more cohesively packed, influencing positively chemo-physical stability of composite.[2,3] What is also important to consider is the absence of translucency changes for specimens stored in wine; with the only exception occurring for SB group after 12 months of storage. It is critical to note that wine is a potent staining medium that has low pH and moderately high alcoholic content compared to distilled water; these characteristics would allow a more aggressive change in optical properties. However, wine stains may equally impregnate on the surface of specimens, regardless of the presence or absence of modeling liquids;[2] thereby, explaining the similar TP values among groups. Despite these results, only specimens containing SB showed different translucency after 12 months of storage, once again confirming that the presence of hydrophilic molecules within the composite may compromise translucency stability over time.

Hydrolytic degradation of composite restorations may not affect only translucency; more importantly, color shade of the material may be negatively altered. In the present study, color change was monitored after one year of water/wine storage. Specimens stored in water showed ΔE^* values lower than 3.3 after 6 months (Table 2), which may be considered clinically acceptable, since 3.3 is a threshold for visual perception of color change;[17] upon that limit, color change would be easily detected by laypersons. Here, we used the CIE $L^*a^*b^*$ system to evaluate color change, although some recent studies have demonstrated that another measurement system, i.e., CIEDE2000, may provide a better fit than the former in the evaluation of color difference thresholds.[10,18,19,20] Even so, many studies have used the CIE L*a*b* color system to analyze color outcomes in dentistry,[3,5,21,22,23] thereby possessing predictability and clinical importance.

Color change was not increased after 12 months of storage for specimens prepared with modeling liquids. However, control specimens exhibited higher ΔE^* after 12 months. Again, hydrolysis is a common phenomenon that degrades composites, thus affecting optical properties; but the presence of modeling liquid may have prevented fast degradation of the material. Despite the absence of statistical color change for SB group after 12 months of water storage, ΔE^* was higher than 3.3, thus indicating that color perception would be clinically different than baseline. This finding is important to be considered, showing that less hydrophilic compositions, such as SBMP, should be considered first as modeling liquids for resin composite restorations.

Color change was intense for specimens stored in red wine (Figure 1c), although no significant changes were seen after 6 months of storage. Indeed, wine is a potent staining solution, with high pigmentation potential;[24] its low pH and alcoholic content make it possible to degrade composites by matrix decomposition and filler leakage.[25] According to the present findings, specimens stored in wine demonstrated more surface degradation than specimens stored in water (Figure 2), thus corroborating the color change results. Moreover, SBMP showed 53% and 58% less discoloration than the control after 6 and 12 months of storage, respectively; whereas, SB exhibited similar discoloration than the control (almost 2% more and

26% less discoloration at 6 and 12 months, respectively). The hydrophobic composition of SBMP has probably protected the polymer-based matrix of the composite from fast staining, differently from the hydrophilic composition of SB. In a study by Münchow et al.,[3] specimens prepared with SB as modeling liquid resulted in higher water sorption than specimens prepared with SBMP, thereby contributing for enhanced hydrolytic degradation within the bulk of composite and more pigmentation from dies of the staining medium.

Gathering all the presented findings together, the null hypothesis tested here was accepted for translucency, but rejected for color stability. While composites prepared following the proposed RDMIT showed similar translucency as compared to the control after aging, color change was less intense for composites containing SBMP. Lastly, but not less important, it is noteworthy to consider that although color measurement using a digital spectrophotometer may not comprise a real condition for evaluation, it is a useful approach for quantifying color coordinates from distinct groups, thus allowing proper control and monitoring of specimens submitted to aging processes.

Conclusions

The Restorative Dental Modeling Insertion Technique used in this study may be an interesting approach to reduce color change of resin composites over time, at least for composites of similar composition to that investigated here (Filtek™ Z350 XT). Also, the proposed technique did not cause any negative effects on translucency of the material. However, the modeling liquid should present a hydrophobic composition, similar to that used in the SBMP group.

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

Not applicable.

References

1. Caughman WF, Comer RW, Zardiackas LD. Effects of diluents on physical properties of a light-cured composite Prisma-Fill. Oper Dent. 1984;9(3):82-5.
2. Barcellos DC, Pucci CR, Torres CR, Goto EH, Inocencio AC. Effects of resinous monomers used in restorative dental modeling on the cohesive strength of composite resin. J Adhes Dent. 2008;10(5):351-4.
3. Munchow EA, Sedrez-Porto JA, Piva E, Pereira-Cenci T, Cenci MS. Use of dental adhesives as modeler liquid of resin composites. Dent Mater. 2016;32(4):570-7. doi: 10.1016/j.dental.2016.01.002
4. Tuncer S, Demirci M, Tiryaki M, Unlu N, Uysal O. The effect of a modeling resin and thermocycling on the surface hardness, roughness, and color of different resin composites. J Esthet Restor Dent. 2013;25(6):404-19. doi: 10.1111/jerd.12063
5. Sedrez-Porto JA, Münchow EA, Brondani LP, Cenci MS, Pereira-Cenci T. Effects of modeling liquid/resin and polishing on the color change of resin composite. Braz Oral Res. 2016;30(1):e88. doi: 10.1590/1807-3107BOR-2016
6. Prodan DA, Gasparik C, Mada DC, Miclaus V, Baciut M, Dudea D. Influence of opacity on the color stability of a nanocomposite. Clin Oral Investig. 2015;19(4):867-75. doi: 10.1007/s00784-014-1315-1
7. Llena C, Fernandez S, Forner L. Color stability of nanohybrid resin-based composites, ormocers and compomers. Clin Oral Investig. 2016;May 16. [Epub ahead of print].
8. Ferracane JL. Resin composite--state of the art. Dent Mater. 2011;27(1):29-38. doi: 10.1016/j.dental.2010.10.020
9. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent. 2010;38(Suppl 2):e2-16. doi: 10.1016/j.jdent.2010.07.001

10. Pecho OE, Ghinea R, Alessandretti R, Perez MM, Della Bona A. Visual and instrumental shade matching using CIELAB and CIEDE2000 color difference formulas. Dent Mater. 2016;32(1):82-92. doi: 10.1016/j.dental.2015.10.015
11. Johnston WM, Ma T, Kienle BH. Translucency parameter of colorants for maxillofacial prostheses. Int J Prosthodont. 1995;8(1):79-86.
12. CIE Technical report: colorimetry. CIE Pub No. 15.3. Vienna, Austria: CIE Central Bureau; 2004.
13. Miletic V, Jakovljevic N, Manojlovic D, Marjanovic J, Rosic AA, Dramicanin MD. Refractive indices of unfilled resin mixtures and cured composites related to color and translucency of conventional and low-shrinkage composites. J Biomed Mater Res B Appl Biomater. 2015;105(1):7-13. doi: 10.1002/jbm.b.33523
14. Drelich J. Nanoparticles in a liquid: new state of liquid? J Nanomater Mol Nanotechnol. 2013;2(1):1-2. doi: 10.4172/2324-8777.1000e105
15. Patel MP, Davy KW, Braden M. Refractive index and molar refraction of methacrylate monomers and polymers. Biomaterials. 1992;13(9):643-5.
16. Ferracane JL. Hygroscopic and hydrolytic effects in dental polymer networks. Dent Mater. 2006;22(3):211-22.
17. Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater. 1987;3(5):246-51.
18. Ghinea R, Perez MM, Herrera LJ, Rivas MJ, Yebra A, Paravina RD. Color difference thresholds in dental ceramics. J Dent. 2010;38(Suppl 2):e57-64. doi: 10.1016/j.jdent.2010.07.008
19. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, et al. Color difference thresholds in dentistry. J Esthet Restor Dent. 2015;27(Suppl 1):S1-9. doi: 10.1111/jerd.12149
20. Pecho OE, Ghinea R, Perez MM, Della Bona A. Influence of gender on visual shade matching in dentistry. J Esthet Restor Dent. 2017 Feb 10. doi: 10.1111/jerd.12292
21. Fontes ST, Fernandez MR, de Moura CM, Meireles SS. Color stability of a nanofill composite: effect of different immersion media. J Appl Oral Sci. 2009;17(5):388-91.
22. Meireles SS, Santos IS, Bona AD, Demarco FF. A double-blind randomized clinical trial of two carbamide peroxide tooth bleaching agents: 2-year follow-up. J Dent. 2010;38(12):956-63. doi: 10.1016/j.jdent.2010.08.003.
23. Hernandes DK, Arrais CA, Lima E, Cesar PF, Rodrigues JA. Influence of resin cement shade on the color and translucency of ceramic veneers. J Appl Oral Sci. 2016;24(4):391-6. doi: 10.1590/1678-775720150550
24. Barutcigil C, Yildiz M. Intrinsic and extrinsic discoloration of dimethacrylate and silorane based composites. J Dent. 2012;40(Suppl 1):e57-63. doi: 10.1016/j.jdent.2011.12.017
25. Ortengren U, Andersson F, Elgh U, Terselius B, Karlsson S. Influence of pH and storage time on the sorption and solubility behaviour of three composite resin materials. J Dent. 2001;29(1):35-41.

Figure legends

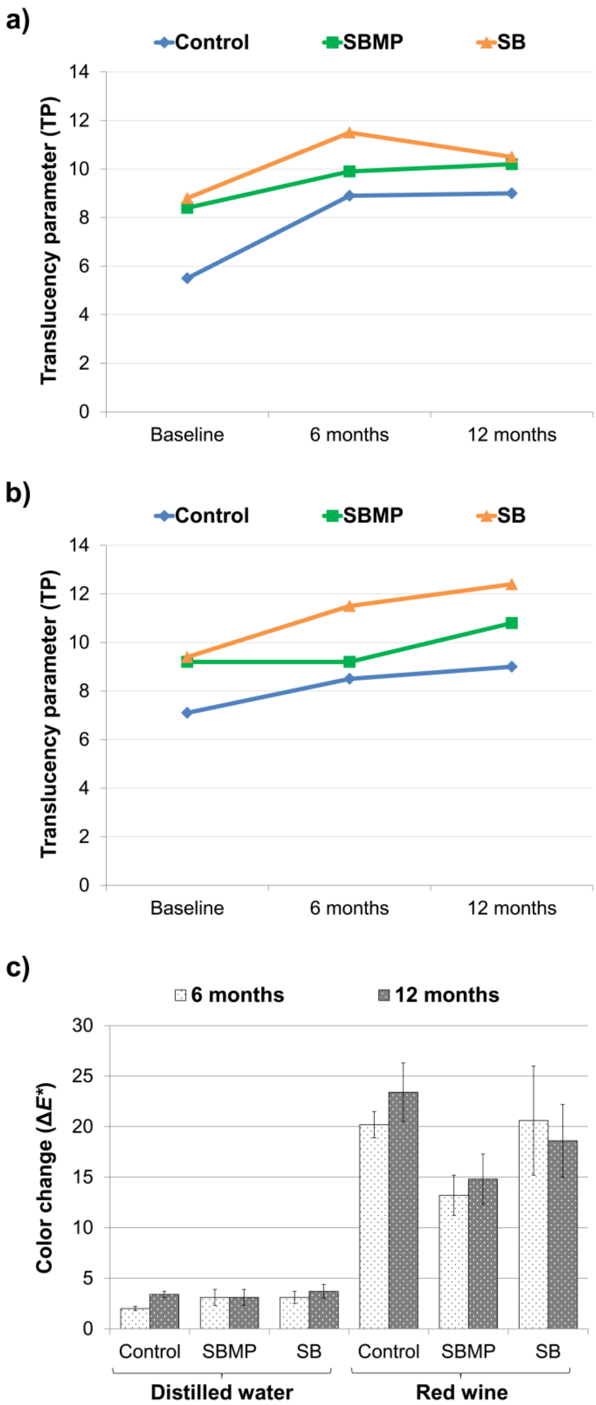

Figure 1. Translucency parameter (TP) of groups at different time points after immersion in distilled water (a) or red wine (b). Color change (ΔE^{*}) of groups at 6 and 12 months of distilled water or red wine storage (c).

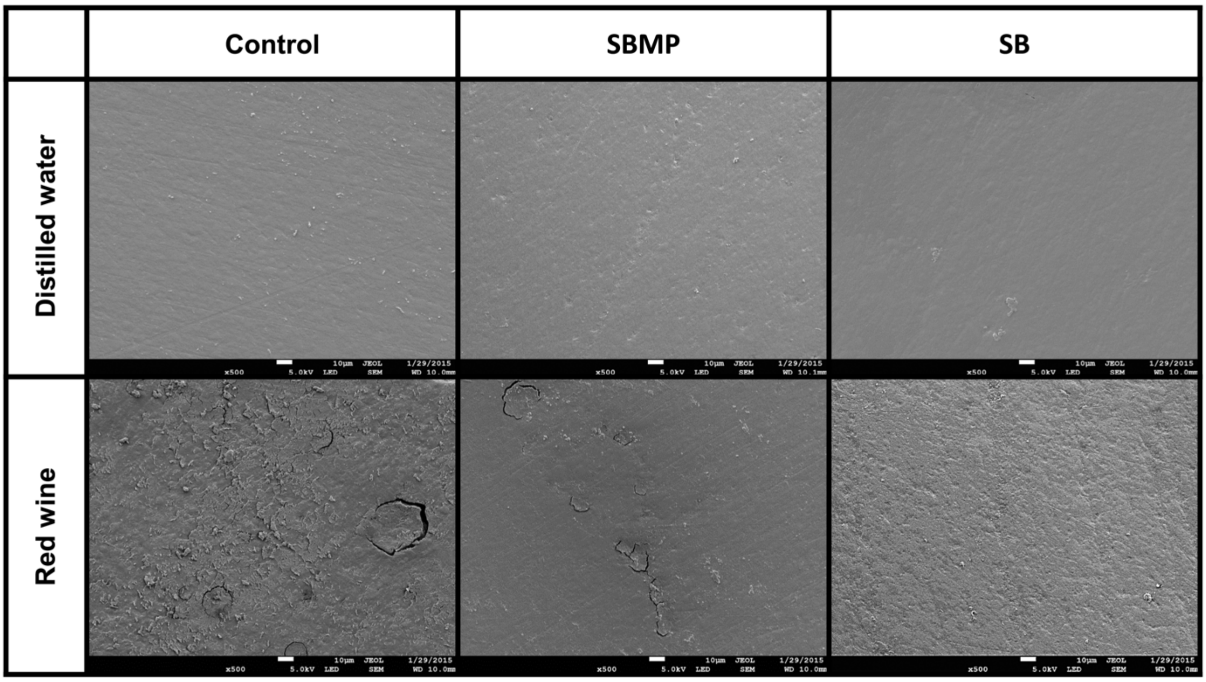

Figure 2. SEM micrographs showing the surface topography of specimens prepared with (SBMP and SB) or without (control) modeling liquid after 12 months of distilled water or red wine storage.

Table 1. Means and standard deviation (± SD) for the translucency parameter (TP) of groups after different periods of water or wine storage.

Groups	Storage condition					
	Distilled water			Red wine		
	Baseline	6 months	12 months	Baseline	6 months	12 months
Control	5.5 ± 1.4 ^{B,b}	8.9 ± 2.8 ^{A,a}	9.0 ± 0.7 ^{A,a}	7.1 ± 1.3 ^{A,a}	8.5 ± 1.3 ^{A,a}	9.0 ± 1.3 ^{A,a}
SBMP	8.4 ± 2.1 ^{A,a}	9.9 ± 1.9 ^{A,a}	10.2 ± 1.2 ^{A,a}	9.2 ± 1.7 ^{A,a}	9.2 ± 1.6 ^{A,a}	10.8 ± 2.8 ^{A,a}
SB	8.8 ± 1.7 ^{A,b}	11.5 ± 2.4 ^{A,a}	10.5 ± 0.5 ^{A,ab}	9.4 ± 0.5 ^{A,b}	11.5 ± 2.9 ^{A,ab}	12.4 ± 3.6 ^{A,a}

Distinct superscript uppercase and lowercase letters indicate, respectively, statistical significant differences among groups (columns) and between time points tested (rows) ($p < 0.05$).

Table 2. Color change (ΔE^*) means and standard deviation (± SD) of groups after 6 and 12 months of water or wine storage.

Groups	Storage condition			
	Distilled water		Red wine	
	6 months	12 months	6 months	12 months
Control	2.0 ± 0.2 ^{A,b}	3.4 ± 0.3 ^{A,a}	20.2 ± 1.3 ^{A,a}	23.4 ± 2.9 ^{A,a}
SBMP	3.1 ± 0.8 ^{A,a}	3.1 ± 0.8 ^{A,a}	13.2 ± 2.0 ^{B,a}	14.8 ± 2.5 ^{B,a}
SB	3.1 ± 0.6 ^{A,a}	3.7 ± 0.7 ^{A,a}	20.6 ± 5.4 ^{A,a}	18.6 ± 3.6 ^{AB,a}

Distinct superscript uppercase and lowercase letters indicate, respectively, statistical significant differences among groups (columns) and between time points tested (rows) ($p<0.05$).

5 Capítulo 4

Endocrown restorations: role of restorative material and direct/indirect technique[4].

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Abstract

The purpose of this study was to evaluate the mechanical performance and fracture behavior after mechanical aging (fatigue) of endocrowns using distinct restorative materials. Eighty-four sound molars with similar crown size/shape were selected, cut at 2 mm above the cementoenamel junction, and endodontically treated until proper sealing of the root canals. The teeth were allocated (n=7) according to a direct or indirect technique of endocrown bonding as well as according to the restorative material(s) used, namely: conventional composite (Filtek™ Z350 XT); bulk fill composite (Filtek™ Bulk Fill); conventional composite modeled using resin adhesives (SBMP: Scotchbond™ Multipurpose Adhesive; or SBU: Scotchbond™ Universal Adhesive); glass-fiber post combined with conventional or bulk fill composite. Glass-ceramic endocrowns were prepared as control group of indirect technique. Sound teeth were used as control of the study. Direct endocrowns were bonded directly to the tooth following an etch-and-rise adhesive approach, whereas indirect endocrowns were indirectly bonded using self-adhesive resin cement. All teeth (sound or restored) were submitted to fatigue (Byocycle) and fracture (EMIC DL500) testing. Fracture strength (in N) and work of fracture (W_f; in J/m^2) data were analyzed with ANOVA and post hoc Tukey test ($p<0.05$). Bulk fill-based endocrowns showed better results followed by direct endocrowns, showing similar mechanical performance to the indirect ones. Within the direct groups, all endocrowns demonstrated similar properties, except for the bulk fill-based endocrown, which was stronger than the sound teeth and endocrowns prepared with conventional composite only. Direct groups and glass-ceramic endocrowns displayed more aggressive failures (root fracture) compared to other indirect groups, which produced a greater rate of repairable fractures. Dental practitioners may restore severely damaged non-

vital teeth with an endocrown technique, whereas when stronger restorations are need, a direct or direct technique may be selected, with the latter more resistant to root fractures.

Keywords

Composite; Ceramic; Glass-fiber post; Endocrowns; Fatigue; Modeler Liquid.

Introduction

Tooth rehabilitation may depend on several factors, including but not limited to the professional' understanding of the potentials and limitations of the restorative technique, the amount of remaining tooth structure, the presence or absence of endodontic treatment, as well as the patient' expectations (Roscoe et al., 2013). Minimally invasive procedures have been pursued, since they may protect frightened teeth and, perhaps increase the longevity of the treatment. Considering that a high amount of remaining tooth structure is present, i.e., at least 50% of the crown, direct restorative materials are usually the first treatment option. On the other hand, in the cases of severely compromised teeth, the use of indirect restoratives (e.g., resin composites, ceramics) combined or not with the use of intraradicular posts seems to be more advisable (Hamburger et al., 2014; Ragauska et al., 2008).

The major concern with severely damaged teeth is to restore, as close as possible the natural biomechanical characteristics of the dental substrates. Notwithstanding, this may never occur completely, especially due to the rigidity of current dental restoratives, which is usually different from dentin (Chun and Lee, 2014). While some restoratives are more rigid than dentin, as in the case of dental ceramics and metal-based materials, others, despite showing similar rigidity and toughness properties (e.g., resin composites and glass-fiber posts), may result in a weaker behavior, thus contributing for early wear and/or failure of the restoration. For many years, rehabilitation of non-vital teeth have been performed by combining metal-based posts with core materials, followed by placement of ceramic crowns (Guncu et al., 2015). Indeed, the foregoing restorative technique was demonstrated to be effective (Brondani et al., 2017; Skupien et al., 2016), although fracture extending to the root was revealed to be a frequent consequence when failure occurs, probably due to the high rigidity of the restorative system (Alharbi et al., 2014). Unfortunately, the complexity of the treatment may increase under that failure condition, resulting in tooth loss (Soares et al., 2012). In light of this, less rigid materials such as resin composites have been currently employed to restore severely damaged non-vital teeth, showing and adequate survival rate as well as a considerably lower rate of root fractures when compared to conventional treatment using metal posts and ceramics (Goracci and Ferrari, 2011; Skupien et al., 2016). Also, the use of these less rigid materials allows the professional to perform a direct restorative technique.

Currently, rehabilitation of severely destroyed non-vital teeth is the use of glass-fiber post retained resin composite direct technique (Goracci and Ferrari, 2011; Sorrentino et al., 2016). An alternative treatment modality that does not involve the placement of glass-fiber posts into the root canal is endocrown restoration (Belleflamme et al., 2017), i.e., one single system that is placed into non-vital teeth and that is anchored to the internal portion of the pulp chamber and at the cavity margins, thereby resulting in both macro-mechanical (due to the circumferential walls of the pulp chamber) and micro-mechanical (due to the use of adhesive materials) retention (Bindl and Mormann, 1999; Lander and Dietschi, 2008). Endocrown restorations were firstly prepared using glass-ceramics, but due to the high rigidity of that system, fractures extending to the root were also frequently observed (Yeh, 1997; Zarone et al., 2006). According to a recent systematic review and meta-analysis regarding endocrown restorations (Sedrez-Porto et al., 2016b), endocrowns may perform similarly or better than the conventional treatments using intraradicular posts, direct resin composite or inlay/onlay restorations. In addition, (Rocca and Krejci, 2013) endocrowns may result in occlusal forces more homogeneously when compared to the use of intraradicular posts. Also, resin composite endocrowns present a more compliant behavior, i.e., with more similar biomechanical characteristics to dentin (Belleflamme et al., 2017; Ramirez-Sebastia et al., 2014). Nevertheless, placing resin composites by using a direct technique may produce cohesive failures within the body of the restoration (Munchow et al., 2016) as well as develop a significant amount of polymerization stress (Mantri and Mantri, 2013), which would contribute for jeopardizing the clinical performance of the endocrown survival.

Although two recent strategies may be useful to control the foregoing limitations of composite endocrowns, the use of resin adhesives as modeler liquid of composite restorations and the use of new generation, bulk fill resin composites instead of conventional composites, those were never tested altogether. According to some studies, the cohesive strength of a nanofilled resin composite (Filtek™ Z350 XT; 3M ESPE) was significantly improved if the composite was modeled using resin adhesives as modeler liquid of composite restorations (Munchow et al., 2016); also, color and translucency properties were more stable over time when the composite was modeled with resin adhesives (Sedrez-Porto et al., 2016a). Polymerization stress would be also less intense within the bulk of composites containing modeler liquid, since the presence of this more compliant material (unfilled resin) would serve as stress relieving sites within the body of the restoration (Braga et al., 2003). Still, there is a positive effect in reducing the development of polymerization stress, probably due to a more compliant system that would be important for relieving stress (El-Damanhoury and Platt, 2014). As bulk fill are usually less viscous than conventional composites, this would improve cohesiveness within the restoration

(Kim et al., 2015). From the best of our knowledge, the two foregoing strategies have never been investigated as potential restorative materials for endocrown restoration.

A meta-analysis showed that endocrowns had fracture strength similar to resin composite restorations while in vitro studies demonstrated that the presence of modeler liquid (resin adhesive) in-between the layers of resin composite improved the physic-mechanical performance of the material. Hence, the purpose of the present study was to prepare endocrown restorations using distinct restorative materials, and second to evaluate the mechanical performance and fracture behavior of the restorations after mechanical aging (fatigue). Two hypotheses were proposed: (i) the type of endocrown restorative material would influence its mechanical performance; and (ii) the use of a direct restorative technique would result in similar performance compared to to an indirect technique.

Materials and methods

The study design is shown in Figure 1, which displays all groups that were investigated with their respective characteristics and the brief protocol used to prepare the samples.

Ninety-one sound lower first molars with similar crown size and shape were obtained from the Tooth bank/UNOESC (Faculdade do Oeste de Santa Catarina – Joaçaba/SC), and approved by the Local Ethics Committee, #1.634.774/2016). The teeth were stored in 0.5% aqueous chloramine solution at 4°C until their use (maximum of three months). Seven teeth were kept unmodified to serve as control (sound tooth group). All the other eighty-four teeth (experimental ones) were impressed at the coronal portion with a polyvinylsiloxane (Futura AD; Nova DFL, Jacarepaguá, RJ, Brazil) in order to facilitate the following build-up process of the restoration to its original shape and size (Figure 1b).

Tooth preparation, endodontic treatment, and group allocation

The crown of each experimental tooth was sectioned 2.0 mm above the cementoenamel junction (CEJ). The pulp chamber was then opened following a standardized procedure, and root canals were instrumented using stainless steel K-files nos. 15, 20, 25 and 30 (Dentsply Maillefer, Ballaigues, Switzerland), followed by rotary Ni-Ti instruments (Protaper Universal 21mm SX-F3; Dentsply Maillefer) according to the manufacturer's instructions. Root canals were irrigated between each of the instrumentation with 1 ml of 2.5% sodium hypochlorite. The roots were filled using vertical condensation technique and combining calibrated gutta-percha f2 and f3 (Protaper; Dentsply Maillefer) with an endodontic sealer (AH Plus, Dentsply Maillefer). The teeth were stored under dark condition, and after a setting period of 48 h, they were randomly allocated into two major groups, according to the restorative technique used: direct or indirect (Figure 1a).

Within the direct group, teeth were allocated (n=7) according to the restorative(s) material(s) used:

- Z350: conventional resin composite (Filtek™ Z350 XT; 3M ESPE);
- Z350+SBMP: conventional resin composite combined with the bond component of Adper™ Scotchbond™ Multi-Purpose Adhesive (SBMP; 3M ESPE), which was used as modeler liquid of resin composite (Munchow et al., 2016);
- Z350+SBU: conventional resin composite combined with Scotchbond™ Universal Adhesive (SBU; 3M ESPE), which was used as modeler liquid of resin composite;

- Bulk Fill: resin composite (Filtek™ Bulk Fill; 3M ESPE);
- GFP+Z350: glass-fiber post (White Post DC no. 2; FGM, Joinville, SC, Brazil) combined with conventional resin composite;
- GFP+Z350+SBMP: glass-fiber post combined with conventional resin composite and SBMP;
- GFP+Bulk Fill: glass-fiber post combined with resin composite.

Within the indirect group, teeth were also allocated (n=7) according to the restorative(s) material(s) used:

- Z350: conventional resin composite;
- Z350+SBMP: conventional resin composite combined with SBMP;
- Z350+SBU: conventional resin composite combined with SBU;
- Bulk Fill: resin composite;
- E.max: IPS e.max lithium disilicate (Ivoclar Vivadent, Liechtenstein, Germany).

The materials used to fabricate the endocrowns are presented in Table 1 with their respective manufacturer, batch number and composition information.

Periodontal ligament simulation

Teeth were simulated by embedding each root into plastic cylinders with self-cured acrylic resin (Jet Clássico, São Paulo, SP, Brazil) and by using a polyether impression material (Impregum Soft, 3M ESPE)(Soares et al., 2005). In brief, root surfaces were dipped into melted wax (Lysanda®, São Paulo, SP, Brazil) up to 2.0 mm below the CEJ, resulting in a 0.2 to 0.3 mm-thick wax layer (Figure 1c). The roots were then positioned downward over a perforated wax plate of approximately 4.0 mm-thick, so that the alveolus simulation was prepared at 2.0 mm below the CEJ (Figure 1d). One plastic cylinder with 25.0 mm in diameter was positioned around each root and fixed over the wax plate, followed by the acrylic resin manipulation according to the manufacturers' instructions and consequent insertion into the cylinder (Figure 1d). After resin polymerization, the roots were removed from the cylinder, and the wax found over each root surface and into each resin cylinder "alveolus", properly removed. The polyether impression material was manipulated following the manufacturer instructions, placed in the resin cylinder, and the roots were re-inserted into the cylinder (Figure 1e); any excess impression material was removed with a scalpel blade (Soares et al., 2005).

Endocrown preparation

The endocrown restorations were prepared in the present study following two distinct restorative techniques: direct or indirect. For the direct technique, the crown was built-up after acid-etching (37% phosphoric acid) the enamel and dentin substrates for 30 and 15s, respectively, followed by water rinsing, air-drying, and adhesive application (Scotchbond™ Multi-Purpose™; 3M ESPE); the adhesive resin was light-activated using a light-emitting diode (LED) curing unit for 20 s, followed by insertion of the restorative(s) material(s), which were bonded directly to the tooth. For the indirect technique, the crown was built-up without any superficial treatment of the substrate. However, an isolating gel (KY; Johnson & Johnson, São José dos Campos, SP, Brazil) was applied into the pulp chamber before insertion of the materials, and after light-activation of each material increment, the restoration was removed from the cavity and subsequently re-inserted, in order to assure its easy removal after finishing the restoration. For both techniques, the crown was built-up using the previous impression of the coronal portion of each tooth as a guide, thus facilitating restoration of the tooth to its original shape and size (Figure 1b).

Within the direct groups, four of them were restored without using glass-fiber posts (Z350, Z350+SBMP, Z350+SBU, and Bulk Fill), so the endocrown preparation was limited to the pulp chamber and to the entrance of each of the root canals present in the tooth. The largest root canal (distal) was unsealed up to 2.0 mm-deep, whereas any other root canals (mesial ones) were unsealed by only 1.0 mm-deep (Figure 1e). Three groups were restored using glass-fiber posts (GFP+Z350, GFP+Z350+SBMP, and GFP+Bulk Fill), which were placed always into the largest root canal (distal). Thus, the endocrown preparation was limited to the pulp chamber, to the entrance of the mesial root canals (1.0 mm-deep), and to the length of the distal root canal, except for the 4.0 mm of root filling left to preserve the apical seal.

The direct and indirect groups had four groups in common, differing only by the way the crown was bonded to the tooth. While for the direct groups the endocrowns were bonded directly since they were built-up after application of an etch-and-rinse adhesive system; for the indirect groups the endocrowns were luted with self-adhesive resin cement (Rely-X™ U200, 3M ESPE), thus comprising an indirect technique. The groups in common were as follows: Z350 – the endocrowns were prepared by placing up to 2.0 mm-thick increments of conventional resin composite; Z350+SBMP or Z350+SBU – the endocrowns were prepared by placing up to 2.0 mm-thick increments of conventional resin composite, which were modeled using adhesive resins (SBMP or SBU) as modeler liquids; and Bulk Fill – the endocrowns were prepared by placing up to 4.0-5.0 mm-thick increments of resin composite.

Ceramic endocrowns (E.max; n=7) were also prepared to serve as control in the indirect group. The teeth were prepared similarly to the previous groups, so the largest root canal (distal) and the mesial one(s) were unsealed by up to 2.0 mm- and 1.0 mm-deep, respectively. Next, impression of the tooth was performed (Futura AD; DFL), and the endocrown manufactured (IPS e.max lithium disilicate, Ivoclar

Vivadent). All indirect endocrowns (resin-based and ceramic) were luted to the teeth using self-adhesive resin cement (Rely-X™ U200) and following the manufacturers' instructions. A Centrix® syringe (DFL) was used to insert the luting cement (Figure 1f), and pressure was performed by holding the restoration for 6 minutes (Figure 1g); excess material was removed and light-activation was performed for 40s on each face.

Fatigue test

All teeth investigated in the present study (sound or restored) were submitted to fatigue testing, which was performed using a piston (6 mm in diameter) in a fatigue simulator (Biocycle V2; Biopdi, São Carlos, SP, Brazil). Each sample (plastic cylinder plus tooth) was positioned in a metal base in a tank filled with distilled water (37°C), forming a 90° angle between the horizontal plane and the piston under the following regimen: load of 125N at a frequency of 4Hz. The piston touched the internal part of the buccal and lingual cusps, and each load cycle consisted of the indenter coming into contact with the specimens, loading to a maximum, holding for 0.125 s and completely unloading for 0.125 s. In total, 1,200,000 cycles were performed for fatigue testing. Before simulating chewing cycles, the equipment was calibrated with the pressure necessary to achieve appropriate force. Chipping of the restorative material (resin, ceramic), cracks, catastrophic fracture of the restoration, and debonding of crowns were considered failures; if none of these was observed, the specimens continued to be subjected to fatigue test until the test was complete (Ramos et al., 2015).

Fracture test, Work of fracture (W_f), and Failure analysis

The fracture test was performed in a Universal Testing Machine (EMIC DL500; EMIC, São José dos Pinhais, PR, Brazil). All samples were mounted in a metal base and the stainless steel round load cell was applied perpendicular (axial loading) to the occlusal plane, at the central fissure (Gresnigt et al., 2016). The maximum force (N) to produce fracture was recorded. Load-displacement curves obtained during fracture testing were used to quantify the W_f of restored and sound teeth, which was determined by dividing the area under the load-displacement curve by the cross-sectional area of specimens (i.e., width × thickness). The data were expressed in J/m^2 (Borges et al., 2015).

Failure sites were observed using an optical microscope at a magnification of 100×. Next, digital photos were made from the samples, and failure types were classified as follows: Type I – cohesive failure in the endocrown material; Type II – adhesive failure between the endocrown material and dentin; Type III – cohesive failure in enamel/dentin; and Type IV – fracture extending to root. Failures above the CEJ were considered as ‘repairable’ and those below the CEJ extending the root were classified as ‘irrepairable’ (Gresnigt et al., 2016):

Statistical analysis

All data were statistically analyzed with SigmaPlot version 12 (Systat Software Inc., San Jose, CA, USA). One-Way ANOVA followed by the Tukey’s post hoc test (α=5%) were used to compare groups within the same restorative technique; whereas Two-Way ANOVA followed by the Tukey’s test (α=5%) were used to compare direct and indirect groups which used common restorative materials. Lastly, t-tests (α=5%) were used to compare direct groups restored with glass-fiber posts to the control group of the indirect technique (E.max).

Results

Fracture strength

Figure 2 shows the fracture strength results obtained for groups of the direct (image *a*) and indirect (image *b*) restorative techniques. There was a statistically significant difference for the former (p=0.003), but no significant difference for the latter (p=0.157). Within the direct groups, Bulk Fill produced the highest mean value, and greater than the fracture strength supported by the sound tooth (p=0.001) and Z350 (p=0.022) groups; all the other groups showed similar fracture strength results (p≥0.073). Within the indirect groups, all endocrowns resulted in similar fracture strength when compared to the sound tooth group.

Considering the results obtained with the comparison between direct and indirect groups that used common restorative materials, which results are shown in Table 2, both factors were significant (*type of restorative material* – p=0.013; and *type of restorative technique* – p=0.019), although no significant interaction between factors were detected (p=0.264). Within the direct groups, Bulk Fill exhibited greater fracture strength than Z350 (p=0.011) and Z350+SBMP (p=0.043), but similar to Z350+SBU (p=0.315); for the indirect groups, they have not differed among each other (p≥0.377) regardless of the restorative(s) material(s) used to prepare the endocrowns. Comparing the direct and indirect groups, only Bulk Fill bonded directly to the tooth showed a stronger behavior when compared to its indirect counterpart (p=0.013).

Table 3 shows the fracture strength results of the three direct groups prepared with glass-fiber posts (GFP) compared to the indirect control group (E.max). According to the statistical analysis, all GFP-based groups presented greater fracture strength than E.max (p≤0.016).

Work of fracture (W_f)

Load × deflection curves (representative of the mean values) obtained during fracture strength testing are shown in Figure 2 (image *c* for direct groups; and image *d* for indirect groups). For the direct groups, while Z350 and Z350+SBU displayed a similar pattern to the sound tooth group, endocrowns prepared using GFP or Z350 combined with SBMP or Bulk Fill restoratives resulted in superior maximum loads and greater deflection ability than the others (Figure 2c). For the indirect groups, endocrowns prepared with Z350 and SBMP or SBU supported apparent greater deflection than the other groups, which demonstrated a similar pattern to the sound tooth group (Figure 2d).

Table 2 shows the W_f results obtained in the study. While the factor *restorative technique* was significant (p=0.012), the factor *restorative material* and the interaction between factors were not significant (p=0.268 and p=0.558, respectively). All groups presented similar W_f mean values regardless of the restorative technique (p≥0.353). However, Bulk Fill bonded directly to the tooth showed greater W_f than its indirect counterpart (p=0.020). Concerning the W_f results obtained for the three direct groups prepared with GFP compared to the E.max group (control), which are shown in Table 3, the combination of GFP with conventional resin composite (Z350) or Z350 and SBMP (hydrophobic modeler liquid) resulted in greater W_f than the control (p≤0.014), although no significant difference was observed between the GFP+Bulk Fill and the control (p=0.119).

Fracture analysis

Table 4 shows the results for each failure mode obtained in the study. All groups produced at least one fracture extending to the root. Sound teeth fractured mostly within the cohesiveness of enamel and dentin, corresponding to approximately 86% of repairable fractures. Endocrowns bonded indirectly to the tooth resulted in a greater range of repairable fractures when compared to the direct groups, except for the ceramic group (E.max), which fractures extended to the root in around 71% of the cases. Within the indirect groups, endocrowns prepared by using Z350 and SBMP as modeler liquid resulted in the least harsh fractures, opposed by endocrowns prepared with Z350 only, which showed equilibrium between repairable and irrepairable fractures. Within the direct groups, most of them exhibited more than 50% of irrepairable fractures, except for endocrowns prepared using Bulk Fill only or Z350 combined with SBMP, which resulted in 29% of irrepairable fractures *versus* 71% of repairable fractures. Figure 3 shows a representative image of the most frequent failure mode found for all groups tested in the study.

Discussion

This is the first study to assess endocrown restorations comparing direct and indirect techniques, with or without the use of posts and modeling liquid. Endocrowns performed similarly or better than the tested techniques, depending on the tested combination. Usually, endocrowns are prepared with glass-ceramics with an indirect technique, i.e., by bonding the restoration with resin-based luting cements. The main disadvantage of this procedure compared to other treatment modalities (e.g., post-retained crown) is that glass-ceramics are very friable, showing high rigidity, but little elastic behavior (Belli et al., 2014), which thereby favors the occurrence of catastrophic failures (Figure 3). This fact corroborates our findings, since the E.max group showed the lowest fracture strength values of the study (Figure 2b) and a high frequency of Type IV failures (Table 4). Despite the lack of statistical differences among groups, E.max resulted in greater amount (approximately 71%) of irrepairable failures when compared to the other indirect groups, probably due to the resin nature of the latter, which allows better stress distribution during fatigue and fracture testing (Belli et al., 2014), and consequently, the occurrence of less aggressive fractures (mostly Type I failure mode). Thus, it seems that the use of less rigid materials would produce a better biomechanical match between restoration and tooth.

Studies reporting on the fracture behavior of ceramic endocrowns usually use conventional crowns restored with intraradicular posts as control group(s) (Biacchi and Basting, 2012; Ramirez-Sebastia et al., 2014). In light of this, endocrowns prepared with glass-fiber posts (GFP+Z350, GFP+Z350+SBMP, and GFP+Bulk Fill) were intended to serve as direct comparison for E.max group. GFP-based groups demonstrated greater fracture strength than E.max and also greater work of fracture (except for GFP+Bulk Fill group). Once again, it can be suggested that the less rigid nature of glass-fiber posts, resin composites and modeler liquid resulted in a more homogeneous system, at least in terms of rigidity, acting synergistically in the stress distribution within the body of the restoration. Indeed, the gain in work of fracture observed for the GFP-based groups can be an important factor when choosing the best restorative system for preparing endocrowns. Work of fracture has been commonly used to predict the interfacial fracture toughness of materials, consisting in the ability of a material containing a crack to resist fracture (Mayer, 2011). Simply speaking, work of fracture corresponds to the total energy required to grow a thin crack (Cheetham et al., 2014), and restorations with greater work of fracture would probably resist longer and more intensively to fatigue/fracture. Considering all of the foregoing, it seems that using glass-ceramics for the preparation of endocrowns would not be the most advisable option, since combination of alternative resin-based materials would provide a stronger and more compliant behavior for the restoration.

One could suggest that retention of the restoration would not be sufficient, as in the case of using direct composites to restore severely damaged non-vital teeth. In the latter case, the use of intraradicular posts would be paramount (Deliperi, 2008). However, an endocrown has both macro- and micro-retention capability due to its unique design: first, the circumferential walls of the pulp chamber allow proper mechanical retention of the restoration; and second, the use of adhesive materials before placing the restoratives offer satisfactory chemical/mechanical interlocking between restoration and dental substrates (Bindl and Mormann, 1999; Lander and Dietschi, 2008). The only disadvantage of preparing endocrowns with a direct technique would be the need for restoring a whole tooth, which would be considered as a difficult task by several dental practitioners and dependent on their experience level. Notwithstanding, this restoring procedure would not be different from that performed by the technician in the laboratory, so it should be considered as a valid treatment modality. Here, it is worth to mention that the use of a silicon guide to build-up the endocrown allowed the easy handling of the restoration to the original tooth' shape/size.

According to our findings, the type of restorative material influenced the mechanical performance of endocrown restorations. Considering direct groups only, all experimental endocrowns resulted in similar fracture strength to sound teeth, except for the Bulk Fill group (Figure 2a). Indeed, endocrowns prepared with bulk fill resin showed greater strength than sound teeth as well as the endocrowns prepared using only the conventional resin composite (Z350). One possible explanation is that bulk fill composites are usually constituted of lower amount of fillers as compared to conventional composites (Zorzin et al., 2015); in the present study, Filtek™ Bulk Fill possesses 42.5 vol% of fillers *vs.* the 59.5 vol% of Filtek™ Z350 XT (Table 1), which may have influenced modulus development within the restoration, with the former producing lower modulus than the latter. Not less important, bulk fill composites may also generate less amount of polymerization stress when compared to conventional formulations (El-Damanhoury and Platt, 2014). Consequently, low modulus added to the stress-decreasing effect inherent to bulk fill composites may have both contributed for its stronger behavior, since stress distribution would be more homogeneous due to a more compliant system, compared to the Z350 group.

Despite the significant differences discussed before, the Bulk Fill group has not statistically differed from the other direct groups tested (Figure 2a). It can be suggested that the other groups have also allowed proper stress distribution during fatigue/fracture testing. While the Z350+SBMP and Z350+SBU endocrowns were built-up using unfilled resins as modeler liquid, the GFP-based groups were comprised of a heterogeneous composition (post, the adhesive that was bonding the post to the resin, and the resin composite combined or not with modeler liquid). Resin adhesives have been already used as modeler liquid of resin composites, as demonstrated elsewhere (Munchow et al., 2016; Sedrez-Porto et al., 2016a); in fact, the presence of modeler liquid in-between the layers of resin composite improved cohesiveness of the material, hampering hydrolytic degradation (Munchow et al., 2016). This would be important for restoration resistance to fatigue, as simulated in the present study. Remarkably, no endocrown failed during fatigue testing, indicating their probable feasibility for rehabilitation of severely damaged non-vital teeth. Thus, endocrowns prepared by combining resin composites with modeler liquid and/or glass-fiber posts could be considered as compliant systems, contributing for the similar results compared to the Bulk Fill group. Moreover, it seems that crack propagation may occur similarly within restorations that display similar rigidity/flexibility characteristics.

Another important finding of the present study is that the type of restorative material was not the only factor influencing the mechanical performance of the endocrowns, but also the restorative technique employed. Endocrowns bonded directly to the tooth displayed similar fracture strength and work of fracture to their counterparts bonded following an indirect technique, except for the endocrowns prepared using the bulk fill resin composite, in which the direct technique resulted in superior mechanical performance when compared to the indirect technique. The only factor that was different between the two foregoing groups was the adhesion strategy used to bond the endocrown to the tooth: while the direct groups were bonded using a conventional technique, i.e., by applying phosphoric acid followed by rinsing, drying, priming and bonding procedures, the indirect groups were bonded using a self-adhesive resin cement. According to a recent prospective clinical study (Brondani et al., 2017), the use of self-adhesive resin cement is a feasible alternative for dental cementation purposes, achieving high and adequate survival rates. However, the indirect groups resulted in a higher frequency of Type II failures in our study, i.e., adhesive failure between the endocrown material and dentin, as compared to the direct groups (occurrence of failures at the restoration/tooth interface when the endocrown is bonded following an indirect technique). This fact may also explain the lack of statistical differences among the indirect groups.

Even though the bonding strategy might have played a role on the mechanical performance of the endocrowns, it does not seem the most reliable explanation to our findings. First, endocrowns prepared using conventional resin composite resulted in similar fracture strength and work of fracture properties, regardless of the restorative technique; however, indirect groups exhibited 5 Type II failures in total (3 for Z350 and 2 for Z350+SBMP groups) *versus* only 1 Type II failure (Z350+SBU) for the direct groups. Second, endocrowns prepared with the bulk fill resin composite displayed similar failure modes regardless of the restorative technique, although direct restorations performed mechanically better than the indirect ones. It seems that the factor 'restorative material' prevailed over the factor 'restorative technique'. Despite any point previously discussed for the enhanced mechanical behavior of bulk fill-based endocrowns, one can here suggest that hybridization of bulk fill composites is significantly improved by following an etch-and-rinse bonding approach. Indeed, the bulk fill composite used in the present study is less viscous than the conventional composite (Kim et al., 2015), which may have facilitated resin infiltration during direct application of the restorative. Consequently, a stronger hybrid layer was probably achieved, allowing to a more adequate stress distribution within the restoration (Eliguzeloglu et al., 2010) and to the occurrence of cohesive fractures, thus favoring the direct technique over the other.

Despite the restorative system used, when fracture occurs, it is always desired to deal with a repairable fracture rather than an aggressive, irrepairable fracture. In the present study, the direct groups exhibited a considerably higher frequency of Type IV failures as compared to the other indirect groups, and the most reasonable explanation may be related to the quality of the hybrid layer formed. The greater occurrence of Type II failures for the indirect groups suggests the formation of a weaker hybrid layer as compared to the direct groups, thus favoring the occurrence of adhesive failures in opposition to cohesive/root fractures. Considering only the direct groups, fractures extending to the root were more frequent for endocrowns prepared with glass-fiber posts or those prepared with conventional resin composite (except the Z350+SBMP group). It can be suggested that for the GFP-based groups, the presence of the post into the length of the largest root canal may have concentrated stress during fatigue/fracture testing, thereby resulting in root fractures. This is in accordance to several previous studies, although fractures extending to the root were more frequent when metal posts/cores were used (Sarkis-Onofre et al., 2014). In the present study, endocrowns restored with GFP and Z350 resulted in the highest rate of Type IV failures (approximately 86%), so the use of other restorative materials with a much better match with the mechanical behavior of tooth substrates should be pursued in the future. Interestingly, endocrowns prepared with Z350 and SBMP and bonded using resin cement (indirect technique) displayed the most similar fracture pattern when compared to the sound tooth group, showing only 1 Type IV failure. In the sequence, endocrowns prepared using modeler liquid or bulk fill composite showed a satisfactory restorative combination in terms of repairability of fractures. It seems that the presence of the unfilled resin in-between the layers of conventional composite or the use of bulk fill composite allow an adequate mechanical behavior for endocrown restorations.

The type of restorative material used to fabricate the endocrowns influenced the mechanical performance and fracture behavior of the restorations, thus accepting the first hypothesis of the study. Here, the use of less rigid materials (e.g., conventional resin composite combined with modeler liquid, bulk fill resin composite) would allow a better restorative system, especially in comparison to glass-ceramic endocrowns or those prepared with glass-fiber posts. Furthermore, the restorative technique used to bond the endocrown to the tooth had an influence on the mechanical behavior of the restorations, thereby rejecting the second hypothesis of the study. Depending on the restorative system, endocrowns bonded directly to the tooth may show improved mechanical properties compared to those bonded using a self-adhesive resin cement; conversely, the latter may result in the occurrence of less aggressive failures/fractures compared to the former.

Conclusions

Endocrowns performed similarly to sound teeth in the present study, regardless of the restorative material and restorative technique used. Endocrowns bonded directly to the tooth seemed to produce similar fracture strength properties as compared to endocrowns bonded indirectly to the tooth, i.e., by means of using self-adhesive, resin cementation. However, the former produced more aggressive failures. Therefore, and despite of the limitations of this in vitro study, dental practitioners may restore severely damaged non-vital teeth using an endocrown with a direct or indirect technique without of decrease strength.

References

Alharbi FA, Nathanson D, Morgano SM, Baba NZ (2014). Fracture resistance and failure mode of fatigued endodontically treated teeth restored with fiber-reinforced resin posts and metallic posts in vitro. *Dent Traumatol* 30(4):317-25.

Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, Mainjot AK (2017). No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. *J Dent*. [Epub ahead of Print]

Belli R, Geinzer E, Muschweck A, Petschelt A, Lohbauer U (2014). Mechanical fatigue degradation of ceramics versus resin composites for dental restorations. *Dent Mater* 30(4):424-32.

Biacchi GR, Basting RT (2012). Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. *Oper Dent* 37(2):130-6.

Bindl A, Mormann WH (1999). Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. *J Adhes Dent* 1(3):255-65.

Borges AL, Munchow EA, de Oliveira Souza AC, Yoshida T, Vallittu PK, Bottino MC (2015). Effect of random/aligned nylon-6/MWCNT fibers on dental resin composite reinforcement. *J Mech Behav Biomed Mater* 48:134-44.

Braga RR, Hilton TJ, Ferracane JL (2003). Contraction stress of flowable composite materials and their efficacy as stress-relieving layers. *J Am Dent Assoc* 134(6):721-8.

Brondani LP, Pereira-Cenci T, Wandsher VF, Pereira GK, Valandro LF, Bergoli CD (2017). Longevity of metal-ceramic crowns cemented with self-adhesive resin cement: a prospective clinical study. *Braz Oral Res* 31:e22.

Cheetham JJ, Palamara JE, Tyas MJ, Burrow MF (2014). Evaluation of the interfacial work of fracture of glass-ionomer cements bonded to dentin. *J Mech Behav Biomed Mater* 29:427-37.

Chun KJ, Lee JY (2014). Comparative study of mechanical properties of dental restorative materials and dental hard tissues in compressive loads. *J Dent Biomech* 5:1758736014555246.

Deliperi S (2008). Direct fiber-reinforced composite restoration in an endodontically-treated molar: a three-year case report. *Oper Dent* 33(2):209-14.

El-Damanhoury H, Platt J (2014). Polymerization shrinkage stress kinetics and related properties of bulk-fill resin composites. *Oper Dent* 39(4):374-82.

Eliguzeloglu E, Eraslan O, Omurlu H, Eskitascioglu G, Belli S (2010). Effect of hybrid layer and thickness on stress distribution of cervical wedge-shaped restorations. *Eur J Dent* 4(2):160-5.

Goracci C, Ferrari M (2011). Current perspectives on post systems: a literature review. *Aust Dent J* 56(Suppl 1):77-83.

Gresnigt MM, Ozcan M, van den Houten ML, Schipper L, Cune MS (2016). Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. *Dent Mater* 32(5)*:*607-14.

Guncu MB, Cakan U, Muhtarogullari M, Canay S (2015). Zirconia-based crowns up to 5 years in function: a retrospective clinical study and evaluation of prosthetic restorations and failures. *Int J Prosthodont* 28(2)*:*152-7.

Hamburger JT, Opdam NJ, Bronkhorst EM, Huysmans MC (2014). Indirect restorations for severe tooth wear: fracture risk and layer thickness. *J Dent* 42(4)*:*413-8.

Kim RJ, Kim YJ, Choi NS, Lee IB (2015). Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites. *J Dent* 43(4)*:*430-9.

Lander E, Dietschi D (2008). Endocrowns: a clinical report. *Quintessence Int* 39(2)*:*99-106.

Mantri SP, Mantri SS (2013). Management of shrinkage stresses in direct restorative light-cured composites: a review. *J Esthet Restor Dent* 25(5)*:*305-13.

Mayer G (2011). New toughening concepts for ceramic composites from rigid natural materials. *J Mech Behav Biomed Mater* 4(5)*:*670-81.

Munchow EA, Sedrez-Porto JA, Piva E, Pereira-Cenci T, Cenci MS (2016). Use of dental adhesives as modeler liquid of resin composites. *Dent Mater* 32(4)*:*570-7.

Ragauska A, Apse P, Kasjanovs V, Berzina-Cimdina L (2008). Influence of ceramic inlays and composite fillings on fracture resistance of premolars in vitro. *Stomatologija* 10(4)*:*121-6.

Ramirez-Sebastia A, Bortolotto T, Cattani-Lorente M, Giner L, Roig M, Krejci I (2014). Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength. *Clin Oral Investig* 18(2)*:*545-54.

Ramos GF, Monteiro EB, Bottino MA, Zhang Y, Marques de Melo R (2015). Failure Probability of Three Designs of Zirconia Crowns. *Int J Periodontics Restorative Dent* 35(6)*:*843-9.

Rocca GT, Krejci I (2013). Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns. *Eur J Esthet Dent* 8(2)*:*156-79.

Roscoe MG, Noritomi PY, Novais VR, Soares CJ (2013). Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. *J Prosthet Dent* 110(2)*:*116-26.

Sarkis-Onofre R, Jacinto RC, Boscato N, Cenci MS, Pereira-Cenci T (2014). Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. *J Dent* 42(5)*:*582-7.

Sedrez-Porto JA, Munchow EA, Brondani LP, Cenci MS, Pereira-Cenci T (2016a). Effects of modeling liquid/resin and polishing on the color change of resin composite. *Braz Oral Res* 30(1).

Sedrez-Porto JA, Rosa WL, da Silva AF, Munchow EA, Pereira-Cenci T (2016b). Endocrown restorations: A systematic review and meta-analysis. *J Dent* 52*:*8-14.

Skupien JA, Cenci MS, Opdam NJ, Kreulen CM, Huysmans MC, Pereira-Cenci T (2016). Crown vs. composite for post-retained restorations: A randomized clinical trial. *J Dent* 48*:*34-9.

Soares CJ, Pizi EC, Fonseca RB, Martins LR (2005). Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. *Braz Oral Res* 19(1)*:*11-6.

Soares CJ, Valdivia AD, da Silva GR, Santana FR, Menezes Mde S (2012). Longitudinal clinical evaluation of post systems: a literature review. *Braz Dent J* 23(2)*:*135-740.

Sorrentino R, DI MAURO MI, FERRARI M, LEONE R, ZARONE F (2016). Complications of endodontically treated teeth restored with fiber posts and single crowns or fixed dental prostheses-a systematic review. *Clin Oral Investig* 20(7): 1449-57.

Yeh CJ (1997). Fatigue root fracture: a spontaneous root fracture in non-endodontically treated teeth. *Br Dent J* 182(7)*:*261-6.

Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, et al. (2006). Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. *Dent Mater* 22(11)*:*1035-44.

Zorzin J, Maier E, Harre S, Fey T, Belli R, Lohbauer U, et al. (2015). Bulk-fill resin composites: polymerization properties and extended light curing. *Dent Mater* 31(3)*:*293-301.

Figure legends

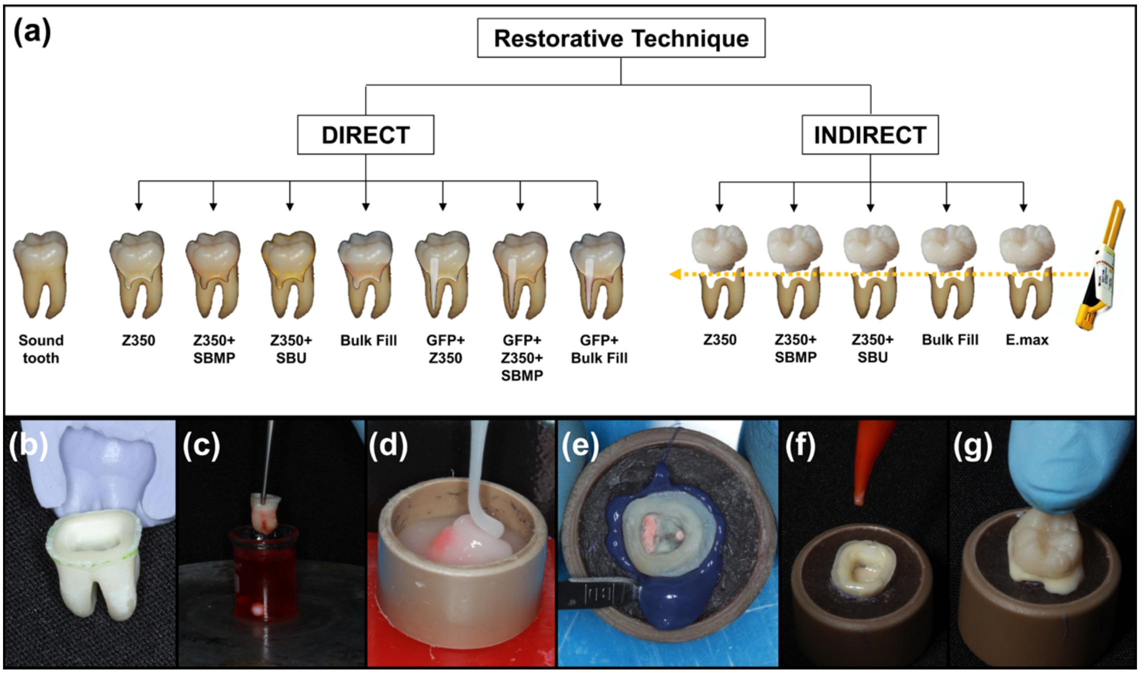

Figure 1. Groups investigated in the study and their respective characteristics (a). Brief protocol used to prepare the tooth samples: impression of the crown portion of each tooth before crown/root separation (b); wax application on each root surface at 2.0 mm below the cementoenamel junction (c); alveolus simulation made with acrylic resin (d); periodontal ligament simulation made with polyether impression (e); endocrown cementation using self-adhesive resin cement and Centrix® syringe (f); and pressure of the restoration for 6min before light-activation (g).

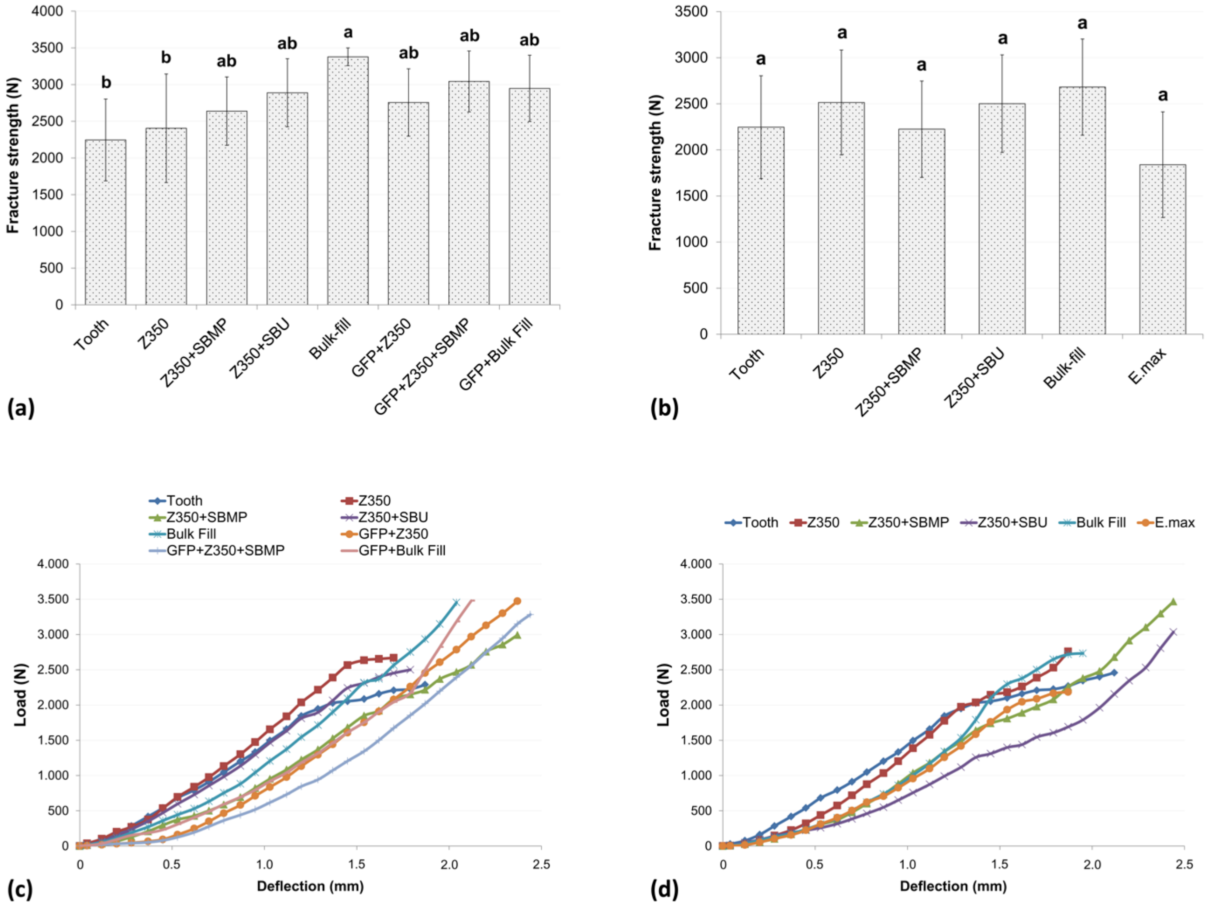

Figure 2. Fracture strength results for endocrowns bonded directly (a) or indirectly (b) to the tooth. Similar letters above the standard deviation bars indicate statistical similarity among groups investigated ($p>0.05$). Load-deflection curves obtained from the average results of endocrowns bonded directly (c) or indirectly (d) to the tooth. Z350: conventional resin composite; SBMP and SBU: resin adhesives used as modeler liquid of resin composite; Bulk fill: bulk fill resin composite; GFP: glass-fiber post; E.max: IPS Empress lithium dissilicate.

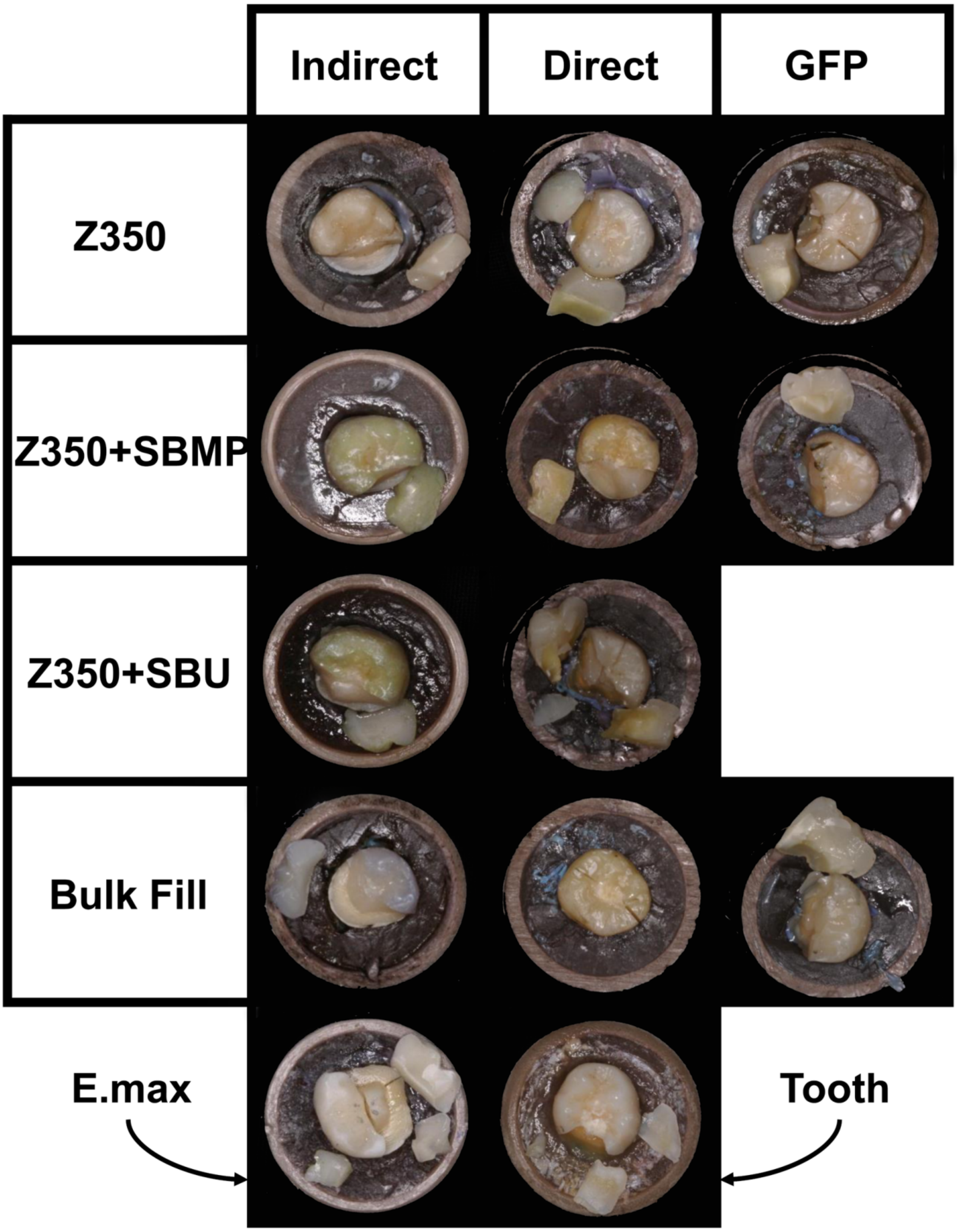

Figure 3. Representative images of the most frequent failure mode observed for all groups tested in the study.

Table 1. Restorative materials used in the present with their respective code, shade (if appropriate), lot number, and composition information.

Material (Code)	Manufacturer (shade, batch no.)	Composition
Filtek™ Z350 XT (Z350)	3M ESPE, St. Paul, MN, USA (A2B, 1535700493)	Bis-GMA, UDMA, TEGDMA, Bis-EMA, zircônia and silica nanoparticles (78.5 wt%/59.5 vol%)
Adper™ Scotchbond™ Multi-Purpose Adhesive (SBMP)	3M ESPE, St. Paul, MN, USA (1516300370)	*Bond*: Bis-GMA, HEMA, photoinitiator
Scotchbond™ Universal Adhesive (SBU)	3M ESPE, St. Paul, MN, USA (579965)	10-MDP phosphate monomer, Vitrebond copolymer, HEMA, Bis-GMA, dimethacrylate resins, filler, silane, initiators, ethanol, water
Filtek™ Bulk Fill (Bulk Fill)	3M ESPE, St. Paul, MN, USA (1521500378)	Bis-GMA, UDMA, Bis-EMA(6), procrylat resins, ytterbium trifluoride, zirconia, silica (64.5 wt%/42.5 vol%)

10-MDP: 10-methacryloyloxi-decyl-dihydrogen-phosphate; Bis-EMA: bisphenol-A polyethylene glycol diether dimethacrylate; Bis-GMA: bisphenol-A diglycidyl ether dimethacrylate; HEMA: 2-hydroxiethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate.

Table 2. Mean and standard deviation (SD) values for the fracture strength and work of fracture properties of groups with similar composition, differing only with regards to the restorative technique: direct or indirect.

Groups	Fracture strength (N)*		Work of fracture (J/m^2)*	
	Direct	Indirect	Direct	Indirect
Z350	2404.9 (739.7) $^{B, a}$	2514.7 (569.1) $^{A, a}$	13.4 (0.7) $^{A, a}$	12.0 (2.3) $^{A, a}$
Z350 + SBMP	2638.5 (465.3) $^{B, a}$	2224.9 (522.6) $^{A, a}$	15.9 (2.9) $^{A, a}$	13.4 (2.5) $^{A, a}$
Z350 + SBU	2888.9 (463.5) $^{AB, a}$	2501.2 (528.9) $^{A, a}$	13.4 (2.4) $^{A, a}$	12.6 (2.4) $^{A, a}$
Bulk Fill	3378.8 (120.6) $^{A, a}$	2681.4 (521.6) $^{A, b}$	15.9 (2.6) $^{A, a}$	12.2 (1.8) $^{A, b}$

Different uppercase and lowercase letters indicate, respectively, statistical significant differences among groups (in the same column) and different techniques (in the same row); $p<0.05$.

* Two-Way Analysis of Variance, followed by the Tukey's *post hoc* test.

Table 3. Mean and standard deviation (SD) values for the fracture strength and work of fracture properties of groups prepared using glass-fiber posts compared to the control group of the indirect groups (E.max).

Groups	**Fracture strength (N)**			**Work of fracture (J/m^2)**		
	Glass-fiber post	E.max (control)	**P value***	Glass-fiber post	E.max (control)	**P value***
Z350	2756.8 (458.3)		0.016	19.4 (1.2)		<0.001
Z350 + SBMP	3044.1 (414.7)	1839.3 (573.8)	0.003	16.6 (1.6)	12.8 (1.8)	0.014
Bulk Fill	2948.9 (451.3)		0.004	15.4 (2.6)		0.119

* t-tests (p<0.05).

Table 4. Results for the failure mode obtained for all samples tested in the study, which were ranked according to their condition for repair, in percentage.

Groups		Failure mode (n=7)				Condition for repair (%)	
		Type 1	**Type 2**	**Type 3**	**Type 4**	**Repairable**	**Irrepairable**
Direct	Z350	2	0	0	5	28.6%	71.4%
	Z350+SBMP	5	0	0	2	71.4%	28.6%
	Z350+SBU	2	1	0	4	42.9%	57.1%
	Bulk Fill	5	0	0	2	71.4%	28.6%
	GFP+Z350	1	0	0	6	14.3%	85.7%
	GFP+Z350+SBMP	3	0	0	4	42.9%	57.1%
	GFP+Bulk Fill	1	1	0	5	28.6%	71.4%
Sound tooth		0	0	6	1	85.7%	14.3%
Indirect	Z350	1	3	0	3	57.1%	42.9%
	Z350+SBMP	4	2	0	1	85.7%	14.3%
	Z350+SBU	5	0	0	2	71.4%	28.6%
	Bulk Fill	4	1	0	2	71.4%	28.6%
	E.max	2	0	0	5	28.6%	71.4%

SBMP: Scotchbond™ Multi-Purpose™ Adhesive; SBU: Scotchbond™ Universal Adhesive; GFP: glass-fiber post; E.max: IPS emax lithium disilicate ceramic.

6. Discussão Geral e Recomendações

Vários fatores relacionados à reabilitação de dentes tratados endodonticamente e com grande destruição coronária vêm sendo discutidos na literatura através de estudos de revisão, estudos clínicos e, principalmente, estudos laboratoriais. Contudo, dentre as diversas modalidades de tratamento nestes casos complexos, uma vem sendo abordada atualmente como possível técnica satisfatória, sendo o caso das restaurações *endocrown*. Porém, são poucos os estudos relacionados ao tema, e, por isso, o objetivo principal desta tese foi o de investigar as variáveis envolvidas no desempenho físico-mecânico de restaurações *endocrown*.

No **capítulo 1** dessa tese, nós comparamos, por meio de revisão sistemática da literatura e meta-análises, a resistência à fratura ou desempenho clínico de restaurações *endocrown* quando comparadas a restaurações convencionais com pinos intrarradiculares, resina composta direta ou *inlay/onlay*. Nesse estudo, concluiu-se que restaurações *endocrown* podem desempenhar semelhantemente ou melhor do que os tratamentos convencionais supracitados. Ainda, e apesar de mais estudos serem necessários para confirmar nossos achados, restaurações *endocrown* demonstram potencial aplicação para a reabilitação de dentes tratados endodonticamente e que apresentem grande destruição coronária.

Os próximos capítulos dessa tese envolveram estudos laboratoriais, sendo um deles diretamente relacionado ao tema das *endocrowns* (capítulo 4), enquanto que os outros dois (capítulos 2 e 3) envolveram estudos indiretamente relacionados ao tema. No **capítulo 2**, adesivos dentários foram utilizados como líquido modelador (resina adesiva) de resina composta, a fim de averiguar o seu efeito, quando presente no interior de restaurações de resina, nas propriedades físico-mecânicas do material. Acreditou-se que a presença de líquido modelador iria melhorar as propriedades do material, tornando-o ainda mais resistente à degradação hidrolítica. Segundo os nossos achados, a presença de adesivo dentário entre as camadas de resina composta aumentou a estabilidade física do material, sendo este efeito mais evidente quando da utilização de um adesivo caracteristicamente hidrófobofo. Este estudo foi o primeiro a demonstrar resultados positivos devido ao uso de adesivos resinosos durante o manuseio ou manipulação/modelagem de resina composta, o que na verdade já vinha sendo realizado clinicamente, mas sem respaldo científco. Em sequência, o **capítulo 3** dessa tese avaliou a estabilidade de cor e de translucidez de espécimes de resina composta preparados com ou sem líquido modelador após um ano de armazenagem em água ou vinho tinto. Este estudo teve por objetivo averiguar se a técnica de uso de líquido modelador iria ser satisfatória quanto aos quesitos estéticos, para assim serem posteriormente investigados no preparo de restaurações *endocrown*. Conforme os resultados obtidos, a técnica que utiliza adesivos resinosos como líquido modelador de resina composta pode ser um método interessante para reduzir alteração de cor da resina composta com o passar do tempo, sem, no entanto resultar em efeitos negativos à translucidez do material. Porém, a resina adesiva deve apresentar uma composição hidrófoba para ampliar estes resultados. Resumindo, a partir dos estudos apresentados nos capítulos 2 e 3, constatou-se que a utilização de resinas adesivas como líquido modelador de resina composta pode favorecer o desempenho físico-mecânico do material, aumentando a sua resistência à degradação e à alteração de cor/translucidez.

Por fim, no **capítulo 4**, nós avaliamos, através de um estudo laboratorial, o desempenho mecânico e comportamento de fratura de restaurações *endocrown* preparadas com diferentes materiais restauradores e seguindo uma técnica direta ou indireta. Os materiais restauradores escolhidos seguiram a lógica de usar resina convencional apenas, resina convencional modelada com resinas adesivas de diferentes composições, resina composta do tipo bulk-fill, ou ainda combinando-se as técnicas recém-apresentadas com pinos intrarradiculares de fibra de vidro. As restaurações *endocrown* foram preparadas simulando-se uma técnica direta de aplicação de todos os materiais restauradores ou simulando-se uma técnica indireta, na qual a restauração seria cimentada na cavidade dentária por meio de cimento resinoso. Constatou-se que ao se comparar a técnica direta com a indireta, as restaurações *endocrown* resultaram em resistência à fratura semelhante, independente do sistema restaurador utilizado, exceto pelas restaurações preparadas com resina composta do tipo bulk-fill, no qual a técnica direta resultou em maior resistência quando comparada à técnica indireta. Comparando os grupos apenas da técnica direta, as restaurações *endocrown* foram todas semelhantes entre si, independentemente do sistema restaurador utilizado, com exceção das restaurações preparadas com a resina composta do tipo bulk-fill, que foi mais resistente do que o dente hígido ou do que as restaurações preparadas somente com resina composta convencional. Restaurações *endocrown* preparadas com a técnica indireta demonstraram comportamento mecânico semelhante independente do material restaurador utilizado. Restaurações *endocrown* preparadas com a técnica direta ou com cerâmica resultaram em fraturas mais agressivas (fraturas corono-radiculares) quando comparadas aos demais grupos indiretos. Estes últimos produziram fraturas mais fáceis de serem reparadas. Dessa forma, os achados desse capítulo mostram que profissionais da odontologia podem restaurar satisfatoriamente dentes com ampla destruição coronária por meio do uso de restaurações *endocrown*, e, dependendo do sistema restaurador, poder-se-á obter restaurações mais resistentes à fratura e com melhor capacidade de reparo após a falha, se houver.

Assim sendo, a presente tese recomenda a confecção de restaurações *endocrown* como uma possibilidade viável de tratamento no caso de dentes endodonticamente tratados e com grande destruição coronária. Além da literatura já demonstrar uma taxa de sucesso clínico favorável e comparável aos demais tipos de restaurações, os estudos experimentais realizados aqui corroboram com a utilização de restaurações endocrown, reforçando que dependendo do sistema restaurador escolhido, o comportamento mecânico do dente traumatizado poderá ser restabelecido o mais próximo possível ao de um dente hígido, sem trauma.

7 Conclusões Gerais

Conclui-se que a escolha correta da técnica restauradora, favorável para casos que apresentam dentes tratados endodonticamente com ampla destruição coronária, como apresentado neste trabalho, e através do uso da técnica *endocrown*, favorece uma satisfatória resistência físico-mecânica restauração-dente, podendo ser combinados à escolha correta do sistema restaurador, seja com resina composta, resina adesiva (líquido modelador) e/ou pinos de fibra de vidro, favorecendo assim o sucesso clínico e longevidade da restauração.

Referências

ALHARBI, F. A.; NATHANSON, D.; MORGANO, S. M.; BABA, N. Z. Fracture resistance and failure mode of fatigued endodontically treated teeth restored with fiber-reinforced resin posts and metallic posts in vitro. **Dental Traumatology**, v.30, n.4, p.317-25, 2014.

ANDREWS, J.; GUYATT, G.; OXMAN, A. D.; ALDERSON, P.; DAHM, P.; FALCK-YTTER, Y.; NASSER, M.; MEERPOHL, J.; POST, P. N.; KUNZ, R.; BROZEK, J.; VIST, G.; RIND, D.; AKL, E. A.; SCHUNEMANN, H. J. GRADE guidelines: 14. Going from evidence to recommendations: the significance and presentation of recommendations. **Journal of Clinical Epidemiology**, v.66, n.7, p.719-25, 2013.

AVERSA, R.; APICELLA, D.; PERILLO, L.; SORRENTINO, R.; ZARONE, F.; FERRARI, M. ; APICELLA, A. Non-linear elastic three-dimensional finite element analysis on the effect of endocrown material rigidity on alveolar bone remodeling process. **Dental Materials**, v.25, n.5, p.678-90, 2009.

AZZOPARDI, N.; MOHARAMZADEH, K.; WOOD, D. J.; MARTIN, N. ; VAN NOORT, R. Effect of resin matrix composition on the translucency of experimental dental composite resins. **Dental Materials**, v.25, n.12, p.1564-8, 2009.

BARCELLOS, D. C.; PUCCI, C. R.; TORRES, C. R.; GOTO, E. H. ; INOCENCIO, A. C. Effects of resinous monomers used in restorative dental modeling on the cohesive strength of composite resin. **Journal Adhesive Dental**, v.10, n.5, p.351-4, 2008.

BARUTCIGIL, C. ; YILDIZ, M. Intrinsic and extrinsic discoloration of dimethacrylate and silorane based composites. **Journal of Dentistry**, v.40 Suppl 1, p.e57-63, 2012.

BELLEFLAMME, M. M.; GEERTS, S. O.; LOUWETTE, M. M.; GRENADE, C. F.; VANHEUSDEN, A. J. ; MAINJOT, A. K. No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. **Journal of Dentistry**, doi: 10.1016/j.jdent.2017.04.009. [Epub ahead of print]
2017.

BELLI, R.; GEINZER, E.; MUSCHWECK, A.; PETSCHELT, A. ; LOHBAUER, U. Mechanical fatigue degradation of ceramics versus resin composites for dental restorations. **Dental Materials**, v.30, n.4, p.424-32, 2014.

BIACCHI, G. R. ; BASTING, R. T. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. **Operative Dentistry**, v.37, n.2, p.130-6, 2012.

BIACCHI, G. R.; MELLO, B. ; BASTING, R. T. The endocrown: an alternative approach for restoring extensively damaged molars. **Journal of Esthetic Restoration and Dentistry**, v.25, n.6, p.383-90, 2013.

BINDL, A. ; MORMANN, W. H. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. **Journal of Adhesive Dentistry**, v.1, n.3, p.255-65, 1999.

BORGES, A. L.; MUNCHOW, E. A.; DE OLIVEIRA SOUZA, A. C.; YOSHIDA, T.; VALLITTU, P. K. ; BOTTINO, M. C. Effect of random/aligned nylon-6/MWCNT fibers on dental resin composite reinforcement. **Journal of the Mechanical Behavior Biomed Materials**, v.48, p.134-44, 2015.

BORGES, H.F.; SÁBIO, S.; BENDER, K.R.F.; COSTA, Y.M.; SÁBIO, S.S.; MONDELLI, J. Endocrown - Avaliação da resistência dos cimentos dentários. **Revista Odontológica de Araçatuba**, v.34, n.2, p.23-6, 2013.

BRAGA, R. R.; HILTON, T. J. ; FERRACANE, J. L. Contraction stress of flowable composite materials and their efficacy as stress-relieving layers. **Journal of the American Dental Association**, v.134, n.6, p.721-8, 2003.

BRONDANI, L. P.; PEREIRA-CENCI, T.; WANDSHER, V. F.; PEREIRA, G. K.; VALANDRO, L. F. ; BERGOLI, C. D. Longevity of metal-ceramic crowns cemented with self-adhesive resin cement: a prospective clinical study. **Brazilian Oral Research**, v.31, p.e22, 2017.

CAUGHMAN, W. F.; COMER, R. W. ; ZARDIACKAS, L. D. Effects of diluents on physical properties of a light-cured composite Prisma-Fil). **Operative Dentistry**, v.9, n.3, p.82-5, 1984.

CHANG, C.; KUO, J.; LIN, Y.; CHANG, Y. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. **Journal of Dental Science**, v.4, n.3, p.110-7, 2009.

CHEETHAM, J. J.; PALAMARA, J. E.; TYAS, M. J. ; BURROW, M. F. Evaluation of the interfacial work of fracture of glass-ionomer cements bonded to dentin. **Journal of the Mechanical Behavior Biomed Materials**, v.29, p.427-37, 2014.

CHEN, M. H. Update on dental nanocomposites. **Journal of Dental Research**, v.89, n.6, p.549-60, 2010.

CHU, S. J.; TRUSHKOWSKY, R. D. ; PARAVINA, R. D. Dental color matching instruments and systems. Review of clinical and research aspects. **Journal of Dentistry**, v.38 Suppl 2, p.e2-16, 2010.

CHUN, K. J. ; LEE, J. Y. Comparative study of mechanical properties of dental restorative materials and dental hard tissues in compressive loads. **Journal of Dental Biomechanics**, v.5, p.1-6, 2014.

CIE Technical report: colorimetry. CIE Pub No. 15.3. Vienna, Austria: CIE Central Bureau; 2004.

COELHO, C. S.; BIFFI, J. C.; SILVA, G. R.; ABRAHAO, A.; CAMPOS, R. E. ; SOARES, C. J. Finite element analysis of weakened roots restored with composite resin and posts. **Dental Materials**, v.28, n.6, p.671-8, 2009.

DA COSTA, J.; VARGAS, M.; SWIFT, E. J., JR.; ANDERSON, E. ; RITTER, S. Color and contrast ratio of resin composites for whitened teeth. **Journal of Dentistry**, v.37 Suppl 1, p.e27-33, 2009.

DE ANDRADE, A. K.; DUARTE, R. M.; MEDEIROS E SILVA, F. D.; BATISTA, A. U.; LIMA, K. C.; MONTEIRO, G. Q. ; MONTES, M. A. Resin composite class I restorations: a 54-month randomized clinical trial. **Operative Dentistry**, v.39, n.6, p.588-94, 2014.

DECERLE, N.; BESSADET, M.; MUNOZ-SANCHEZ, M. L.; ESCHEVINS, C.; VEYRUNE, J. ; NICOLAS, E. Evaluation of Cerec endocrowns: a preliminary cohort study. **European Journal of Prosthodontics Restorative Dentistry**, v.22, n.2, p.89-95, 2014.

DELIPERI, S. Direct fiber-reinforced composite restoration in an endodontically-treated molar: a three-year case report. **Operative Dentistry**, v.33, n.2, p.209-14, 2008.

DE SOUZA, G.; BRAGA, R. R.; CESAR, P. F.; LOPES, G. C. Correlation between clinical performance and degree of conversion of resin cements: a literature review. **Journal of Applied Oral Science**, v.23, n.4, p.358-68, 2015.

DRELICH, J. Nanoparticles in a liquid: new state of liquid? **Journal Nanomater Mol Nanotech**, v.2, n.1, p. 1-2, 2013.

EL-DAMANHOURY, H. ; PLATT, J. Polymerization shrinkage stress kinetics and related properties of bulk-fill resin composites. **Operative Dentistry**, v.39, n.4, p.374-82, 2014.

EL-DAMANHOURY, H. M.; HAJ-ALI, R. N. ; PLATT, J. A. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. **Operative Dentistry**, v.40, n.2, p.201-10, 2015.

ELIGUZELOGLU, E.; ERASLAN, O.; OMURLU, H.; ESKITASCIOGLU, G. ; BELLI, S. Effect of hybrid layer and thickness on stress distribution of cervical wedge-shaped restorations. **European Journal of Dentistry**, v.4, n.2, p.160-5, 2010.

F, A. A.; NATHANSON, D.; MORGANO, S. M. ; BABA, N. Z. Fracture resistance and failure mode of fatigued endodontically treated teeth restored with fiber-reinforced resin posts and metallic posts in vitro. **Dental Traumatology**, v.30, n.4, p.317-25, 2014.

FERRACANE, J. L. Hygroscopic and hydrolytic effects in dental polymer networks. **Dental Materials**, v.22, n.3, p.211-22, 2006.

FERRACANE, J. L. Resin composite--state of the art. **Dental Materials**, v.27, n.1, p.29-38, 2011.

FONSECA, A. S.; GERHARDT, K. M.; PEREIRA, G. D.; SINHORETI, M. A. ; SCHNEIDER, L. F. Do new matrix formulations improve resin composite resistance to degradation processes? **Brazilian Oral Research**, v.27, n.5, p.410-6, 2013.

FONTES, S. T.; FERNANDEZ, M. R.; DE MOURA, C. M. ; MEIRELES, S. S. Color stability of a nanofill composite: effect of different immersion media. **Journal of Applied Oral Science**, v.17, n.5, p.388-91, 2009.

FORBERGER, N. ; GOHRING, T. N. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. **Journal of Prosthetic Dentistry**, v.100, n.4, p.264-73, 2008.

GHINEA, R.; PEREZ, M. M.; HERRERA, L. J.; RIVAS, M. J.; YEBRA, A. ; PARAVINA, R. D. Color difference thresholds in dental ceramics. **Journal of Dentistry**, v.38 Suppl 2, p.e57-64, 2010.

GORACCI, C. ; FERRARI, M. Current perspectives on post systems: a literature review. **Australian Dental Journal**, v.56 Suppl 1, p.77-83, 2011.

GREGOR, L.; BOUILLAGUET, S.; ONISOR, I.; ARDU, S.; KREJCI, I. ; ROCCA, G. T. Microhardness of light- and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns. **Journal of Prosthetic Dentistry**, v.112, n.4, p.942-8, 2014.

GRESNIGT, M. M.; OZCAN, M.; VAN DEN HOUTEN, M. L.; SCHIPPER, L. ; CUNE, M. S. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. **Dental Materials**, v.32, n.5, p.607-14, 2016.

GUNCU, M. B.; CAKAN, U.; MUHTAROGULLARI, M. ; CANAY, S. Zirconia-based crowns up to 5 years in function: a retrospective clinical study and evaluation of prosthetic restorations and failures. **International Journal of Prosthodontics**, v.28, n.2, p.152-7, 2015.

HAMBURGER, J. T.; OPDAM, N. J.; BRONKHORST, E. M. ; HUYSMANS, M. C. Indirect restorations for severe tooth wear: fracture risk and layer thickness. **Journal of Dentistry**, v.42, n.4, p.413-8, 2014.

HERNANDES, D. K.; ARRAIS, C. A.; LIMA, E.; CESAR, P. F. ; RODRIGUES, J. A. Influence of resin cement shade on the color and translucency of ceramic veneers. **Journal of Applied Oral Science**, v.24, n.4, p.391-6, 2016.

HIGGINS, J.P.T.; GREEN, S. Cochrane handbook for systematic reviews of interventions. **Wiley-Blackwell**, v.1, p.673, 2008.

IKEDA, T.; SIDHU, S. K.; OMATA, Y.; FUJITA, M. ; SANO, H. Colour and translucency of opaque-shades and body-shades of resin composites. **European Journal Oral Science**, v.113, n.2, p.170-3, 2005.

IVOCLAR VIVADENT. IPS InLine® Instructions for Use. Retrieved online on November 29, 2014 from: http://www.ivoclarvivadent.us/en/products/metalceramics/ips-inline-system/ips-inline. **Ivoclar Vivadent**, p. 20-23, 2012.

JOHNSTON, W. M.; MA, T. ; KIENLE, B. H. Translucency parameter of colorants for maxillofacial prostheses. **International Journal of Prosthodontics**, v.8, n.1, p.79-86, 1995.

JOTKOWITZ, A. ; SAMET, N. Rethinking ferrule--a new approach to an old dilemma. **Brazilian Dental Journal**, v.209, n.1, p.25-33, 2010.

KAIZER MDA, R.; DIESEL, P. G.; MALLMANN, A. ; JACQUES, L. B. Ageing of silorane-based and methacrylate-based composite resins: effects on translucency. **Journal of Dentistry**, v.40 Suppl 1, p.e64-71, 2012.

KARABELA, M. M. ; SIDERIDOU, I. D. Effect of the structure of silane coupling agent on sorption characteristics of solvents by dental resin-nanocomposites. **Dental Materials**, v.24, n.12, p.1631-9, 2008.

KIM, D. H. ; PARK, S. H. Evaluation of resin composite translucency by two different methods. **Operative Dentistry**, v.38, n.3, p.E1-15, 2013.

KIM, R. J.; KIM, Y. J.; CHOI, N. S. ; LEE, I. B. Polymerization shrinkage, modulus, and shrinkage stress related to tooth-restoration interfacial debonding in bulk-fill composites. **Journal of Dentistry**, v.43, n.4, p.430-9, 2015.

KWON, S. R.; OYOYO, U. ; LI, Y. Influence of application techniques on contact formation and voids in anterior resin composite restorations. **Operative Dentistry**, v.39, n.2, p.213-20, 2014.

LANDER, E. ; DIETSCHI, D. Endocrowns: a clinical report. **Quintessence International**, v.39, n.2, p.99-106, 2008.

LAZARI, P. C.; OLIVEIRA, R. C.; ANCHIETA, R. B.; ALMEIDA, E. O.; FREITAS JUNIOR, A. C.; KINA, S. ; ROCHA, E. P. Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite element analysis based on micro-CT data. **Journal of Applied Oral Science**, v.21, n.6, p.511-7, 2013.

LEE, Y. K. Influence of filler on the difference between the transmitted and reflected colors of experimental resin composites. **Dental Materials**, v.24, n.9, p.1243-7, 2008.

LI, X.; LIU, W.; SUN, L.; AIFANTIS, K. E.; YU, B.; FAN, Y.; FENG, Q.; CUI, F. ; WATARI, F. Resin composites reinforced by nanoscaled fibers or tubes for dental regeneration. **Biomedical Research International**, v.2014, p.542958, 2014.

LIN, C. L.; CHANG, Y. H.; HSIEH, S. K. ; CHANG, W. J. Estimation of the failure risk of a maxillary premolar with different crack depths with endodontic treatment by computer-aided design/computer-aided manufacturing ceramic restorations. **Journal of Endodontics**, v.39, n.3, p.375-9, 2013.

LIN, C. L.; CHANG, Y. H. ; PA, C. A. Estimation of the risk of failure for an endodontically treated maxillary premolar with MODP preparation and CAD/CAM ceramic restorations. **Journal of Endodontics**, v.35, n.10, p.1391-5, 2009.

LIN, C. L.; CHANG, Y. H. ; PAI, C. A. Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. **Dental Materials**, v.27, n.5, p.431-8, 2011.

LLENA, C.; FERNANDEZ, S. ; FORNER, L. Color stability of nanohybrid resin-based composites, ormocers and compomers. **Clinical Oral Investigation**, v.21, n.4, p.1071-1077, 2017.

LOHBAUER, U.; BELLI, R. ; FERRACANE, J. L. Factors involved in mechanical fatigue degradation of dental resin composites. **Journal of Dental Research**, v.92, n.7, p.584-91, 2013.

MAGNE, P.; CARVALHO, A. O.; BRUZI, G.; ANDERSON, R. E.; MAIA, H. P. ; GIANNINI, M. Influence of no-ferrule and no-post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns. **Operative Dentistry**, v.39, n.6, p.595-602, 2014.

MANTRI, S. P. ; MANTRI, S. S. Management of shrinkage stresses in direct restorative light-cured composites: a review. **Journal of Esthetic and Restorative Dentistry**, v.25, n.5, p.305-13, 2013.

MAYER, G. New toughening concepts for ceramic composites from rigid natural materials. **Journal of the Mechanical Behavior Biomedical Materials**, v.4, n.5, p.670-81, 2011.

MEIRELES, S. S.; SANTOS, I. S.; BONA, A. D. ; DEMARCO, F. F. A double-blind randomized clinical trial of two carbamide peroxide tooth bleaching agents: 2-year follow-up. **Journal of Dentistry**, v.38, n.12, p.956-63, 2010.

MILETIC, V.; JAKOVLJEVIC, N.; MANOJLOVIC, D.; MARJANOVIC, J.; ROSIC, A. A. ; DRAMICANIN, M. D. Refractive indices of unfilled resin mixtures and cured composites related to color and translucency of conventional and low-shrinkage composites. **Journal of Biomedical Materials Research B Applied Biomaterials**, v.105, n.1, p.7-13, 2017.

MOHER, D.; LIBERATI, A.; TETZLAFF, J.; ALTMAN, D. G. ; GROUP, P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. **Journal of Clinical Epidemiology**, v.62, n.10, p.1006-12, 2009.

MOTTA, A. B.; PEREIRA, L. C.; DUDA, F. P. ; ANUSAVICE, K. J. Influence of substructure design and occlusal reduction on the stress distribution in metal ceramic complete crowns: 3D finite element analysis. **Journal of Prosthodontics**, v.23, n.5, p.381-9, 2014.

MUNCHOW, E. A.; SEDREZ-PORTO, J. A.; PIVA, E.; PEREIRA-CENCI, T. ; CENCI, M. S. Use of dental adhesives as modeler liquid of resin composites. **Dental Materials**, v.32, n.4, p.570-7, 2016.

MUNCHOW, E. A.; ZANCHI, C. H.; OGLIARI, F. A.; SILVA, M. G.; DE OLIVEIRA, I. R. ; PIVA, E. Replacing HEMA with alternative dimethacrylates in dental adhesive systems: evaluation of polymerization kinetics and physicochemical properties. **Journal of Adhesive Dentistry**, v.16, n.3, p.221-8, 2014.

ORTENGREN, U.; ANDERSSON, F.; ELGH, U.; TERSELIUS, B. ; KARLSSON, S. Influence of pH and storage time on the sorption and solubility behaviour of three composite resin materials. **Journal of Dentistry**, v.29, n.1, p.35-41, 2001.

OTTO, T. Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. **International Journal Periodontics Restorative Dentistry**, v.24, n.5, p.446-55, 2004.

OZAKAR ILDAY, N.; CELIK, N.; BAYINDIR, Y. Z. ; SEVEN, N. Effect of water storage on the translucency of silorane-based and dimethacrylate-based composite resins with fibres. **Journal of Dentistry**, v.42, n.6, p.746-52, 2014.

PARAVINA, R. D.; GHINEA, R.; HERRERA, L. J.; BONA, A. D.; IGIEL, C.; LINNINGER, M.; SAKAI, M.; TAKAHASHI, H.; TASHKANDI, E. ; PEREZ MDEL, M. Color difference thresholds in dentistry. **Journal Esthetic Restorative Dentistry**, v.27 Suppl 1, p.S1-9, 2015.

PATEL, M. P.; DAVY, K. W. ; BRADEN, M. Refractive index and molar refraction of methacrylate monomers and polymers. **Biomaterials**, v.13, n.9, p.643-5, 1992.

PECHO, O. E.; GHINEA, R.; ALESSANDRETTI, R.; PEREZ, M. M. ; DELLA BONA, A. Visual and instrumental shade matching using CIELAB and CIEDE2000 color difference formulas. **Dental Materials**, v.32, n.1, p.82-92, 2016.

PECHO, O. E.; GHINEA, R.; PEREZ, M. M. ; DELLA BONA, A. Influence of Gender on Visual Shade Matching in Dentistry. **Journal Esthetic Restorative Dentistry**, v.29, n.2, p.E15-E23, 2017.

PRODAN, D. A.; GASPARIK, C.; MADA, D. C.; MICLAUS, V.; BACIUT, M. ; DUDEA, D. Influence of opacity on the color stability of a nanocomposite. **Clinical Oral Investigation**, v.19, n.4, p.867-75, 2015.

RAGAUSKA, A.; APSE, P.; KASJANOVS, V. ; BERZINA-CIMDINA, L. Influence of ceramic inlays and composite fillings on fracture resistance of premolars in vitro. **Stomatologija**, v.10, n.4, p.121-6, 2008.

RAMIREZ-SEBASTIA, A.; BORTOLOTTO, T.; CATTANI-LORENTE, M.; GINER, L.; ROIG, M. ; KREJCI, I. Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength. **Clinical Oral Investigation**, v.18, n.2, p.545-54, 2014.

RAMIREZ-SEBASTIA, A.; BORTOLOTTO, T.; ROIG, M. ; KREJCI, I. Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation. **Operative Dentistry**, v.38, n.6, p.663-73, 2013.

RAMOS, G. F.; MONTEIRO, E. B.; BOTTINO, M. A.; ZHANG, Y. ; MARQUES DE MELO, R. Failure Probability of Three Designs of Zirconia Crowns. **International Journal Periodontics Restorative Dentistry**, v.35, n.6, p.843-9, 2015.

ROCCA, G. T. ; KREJCI, I. Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns. **European Journal Esthetic Dentistry**, v.8, n.2, p.156-79, 2013.

ROCCA, G. T.; SARATTI, C. M.; PONCET, A.; FEILZER, A. J. ; KREJCI, I. The influence of FRCs reinforcement on marginal adaptation of CAD/CAM composite resin endocrowns after simulated fatigue loading. **Odontology**, v.104, n.2, p.220-32, 2016.

RODRIGUES FILHO, L. E.; BURGER, L. A.; KENSHIMA, S.; BAUER, J. R.; MEDEIROS, I. S. ; MUENCH, A. Effect of light-activation methods and water storage on the flexural strength of two composite resins and a compomer. **Brazilian Oral Research**, v.20, n.2, p.143-7, 2006.

ROSA, W. L.; PIVA, E. ; SILVA, A. F. Bond strength of universal adhesives: A systematic review and meta-analysis. **Journal of Dentistry**, v.43, n.7, p.765-76, 2015.

ROSCOE, M. G.; NORITOMI, P. Y.; NOVAIS, V. R. ; SOARES, C. J. Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. **Journal of Prosthetic Dentistry**, v.110, n.2, p.116-26, 2013.

RUBEN, J. L.; ROETERS, F. J.; MONTAGNER, A. F. ; HUYSMANS, M. C. A multifunctional device to simulate oral ageing: the "Rub&Roll". **Journal of Mechanical Behavior Biomedical Materials**, v.30, p.75-82, 2014.

RUYTER, I. E.; NILNER, K. ; MOLLER, B. Color stability of dental composite resin materials for crown and bridge veneers. **Dental Materials**, v.3, n.5, p.246-51, 1987.

SARKIS-ONOFRE, R.; JACINTO, R. C.; BOSCATO, N.; CENCI, M. S. ; PEREIRA-CENCI, T. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. **Journal of Dentistry**, v.42, n.5, p.582-7, 2014.

SARKIS-ONOFRE, R.; SKUPIEN, J. A.; CENCI, M. S.; MORAES, R. R. ; PEREIRA-CENCI, T. The role of resin cement on bond strength of glass-fiber posts luted into root canals: a systematic review and meta-analysis of in vitro studies. **Operative Dentistry**, v.39, n.1, p.E31-44, 2014.

SCHMIDLIN, P. R.; STAWARCZYK, B.; DEABREU, D.; BINDL, A.; ENDER, A. ; ICHIM, I. P. Fracture resistance of endodontically treated teeth without ferrule using a novel H-shaped short post. **Quintessence International**, v.46, n.2, p.97-108, 2015.

SEDREZ-PORTO, J. A.; MUNCHOW, E. A.; BRONDANI, L. P.; CENCI, M. S. ; PEREIRA-CENCI, T. Effects of modeling liquid/resin and polishing on the color change of resin composite. **Brazilian Oral Research**, v.30, n.1, 2016.

SEDREZ-PORTO, J. A.; ROSA, W. L.; DA SILVA, A. F.; MUNCHOW, E. A. ; PEREIRA-CENCI, T. Endocrown restorations: A systematic review and meta-analysis. **Journal of Dentistry**, v.52, p.8-14, 2016.

SIDERIDOU, I. D.; KARABELA, M. M. ; VOUVOUDI, E. Physical properties of current dental nanohybrid and nanofill light-cured resin composites. **Dental Materials**, v.27, n.6, p.598-607, 2011.

SILVA, G. R.; SANTOS-FILHO, P. C.; SIMAMOTO-JUNIOR, P. C.; MARTINS, L. R.; MOTA, A. S. ; SOARES, C. J. Effect of post type and restorative techniques on the strain and fracture resistance of flared incisor roots. **Brazilian Dental Journal**, v.22, n.3, p.230-7, 2011.

SKUPIEN, J. A.; CENCI, M. S.; OPDAM, N. J.; KREULEN, C. M.; HUYSMANS, M. C. ; PEREIRA-CENCI, T. Crown vs. composite for post-retained restorations: A randomized clinical trial. **Journal of Dentistry**, v.48, p.34-9, 2016.

SOARES, C. J.; PIZI, E. C.; FONSECA, R. B. ; MARTINS, L. R. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. **Brazilian Oral Research**, v.19, n.1, p.11-6, 2005.

SOARES, C. J.; VALDIVIA, A. D.; DA SILVA, G. R.; SANTANA, F. R. ; MENEZES MDE, S. Longitudinal clinical evaluation of post systems: a literature review. **Brazilian Dental Journal**, v.23, n.2, p.135-740, 2012.

SORRENTINO, R.; DI MAURO, M. I.; FERRARI, M., LEONE, R.; ZARONE, F. Complications of endodontically treated teeth restored with fiber posts and single crowns or fixed dental prostheses-a systematic review. **Clinical Oral Investigation**, v.20, n.7, p.1449-57, 2016.

TAKESHIGE, F.; KAWAKAMI, Y.; HAYASHI, M. ; EBISU, S. Fatigue behavior of resin composites in aqueous environments. **Dental Materials**, v.23, n.7, p.893-9, 2007.

TAN, B. L.; YAP, A. U.; MA, H. N.; CHEW, J. ; TAN, W. J. Effect of beverages on color and translucency of new tooth-colored restoratives. **Operative Dentistry**, v.40, n.2, p.E56-65, 2015.

TAY, F. R. ; PASHLEY, D. H. Monoblocks in root canals: a hypothetical or a tangible goal. **Journal of Endodontics**, v.33, n.4, p.391-8, 2007.

TUNCER, S.; DEMIRCI, M.; TIRYAKI, M.; UNLU, N. ; UYSAL, O. The effect of a modeling resin and thermocycling on the surface hardness, roughness, and color of different resin composites. **Journal of Esthetic and Restoration Dentistry**, v.25, n.6, p.404-19, 2013.

YE, Q.; SPENCER, P.; WANG, Y. ; MISRA, A. Relationship of solvent to the photopolymerization process, properties, and structure in model dentin adhesives. **Journal of Biomedical Materials Research A**, v.80, n.2, p.342-50, 2007.

YEH, C. J. Fatigue root fracture: a spontaneous root fracture in non-endodontically treated teeth. **Brazilian Dental Journal**, v.182, n.7, p.261-6, 1997.

ZARONE, F.; SORRENTINO, R.; APICELLA, D.; VALENTINO, B.; FERRARI, M.; AVERSA, R. ; APICELLA, A. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. **Dental Materials**, v.22, n.11, p.1035-44, 2006.

ZHU, Z.; DONG, X. Y.; HE, S.; PAN, X. ; TANG, L. Effect of Post Placement on the Restoration of Endodontically Treated Teeth: A Systematic Review. **International Journal of Prosthodontics**, v.28, n.5, p.475-83, 2015.

ZORZIN, J.; MAIER, E.; HARRE, S.; FEY, T.; BELLI, R.; LOHBAUER, U.; PETSCHELT, A. ; TASCHNER, M. Bulk-fill resin composites: polymerization properties and extended light curing. **Dental Materials**, v.31, n.3, p.293-301, 2015.

Apêndices

Apêndice A – Nota da Tese

Nota da Tese

Influência do tipo de material e protocolo restaurador no desempenho físico-mecânico de restaurações *endocrown*.

Influence of the restorative material and restorative protocol on the physic-mechanical performance of endocrown restorations.

A presente tese avaliou diferentes fatores relacionados à reabilitação de dentes tratados endodonticamente e com grande destruição coronária que vêm sendo discutidos na literatura. Dentre as diversas modalidades de tratamento nestes casos complexos, apresentam-se as restaurações *endocrown*. No entanto, existem poucos estudos relacionados à técnica *endocrown* que apresentem uma boa qualidade científica. Essa tese discutiu as variáveis envolvidas no desempenho físico-mecânico de restaurações *endocrown*, apresentando novas perspectivas quanto ao uso dessas restaurações. Através dos estudos desenvolvidos, restaurações *endocrown* demonstraram potencial aplicação para a reabilitação de dentes tratados endodonticamente e que apresentem grande destruição coronária. Aliado a isto, as restaurações poderão apresentar-se mais resistentes à fratura e com melhor capacidade de reparo após sofrer fratura, quando aliado ao uso de líquidos modeladores de resina composta, prática clínica também avaliada nesta tese, na qual mostrou que a presença de resina adesiva entre as camadas de resina composta, favoreceu o desempenho físico-mecânico do material, aumentando a sua resistência à degradação e à alteração de cor/translucidez.

Campo da pesquisa: Clínica Odontológica/Materias Dentários.

Candidato: José Augusto Sedrez Porto, Cirurgião-dentista (2013) e Mestre em Odontologia (Prótese Dentária) pela Universidade Federal de Pelotas (2015).

Data da defesa e horário: 26/05/2017 às 14:00 horas.

Local: Auditório do Programa de Pós-graduação em Odontologia da Universidade Federal de Pelotas. 5º andar da Faculdade de Odontologia de Pelotas. Rua Gonçalves Chaves, 457.

Membros da banca: Prof. Dr. Aloísio Oro Spazzin, Prof. Dr. Rafael Sarkis Onofre, Prof. Dra. Giana da Silveira Lima, Prof. Dr. Mateus Bertolini Fernandes dos Santos, Prof. Dr. Carlos José Soares (Suplente) e Prof. Dr. Rafael Ratto de Moraes (Suplente).

Orientadora: Profa. Dra. Tatiana Pereira Cenci

Co-orientador: Prof. Dr. Eliseu Aldrighi Münchow

Informação de contato: José Augusto Sedrez Porto, jsedrezporto@gmail.com, Rua Gonçalves Chaves, 457- Programa de Pós-Graduação em Odontologia.

Apêndice B – Súmula do currículo do candidato

Súmula do currículo

José Augusto Sedrez Porto, nasceu em 08 de abril de 1986, em Pelotas, Rio Grande do Sul (RS). Completou o ensino fundamental e médio em Escola pública na cidade de Pinheiro Machado, RS. Possui graduação em Odontologia pela Universidade Federal de Pelotas (2013). Realizou mestrado (2015) em Odontologia (Prótese Dentária) no Programa de Pós-graduação em Odontologia da Universidade Federal de Pelotas, onde atualmente realiza doutorado com orientação da Profa. Dra. Tatiana Pereira Cenci. Realizou aperfeiçoamento em Dentística – ênfase na área estética em dentes anteriores e posteriores, no Instituto de Ensino, Aperfeiçoamento e Pesquisa em Odontologia do Mercosul (IEAPOM), Porto Alegre, RS (2015). Desenvolve pesquisas relacionadas à longevidade de restaurações de dentes tratados endodonticamente com extenso comprometimento coronário e fatores associados. Apresenta experiência em odontologia baseada em evidência, tendo foco em ensaios clínicos, pesquisas científicas laboratoriais e revisões sistemáticas. Atualmente, cursa especialização em Ortodontia, no IEAPOM, Porto Alegre, RS e trabalha como Cirurgião-dentista do Exército Brasileiro no 12º Regimento de Cavalaria Mecanizado, Jaguarão, RS.

Publicações:

Cleaning methods for removable dentures: A critical review of the literature. SEDREZ-PORTO JA, SANTOS MBF, PEREIRA-CENCI T. Brazilian Dental Science. 2016.

Use of dental adhesives as modeler liquid of resin composites. MÜNCHOW EA, SEDREZ-PORTO JA, PIVA E, PEREIRA-CENCI T, CENCI MS. Dental Materials. 2016.

Accuracy of color measurement of endondontically treated teeth after aging. PEREIRA-CENCI T, SKUPIEN JA, SEDREZ-PORTO JA, JACOBOVITZ M, DELLA-BONA A, PAPPEN FG. Brazilian Dental Science. 2016.

Endocrown restorations: A systematic review and meta-analysis. SEDREZ-PORTO JA, ROSA WLO, DA SILVA AF, MÜNCHOW EA, PEREIRA-CENCI, T. Journal of Dentistry. 2016.

Effects of modeling liquid/resin and polishing on the color change of resin composite. SEDREZ-PORTO JA; MÜNCHOW EA, BRONDANI LP, CENCI MS, PEREIRA-CENCI T. Brazilian Oral Research. 2016.

Impairment of resin cement application on the bond strength of indirect composite restorations. SKUPIEN JA, PORTO, JAS, MÜNCHOW EA, CENCI MS, Pereira-Cenci T. Brazilian Oral Research. 2015.

Invited Commentary: Should Occlusal Splints Be a Routine Prescription for Diagnosed Bruxers Undergoing Implant Therapy? MESKO M, ALMEIDA R, PORTO J, KOLLER C, ROSA W, BOSCATO N. The International Journal of Prosthodontics. 2014.

Anexos

Anexo A

Parecer do Comitê de Ética

FACULDADE DE ODONTOLOGIA DA UNIVERSIDADE FEDERAL DE

Plataforma Brasil

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Influência do tipo de material e protocolo restaurador no desempenho físico-mecânico de restaurações endocrown

Pesquisador: Tatiana Pereira Cenci

Área Temática:

Versão: 2

CAAE: 53852616.0.0000.5318

Instituição Proponente: Faculdade de Odontologia da Universidade Federal de Pelotas/ FO-UFPel

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 1.634.774

Apresentação do Projeto:

Este projeto tem por objetivo realizar uma revisão da literatura, testes mecânicos e fiscas sobre resinas confeccionadas com técnicas diferentes e, de interesse ao CEP testar, em dentes molares extraídos, o efeito de dois materiais restauradores e da técnica de confecção desta restauração sobre a resistência à fadiga da mesma.

Objetivo da Pesquisa:

Além da revisão da literatura e da obtenção dos dados sobre propriedades físicas e mecânicas da restauração o projeto visa tentar elucidar qual a técnica/material de confecção de restaurações em dentes molares extensamente destruídos mostra-se mais resistente, in vitro, à fadiga.

Avaliação dos Riscos e Benefícios:

Os autores propõem uma seleção dos dentes a serem utilizados, a fim de evitar o uso de dentes que não trariam benefícios à pesquisa, evitando a destruição inútil dos dentes. A resposta à indagação dos pesquisadores é de interesse da odontologia e pode vir a contribuir com melhores protocolos restauradores.

Comentários e Considerações sobre a Pesquisa:

A pesquisa é justificada e bem delineada. Apresenta-se documento em que a mesma foi aprovada em análise de qualificação por banca competente para tal. Não foram descritos os paramêtros referentes à indicação de falha por fadiga das restaurações. Os pesquisadores e banca, entretanto, pertencem a grupo de pesquisa qualificado à execução deste teste, o que pode tornar sua descrição desnecessária.

Considerações sobre os Termos de apresentação obrigatória:

Todos apresentados de forma adequada

Recomendações:

Nenhuma

Conclusões ou Pendências e Lista de Inadequações:

Nenhuma pendência e todas as solicitações do parecer número 1.478.606 foram acatadas de forma adequada.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_665480.pdf	13/05/2016 16:03:40		Aceito
Outros	Item3_Justificativa_de_dispensa_do_TCLE.pdf	13/05/2016 16:02:27	Tatiana Pereira Cenci	Aceito
Outros	Item2_Cronograma_Estudos_com_o_uso_de_dentes_humanos.pdf	13/05/2016 16:02:00	Tatiana Pereira Cenci	Aceito
Outros	Item1e4_Declaracao_do_BancosdeDentes_UNOES0008.pdf	13/05/2016 16:01:23	Tatiana Pereira Cenci	Aceito
Outros	ProjetoAdequadoTeseJoseAugustoSPorto13052016.pdf	13/05/2016 16:00:39	Tatiana Pereira Cenci	Aceito
Outros	Carta_Resposta.pdf	13/05/2016 16:00:02	Tatiana Pereira Cenci	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	Termo_de_Consentimento_Livre_e_Esclarecido.pdf	25/02/2016 17:05:45	Jose Augusto Sedrez Porto	Aceito
Outros	Qualificacao_aprovada_de_Tese_PPGO.pdf	23/02/2016 23:48:29	Jose Augusto Sedrez Porto	Aceito
Orçamento	Orcamento.pdf	23/02/2016 23:35:03	Jose Augusto Sedrez Porto	Aceito
Cronograma	CronogramaFinal.pdf	23/02/2016 23:34:03	Jose Augusto Sedrez Porto	Aceito
Projeto Detalhado	ProjetoFinalTeseJoseAugustoSPorto0	23/02/2016	Jose Augusto	Aceito

Endereço: Rua Gonçalves Chaves, 457
Bairro: Centro **CEP:** 96.015-560
UF: RS **Município:** PELOTAS
Telefone: (53)3222-4439 **Fax:** (53)3222-4439 **E-mail:** cep.fop@gmail.com

/ Brochura Investigador	22016.pdf	23:30:42	Sedrez Porto	Aceito
Folha de Rosto	Folha_de_Rosto.pdf	23/02/2016 23:02:09	Jose Augusto Sedrez Porto	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

PELOTAS, 13 de Julho de 2016

Assinado por:
ANDREIA MORALES CASCAES
(Coordenador)

Endereço: Rua Gonçalves Chaves, 457
Bairro: Centro **CEP:** 96.015-560
UF: RS **Município:** PELOTAS
Telefone: (53)3222-4439 **Fax:** (53)3222-4439 **E-mail:** cep.fop@gmail.com

Anexo B

Declaração de doação de dentes humanos – Banco de Dentes Humanos/ Universidade do Oeste de Santa catarina

UNOESC

Universidade do Oeste de Santa Catarina

DECLARAÇÃO

Declaro para os devidos fins e efeitos legais que o Banco de Dentes Humanos da UNOESC aprovado pelo CEP número 157/09 em 18 de outubro de 2009, objetivando atender as exigências para a obtenção de parecer do Comitê de Ética em Pesquisa com Seres Humanos, e como representante legal da Instituição, Universidade do Oeste de Santa Catarina - UNOESC, tenho conhecimento do projeto de pesquisa: INFLUÊNCIA DO TIPO DE MATERIAL E PROTOCOLO RESTAURADOR NO DESEMPENHO FÍSICO-MECÂNICO DE RESTAURAÇÕES ENDOCROWN, e nos comprometemos a fornecer os dentes humanos necessários para o desenvolvimento da pesquisa.

Joaçaba, 02/05/2016

Professora Ms. Léa Maria Franceschi Dallanora.

Responsável técnica