UNICAMP

ADRIANA OLIVEIRA CARVALHO

“INFLUENCE OF RESTORATIVE MATERIAL AND TECHNIQUE ON THE MECHANICAL PERFORMANCE OF INDIRECT RESTORATIONS OF ENDODONTICALLY TREATED MOLARS OR NOT”

“INFLUÊNCIA DO MATERIAL E TÉCNICA RESTAURADORA NA PERFORMANCE MECÂNICA DE COROAS INDIRETAS SOBRE MOLARES TRATADOS ENDODONTICAMENTE OU NÃO”

PIRACICABA
2013

UNICAMP

UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

ADRIANA OLIVEIRA CARVALHO

"INFLUENCE OF RESTORATIVE MATERIAL AND TECHNIQUE ON THE MECHANICAL PERFORMANCE OF INDIRECT RESTORATIONS OF ENDODONTICALLY TREATED MOLARS OR NOT"

Orientador: Prof. Dr. Marcelo Giannini

Co-orientador: Prof. Dra Marcela Rocha de Oliveira Carrilho

"INFLUÊNCIA DO MATERIAL E TÉCNICA RESTAURADORA NA PERFORMANCE MECÂNICA DE COROAS INDIRETAS SOBRE MOLARES TRATADOS ENDODONTICAMENTE OU NÃO."

Tese de Doutorado apresentada ao Programa de Pós-Graduação em Materiais Dentários da Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas para a obtenção do título de doutora em Materiais Dentários.

Doctorate thesis presented to the Dental Materials Postgraduation Programme of the Piracicaba Dental School of the State University of Campinas to obtain the Ph.D. grade in Dental Materials.

Este exemplar corresponde à versão final da tese defendida pela aluna Adriana Oliveira Carvalho e orientada pelo Prof. Dr. Marcelo Giannini.

PIRACICABA, 2013

FICHA CATALOGRÁFICA ELABORADA POR
JOSIDELMA F COSTA DE SOUZA – CRB8/5894 - BIBLIOTECA DA
FACULDADE DE ODONTOLOGIA DE PIRACICABA DA UNICAMP

C253i

Carvalho, Adriana Oliveira, 1981-
Influência do material e técnica restauradora na performance mecânica de coroas indiretas sobre molares tratados endodonticamente ou não / Adriana Oliveira Carvalho. -- Piracicaba, SP : [s.n.], 2013.

Orientador: Marcelo Giannini.
Coorientadora: Marcela Rocha de Oliveira Carrilho.
Tese (Doutorado) - Universidade Estadual de Campinas, Faculdade de Odontologia de Piracicaba.

1. Coroas. 2. Sistemas CAD/CAM. I. Giannini, Marcelo, 1969- II. Magne, Pascal. III.Universidade Estadual de Campinas. Faculdade de Odontologia de Piracicaba. IV. Título.

Informações para a Biblioteca Digital

Título em Inglês: Influence of restorative material and technique on the mechanical performance of indirect restoratios of endodontically treated molars or not
Palavras-chave em Inglês:
Crowns
CAD/CAM systems
Área de concentração: Materiais Dentários
Titulação: Doutora em Materiais Dentários
Banca examinadora:
Marcelo Giannini [Orientador]
Paulo Francisco César
Paulo Vicente Rocha
André Figueiredo Reis
Regina Maria Puppin Rontan
Data da defesa: 25-01-2013
Programa de Pós-Graduação: Materiais Dentários

UNIVERSIDADE ESTADUAL DE CAMPINAS
Faculdade de Odontologia de Piracicaba

A Comissão Julgadora dos trabalhos de Defesa de Tese de Doutorado, em sessão pública realizada em 25 de Janeiro de 2013, considerou a candidata ADRIANA OLIVEIRA CARVALHO aprovada.

Prof. Dr. MARCELO GIANNINI

Prof. Dr. PAULO FRANCISCO CESAR

Prof. Dr. PAULO VICENTE BARBOSA DA ROCHA

Profa. Dra. REGINA MARIA PUPPIN RONTANI

Prof. Dr. ANDRÉ FIGUEIREDO REIS

DEDICO ESTE TRABALHO,

A **Deus**, por iluminar o meu caminho e me amparar nesta jornada...

Aos meus pais, **Adelço e Diana,** por não pouparem esforços na minha formação educacional e profissional. Por estarem sempre presentes, mesmo longe, em todos os momentos da minha vida, orientando minhas atitudes, e mais do que ninguém, torcendo sempre por mim.

Aos meus irmãos **Del** e **Jorginho,** pela amizade, força e apoio em todas as minhas decisões.

A **Roni** pelo carinho, paciência e compreensão quanto à necessidade da minha ausência.

A **Vó Iá** (*in memorian*) e meu **avô Antonio** (*in memorian*), pela torcida incondicional pela minha vitória.

A **Dinda, Tio Luis e Keyla** por estarem sempre torcendo pela realização deste sonho.

A minha amada afilhada **Maria Carolina**, que você chegue cheia de saúde e nos traga muita alegria!

AGRADECIMENTOS ESPECIAIS

Ao meu orientador **Prof. Dr. Marcelo Giannini,** por ser um orientador brilhante! A palavra obrigada é insuficiente para agradecê-lo pelos ensinamentos, conselhos, incentivos, oportunidades oferecidas e confiança em mim depositada. Sempre serei grata pela sua contribuição na minha formação.

Ao meu orientador no exterior **Prof. Dr. Pascal Magne**, por ter gentilmente aceitado me orientar durante o doutorado sanduíche na University of Southern California / USC. Obrigada por me dar essa oportunidade de crescimento não só profissional mas também pessoal. Estes 14 meses em Los Angeles jamais serão esquecidos! Sentirei falta dos almoços diários, cafés e intermináveis conversas sobre todos os assuntos.

AGRADECIMENTOS

À Faculdade de Odontologia de Piracicaba (FOP), da Universidade Estadual de Campinas (UNICAMP), representada na pessoa do diretor **Prof. Dr. Jacks Jorge Junior** e do diretor associado **Prof. Dr. Alexandre Augusto Zaia**;

À coordenadora dos cursos de Pós-graduação da FOP-UNICAMP **Profa. Dra. Renata Cunha Matheus R. Garcia** e ao **Prof. Dr. Marcelo Giannini,** coordenador do programa de Pós-graduação em Materiais Dentários;

Aos professores do programa de materiais dentários: **Prof. Dr. Mário Alexandre Coelho Sinhoreti, Prof Dr. Mario Fernando de Goes, Prof. Dr. Lourenço Correr Sobrinho, Prof. Dr. Simonides Consani, Profª. Drª. Regina Maria Puppin Rontan, Profª. Drª. Marcela Rocha de Oliveira Carrilho, Prof Dr Rafael Leonardo Xediek Consani e Prof Dr Luis Roberto Marcondes Martins** que me honraram com seu exemplo de trabalho, sabedoria e seriedade. Serei eternamente grata a vocês pelos momentos singulares vividos durante o curso;

Aos professores que participaram da **banca de exame de qualificação**: **Prof. Dr. Oswaldo Scopin, Profª. Drª Vanessa Cavalli e Profª. Drª Sandrine Berger** pela valiosa contribuição a este trabalho;

A **Coordenação de Aperfeiçoamento Profissional de Nível Superior / Capes** pela concessão da bolsa de estudo durante o curso de Doutorado e ao **Conselho Nacional de Desenvolvimento Científico e Tecnológico / CNPq,** pela bolsa Doutorado Sanduiche no Exterior;

Ao Engenheiro Mecânico **Marcos Blanco Cangiani**, pela disposição, ajuda indispensável e seu extremo bom humor;

À funcionária **Selma Segalla**, sempre disposta a nos ajudar com muita competência, até mesmo em atividades que não correspondiam a sua função. Minha gratidão, admiração e eterna amizade;

Aos funcionários **Adriano Luis Martins e Eliene Orsini N. Romani**, pela atenção e disponibilidade em ajudar;

A todos os colegas do curso de Pós-Graduação em especial aos amigos da minha turma de Doutorado: **Ailla Lancelotti, Aloisio Spazzin, Ana Rosa Costa, Cristiana Azevedo, Cristina, Karla Oliveira, Gislaine Padovani, Lucas Naves, Nadja, Polliana, Rinaldo Matta (in memorian) e Rafael Vitti** pelo companheirismo e amizade em todos os momentos;

Aos grandes amigos que ganhei em Piracicaba: **Aílla, Ariene, Carla Arita, Cris, Ian, Karlinha, Leane, Lorena, Paula Paes, Poli, Rafael Vitti, Sandrine e Thaiane,** por terem me proporcionado uma verdadeira amizade, que esse laço continue para sempre;

À **Sandrine, Thaiane, Ana Paula, Carol, Rafael Pacheco e Renata** pelas milhões de ajuda e ótima convivência diária;

As minhas queridas amigas: **Maya, Caliandra, Amanda, Jú e Roberta Suñé** pelos conselhos e companheirismo em todos os momentos;

Aos grandes amigos adquiridos em Los Angeles: **Greciana Bruzi, Elisa Oderich, Luís Boff, Daniel Malta, Silvana Batalha, Ainara Espinosa, Arash Nejad, Drew, Kyle Stanley, Joseph Hanna, Ashley Ahuja, Maria Paula Paranhos, Marcelo Montenegro, Antonia Castellon, Eduardo Oliveira, Giuseppe Romeo, Sevah e Geibe Magne** por tornarem a vida nos EUA tão prazerosa e divertida. Em especial aos amigos **Ana Luiza e Eric Lumba** pelo apoio e amizade que se firmou desde o primeiro dia**.**

À minha grande parceira e amiga**, Greciana Bruzi**, pela amizade e companheirismo tanto nos momentos de diversões quanto nas madrugadas de trabalho no laboratório. Sua participação no desenvolvimento desse trabalho foi muito importante!

À **Maria Paula Paranhos** minha eterna gratidão pela amizade, ajuda e apoio incessante para tornar o meu sonho de estudar com o Prof Dr. Pascal Magne uma realidade!

Ao residente do curso de Endodontia da USC, **Robert Anderson**, por ter realizado todos os tratamentos endodonticos das amostras utilizadas no estudo.

Às Profas. **Dra. Carolina Baptista Miranda, Dra Márcia Noya e Dra Rebeca Bezerra**, pela amizade e apoio à pesquisa. Os seus incentivos aprimoraram o meu interesse pela vida acadêmica e hoje, também dedico essa vitória a vocês;

À empresa **3M ESPE / USA** pela doação dos materiais utilizados neste trabalho;

A toda minha **família** que sempre participou da minha formação pessoal. E que, mesmo de longe, estão sempre comigo e também torcem pelo meu sucesso;

A todos que direta ou indiretamente contribuíram para a realização deste trabalho,

MEUS SINCEROS AGRADECIMENTOS!

RESUMO

Objetivos: Comparar a resistência à fadiga(RFAD) e à fratura(RFRA), o modo de falha e o desgaste do antagonista em contato com os diferentes *designs* de coroas CAD/CAM utilizadas para restaurar molares tratados endodonticamente/TE ou não, fabricadas em cerâmica feldspática/FEL, dissilicato de lítio/DL ou resina nano cerâmica/RNC e fixadas com cimento resinoso auto-adesivo. **Materiais e Métodos:** Para os capítulos um e dois, 90 molares foram preparados e restaurados com coroas com espessura de 1,5mm ou 0,7mm respectivamente, em FEL, DL ou RNC. Para os capítulos três e quatro, outros 90 molares tiveram a porção coronária removida (nível da junção cemento-esmalte), foram TE e restaurados utilizando três diferentes *designs* de núcleo de preenchimento em resina composta/NPRC (4-mm de altura, 2-mm ou sem núcleo de preenchimento/endocrown) associados a coroas em RNC ou DL respectivamente. Para o capítulo cinco, grupos dos capítulos um (RNC/1,5mm e DL/1,5mm), três (NPRC de 4-mm de altura/RNC) e quatro (NPRC de 4-mm de altura/DL) foram combinados. Todas as coroas do estudo foram confeccionadas pelo sistema CAD/CAM Cerec 3 e cimentadas com o cimento RelyX Unicem II Automix. As coroas em FEL e DL foram previamente condicionadas com ácido fluorídrico e silanizadas. As coroas em RNC, assim como os dentes preparados foram apenas jateados. Todas as restaurações foram submetidas ao teste de RFAD com um carregamento cíclico isométrico aplicados por uma esfera de resina composta. O carregamento começou com cargas de 200N (5.000x) seguidos por estágios de 400, 600, 800, 1000, 1200 e 1400N à um máximo de 30.000 ciclos cada. Os espécimes foram submetidos ao carregamento até a fratura ou por no máximo 185.000 ciclos. Os espécimes que resistiram a todos os ciclos foram novamente testados axialmente até a falha ou até uma carga máxima de 4.500N. Os espécimes foram classificados quanto ao modo de falha em: catastrófica, possivelmente reparável e reparável. Os grupos foram comparados utilizando uma análise de sobrevida para o teste de RFAD e t-test ou ANOVA para o teste de RFRA. Comparações *Post hoc* também foram utilizadas para comparar os diferentes grupos. **Resultados:** A taxa de sobrevida das coroas sobre os molares não TE foram: 80%(RNC/1,5mm), 6,6%(RNC/0,7mm), 93,3%(DL/1,5mm), 13,2%(DL/0,7mm), 6,6%(FEL/1,5mm) e 0%(FEL/0,7mm). A RFRA das coroas com 1,5mm de espessura foi: 3122N-RNC, 3237N-DL e 2500N-FEL. As coroas cimentadas sobre molares TE tiveram taxa de sobrevida e RFRA respectivamente de: 53%/2969N (RNC-4mm de altura), 100%/3181N (DL-4mm de altura), 87%/2794N (RNC-2mm de altura), 93%/3759N (DL-2mm de altura), 87%/2606N (RNC-*endocrown*) e 100%/3265N (DL-*endocrown*). No teste de RFAD houve falha catastrófica apenas para as coroas confeccionadas em RNC-4mm. Após o teste de RFRA todos os espécimes falharam catastroficamente. As coroas em RNC induziram menor desgaste aparente ao antagonista. **Conclusão:** Apenas as coroas FEL-0,7mm não sobreviveram além da máxima força mastigatória humana. Para os dentes não TE, as coroas em DL e RNC com espessuras de 1,5mm tiveram o melhor desempenho mecânico. Para os molares TE, uma maior carga para fratura foi requerida com o uso de coroas em DL-2mm. O tratamento endodontico não teve influência sobre a RFAD de molares restaurados com coroas CAD/CAM de DL mas diminuiu a performance das RNC.

PALAVRAS-CHAVE: coroas, CAD/CAM, resistência à fadiga, núcleo de preenchimento, resina nano cerâmica, disilicato de lítio, molar tratado endodonticamente, dente vital.

ABSTRACT

Objectives: To evaluate the fatigue resistance, load-to-failure, failure mode and antagonistic wear in contact with different designs of full CAD/CAM crowns made of feldspathic ceramic/FEL, lithium disilicate/LD or resin nano ceramic/RNC. These prosthetic materials were used to restore endodontic treated molars or not, using a simplified cementation process. **Materials and Methods:** Chapters One and Two used 90 molars, which had a standardization of full crown preparation and teeth were restored using crown made of FEL, LD and RNC with thickness of 1.5mm or 0.7mm, respectively. Chapters Three and Four used 90 molars decoronated at the level of CEJ, endodontically-treated and restored using three different Filtek Z100 adhesive core build-ups designs (4-mm-build-up; 2-mm-build-up; and no build-up/endocrown preparation) combined to crowns made of RNC and LD, respectively. For Chapter Five, groups of Chapters One (RNC/1,5mm and LD/1,5mm), Three (4-mm-build-up/RNC) and Four (4-mm-build-up/LD) were combined. All molars were restored using the Cerec 3 CAD/CAM system and cemented with RelyX Unicem II Automix cement. FEL and LD restorations were conditioned by hydrofluoric acid etching and silanated. RNC restorations as well as all preparations were treated only with airborne-particle abrasion. All restorations were submitted to cyclic isometric loading applied through a composite resin hemi-sphere. The cyclic loading started with a load of 200N (x5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400N at a maximum of 30,000 cycles each. Specimens were loaded until failure or for a maximum of 185,000 cycles. Survived specimens were axially loaded until failure or to a maximum load of 4,500N. After load tests, the specimens were analyzed for the failure mode: "catastrophic" tooth/root failure, "possibly reparable" failure and "reparable" failure. Groups were compared using the life table survival analysis (fatigue test) and the t-test, one-way or two-way ANOVA for the survived samples loaded to failure. Pairwise post hoc comparisons were used to compare the different groups. **Results:** The survival rates for the vital teeth were: 80% (RNC – 1.5mm), 6.6% (RNC – 0.7mm), 93.3% (LD – 1.5mm), 13.2% (LD – 0.7mm), 6.6% (FEL – 1.5mm) and 0% (FEL – 0.7mm). Post-fatigue load-to-failure for 1.5mm crowns ranged between 3122N (RNC), 3237N (LD) and 2500N (FEL). The survival rate and post-fatigue load to failure for non-vital teeth were 53% / 2969N (4mm - RNC), 100% / 3181N (4mm - DL), 87% / 2794N (2mm - RNC), 93% / 3759N (2mm - DL), 87% / 2606N (endocrown - RNC) e 100% / 3265N (*endocrown* - LD), respectively. There were only catastrophic failures for 4mm–build-up RNC during the fatigue test. All of specimens in the load-to-failure test exhibited non-restorable catastrophic fractures. Crowns made of RNC seemed to generate the least amount of antagonistic wear. **Conclusions**: FEL crowns with 0.7mm of thickness didn't survived beyond the maximum masticatory forces. RNC and LD crowns with 1.5mm thick had the best performance on vital teeth. LD crowns combined with short build-ups (2mm) were associated to highest loads to failure. Endodontic treatment did not influence the fatigue resistance of molars restored with LD CAD/CAM complete crowns but decreased the performance of RNC crowns.

Key words: crowns, CAD/CAM, fatigue resistance, build-up, resin nano ceramic, lithium disilicate, endodontically-treated molar, vital teeth.

SUMÁRIO

INTRODUÇÃO

O aumento da exigência estética aliado às preocupações ambientais e com à saúde tem estimulado o crescimento da demanda por restaurações livres de metal. O progresso tecnológico associados a esses fatores tem contribuído para o desenvolvimento de novas técnicas restauradoras. A tecnologia computer-aided design/computer-aided manufacturing (CAD/CAM) representa a aplicação da tecnologia computadorizada na Odontologia. O sistema CEREC é um sistema CAD/CAM que permite a produção automatizada de restaurações indiretas sobre dentes vitais ou não-vitais em apenas uma consulta. Este sistema tem adquirido popularidade e conseqüentemente novas versões de equipamentos e materiais restauradores estéticos tem sido desenvolvidos (1-3).

Dentre as categorias de materiais estéticos restauradores disponíveis para o sistema CAD/CAM estão principalmente as cerâmicas odontológicas. Este material é atraente graças à sua habilidade em mimetizar as características ópticas do esmalte e da dentina, por ser biocompatível, possuir estabilidade de cor em longo prazo, estabilidade química e ser resistente ao desgaste (1, 4-6). Entretanto, as restaurações em cerâmica também apresentam friabilidade e suscetibilidade a fratura, além de provocar o desgaste do dente antagonista (7-11).

Outro material estético usinável disponível para o sistema CAD/CAM é a resina composta. Estas são caracterizadas por possuírem propriedades mecânicas similares a da dentina. Possuem baixo módulo de elasticidade, permitindo uma maior absorção das tensões gerados durante a mastigação (12) e baixa abrasividade ao dente antagonista (9). No entanto, as restaurações em resina composta são mais susceptíveis ao desgaste, à fratura, à deterioração da margem e possuem menor estabilidade de cor quando comparado ao material cerâmico (13, 14). Recentemente, uma nova classe de materiais usináveis, a nano cerâmica resinosa (Resin Nano Ceramic – RNC / Lava Ultimate - 3M ESPE), foi desenvolvida especialmente para uso com o sistema CAD/CAM. Este material combina componentes nano cerâmicos (80% em peso) com uma matriz resinosa. Segundo o fabricante, a RNC é um material flexível e resistente à fratura como as resinas compostas, e com excelente capacidade de retenção do polimento como as cerâmicas.

Além da vantagem estética, a utilização destes materiais (cerâmicas, resinas compostas e

RNC) permite aos profissionais utilizarem técnicas minimamente invasivas (realização de preparos mais conservadores) devido à falta da subestrutura metálica e a capacidade destes materiais de unir-se “adesivamente” à estrutura dental. Estas características tornam o uso destes materiais estéticos mais amplo, podendo ser utilizados em preparos conservadores e em restaurações extensas com grande destruição coronária. Entretanto, não existem informações científicas suficientes considerando a resistência à fratura dos materiais estéticos usináveis (blocos para uso no sistema CAD/CAM) quando utilizados para a fabricação de coroas com espessuras menores do que aquelas recomendadas pelos fabricantes ou até mesmo com espessuras convencionais (1.5 à 2.0 mm) ou maiores. Técnicas restauradoras utilizando estes materiais estéticos usináveis associados ao sistema CAD/CAM que consigam devolver a função e a integridade estrutural de dentes vitais ou não-vitais tem sido sugeridas, entretanto também pouco investigadas cientificamente para o seu uso clínico.

As restaurações de dentes tratados endodonticamente são consideradas procedimentos mais complexos que as restaurações de dentes vitalizados, desde o planejamento até a sua execução, pois na maioria dos casos envolvem preparos cavitários com maior perda de tecido dental (15), que afeta a tenacidade e resistência à fratura das estruturas remanescentes. Para dentes tratados endodonticamente e extensamente destruídos indica-se a utilização de mecanismos que auxiliem na retenção da restauração. Embora alguns trabalhos (16-18) indiquem a utilização de pinos de fibra para auxiliar nesta retenção, outros estudos (19-23) tem confirmado que molares tratados endodonticamente sem o uso de pino intra-radicular possuem similar resistência a fratura e modo de falha que aqueles restaurados com o uso do pino. Ou seja, a presença do pino além de não ser necessariamente requerida, durante o preparo radicular corre-se o risco de ocorrer perfuração radicular ou no assoalho câmara pulpar (24).

A preservação da estrutura cervical para criar um efeito férula é considerada crucial para um bom comportamento biomecânico do dente restaurado (21, 25). Para que se obtenha este efeito férula em dentes extensivamente destruídos pode-se indicar a utilização de núcleos de preenchimento confeccionados com compósitos. No entanto, não existe um consenso com relação ao *design* ideal do núcleo de preenchimento para restaurar molares extensamente destruídos.

Uma alternativa restauradora para os casos de dentes tratados endodonticamente extensamente destruídos é a técnica denominada *Endocrown ou* coroa "endodôntica adesiva" (26). Sua característica principal é a simplificação do protocolo restaurador, com diminuição de custo e dos erros operacionais durante o preparo coronário e intra-radicular. Este tipo de restauração consiste em um grande bloco que se projeta no espaço da câmara pulpar e que é fixado com sistemas adesivos e cimentos resinosos no substrato dental (27). Esta técnica utiliza toda a superfície disponível na câmara pulpar para assegurar estabilidade e retenção da restauração, dispensando o uso de núcleo de preenchimento e pino intra-radicular. Uma indicação específica e conservadora deste tipo de restauração é quando dentes apresentam pouco espaço inter-oclusal para a confecção dos preparos tradicionais indiretos (27, 28).

Considerando-se que a resistência à fratura dos materiais restauradores fornece importantes informações sobre o comportamento biomecânico das diferentes técnicas restauradoras, o presente estudo apresentado em cinco capítulos teve como objetivos avaliar a resistência à fadiga, resistência à fratura, o modo de falha e o desgaste de diferentes *designs* de coroas CAD/CAM fabricadas em cerâmica feldspática, dissilicato de lítio ou resina nano cerâmica fixadas com cimento resinoso auto-adesivo em molares tratados endodonticamente ou não.

Os objetivos específicos foram:

1. Avaliar a resistência à fadiga, a resistência à fratura, o modo de falha e o desgaste do antagonista de molares restaurados com coroas CAD/CAM de cerâmica feldspática, dissilicato de lítio ou RNC com espessuras que estavam de acordo com as recomendações dos fabricantes.

2. Avaliar a influência da redução da espessura de materiais CAD/CAM de cerâmica feldspática, dissilicato de lítio e RNC na resistência à fadiga e o modo de falha de coroas ultra-finas (0.7 mm).

3. Avaliar a influência do núcleo de preenchimento com alturas de 4-mm, 2-mm ou a sua ausência (endocrown) na resistência à fadiga e fratura e o modo de falha de molares tratados endodonticamente restaurados com coroas CAD/CAM confeccionadas com RNC.

4. Avaliar a influência do núcleo de preenchimento com alturas de 4-mm, 2-mm ou a sua ausência (endocrown) na resistência à fadiga e fratura e o modo de falha de molares tratados endodonticamente restaurados com coroas CAD/CAM de dissilicato de lítio.

5. Avaliar a influência do tratamento endodôntico na resistência à fadiga e fratura de

molares restaurados com coroas CAD/CAM de dissilicato de lítio ou RNC, quando comparados aos preparos para dentes vitalizados.

CAPÍTULO 1 [1]

Fatigue Resistance of CAD/CAM Complete Crowns with a Simplified Cementation Process

Adriana O. Carvalho, DDS, MS,[a] Greciana Bruzi, DDS, MS,[b] Marcelo Giannini, DDS, MS, PhD[c], Pascal Magne, DMD, PhD[d]

Piracicaba School of Dentistry, Campinas State University, Piracicaba, SP, Brazil; Federal University of Santa Catarina, Florianópolis, SC, Brazil; Ostrow School of Dentistry, University of Southern California, Los Angeles, Calif, USA.

This study was supported by 3M ESPE and Brazilians Federal Agencies for Support: CNPq 20092/2011-6, CAPES 3110/2010 and CAPES 4979/11-7.

[a]PhD Student, Department of Restorative Dentistry, Piracicaba School of Dentistry, Campinas State University, Piracicaba, SP, Brazil.

[b]PhD Student, Department of Operative Dentistry, Federal University of Santa Catarina, Florianópolis, Santa Catarina, Brazil.

[c]Associate Professor, Department of Restorative Dentistry, Piracicaba School of Dentistry, Campinas State University, Piracicaba, SP, Brazil.

[d]Don and Sybil Harrington Professor of Esthetic Dentistry, Restorative Sciences, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA.

Corresponding Author

Dra. Adriana Oliveira Carvalho

PIRACICABA DENTAL SCHOOL / STATE UNIVERSITY OF CAMPINAS

Dental Materials Division

Rua Professor Sabino Silva, 965, apt 1003, Jardim Apipema,

Salvador, BA, Brazil, 40.155-250

Phone (+55) 71 8194-8399

---

[1] Artigo submetido a Revista *The Journal of Prosthetic Dentis*try

ABSTRACT

Statement of problem: Various CAD/CAM materials are available to fabricate complete crowns. The type of material may have an effect on the longevity of these restorations. **Purpose:** To evaluate the fatigue resistance, load-to-failure, failure mode and antagonistic wear of full molar CAD/CAM crowns made of resin nano ceramic/RNC, feldspathic ceramic/FEL or lithium disilicate/LD placed with a simplified cementation process. **Material and Methods:** Forty-five molars received a standardized complete crown preparation and were restored using CAD/CAM crown (1.5mm thickness /n=15) made of RNC, FEL and LD. FEL and LD crowns were HF-etching and silane. Airborne-particle abrasion was used instead to condition RNC restorations as well as all preparations. Following cementation, restorations were submitted to cyclic isometric loading: 200N (x5000cycles), 400, 600, 800, 1000, 1200, and 1400N at a maximum of 30,000cycles each. Survived specimens were axially loaded until failure or to a maximum load of 4,500N. Specimens were analyzed for the failure mode: "catastrophic", "possibly reparable" and "reparable". Groups were compared using the life table survival analysis and the t-test. **Results:** All specimens survived the fatigue until the 800N-step. RNC, LD and FEL demonstrated survival rates of 80%, 93.3% and 6.6%, respectively. Survival of RNC and LD crowns did not differ from each other but far exceeded that of FEL. Post-fatigue load-to-failure ranged between 2500N (FEL), 3122N (RNC), 3237N (LD). There was no catastrophic failure in the fatigue test while all of specimens in the load-to-failure test exhibited catastrophic fractures. Crowns made of RNC seemed to generate the least amount of antagonistic wear. **Conclusions**: Posterior full crowns made of RNC and LD were statistically not different, and both had significantly higher fatigue resistance compared to FEL. All materials survived beyond the normal range of masticatory forces and all failures were possibly reparable except in the load-to failure test. RNC crowns seemed to induce less wear of the antagonist.

Key words: cerec, CAD/CAM, fatigue resistance, resin nano ceramic, crowns.

CLINICAL IMPLICATION

All materials tested in this work far survived physiological masticatory forces. Using a simplified cementation process, RNC and LD crowns demonstrated better resistance to cyclic loading and load failure probability than the FEL crowns. RNC also demonstrated significant practical advantages such as less mill time, less milling bur usage, no need for firing, extreme polishability, and great clinical potential (ease of occlusal adjustment and repairability, wear-friendly to antagonistic teeth).

INTRODUCTION

Research in metal-free, tooth-colored restorations has been stimulated by the increasing demand for esthetics, combined with health and environmental concerns about some metallic restorations. In addition, new and improved options for indirect prosthetic treatments have been developed. Computer-aided design/computer-assisted manufacture (CAD/CAM) restorations is the best example of application fueling this trend. CAD/CAM machines are gaining popularity therefore machinable versions of these esthetic materials have been introducing on the market (1-3).

In spite of the advantages of all-ceramic restorations, including esthetic appearance, color stability, biocompatibility, and durability (1, 4-6) such materials also present some drawbacks like brittleness, susceptibility to fracture and abrasive wear of the opposing natural teeth (7-11). Other materials used for indirect esthetic restorations are composite resins. Their main properties include low abrasiveness to antagonistic teeth (enamel preservation) (9) and low elastic modulus, allowing more absorption of functional stresses through deformation (12). Some clinical studies report that longevity of all-ceramic restorations is better than all-composite resin crowns (13-15). Some disadvantages of composite resin remain, such a wear, deterioration of surface finish, color instability and fracture. However another authors report that the performance of composite resins has exceeded that of ceramics (8, 11, 16-22). Still other reports have shown that the behavior of teeth with both ceramic and composite resin crowns is similar (2, 8, 23, 24). Overall, there isn't a consensus about the best material to restore posterior teeth, both materials have been evaluated for their potential to restore posterior crowns and have proven appropriate.

Millable composite resin materials have recently gained popularity for use as a CAD/CAM block because of their simple use, millability (1, 19, 20). Recently, a new class of millable Resin Nano Ceramic (RNC) blocks (LAVA Ultimate, 3M ESPE, St Paul, MN, USA) were introduced for use with CAD/CAM systems. According to the manufacturer, this material is not a resin or a pure ceramic. RNC combines benefits of highly cross-linked resin matrix and ceramics. It consists primarily of ceramic (80% in weight). Recently, the ADA has accepted to broaden its definition of porcelain/ceramic materials (effective January 1, 2013) in its CDT Code for insurance reimbursement, allowing RNC to be classified as a porcelain/ceramic. Like composite resins, RNC is flexible and fracture resistant. But in additional it features excellent polish retention for lasting esthetics as with glass ceramic. However, limited scientific information is available regarding the properties of RNC.

Therefore, the purpose of this study was to evaluate the fatigue resistance, load-to-failure, failure mode and antagonistic wear of full molar CAD/CAM crowns made with RNC, feldspathic ceramic and lithium disilicate (thickness according to manufacturer's instruction for use for each material). The null hypothesis was that no significant difference would be found with respect to fatigue resistance, failure mode and the wear of the antagonist among the three materials used in this study for full molar crowns.

MATERIAL AND METHODS

Once approval was obtained from both the Ethical Committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California Review Board, forty-five freshly extracted, sound human maxillary molars stored in solution saturated with thymol were collected. Teeth were mounted in a special positioning device with acrylic resin (Palapress; Heraeus Kulzer, Armonk, NY, USA) embedding the root up to 3.0 mm below the cemento-enamel junction (CEJ).

Tooth preparation

A standardized tooth preparation was applied to all specimens. Detailed measurements and dimensions are shown at Figure 1.

First, axial reduction of 1.5 mm was obtained with a circular chamfer size of 1.0 mm following CEJ and 6° convergence angle between tooth axis and lateral wall. Second, anatomical occlusal reduction was carried out and the buccal and palatal cusp tips were maintained at approximately 4.0 mm from the gingival margin and the central groove at approximately 2.0 mm from the gingival margin. Special care was taken to obtain a smooth and rounded internal line angles. Margins were always finished with fine-grain diamonds.

Design and manufacturing of restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). All specimens were fitted with a crown of standardized thickness: average thickness of 1.5 mm at the central grove, a maximum of 2.0 mm at the cusp (measured with a caliper after milling and polishing); and standardized occlusal anatomy (third maxillary molar, Lee Culp Youth database). Using the Crown Master Mode and the Design Tools of the Cerec software (v. 3.6, Sirona Dental Systems), the occlusal surface was moved and rotated in order to make parallel the cusp tips and the preparation surface as well as to align the central groove (Figure 1B). For fifteen specimens, restorations were milled in the feldspathic ceramic Vitablocs Mark II blocks (Vita Zahnfabrik, Bad Säckingen, Germany) (group FEL), another fifteen using the lithium dissilicate IPS e.max CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein) (group LD) and the last fifteen specimens using the resin nano ceramic Lava Ultimate blocks (3M ESPE, MN, USA) (group RNC). All restorations were milled in Endo mode with the sprue located at the lingual surface and inspected to detect possible milling cracks. The crowns milled with lithium disilicate blocks required crystallization firing. Thus, after milling, IPS e.max CAD ceramic crowns were fired in a ceramic furnace (Austromat 624; DEKEMA Dental-Keramiköfen GmgH, Freilassing, Germany) following the manufacturer's instructions. For RNC group the polishing procedure was carried out by use of commercial polishing kit (Dialite, Ultra Polisher, Brasseler, Savannah, GA, USA) and for groups FEL and LD, the specimens were glazed with Akzent glaze (Vivadent) and IPS e.max CAD Cristall/Glaze (Ivoclar) respectively, according to the manufacturer's instructions.

Adhesive placement of restoration

Before luting, each crown was seated on its respective tooth to check its marginal fit. The ceramic crowns surface were cleaned in a steam cleaner and etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) for 60 s (FEL) or 20 s (LD), rinsed, cleaned in ultrasonic bath in distilled water for 1 minute and then silanized (Rely X Ceramic Primer, 3M/ESPE, Seefeld, Germany) according to the manufacturer's instructions. RNC crowns were cleaned in a steam cleaner, sandblasted with 50 µm – aluminum oxide (Danville, San Ramon, CA, USA), rinsed and cleaned in ultrasonic bath in distilled water for 1 minute. The teeth were also pre-treated before cementation. The preparations were sandblasted with 27 µm - aluminum oxide, rinsed and dried.

Dual-curing self-adhesive resin cement (RelyX Unicem 2 Automix, 3M ESPE, St. Paul, MN, USA) was used for the cementation. Cement was applied inside the restoration and the crown was seated on the tooth with an approximate digital pressure of 70 N. Excess cement was removed after brief light exposure (approximately 2 seconds) with a LED light (VALO Curing Light, Ultradent Products, INC., UT, United States) and each surface was then light polymerized for 20 seconds. All margins were covered with an air-blocking barrier (KY Jelly; Johnson & Johnson Inc., Montreal, QC, CA) and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler, Savannah, GA, USA), polishing brush (soft bristle brush) with diamond paste (Diamord Twist SCL, Premier, EC Representative: MDSS GmbH * Schiffgraben, Hannover, GE) and buff with a muslin rag wheel.

Testing

1) Fatigue testing

Each specimen was stored in distilled water at room temperature for at least 24 hours following adhesive restoration placement. Masticatory forces were then simulated with an artificial mouth using closed-loop servo hydraulics (Mini Bionix II; MTS Systems, Eden Prairie, MN, USA). Each specimen was placed into the load chamber and situated with a positioning device (sliding table). The chewing cycle was simulated by an isometric contraction (load control) applied through a composite resin hemi-hemi-sphere (Filtek Z100, 3M EPSE, St. Paul, MN, USA) with a diameter of 10.0 mm. Because of the standardized occlusal anatomy, all specimens could be adjusted (through the positioning device) in the same reproducible position with the hemi-hemi-sphere contacting the mesio-buccal, disto-buccal and palatal cusps (tripod contact). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 10 Hz, starting with a load of 200 N for 5,000 cycles (pre-conditioning phase to guarantee predictable positioning of the hemi-hemi-sphere with the specimen), followed by stages of 400, 600, 800, 1,000, 1,200 and 1,400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. Following a two-examiner agreement under optical microscope, a distinction was made between fractures above (reparable) or below (catastrophic) the CEJ or for cohesive fracture or fracture at the interface.

2) Load-to-failure testing of survived specimen

After the fatigue test, survived specimens were axially loaded until failure or to a maximum load of 4,500 N with a 10-mm composite resin hemi-hemi-sphere. The hemi-hemi-sphere had the same three-point occlusal contacts as in the fatigue test. The crosshead speed was 0.5mm/min. The maximum post-fatigue load before failure was recorded in Newtons and mean values were calculated per group. After load tests, the specimens were analyzed for one of the three failure modes: "reparable" tooth fracture (cohesive chipping within the material, or adhesive failure with fragment but no loss or damage to underlying tooth structure), possibly reparable (adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure) or "catastrophic" tooth/root fracture (below CEJ) that would require tooth extraction or for cohesive fracture or fracture at the interface.

Statistical analysis

The fatigue resistance of the three groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability (%) at each interval. The influence of the restorative material on the fracture strength (load step at which failure occurred) was analyzed by using the Log-rank test at a significance level of .05. Differences were localized using pairwise post hoc comparisons with the same test at a significance level of .016 (Bonferroni correction for 3 comparisons).

The post-fatigue load-to-failure resistance of the survived specimens was compared using t-test (data tested normal with Kolmogorov-Smirnov test). For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, V. 11.0.1; MedCalc Software, Mariakerke, Belgium).

RESULTS

During the fatigue test, the specimens of group FEL fractured at a mean load of 1,171 N (128,517 cycles). Only one FEL sample survived all 185,000 load cycles but multiple cracks were visible at the surface of the restoration (Figure 2). The same specimen fractured at 2,500 N in the load to failure test. LD and RNC crowns that survived the fatigue test did not show any evidence of fractures and/or cracks. Groups LD and RNC demonstrated survival rate after the fatigue test significantly higher than FEL (93.3%, 80%, and 6.6 %, respectively) ($p<0.001$). Survival of restored molars with LD and RNC was no significantly different ($p=0.28$). Different failure modes were observed during the fatigue test (Table 1 and Figure 3) but there was no apparent catastrophic failure in the fatigue test. Only small subgingival delamination fractures and cracks, especially in FEL (10 specimens) could be observed (Figure 4).

Average post-fatigue failure loads were 3237 N for LD (14 specimens) and 3122 N for RNC (12 specimens). T-test was considered to compare the post-fatigue strength of those two materials and indicated no significant differences ($p=0.339$). All crowns loaded until failure exhibited catastrophic failure (Table 2 and Figure 3).

Following the fatigue test, RNC crowns demonstrated less wear at the resin hemi-hemi-sphere (antagonist) than LD and FEL crowns. The opposite can be said about the materials themselves as well-defined wear facets could be seen at the contact with RNC specimens while contact areas in LD and FEL were barely noticeable once specimens were cleaned. In LD specimens contact areas could be detected because of the delamination of the glaze material (Figure 5).

DISCUSSION

The null hypothesis, namely, that no significant difference would be found with respect to fatigue resistance, failure mode and the wear of the antagonist among the three materials used in this study for full molar crowns was rejected in part. The results revealed a superior fatigue resistance of posterior crowns made of RNC and LD when compared to FEL ceramic. RNC crowns also showed less wear to antagonist hemi-hemi-sphere than LD and FEL. Failure modes, however, were similar across materials (reparable after fatigue test, catastrophic after load-to-failure).

The use of full coverage crown restorations have significantly decreased as the first treatment option due to its invasive nature and the development of sustainable noninvasive alternative, especially bonded inlays/onlays and occlusal veneers (25). Nevertheless, the complete crown is still a useful option when replacing an existing complete coverage restoration. In an effort to standardize and approximate the clinical situation as much as possible, natural teeth of similar dimensions were selected. Using natural teeth has been recommended due to modulus of elasticity, bonding characteristics and strength characteristics that better match the clinical situation (26). The application of a standardized occlusal surface by the Cerec machine and standardized load configuration eliminated confounding variables from the anatomy of natural teeth and masticatory habits. A composite resin hemi-hemi-sphere was preferred, rather than stainless steel, to simulate the antagonist tooth. The use of a composite resin hemi-hemi-sphere was previously suggested by Magne and Knezevic (27) and Kelly (28). The lower stiffness and higher wear of the composite resin allow more realistic simulation of tooth contacts (17) and antagonistic enamel. Resin hemi-hemi-sphere contacted the functional and nonfunctional cusps in a position close to that found clinically. None of the hemi-hemi-spheres failed during the test. Like in previous studies (17, 18, 27), the periodontal ligament was not simulated because elastomers or silicone films usually used for this purpose show accelerated degradation; this would allow excessive displacement of the tooth and would destabilize the servohydraulic control system.

All crowns were cemented with self-adhesive resin cement (Rely X Unicem 2 Automix / 3M ESPE). This system was developed with the rationale of simplifying the cementation procedure by eliminating the pre-treatment step involving the tooth structure (29). Because these systems don't require any pre-treatment on the tooth, the immediate dentin sealing technique was not used neither a dentin bonding agent. Beyond that, the instruction for use of this cement recommends only sandblasting and cleaning resin-based restoration surface before cementation. Hence, no ceramic primer (silane) was used on RNC restorations surface. This simplified delivery protocol was chosen because it is clinically relevant, fast and appreciated by clinicians. It is also approved by the block manufacturers.

In the present study, the mean fracture strength of FEL crowns was 1,171 N, which lies within the range reported in earlier studies (8, 30). It is interesting to note that one survived FEL sample with crack still resisted to 2,500 N in the post-fatigue load-to-failure test. This indicates that fatigue generated cracks alone do not always compromise the static load performance. Flexural strength values for FEL, RNC and LD are 150, >204 and 360 MPa, respectively (manufacturer's information). The inferior performance of FEL is in agreement with various authors (8, 11, 16, 27, 31) and correlates with its lower flexural strength compared to the two other materials. On the other hand, it is interesting to note the similar performance of RNC and

LD crowns in spite of different flexural strength. This situation can be explained by taking into account the elastic modulus of the material. The work of fracture (32) , which is the energy required to create a new surface in a propagating flaw, is inversely related to the elastic modulus of the material. In other word, the similarity of LD and RNC may be explained by the ratio between strength and elastic modulus (both lower for RNC compared to LD). All those results have to be placed in the overall perspective of masticatory forces in the human dentition.

Maximum bite forces lie in the 600-900 N range (33, 34). Mean fracture loads for FEL (1,171 N), RNC (1,333 N) and LD (1,400 N) crowns in the present study far exceeded those values therefore indicating that all three materials tested can be potentially used for cemented crown restorations in vital teeth. However, when in presence of particularly high load patients (possibly reaching 900N in males according to maximum values reported (35)), it is more likely that LD or RNC will survive. FEL may be used in such a situation but would then require adhesive luting to supplement its lower strength.

The positive outcome of the fatigue test is not only the relatively high fracture loads (despite the use of a simplified cementation process) but also the fact that all failures would have been easily repairable (especially with RNC). No intact tooth structure was lost and the tooth could have been maintained. Even with the small subgingival margin dentin fracture and chipping, it is clinically feasible to smoothen those margins or apply the margin elevation technique when needed (36) and re-restore. Non-restorable catastrophic failure in the load-to-failure test can be explained by the extremely high load required to induce fracture. At those levels of forces, the underlying tooth structure yielded together with the restorative material.

From a clinical perspective, RNC presents with significant advantages compared to the other materials. The milling/fabrication time is reduced, the material is expected induces less wear of the milling burs and more precise margins are anticipated because of the resin content (19). RNC is also extremely polishable and does not require firing. The clinical potential is enhanced by the ease cementation (no HF/silane required), occlusal adjustment and intraoral reparability. Finally, observations from the present study revealed that it appears wear-friendly to the antagonistic cusp (LD and FEL crowns demonstrated more wear at the resin hemi-hemi-sphere antagonist when compared to RNC). The opposite can be said about the material wear because once specimens were cleaned, well-defined wear facets could be seen at the contact with

RNC specimens while worn contact areas in LD and FEL were barely noticeable. This is in agreement with the findings of Kunzelman et al., (9) showing that resin-based materials will wear themselves and protect the antagonistic cusp. From these observations, it can also be speculated that the wear resistance of RNC was slightly less than to that of the Z100 antagonist. This might be from the slightly different ceramic filler content, 85 wt% versus 80 wt% in RNC.

One limitation of the study was the direction of the load application. The loads were applied only axially. Lateral forces that may occur clinically during clenching were not simulated. Therefore the clinical implication of the results in this study should be limited to the vertical loading situation. Another limitation is the use of higher frequency (10-20Hz) in the cyclic loading test, which was suggested by Kelly et al., (37) and facilitated the experiment, allowing testing of 3 specimens per day. However, such high frequency may lead to more heat generation compared to 1 to 2 Hz and may not give a time for stress relaxation (38).

Further research should explore the bondability of the new Resin Nano Ceramic and the potential for adding contacts or esthetic characterizations using light polymerized composite resin. No corrections or esthetic characterization were applied to the crowns in this in-vitro study. Clinical applications require sometime to add contact or to make esthetic veneering onto the monolithic base. While those modifications are normally carried out through additional ceramic firing when using LD or FEL, only composite resin additions can be used with RNC. Additional research should also be carried out using the same testing protocol and materials but in combination to adhesive luting procedures, possibly including the immediate dentin sealing technique and the use of a silane with RNC. Advanced bonding may yield different results knowing that 1.2 mm-thick polymer-based bonded occlusal veneers performed better than LD in a recent study by Magne & Schlichting. Finally, studies about similar restorations on nonvital teeth are under way because endodontically treated molars present a whole set of specific challenges due to their brittleness and loss of structural integrity.

CONCLUSION

Within the limitations of this simulated fatigue study, it was found that CAD/CAM crowns placed with a simplified cementation process and made of a new Resin Nano Ceramic material or lithium disilicate had significantly higher fatigue resistance compared to feldspathic porcelain. All materials survived beyond the normal range of masticatory forces and all failures during fatigue were possibly reparable (except in the load-to failure test). For similar performances, the new Resin Nano Ceramic features major clinical and practical advantages compared to LD (mill time, mill bur usage, polishability, simplicity of delivery and reparability).

Acknowledgments

This study was supported by 3M ESPE, CNPq 20092/2011-6, CAPES 3110/2010 and CAPES 4979/11-7.

REFERENCES

1. Fasbinder DJ. Materials for chairside CAD/CAM restorations. *Compend Contin Educ Dent* 2010 Nov-Dec;**31**(9):702-4, 6, 8-9.

2. Tsitrou EA, Helvatjoglu-Antoniades M, van Noort R. A preliminary evaluation of the structural integrity and fracture mode of minimally prepared resin bonded CAD/CAM crowns. *J Dent* 2009 Jan;**38**(1):16-22.

3. Fasbinder DJ. Restorative material options for CAD/CAM restorations. *Compend Contin Educ Dent* 2002 Oct;**23**(10):911-6, 8, 20 passim; quiz 24.

4. Fasbinder DJ, Dennison JB, Heys D, Neiva G. A clinical evaluation of chairside lithium disilicate CAD/CAM crowns: a two-year report. *J Am Dent Assoc* 2010 Jun;**141 Suppl 2**:10S-4S.

5. Reich S, Fischer S, Sobotta B, Klapper HU, Gozdowski S. A preliminary study on the short-term efficacy of chairside computer-aided design/computer-assisted manufacturing-generated posterior lithium disilicate crowns. *Int J Prosthodont* 2010 May-Jun;**23**(3):214-6.

6. Stawarczyk B, Sener B, Trottmann A, Roos M, Ozcan M, Hammerle CH. Discoloration of manually fabricated resins and industrially fabricated CAD/CAM blocks versus glass-ceramic: Effect of storage media, duration, and subsequent polishing. *Dent Mater J* 2012;**31**(3):377-83.

7. Brunton PA, Cattell P, Burke FJ, Wilson NH. Fracture resistance of teeth restored with onlays of three contemporary tooth-colored resin-bonded restorative materials. *J Prosthet Dent* 1999 Aug;**82**(2):167-71.

8. Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. *J Prosthet Dent* 2006 Feb;**95**(2):117-23.

9. Kunzelmann KH, Jelen B, Mehl A, Hickel R. Wear evaluation of MZ100 compared to ceramic CAD/CAM materials. *Int J Comput Dent* 2001 Jul;**4**(3):171-84.

10. Park S, Quinn JB, Romberg E, Arola D. On the brittleness of enamel and selected dental materials. *Dent Mater* 2008 Nov;**24**(11):1477-85.

11. Magne P, Knezevic A. Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars. *Quintessence Int* 2009 Feb;**40**(2):125-33.

12. Magne P, Perakis N, Belser UC, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: a finite element analysis of the influence of restorative materials and abutment preparation design. *J Prosthet Dent* 2002 May;**87**(5):516-27.

13. Dejak B, Mlotkowski A. Three-dimensional finite element analysis of strength and adhesion of composite resin versus ceramic inlays in molars. *J Prosthet Dent* 2008 Feb;**99**(2):131-40.

14. Khairallah C, Hokayem A. [Long-term clinical evaluation of 2 dental materials used for the preparation of esthetic inlays]. *Odontostomatol Trop* 2009 Sep;**32**(127):5-13.

15. Vanoorbeek S, Vandamme K, Lijnen I, Naert I. Computer-aided designed/computer-assisted manufactured composite resin versus ceramic single-tooth restorations: a 3-year clinical study. *Int J Prosthodont* 2010 May-Jun;**23**(3):223-30.

16. Kassem AS, Atta O, El-Mowafy O. Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns. *J Prosthodont* 2012 Jan;**21**(1):28-32.

17. Schlichting LH, Maia HP, Baratieri LN, Magne P. Novel-design ultra-thin CAD/CAM composite resin and ceramic occlusal veneers for the treatment of severe dental erosion. *J Prosthet Dent* 2011 Apr;**105**(4):217-26.

18. Magne P, Schlichting LH, Maia HP, Baratieri LN. In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. *J Prosthet Dent* 2010 Sep;**104**(3):149-57.

19. Tsitrou EA, van Noort R. Minimal preparation designs for single posterior indirect prostheses with the use of the Cerec system. *Int J Comput Dent* 2008;**11**(3-4):227-40.

20. Tsitrou EA, Northeast SE, van Noort R. Brittleness index of machinable dental materials and its relation to the marginal chipping factor. *J Dent* 2007 Dec;**35**(12):897-902.
21. Tsitrou EA, Northeast SE, van Noort R. Evaluation of the marginal fit of three margin designs of resin composite crowns using CAD/CAM. *J Dent* 2007 Jan;**35**(1):68-73.
22. Akbar JH, Petrie CS, Walker MP, Williams K, Eick JD. Marginal adaptation of Cerec 3 CAD/CAM composite crowns using two different finish line preparation designs. *J Prosthodont* 2006 May-Jun;**15**(3):155-63.
23. Ghazy M, El-Mowafy O, Roperto R. Microleakage of porcelain and composite machined crowns cemented with self-adhesive or conventional resin cement. *J Prosthodont* 2010 Oct;**19**(7):523-30.
24. Kuijs RH, Fennis WM, Kreulen CM, Roeters FJ, Verdonschot N, Creugers NH. A comparison of fatigue resistance of three materials for cusp-replacing adhesive restorations. *J Dent* 2006 Jan;**34**(1):19-25.
25. Magne P. Composite resins and bonded porcelain: the postamalgam era? *J Calif Dent Assoc* 2006 Feb;**34**(2):135-47.
26. Chitmongkolsuk S, Heydecke G, Stappert C, Strub JR. Fracture strength of all-ceramic lithium disilicate and porcelain-fused-to-metal bridges for molar replacement after dynamic loading. *Eur J Prosthodont Restor Dent* 2002 Mar;**10**(1):15-22.
27. Magne P, Knezevic A. Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars. *Quintessence Int* 2009 Oct;**40**(9):729-37.
28. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. *J Prosthet Dent* 1999 Jun;**81**(6):652-61.
29. El-Badrawy W, Hafez RM, El Naga AI, Ahmed DR. Nanoleakage for Self-Adhesive Resin Cements used in Bonding CAD/CAD Ceramic Material to Dentin. *Eur J Dent* 2011 Jul;**5**(3):281-90.
30. Zahran M, El-Mowafy O, Tam L, Watson PA, Finer Y. Fracture strength and fatigue resistance of all-ceramic molar crowns manufactured with CAD/CAM technology. *J Prosthodont* 2008 Jul;**17**(5):370-7.

31. Chen HY, Hickel R, Setcos JC, Kunzelmann KH. Effects of surface finish and fatigue testing on the fracture strength of CAD-CAM and pressed-ceramic crowns. *J Prosthet Dent* 1999 Oct;**82**(4):468-75.

32. Kobashigawa A, Magne P, Schlichting L. Correlation of Fatigue Resistance to Mechanical Properties of CAD-CAM Blocks [abstract 1170] *IADR / AADR /CADR 89th General Session and Exhibition* 2011.

33. Mantyvaara J, Sjoholm T, Kirjavainen T, Waltimo A, Iivonen M, Kemppainen P, et al. Altered control of submaximal bite force during bruxism in humans. *Eur J Appl Physiol Occup Physiol* 1999 Mar;**79**(4):325-30.

34. Kiliaridis S, Kjellberg H, Wenneberg B, Engstrom C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. *Acta Odontol Scand* 1993 Oct;**51**(5):323-31.

35. Waltimo A, Nystrom M, Kononen M. Bite force and dentofacial morphology in men with severe dental attrition. *Scand J Dent Res* 1994 Apr;**102**(2):92-6.

36. Magne P, Spreafico RC. Deep Margin Elevation: A Paradigm Shift. *Am J Esthet Dent* 2012(2):86-96.

37. Kelly JR, Rungruanganunt P, Hunter B, Vailati F. Development of a clinically validated bulk failure test for ceramic crowns. *J Prosthet Dent* 2010 Oct;**104**(4):228-38.

38. Karl M, Kelly JR. Influence of loading frequency on implant failure under cyclic fatigue conditions. *Dent Mater* 2009 Nov;**25**(11):1426-32.

Table 1. Failure mode during fatigue testing.

	Reparable		Possibly reparable		Not reparable
	Cohesive failure	Adhesive failure	Adhesive failure + chip or crack in dentin	Adhesive failure + DEEP chip or crack in dentin	Catastrophic failure
FEL	1	3	1	9	-
LD	-	-	1	-	-
RNC	-	-	1	2	-

Table 2. Failure mode after Load to Failure.

Material	Reparable		Possible reparable		Not reparable
	Cohesive failure	Adhesive failure	Adhesive failure + chip or crack dentin	Adhesive failure + DEEP chip or crack dentin	Catastrophic failure
FEL	-	-	-	-	1
LD	-	-	-	-	14
RNC	-	-	-	-	12

LEGENDS:

Figure 1. (A) Prepared tooth and related dimensions. (B) Crown restoration and corresponding measurements and dimensions.

Figure 2. Life table survival distributions by materials at each load step (n=15).

Figure 3. Failure modes: (A) Cohesive failure, (B) Adhesive failure, (C) Adhesive failure + chip or crack dentin (Arrow – chip dentin), (D) Adhesive failure + DEEP chip or crack dentin (Arrow – deep crack dentin), (E) Catastrophic failure.

Figure 4. Magnified photographs of subgingival delamination fractures and cracks.

Figure 5. Aspect of the wear at the crown produced by RNC, LD and FEL and resin hemi-hemi-sphere. A- Crown before Fatigue Test; B- Wear of crowns after Fatigue Test; C- Wear of the Z100 composite resin hemi-sphere after Fatigue Test.

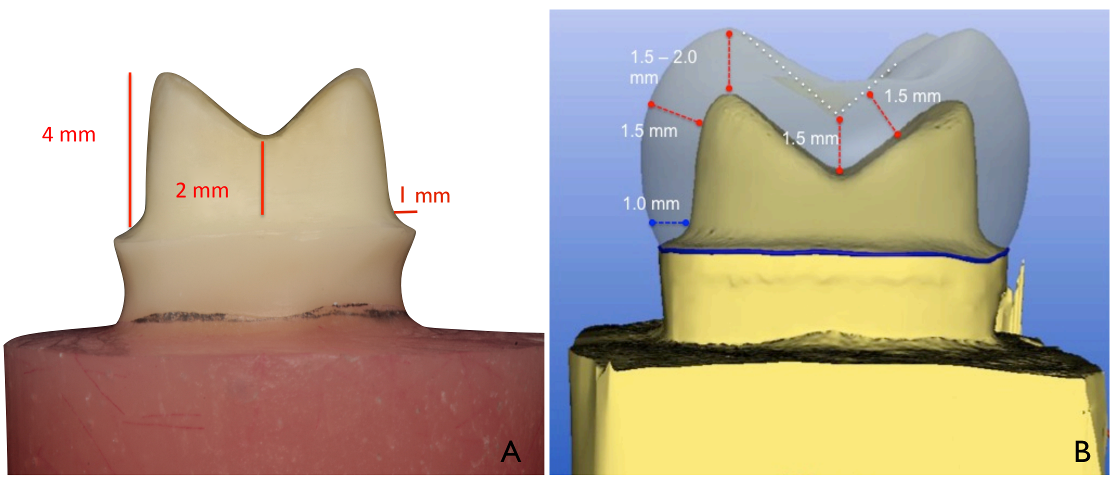
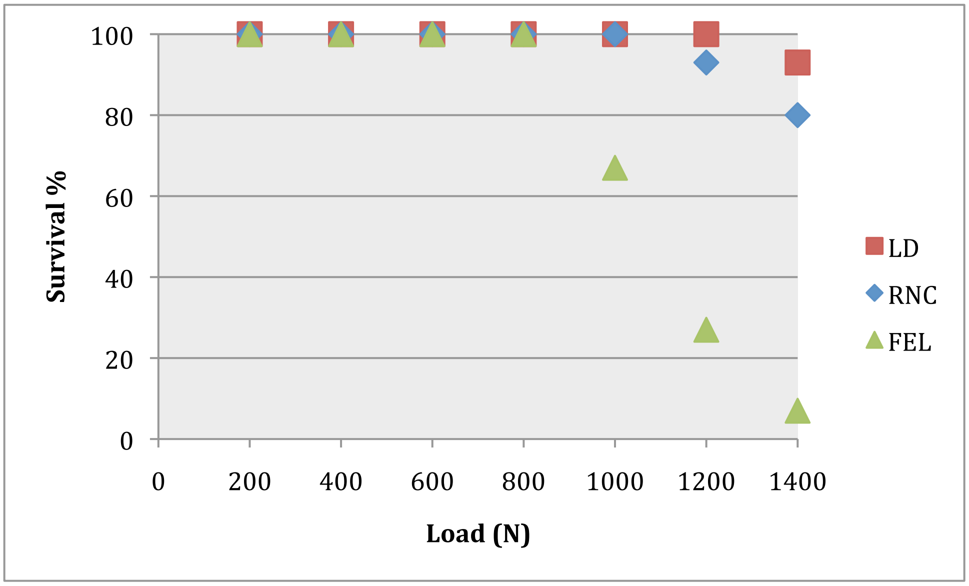


Figure 1.


100
80
60
40
20
0
Survival %
0
200
400
600
800
1000
1200
1400
Load (N)
LD
RNC
FEL
Figure 2.

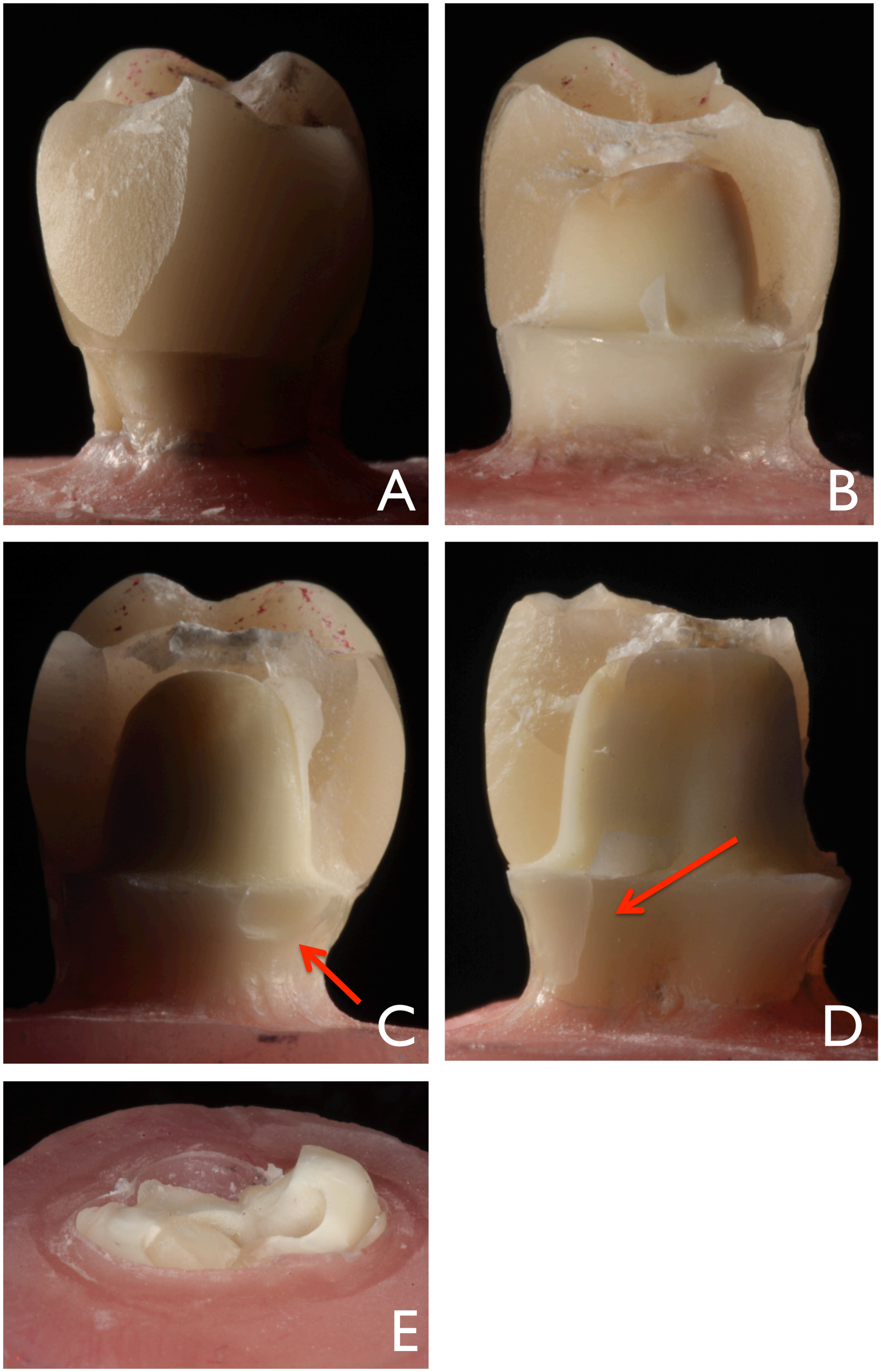


Figure 3.

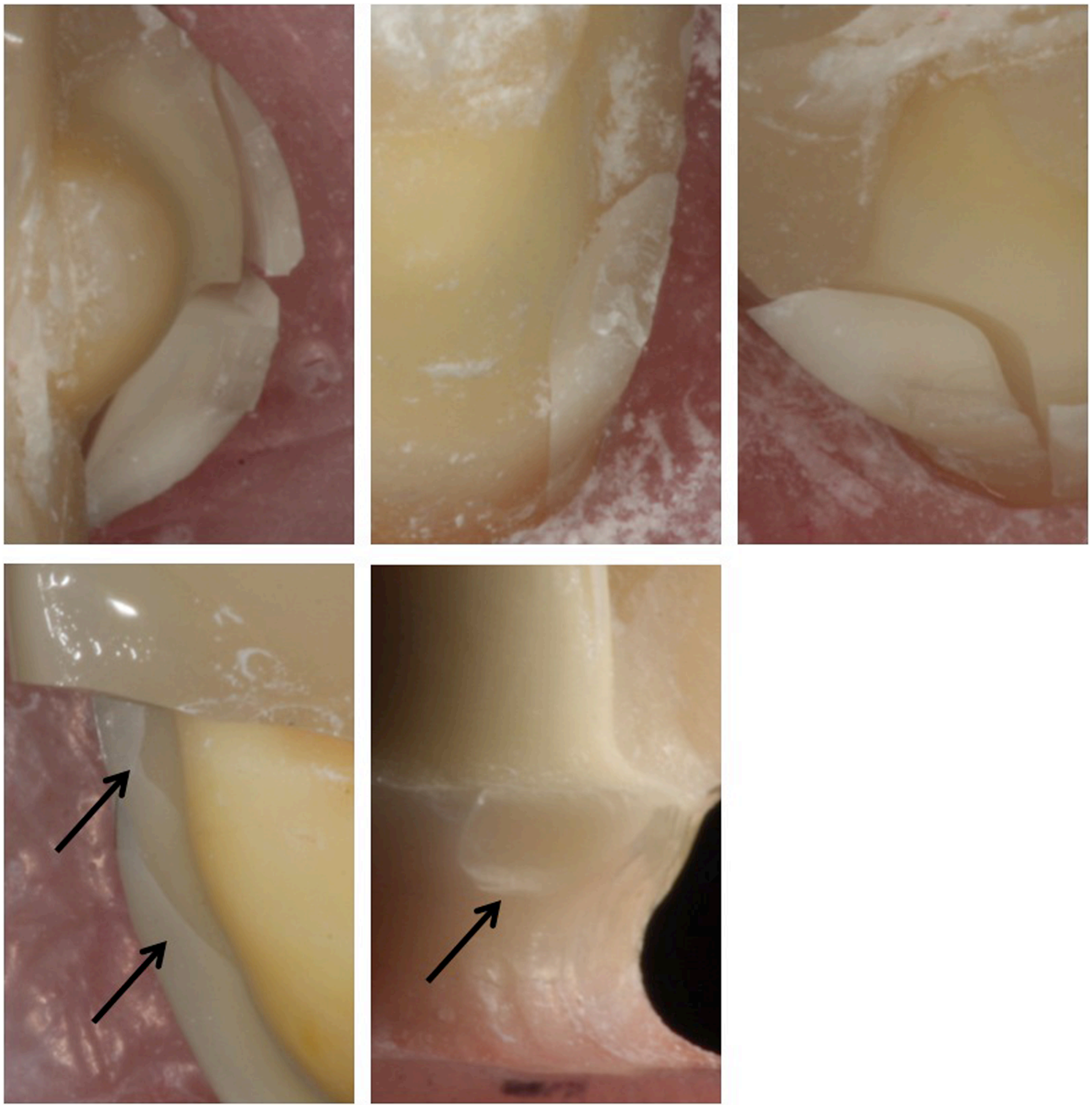


Figure 4.

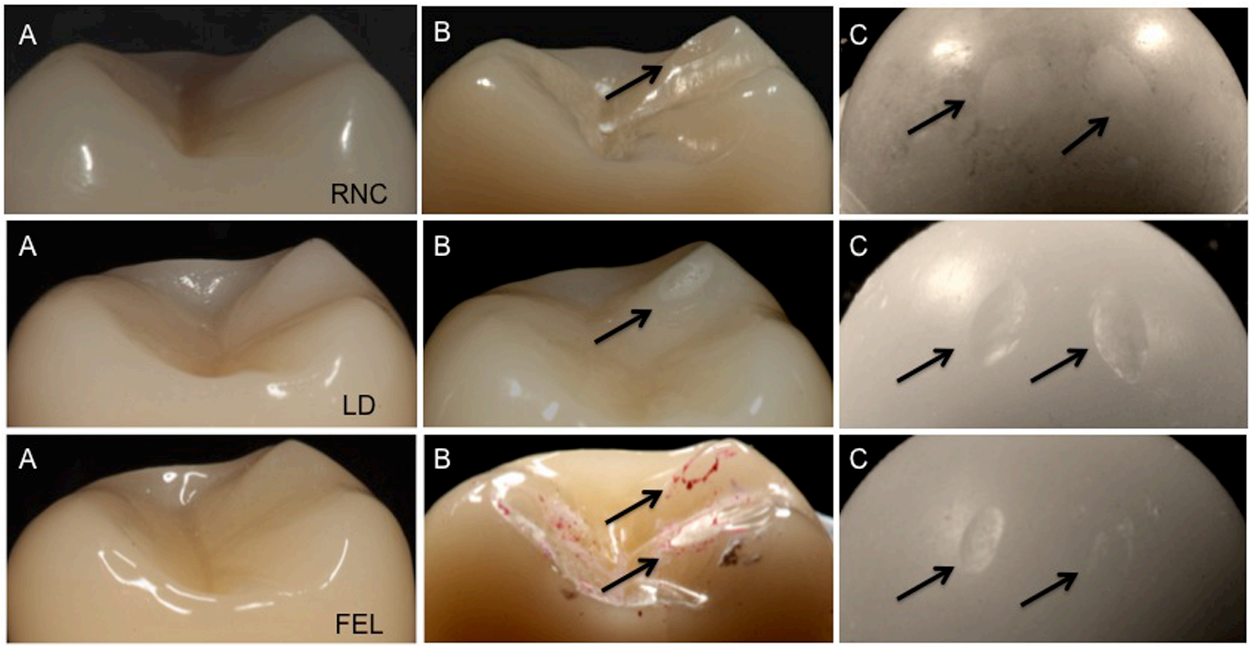


Figure 5.

CAPÍTULO 2 [1]

Fatigue Resistance of ultra-thin CAD/CAM Full Veneer Crowns with a Simplified Cementation Process

Magne P[1], Carvalho AO[2], Bruzi G[3], Maia HP[4] , Giannini M[5]

[1] Don and Sybil Harrington Professor of Esthetic Dentistry, Restorative Sciences, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA.
[2] PhD Student, Department of Restorative Dentistry, Dental Material Division, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.
[3] PhD Student, Department of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil.
[4] DDS, MS, PhD, Professor of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil.
[5] Associate Professor, Department of Restorative Dentistry, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.

Corresponding Author

Dr. Pascal Magne

UNIVERSITY OF SOUTHERN CALIFORNIA

Division of Restorative Sciences

School of Dentistry – Oral Health Center

3151 S. Hoover St

Los Angeles, CA 90089-7792

Phone (213) 740-4239

Fax (213) 821-5324

[1] Artigo formatado baseado nas normas da Revista *The Journal of Prosthetic Dentis*try.

ABSTRACT

Statement of problem: Traditional tooth preparation for complete crowns requires substantial amount of hard tissue reduction. This is in contrast with the principles of minimally-invasive dentistry. An ultra-thin full veneer crown preparation is proposed instead.

Objectives: To assess the fatigue resistance and failure mode of CAD/CAM ultra-thin full veneer molar crowns placed with self-adhesive cement. Different restorative materials (resin nano ceramic, feldspathic ceramic and lithium disilicate) were compared.

Materials and Methods: Forty-five extracted molars with a standardized veneer crown preparation were restored with Cerec 3 CAD/CAM system using feldspathic ceramic / FEL (Vitabloc Mark II), lithium disilicate / LD (IPS e.max CAD), or resin nano ceramic / RNC (Lava Ultimate) (n=15). FEL and LD restorations were conditioned by hydrofluoric acid etching and silanated. RNC restorations as well as all preparations were treated with airborne-particle abrasion. All restorations (thickness=0.7mm) were cemented with RelyX Unicem II Automix resin cement and submitted to cyclic isometric loading at 10Hz, beginning with a load of 200 N (x 5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or for a maximum of 185,000 cycles (10 mm-diameter composite resin hemi-hemi-sphere antagonist) and the failure mode was analyzed as "catastrophic" (tooth/root fracture that would require tooth extraction), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure) or "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only). Groups were compared using the life table survival analysis (Log rank test at P=.05). Previously published data from the same authors about traditional complete crowns (thickness 1.5 mm) using the same experimental set-up were included for comparison.

Results: All specimens survived the fatigue test until the 600 N-step. RNC, LD and FEL failed at an average load of 1,014 N (1 survival), 1,123 N (2 survivals) and 987 N (no survivals), and no difference in survival rate was found. There were no catastrophic failures after the fatigue test. Comparison with previously published data showed that 1.5 mm-thick full crowns demonstrated higher survival rates than those ultra-thin restorations, independent of the material.

Conclusions: The fatigue resistance of ultra-thin full veneer molar crowns (placed with a simplified cementation process) made of RNC, LD and FEL were not significantly different. All

materials survived the normal range of masticatory forces. All failures were reparable. Regular crowns with 1.5- 2.0 mm-thick may present higher survival rates than ultra-thin ones.

Key words: Cerec, CAD/CAM, fatigue resistance, resin nano ceramic, crowns.

CLINICAL IMPLICATION

This study revealed the feasibility and acceptable *in-vitro* performance of minimally invasive CAD/CAM crowns using resin nano ceramic, lithium disilicate or feldspatic ceramic. This approach could be recommended whenever excessive reduction of intact hard tissues is desirable (as in cases of severe erosion or replacement of thin existing restorations such as gold and alloys crowns).

INTRODUCTION

This study revealed the feasibility and acceptable *in-vitro* performance of minimally invasive CAD/CAM crowns using resin nano ceramic, lithium disilicate or feldspatic ceramic. This approach could be recommended whenever excessive reduction of intact hard tissues is desirable (as in cases of severe erosion or replacement of thin existing restorations such as gTechnological improvements associated with more conservative approaches to treat dental diseases and the progress of news adhesive materials have led to the development of ultraconservative dentistry. Minimally invasive treatment options should always be considered. The ultimate goal of conservation of tooth structure is usually fulfilled when using direct adhesive restorations. Indirect restorations, on the other hand, tend to require significantly more tooth reduction, sometime up to 75% of the intact coronal substance (1, 2). Lately, there is an increasing tendency to apply the ultraconservative principles of direct techniques to indirect restorations as well; therefore more conservative indirect preparations have been advocated. According to Simonsen (3), failing to recognize the importance and benefits of maintenance of as much tooth structure as possible is inexcusable in light of the technique options that the acid-etch procedure and the new resin materials offer the profession. The loss of tooth structure during preparation affects tooth stiffness, reduces its resistance to fracture and consequently limits its prognosis.

The benefits of decreased retentive features in the tooth preparation (or non-retentive preparations) have already been demonstrated, such as in bonded porcelain veneers (4). The translational application of these principles can be found in the posterior dentition in the form of occlusal veneers or full veneer crown restorations (5, 6). Currently, the trend is to avoid traditional full crown preparations whenever possible. Yet, replacement of existing full veneer crowns is common in dental practice. Many options of restorative materials exist in presence of traditional preparations, usually featuring at least 1-2 mm of axial and occlusal clearance, such as found under PFMs. In other instances, the existing preparation may be particularly conservative such as in gold and alloy crowns. Other similar situations include the ultraconservative approach in cases of severe erosion (7-11) that involve the entire tooth circumference. In most of the aforementioned examples, the use of traditional PFMs or zirconia-based ceramics would result in significant additional reduction of intact tooth substance in order to provide clearance for the cosmetic veneering material. Instead, ultra-thin full veneer crown restorations using cosmetic materials could provide an esthetic and conservative alternative because no additional cutting of intact tooth substrate is required. The minimal design of the preparation, however may affect the stability, resistence/strength and the longevity of those ultra-thin dental restorations.

From a practical standpoint, previous findings (5, 12) showed that it is possible to produce thin restorations (ca. 0.6mm) with the Cerec system. Various CAD/CAM blocks are available to fabricate those crowns. However, thicknesses of less than 1.5 mm do not comply with the corresponding manufacturer's instructions for use and there is a lack of data about the use of those materials for ultra-thin crowns. Therefore, the aim of this study was to assess the influence of CAD/CAM restorative materials - resin nano ceramic, feldspathic ceramic and lithium disilicate - on the fatigue resistance and failure mode of ultra-thin full veneer molar crowns placed with a self-adhesive cement. The null hypotheses were that (1) there is no significant difference among the fatigue resistance and failure mode of the three materials tested in this *in vitro* study for ultra-thin full veneer molar crowns, and (2) the fatigue resistance of these restorations would not be influenced by the thickness of the material. Data regarding 1.5 mm-thick full veneer crowns, previously published by the same authors using a similar experimental set-up, were used to test this second null hypothesis.

MATERIAL AND METHODS

Forty-five freshly extracted carious-free human maxillary molars were selected and stored in solution saturated with thymol after approval from both the Ethical Committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California Review Board. Teeth were mounted in a special positioning device with acrylic resin (Palapress; Heraeus Kulzer, Armonk, NY, USA) and the root was embedded up to 3.0 mm below the cemento-enamel junction (CEJ).

Tooth preparation

A minimally invasive full veneer crown preparation was applied to all specimens (Figure 1A) with an axial reduction of 0.7 mm, circular chamfer size of 0.5 mm following CEJ and a convergence angle of 6° between tooth axis and lateral wall. Anatomical occlusal reduction was carried out and the buccal and palatal cusp tips were maintained at approximately 4.5 mm from the gingival margin and the central groove at approximately 2.5 mm from the gingival margin. Special care was taken to obtain a smooth and rounded internal line angles. Margins were always finished with fine-grain diamonds (Brasseler, Savannah, GA, USA).

Design and manufacturing of restorations

The Cerec 3 system (Sirona Dental Systems GmbH, Bensheim, Germany) with software v. 3.6 (Sirona Dental Systems) was used to fabricate crowns with an average thickness of 0.7 mm at the central grove and a maximum of 1.0 mm at the cusp tips (measured with a caliper after milling and polishing). A standardized occlusal anatomy was used (third maxillary molar, Lee Culp Youth database). The occlusal surface was moved and rotated with the design tools of the Cerec software in order to make the cusp tips parallel to the preparation surface as well as to align the central groove (Figure 1B). Fifteen monolithic crowns were fabricated from ceramic Vitablocs Mark II blocks (Vita Zahnfabrik, Bad Säckingen, Germany) (group FEL), another fifteen using the IPS e.max CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein) (group LD) and the last fifteen specimens using the resin nano ceramic resin Lava Ultimate blocks (3M ESPE, St. Paul, MN, USA) (group RNC). All restorations were milled in Endo mode with the sprue located at the lingual surface and inspected to detect possible milling cracks. Following the manufacturer's instructions, the milled lithium disilicate crowns underwent crystallization firing in a ceramic furnace (Austromat 624; DEKEMA Dental-Keramiköfen GmgH, Freilassing, Germany). For RNC group the polishing procedure was carried out by a use of commercial polishing kit (Dialite, Ultra Polisher, Brasseler, Savannah, GA, USA) and for groups FEL and LD, the specimens were glazed using an Akzent glazing kit (Ivoclar Vivadent, Schaan, Liechtenstein) and IPS e.max CAD Crystall Glaze (Ivoclar Vivadent, Schaan, Liechtenstein) respectively, according to the manufacturer's instructions.

Crown placement

All crowns were cemented with a dual-curing self-adhesive resin cement (RelyX Unicem 2 Automix cement 3M ESPE, St. Paul, MN, USA). Before cementation, each crown was fitted on its respective tooth to check its marginal adaptation and steam cleaned. The inner surface of ceramic crowns was etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) for 60 s (FEL) or 20 s (LD), rinsed, cleaned in ultrasonic bath in distilled water for 1 minute and then silanized (RelyX Ceramic Primer, 3M ESPE, Seefeld, Germany) according to the manufacturer's instructions. For RNC group, the crowns were sandblasted with 50 µm – aluminum oxide (Danville, San Ramon, CA, USA), rinsed and cleaned in ultrasonic bath in distilled water for 1 minute. The prepared teeth were sandblasted with 27 µm - aluminum oxide, rinsed and dried. The cement was applied to the inner surface of the crowns, which were then seated on the tooth with an approximate pressure of 70 N. Cement excesses were removed after a brief light exposure (approximately 2 seconds) with a LED light (VALO Curing Light, Ultradent Products, INC., UT, USA) and followed by light polymerized for 20 seconds on each surface. Air-blocking barrier (KY Jelly; Johnson & Johnson Inc., Montreal, Canada) was used to cover all margins and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler, Savannah, GA, USA), polishing brush (soft bristle brush) with diamond paste (Diamord Twist SCL, Premier, EC Representative: MDSS GmbH * Schiffgraben, Hannover, Germany) and buff with a muslin rag wheel.

Fatigue testing

All specimens were stored in distilled water at room temperature for at least 24 hours following cementation. Masticatory forces were applied using closed-loop servo hydraulics (Mini Bionix II; MTS Systems, Eden Prairie, MN, USA). The chewing cycle was simulated by an isometric contraction (load control) applied through a composite resin hemi-hemi-sphere

(Filtek Z100, 3M ESPE, St. Paul, MN, USA) with a diameter of 10.0 mm. Because of the standardized occlusal anatomy, all specimens could be adjusted (through the positioning device) in the same reproducible position with the hemi-hemi-sphere contacting the mesio-buccal, disto-buccal and palatal cusps (tripod contact). The load chamber was filled with distilled water until complete submersion of the sample. Cyclic loading was carried out at a frequency of 10 Hz, beginning with a load of 200 N for 5,000 cycles (pre-conditioning phase to guarantee predictable positioning of the hemi-hemi-sphere with the specimen), followed by stages of 400, 600, 800, 1,000, 1,200 and 1,400 N at a maximum of 30,000 cycles each. Specimens were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. Following a two-examiner agreement under optical microscope, the specimens were analyzed for one of the three failure modes: "catastrophic" (tooth/root fracture that would require tooth extraction), "possibly reparable" (cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure) or "reparable" fracture (cohesive or cohesive/adhesive fracture of restoration only).

Statistical analysis

The fatigue resistance of the three groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability (%) at each interval. The influence of the restorative material on the fracture strength (load step at which failure occurred) was analyzed by using the Log-rank test at a significance level of .05. The data were analyzed with statistical software (MedCalc, V. 11.0.1; MedCalc Software, Mariakerke, Belgium). Differences were localized using pairwise post hoc comparisons with the same test at a significance level of .016 (Bonferroni correction for 3 comparisons). Supplementary data from a previous study about 1.5 mm-thick complete molar crowns by the same authors in strictly identical experimental conditions were combined to the present data for additional computation and comparison.

RESULTS

For RNC, LD and FEL groups, the specimens failed at an average load of 1014 N (106589 cycles), 1123 N (120390 cycles) and 987 N (100362 cycles), respectively and survival rates did not differ statistically among themselves (p=0.17) (Figure 2; Table 1). In groups RNC and LD, all specimens survived until 800 N-step while for FEL group, samples started to fail at 600 N-step. None of 15 FEL crowns survived the fatigue test, but one of the RNC and two of the LD crowns survived all 185.000 load cycles. For one of the two survived LD crown, multiple cracks were visible at the surface of the restoration at the end of the fatigue test. With regards to the failure mode of the crowns, analysis showed that there was no catastrophic failure for all three materials. Only adhesive failure could be observed, sometime with small subgingival delamination fractures and cracks. (Table 2; Figure 3), especially in case of RNC specimens.

Additional comparisons of 0.7 mm and 1.5 mm-thick full coverage crowns for each material (Table 1) demonstrated higher fatigue resistance of the thick crowns (p<.011).

DISCUSSION

This in vitro study investigated the survival rate and failure mode of ultra-thin-cemented full veneer molar crowns. The first null hypothesis was partially rejected because no significant difference was found in the fatigue resistance of the three materials tested, however, differences in failure mode were observed. The second part of the null-hypothesis was rejected since the crown thickness (combined data with previously published work by the same authors using a similar experimental set-up) did influence the survival rate.

Natural teeth of similar dimensions were selected for this study in an effort to standardize and approximate the clinical situation as much as possible (13). Remaining confounding variables from the anatomy of those natural teeth as well as masticatory habits were minimized by the substitution with the standardized occlusal surface of the Cerec machine, identical restoration thickness and unvarying load configuration of all samples. Those parameters can be easily evaluated and edited when necessary using the numerous tools integrated in the software.

Previous studies (2, 3) showed that the Cerec technology was able to mill ultra-thin restorations. As suggested by Tsitrou & Van Noort (12) the endo milling mode was selected to produce a better milling quality. Each restoration was carefully examined after milling and the above claim was confirmed because no cracks were observed. However, operator subjectively noticed that milled RNC crowns had the best margins compared to the ceramic crowns that tended to present with minor marginal defects (Figure 4). Use of a composite resin hemi-hemi-sphere antagonist was preferred, rather than stainless steel as previously suggested by Magne and Knezevic (14) and Kelly (15). A more realistic simulation of tooth contacts is enabled by the lower stiffness and higher wear of the composite resin (5). None of the hemi-hemi-spheres failed during the test.

In vitro fatigue resistance of dental materials are often evaluated by subjecting a bar-shaped samples of material to cyclic 3- or 4- point flexural loading simulating two modes of fatigue, contact and flexure. This is a clinical limitation of those traditional tests because the performance of an isolated beam of restorative material may not be used as a predictor of its clinical behavior (15). Therefore, as the authors used restored teeth, a standardized 3 point/facet contact could be created and generated a wider variety of clinically relevant fatigue modes (flexure, contact, water sorption and aging in wet condition). Fatigue is described as a change of material characteristics over time under cyclic conditions. In the intraoral environment restorations may be loaded during their lifetime up to 10^7 cycles, which can cause up to 50% reduction in strength of the ceramic due to fatigue (16, 17). Unfortunately, the time-consuming aspect of true fatigue tests (number of cycles in the 10^6 range) is a significant limitation as well. As in previous studies (5, 14, 18-20), a progressive load was applied (from 200N to 1400N – max. 185,000 cycles), which is a compromise between the load-to-failure test (single load until failure) and the traditional fatigue test (low load/high cycles). At the beginning of the test (200 N load step) the contact pressure was estimated approximately at 200 MPa (3 contacts for approximately 1 mm^2) by the intact resin hemi-sphere. This pressure increased only progressively until the 1400-N step. At this load, the worn hemi-sphere generated a contact pressure of merely 350 MPa (approximately 4 mm^2). In other words, the intrinsic wear of the antagonistic load hemi-sphere allowed the contact pressure not to increase as fast as the increasing load. According Kelly (15) loaded restorations and teeth should show wear facets and not point contacts. Authors in the present study observed such wear facets both at the restorations and resin hemi-sphere antagonists. As was the case in their previous data (21), RNC demonstrated more material wear but less antagonistic wear. Worn contact areas in LD and FEL were barely noticeable but at the cost of more antagonistic wear (resin hemi-sphere).

In a previous study (21), the survived rate for complete crown (1.5-2.0 mm) made of RNC, LD, FEL and cemented with RelyX Unicem II was 80%, 93% and 6,6% respectively.

RNC and LD crowns did not differ and had significantly higher fatigue resistance compared to FEL. In the present study, the survival rate of ultra-thin full veneer crowns (0.7 mm) made of the same three materials was 6.6%, 13,2 % and 0% respectively. There was no significant difference among them. The results of these two studies indicate that the fatigue resistance of crowns made of RNC, LD or FEL may be influenced by the thickness of those materials, which is in agreement with Schlichting et al. (5) and Federlin et al. (22). Tsitrou et al., (23), on the other hand, found that the use of minimal preparation design did not compromise the structural integrity of crown-restored teeth when using composite resin (Paradigm MZ100 – 1.5 – 2 mm compared to 0.4 - 0.6 mm) cemented with a self-adhesive dual cured resin cement (RelyX Unicem II) or leucite glass-ceramic (Pro-CAD – 1.5 – 2 mm compared to 0.8 - 1.2 mm) cemented with a dual-curing luting composite (Variolink II). A probable explanation of this finding could be the fact that no aging methods were used before the load to failure test. According to Kelly (15), there is little clinical relevance of this kind of tests because it is not consistent with the actual swallowing and mastication cycles or maximum force recorded during clenching efforts.

When subjected to the exact same experimental set-up of the present study, occlusal veneers (1.2 mm-thick) made of composite resin (Paradigm MZ100), lithium disilicate (Emax CAD) and feldspathic ceramic (Empress CAD), demonstrated survival rates of 100%, 30% and 0%, respectively (6). Similar ultra-thin occlusal veneer (0.6 mm-thick) showed survival rates of 60% (Paradigm MZ100), 0% (Emax CAD) and 0% (Empress CAD), reiterating the superiority of the composite resin material (5). There are two major differences between those studies and the present work. First, none of the specimens in the previous studies presented with fractured fragments. All specimens survived the accelerated fatigue test but cracks were sometime visible. The failure criterion was therefore adapted to this situation (failure defined as a crack larger than 2 mm at the surface of the restoration). In the present work, cracks were not observed and failures occurred suddenly with the loss of a fragment, which leads to the second difference between those studies, that is the luting procedure. Magne et al. (6), and Schlichting et al. (5) used the immediate dentin sealing (IDS) technique associated with a preheated light-polymerized composite resin as a luting agent. Such procedures result in the development of a strong interface that survived even at the highest loads and in spite of multiple cracking (no fragments separating from the tooth). This constitutes a demonstration of the “biomimetic” behavior of the restoration and underlying tissue, simulating to some degree the enamel cracks that are stopped at the dentin-enamel junction.

Although adhesive luting associated to IDS is a clinically successful option for fracture prevention, the use of self-adhesive resin cements is sometimes necessary. It is a faster and more efficient technique, especially when considering excess cement removal during the replacement of subgingival complete crowns, for which adhesive luting becomes more technique sensitive. Likely due to the use of a simplified cementation process, all failures would have been repairable and the restored tooth could have been maintained. There were small subgingival margin dentin fracture and chipping but it would be feasible to smoothen those margins or apply the margin elevation technique when needed (24) and re-restore.

The results of this study require careful clinical interpretation. RNC and LD ultra-thin full veneer crowns started to fail at 800 N while all FEL survived until 600 N. All complete crowns (1.5 mm-thick) survived until 800 N. Masticatory forces during normal function range from 50N to 250N and 500N to 800N in bruxism (25, 26). Those results suggest that it may be possible occur using RNC and LD cemented with RelyX Unicem II for restoring posterior teeth with regular or ultra-thin crowns even under relatively high loads requirements. However, it is suggested, when using FEL porcelain full-veneer ultra-thin crowns not to use a self-adhesive cement but rather apply the IDS technique and pre-heated composite resin as a luting agent (27-29).

From a clinical perspective, RNC has a significant number of practical advantages when compared to LD, such as reduced milling time, less milling bur usage, no need for firing, extreme polishability, ease of occlusal adjustment, repairability and wear-friendliness to antagonistic teeth. Clinical data is now required to assess the fatigue resistance of those ultra-thin restorations.

CONCLUSION

Within the limitations of this simulation study, it could be concluded that:

- There was no difference in terms of fatigue resistance among a new Resin Nano Ceramic material, lithium disilicate and feldspatic ceramic for ultra-thin full veneer molar crowns placed with a simplified cementation process.
- All failures were reparable.
- Standard dimension crowns with 1.5 – 2.0 mm preparation on occlusal surface had higher survival rates than ultra-thin ones.

This study also confirmed the feasibility of minimally invasive CAD/CAM crowns whenever excessive reduction of intact hard tissues is desirable (as in cases of severe erosion or replacement of thin existing restorations such as gold and alloys crowns).

Acknowledgments

This study was supported by 3M ESPE, CNPq 20092/2011-6, CAPES 3110/2010 and CAPES 4979/11-7.

REFERENCES

1. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. *Int J Periodontics Restorative Dent* 2002 Jun;**22**(3):241-9.
2. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for anterior teeth. *J Prosthet Dent* 2002 May;**87**(5):503-9.
3. Simonsen RJ. From prevention to therapy: minimal intervention with sealants and resin restorative materials. *J Dent* 2011 Dec;**39 Suppl 2**:S27-33.
4. Magne P, Douglas WH. Design optimization and evolution of bonded ceramics for the anterior dentition: a finite-element analysis. *Quintessence Int* 1999 Oct;**30**(10):661-72.
5. Schlichting LH, Maia HP, Baratieri LN, Magne P. Novel-design ultra-thin CAD/CAM composite resin and ceramic occlusal veneers for the treatment of severe dental erosion. *J Prosthet Dent* 2011 Apr;**105**(4):217-26.
6. Magne P, Schlichting LH, Maia HP, Baratieri LN. In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. *J Prosthet Dent* 2010 Sep;**104**(3):149-57.

7. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. Part 2. *Eur J Esthet Dent* 2008 Summer;**3**(2):128-46.

8. Lussi A, Hellwig E, Ganss C, Jaeggi T. Buonocore Memorial Lecture. Dental erosion. *Oper Dent* 2009 May-Jun;**34**(3):251-62.

9. Vailati F, Vaglio G, Belser UC. Full-mouth minimally invasive adhesive rehabilitation to treat severe dental erosion: a case report. *J Adhes Dent* Feb;**14**(1):83-92.

10. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. Part 3. *Eur J Esthet Dent* 2008 Autumn;**3**(3):236-57.

11. Vailati F, Belser UC. Full-mouth adhesive rehabilitation of a severely eroded dentition: the three-step technique. Part 1. *Eur J Esthet Dent* 2008 Spring;**3**(1):30-44.

12. Tsitrou EA, van Noort R. Minimal preparation designs for single posterior indirect prostheses with the use of the Cerec system. *Int J Comput Dent* 2008;**11**(3-4):227-40.

13. Chitmongkolsuk S, Heydecke G, Stappert C, Strub JR. Fracture strength of all-ceramic lithium disilicate and porcelain-fused-to-metal bridges for molar replacement after dynamic loading. *Eur J Prosthodont Restor Dent* 2002 Mar;**10**(1):15-22.

14. Magne P, Knezevic A. Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars. *Quintessence Int* 2009 Oct;**40**(9):729-37.

15. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. *J Prosthet Dent* 1999 Jun;**81**(6):652-61.

16. Jung YG, Peterson IM, Kim DK, Lawn BR. Lifetime-limiting strength degradation from contact fatigue in dental ceramics. *J Dent Res* 2000 Feb;**79**(2):722-31.

17. Peterson IM, Wuttiphan S, Lawn BR, Chyung K. Role of microstructure on contact damage and strength degradation of micaceous glass-ceramics. *Dent Mater* 1998 Jan;**14**(1):80-9.

18. Fennis WM, Kuijs RH, Kreulen CM, Verdonschot N, Creugers NH. Fatigue resistance of teeth restored with cuspal-coverage composite restorations. *Int J Prosthodont* 2004 May-Jun;**17**(3):313-7.

19. Magne P, Knezevic A. Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars. *Quintessence Int* 2009 Feb;**40**(2):125-33.

20. Magne P, Knezevic A. Thickness of CAD-CAM composite resin overlays influences fatigue resistance of endodontically treated premolars. *Dent Mater* 2009 Oct;**25**(10):1264-8.

21. Carvalho AO, Bruzi G, Maia HP, Giannini M, Magne P. Fatigue Resistance of CAD/CAM Complete Crowns with a Simplified Cementation Process. Piracicaba: FOP/UNICAMP; No prelo 2012.

22. Federlin M, Krifka S, Herpich M, Hiller KA, Schmalz G. Partial ceramic crowns: influence of ceramic thickness, preparation design and luting material on fracture resistance and marginal integrity in vitro. *Oper Dent* 2007 May-Jun;**32**(3):251-60.

23. Tsitrou EA, Helvatjoglu-Antoniades M, van Noort R. A preliminary evaluation of the structural integrity and fracture mode of minimally prepared resin bonded CAD/CAM crowns. *J Dent* 2010 Jan;**38**(1):16-22.

24. Magne P, Spreafico RC. Deep Margin Elevation: A Paradigm Shift. *Am J Esthet Dent* 2012(2):86-96.

25. Kampe T. Function and dysfunction of the masticatory system in individuals with intact and restored dentitions. A clinical, psychological and physiological study. *Swed Dent J Suppl* 1987;**42**:1-68.

26. Kiliaridis S, Kjellberg H, Wenneberg B, Engstrom C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. *Acta Odontol Scand* 1993 Oct;**51**(5):323-31.

27. Magne P, Kim TH, Cascione D, Donovan TE. Immediate dentin sealing improves bond strength of indirect restorations. *J Prosthet Dent* 2005 Dec;**94**(6):511-9.

28. Magne P. Immediate dentin sealing: a fundamental procedure for indirect bonded restorations. *J Esthet Restor Dent* 2005;**17**(3):144-54; discussion 55.

29. Daronch M, Rueggeberg FA, De Goes MF. Monomer conversion of pre-heated composite. *J Dent Res* 2005 Jul;**84**(7):663-7.

Table 1. Pairwise post hoc comparisons with the log-rank test including previous data. The significance level is .016 (Bonferroni correction for 3 comparisons).

	RNC 0.7 mm	LD 0.7 mm	FEL 0.7 mm	RNC 1.5 mm	LD 1.5 mm	FEL 1.5 mm
RNC 0.7 mm		0.17	0.17	<0.0001		
LD 0.7 mm			0.17		<0.0001	
FEL 0.7 mm						0.0109
RNC 1.5 mm					0.28	<0.0001
LD 1.5 mm						<0.0001
FEL 1.5 mm						

Bold square: ultra-thin full veneer crowns in present study.

Double-line square: standard dimension complete crowns in previous study.

Shaded cells: comparison of standard dimension and ultra-thin crowns for each material.

Table 2. Failure mode during fatigue testing.

	Reparable	Possibly reparable	
	Adhesive failure	Adhesive failure + chip or crack dentin	Adhesive failure + DEEP chip or crack dentin
RNC	7	6	1
LD	11	2	-
FEL	14	1	-

LEGENDS:

Figure 1. (A) Minimal preparation dimensions of tooth. (B) Ultra-thin full veneer crown restoration and corresponding measurements and dimensions.

Figure 2. Life table survival distributions by materials at each load step (n=15).

Figure 3. Failure modes: (A) adhesive failure, (B) adhesive failure + crack or chip in dentin (Arrow – chip in dentin) and (C) adhesive failure + deep crack or chip in dentin (Arrow – deep chip in dentin).

Figure 4. Chip at the crown's margin - (A) RNC, (B) LD and (C) FEL.

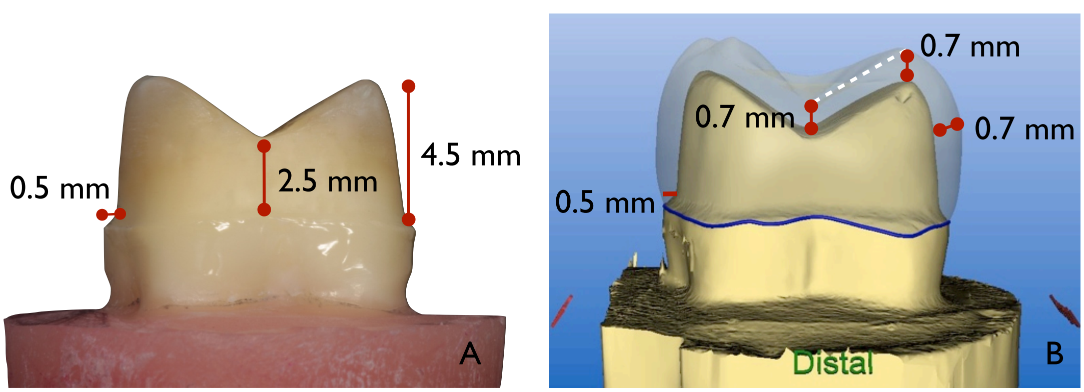


Figure 1.

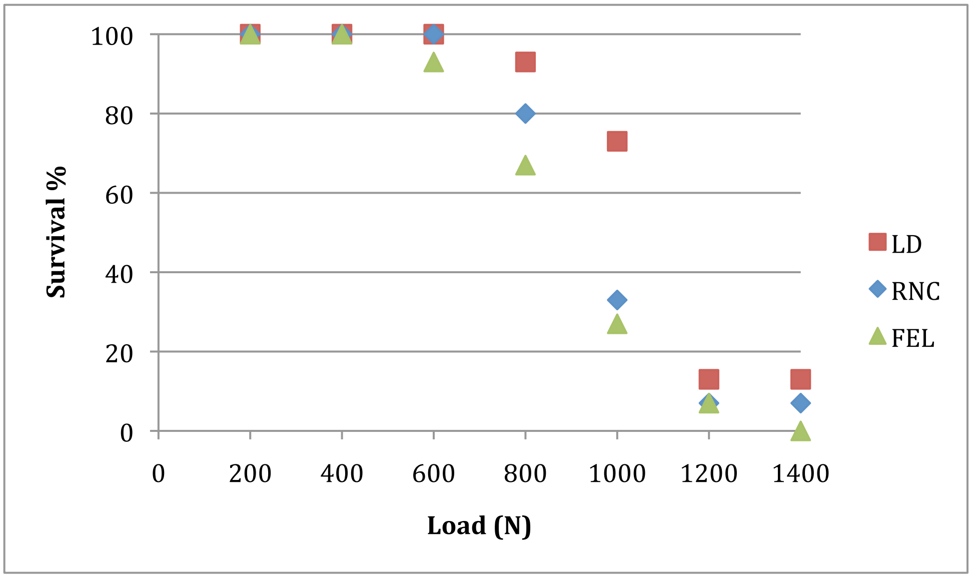


Figure 2.

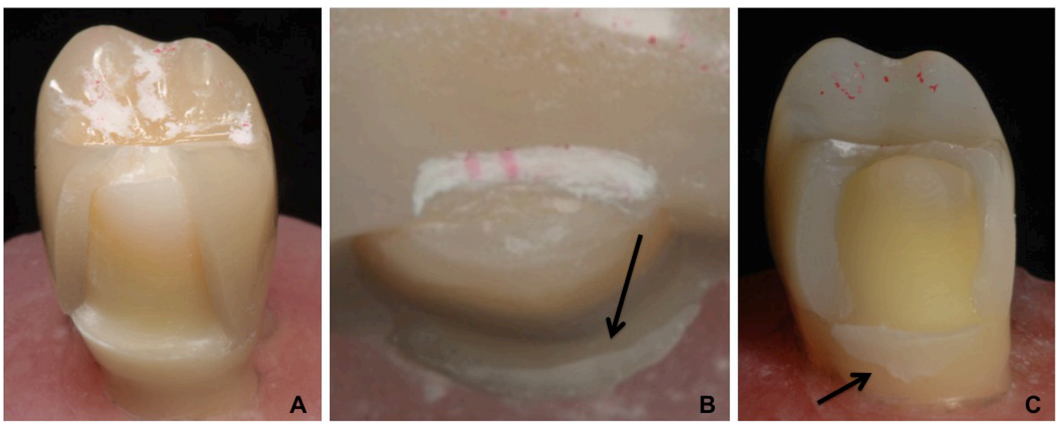


Figure 3.

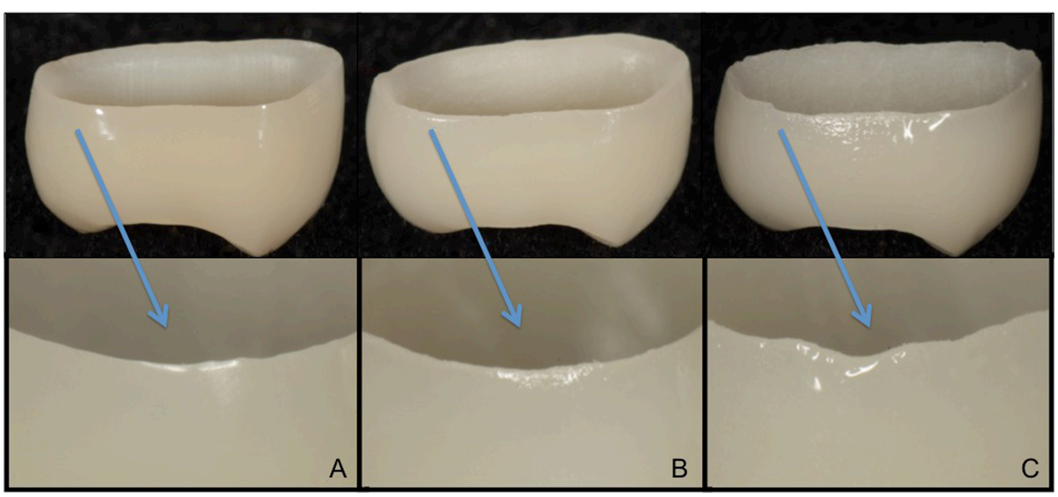


Figure 4.

CAPÍTULO 3 [1]

Influence of no-ferrule and no-post build-up design on the fatigue resistance of endodontically treated molars restored with resin nano ceramic CAD/CAM crowns.

Running Title: Mechanical Performance of endodontically treated molars restored with resin nano ceramic CAD/CAM crowns.

Carvalho AO[1], Bruzi G[2], Anderson RE[3], Maia HP[4], Giannini M[5], Magne P[6].

[1] PhD Student, Department of Restorative Dentistry, Dental Material Division, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.
[2] PhD Student, Department of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianopolis, Santa Catarina, Brazil.
[3] DMD, Endodontics Department, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA.
[4] DDS, MS, PhD, Professor of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianopolis, Santa Catarina, Brazil.
[5] Associate Professor, Department of Restorative Dentistry, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.
[6] Don and Sybil Harrington Professor of Esthetic Dentistry, Restorative Sciences, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA.

Corresponding Author

Dr. Pascal Magne

UNIVERSITY OF SOUTHERN CALIFORNIA

Division of Restorative Sciences

School of Dentistry – Oral Health Center

3151 S. Hoover St

Los Angeles, CA 90089-7792

Phone (213) 740-4239

Fax (213)821-5324

[1] Este artigo foi submetido a revista *Operative Dentistry*.

Clinical Relevance Statement:

Endodontically treated molars with extensive loss of coronal structure and no ferrule effect could be restored successfully with resin nano ceramic CAD/CAM crowns, with or without underlying composite resin build-up.

ABSTRACT

Objectives: To evaluate the influence of adhesive no-ferrule and no-post build-up designs: 4-mm build-up, 2-mm build-up and no build-up (endocrown) on the fatigue resistance and failure mode of endodontically treated molar teeth restored with resin nano ceramic CAD/CAM complete crowns placed with self-adhesive resin cement.

Materials and Methods: Forty-five extracted molars were decoronated at the level of CEJ and the roots were endodontically treated. Specimens received different Filtek Z100 adhesive core build-ups (4-mm build-up; 2-mm build up; and no build-up, endocrown preparation) and were restored with Cerec 3 CAD/CAM resin nano ceramic / RNC crowns (Lava Ultimate). Restorations (n=15) and prepared teeth were treated with airborne-particle abrasion, followed by cementation with RelyX Unicem 2 Automix. Specimens were then subjected to cyclic isometric loading at 10Hz, beginning with a load of 200 N (x 5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles (10 mm-diameter composite resin hemi-sphere antagonist). The failure mode was assessed, “catastrophic” (tooth/root fracture that would require tooth extraction), “possibly reparable” (cohesive/adhesive failure with fragment and minor damage, chip or crack, of underlying tooth structure) or “reparable” fracture (cohesive or cohesive/adhesive fracture of restoration only). Groups were compared using the life table survival analysis. Survived specimens were loaded to failure and compared with one-way ANOVA.

Results: All specimens survived the fatigue test until the 800 N-step. The survival rate for 4-mm, 2-mm and no build-up (endocrown) were 53%, 87% and 87% respectively and were not statistically different even though crowns over 2-mm build-ups only started to fail at 1,200N. Minor cohesive chips were detected in many samples despite having survived all 185,000 cycles. Post-fatigue load to failure ranged among 2969 N with 4-mm build-up (8 specimens), 2794 N for

2-mm build-up (13 specimens) and 2606 N for endocrowns (13 specimens) and were not statistically different as well. There were only two catastrophic failures during the fatigue test and small subgingival delamination fractures and cracks (only with 4-mm build-up). All specimens in the load-to-failure test exhibited non-restorable catastrophic fractures.

Conclusions: There was no influence of the build-up design on the performance of endodontically treated molars restored with RNC CAD/CAM complete crowns placed with self-adhesive cement. All restoration designs survived the normal range of masticatory forces. Failure mode tended to be more favorable with the 2-mm build-up or no build-up (endocrown).

Key words: Crown, endocrown, build-up, self-adhesive resin cement, CAD/CAM, fatigue resistance, resin nano ceramic, endodontically-treated molar.

INTRODUCTION

The decision of how to rehabilitate endodontically treated molars (ETM) with extensive loss of coronal structure is a challenge for the Restorative Dentistry. Those teeth are considered to have a higher risk of fracture than vital teeth because of their inherently poor structural integrity, with loss of root and coronal dentin resulting from pre-existing caries and/or tooth preparation. [1-4] There are controversies regarding which technique would be ideal for ETM restoration.

Although earlier publications have called for stabilization of ETM with intra-canal posts and ferrule, evidence has demonstrated that post reinforcement is not beneficial. [3, 5] Even though posts are frequently used to retain coronal build up materials, they do not reinforce roots and may even weaken them through loss of radicular dentin necessitated by post-space preparation. [5, 6] In addition, preparing a post space also involves a certain degree of risk of accidental root perforation. The loss of tooth structure during preparation affects tooth stiffness, reduces its resistance to fracture and consequently limits its prognosis. Other studies [4, 7, 8] have confirmed that ETM restored without posts have similar fracture resistances and failure modes compared to those with posts, which suggest that posts are not necessarily required. Lima et al., 2009 [7] confirmed that the presence of a ferrule (with a composite resin build-up) is critical rather than the use of a post. However, there is no consensus about the optimal build-up design necessary to restore ETM in the absence of any ferrule. The endocrown restoration is another alternative restorative treatment for ETM. [9, 10] Pissis [9] was a pioneer in proposing this "monobloc" porcelain technique in 1995. This type of restoration preserves root tissue and limits internal preparation of the pulp chamber to its anatomic shape. It constructs both the crown and core build-up as a single unit. Even though the original technique described the use of porcelain, there is significant evidence that endocrowns made of more flexible composite resin or newer resin nanoceramic materials may even perform better. [10-13] Another consideration is the possible use of a core build-up to remove retentions from the endodontic preparation, provide some kind of positive geometry, decrease restoration thickness (allowing for the use of light polymerized luting composites) and to facilitate provisionalization. Yet, there is a lack of data about the biomechanical behavior of different build up designs to restore ETM.

Therefore, the aim of this study was to evaluate the influence of a 4-mm build-up, a 2-mm build-up or no build-up (endocrown) on the mechanical performance and failure mode of ETM restored with resin nano ceramic CAD/CAM complete crowns placed with self-adhesive cement. The null hypotheses was that there is no significant difference in the fatigue resistance and failure mode of ETM among the three different designs tested in this *in vitro* study.

MATERIAL AND METHODS

Once approval was obtained from both the Ethical Committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California Review Board, forty-five freshly extracted, sound human maxillary molars stored in solution saturated with thymol were used. Teeth were mounted in a special positioning device with acrylic resin (Palapress; Heraeus Kulzer, Armonk, NY, USA) embedding the root up to 3.0 mm below the cementoenamel junction (CEJ).

Tooth preparation

A standardized tooth preparation was applied to all specimens. The intact crowns were removed by a horizontal section 1 mm above the CEJ using a diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA), under water lubrication. A standard access opening was prepared to simulate root canal treatment in each tooth. Teeth were accessed using slow speed round and GK269 burs to de-roof the pulp chamber and smoothen the internal walls. Canals were located and patency achieved using #10k files (Dentsply Tulsa Dental, Johnson City, TN, USA).

Coronal flare was created using Gates #3 (Dentsply Tulsa Dental) and canals were chemomechanically debrided using 04 rotary files (Protaper Niti Rotary, Dentsply Tulsa Dental) and NaOCl (5.25%) to within 3 mm of the apex. A final rinse with H_20 was performed and canals were dried using paper points. Warm vertical obturation of the canals was then performed using gutta percha to the orifice level and condensed. An additional horizontal reduction of 1.0 mm was obtained (flat preparation following the CEJ, no ferrule) with the aid of a coarse round diamond bur (Brasseler, Savannah, GA, USA). Finally, a 1.0-1.5 mm – thick glass-ionomer barrier (Ketac Molar, 3M ESPE, St. Paul, MN, USA) was applied to the base of the pulp chamber.

The teeth were randomly divided into three groups according to the different restorative technique (n = 15):

- Group I – large build-up (4-mm height from CEJ at cusp tips, 2-mm height from CEJ at central groove) + complete crown restorations (1.5-mm thick) (Figure 1A);
- Group II – short build-up (2-mm height from CEJ at cusp tips, 1-mm height from CEJ at central groove) + complete crown restorations (2.5-3.5 mm thick) (Figure 1B);
- Group III - Endocrown restoration (ca. 5-5.5-mm thickness) (Figure 1C).

Build-ups for groups I and II were made using Optibond FL adhesive system (Kerr Corp., Orange, CA, USA) and Filtek Z100 composite resin (3M ESPE) placed in 1.5-mm increments polymerized for 20 s each at 1,000 mW/cm^2.

Design and manufacturing of restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). The specimens were fitted with a crown or endocrown of standardized thickness and occlusal anatomy (third maxillary molar, Lee Culp Youth database). Using the Crown Master Mode and the Design Tools of the Cerec software (v. 3.6, Sirona Dental Systems), the occlusal surface was moved and rotated in order to make parallel the cusp tips and the preparation surface as well as to align the central groove. All restorations were milled in resin nano ceramic /RNC (Lava Ultimate blocks - 3M ESPE) using Endo mode with the sprue located at the lingual surface, then polished mechanically with a diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler), polishing brush (soft bristle brush) with diamond paste (Diamord

Twist SCL, Premier, EC Representative: MDSS GmbH * Schiffgraben, Hannover, Germany) and buff with a muslin rag wheel.

Crown placement

All crowns were cemented with a dual-cure self-adhesive resin cement (RelyX Unicem 2 Automix, 3M ESPE). Before cementation, each crown was fitted on its respective tooth to check its marginal adaptation and steam cleaned. The inner surface of RNC crowns were sandblasted with 50 µm – aluminum oxide (Danville, San Ramon, CA, USA), rinsed and cleaned in ultrasonic bath in distilled water for 1 minute. The prepared teeth were sandblasted with 27 µm - aluminum oxide, rinsed and dried. The cement was applied to the inner surface of the crowns, which were then seated on the tooth with an approximate pressure of 70 N. Cement excesses were removed after a brief light exposure (approximately 2 seconds) with a LED light (VALO Curing Light, Ultradent Products, Inc., South Jordan, UT, USA) and followed by light polymerized for 20 seconds on each surface. Air-blocking barrier (KY Jelly; Johnson & Johnson Inc., Montreal, QC, Canada) was used to cover all margins and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler), polishing brush (soft bristle brush) with diamond paste (Diamord Twist SCL, Premier) and buff with a muslin rag wheel.

Testing

1) Fatigue testing

Each specimen was stored in distilled water at room temperature for at least 24 hours following adhesive restoration placement. Masticatory forces were then simulated with an artificial mouth using closed-loop servo hydraulics (Mini Bionix II; MTS Systems, Eden Prairie, MN, USA). Each specimen was placed into the load chamber and situated with a positioning device (sliding table). The chewing cycle was simulated by an isometric contraction (load control) applied through a composite resin hemi-sphere (Filtek Z100, 3M ESPE) with a diameter of 10.0 mm. Because of the standardized occlusal anatomy, all specimens could be adjusted (through the positioning device) in the same reproducible position with the hemi-sphere contacting the mesio-buccal, disto-buccal and palatal cusps (tripod contact). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 10 Hz, starting with a load of 200 N for 5,000 cycles (pre-conditioning phase to guarantee predictable positioning of the hemi-sphere with the specimen), followed by stages of 400, 600, 800, 1,000, 1,200 and 1,400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. Following a two-examiner agreement under optical microscope, a distinction was made between "catastrophic" failure (crown/root fracture that would require tooth extraction), or "reparable" failure (cohesive or cohesive/adhesive failure with or not fragment and minor damage, chip or crack, of underlying tooth structure) (Table 1).

2) Load-to-failure testing of survived specimen

After the fatigue test, survived specimens were axially loaded until failure or to a maximum load of 4,500 N with a 10-mm composite resin hemi-sphere. The hemi-sphere had the same three-point occlusal contacts as in the fatigue test. The crosshead speed was 0.5mm/min. The maximum post-fatigue load before failure was recorded in Newtons and mean values were calculated per group. After load tests, the specimens were analyzed for one of the three failure modes as in the fatigue test.

Statistical analysis

The fatigue resistance of the three groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability (%) at each interval. The influence of the restorative material on the fracture strength (load step at which failure occurred) was analyzed by using the Log-rank test at a significance level of .05. The post-fatigue load-to-failure resistance of the survived specimens was compared using one-way ANOVA (data tested normal). For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, V. 11.0.1; MedCalc Software, Mariakerke, Belgium).

RESULTS

The survival rate after the fatigue test for ETM with 4-mm, 2-mm build-ups and endocrowns were 53% (8 samples), 87% (13) and 87% (13), respectively, and no statistically significant differences were found among them ($p>0.05$) (Figure 2). In groups with large build-ups and endocrowns, all specimens survived until 800 N-step while for specimens with short build-ups, samples started to fail only at 1200 N-step. At the end of the fatigue test, minor surface chips were detected (2 specimens with large build-ups and 9 specimens with short build-ups or endocrowns). All specimens demonstrated less wear at the resin hemi-sphere antagonist than the restoration itself (Figure 3).

Post-fatigue load to failure averaged 2969 N with 4 mm-build-ups (8 specimens), 2794 N for 2 mm-build-ups (13 specimens) and 2606 N for endocrowns (13 specimens). One-way ANOVA revealed that there were no statistically significant differences among all three restorative techniques. Failure mode analysis showed that there were only two evident catastrophic failures during the fatigue test. All failure modes found at the fatigue test are given in Table 1. All of specimens after load-to-failure test exhibited non-restorable catastrophic fractures.

DISCUSSION

Based on the results of this study, the null hypotheses was accepted for the fatigue resistance, but rejected for failure mode analysis of ETM. The failure modes slightly varied, with less favorable outcomes when using a large core build-up.

In an effort to standardize and approximate the clinical situation as much as possible natural teeth of similar dimensions were selected, the anatomy of occlusal surface and the thickness of those restorations were standardized by the Cerec machine and consistent load configuration of all samples was applied. As previously suggested, [12, 14] the use of a composite resin hemi-sphere antagonist was preferred rather than a stainless steel. A more realistic simulation of tooth contacts is enabled by the lower stiffness and higher wear of the composite resin. [15] No failure of the hemi-spheres was noted during the test. Because of simulated natural tooth anatomy of the restorations, a standardized 3 point/facet contact could be created and generated a progressive load protocol (from 200N to 1400N – max. 185,000 cycles). Loaded restorations and teeth should showed wear facets and not point contacts. [14] Such wear facets both at the restorations and resin hemi-sphere antagonists were observed. As was the case in previously published data,[16] the resin nano ceramic material demonstrated more material wear than the antagonistic wear (resin hemi-sphere). It can be explain by the fact that the resin nano ceramic material has 80% of filler content in weight (20% of resin matrix) compared to 85% / 15% for Filtek Z100 composite resin (antagonist hemi-sphere).

The present protocol seems to be the best compromise between available in vitro fatigue testing methods and clinical reality and can be called accelerated fatigue. Even though it is not possible to make a direct clinical correlation about the significance of the load range used in this study, this test lies in-between load-to-failure (very high single load until failure, not clinically relevant unless during trauma) and fatigue tests (time-consuming low load/high cycles). A true fatigue correlation for one year of clinical service is 250,000 cycles at only 13.6 N. [17] Thereby, given the extended range of load in the present study, the accelerated life cycle of the restored tooth may have been simulated.

A higher frequency (10 Hz) in the cyclic loading test, which was suggested by Kelly, [18] was used in this study. It decreases the time of the experiment, allowing testing of 3 specimens per day. One may wonder whether such high frequency might lead to more heat generation compared to 1 to 2 Hz and possibly will not give a time for stress relaxation. [19] Another limitation of this study is the load was applied only axially, limiting the clinical implication to a vertical loading situation. Biacchi and Basting [20] used an oblique compression forces to compare the fracture strength of endocrown and complete crowns retained by glass fiber posts. Yet, alike the present study, the endocrown restorations performed well, even presenting greater fracture strength than the conventional crowns supported on posts and filling cores.

Another specific element in this study was the use of self-adhesive resin cement. It allows for a convenient, fast and efficient delivery of complete crowns. This is especially significant considering excess cement removal in case of subgingival margins (common situation when replacing existing complete crowns), for which adhesive luting becomes more technique sensitive. RelyX Unicem 2 was chosen also because of its self-polymerization component, which was desirable for the thick endocrowns. The same cement was used to deliver the other crowns on the different build-ups in order not to introduce a new variable.

The results of this study demonstrated that the presence of a build-up does not necessarily enhance the fracture resistance of ETM with extensive loss of coronal structure when using RNC crowns. However, the mean fracture loads for 4 mm-build up (1171 N), 2 mm-build up (1300 N) and endocrown (1000 N) failed fatigued restorations far exceeded regular masticatory forces.

The latter, during normal function, range from 50 N to 250 N and 500 N to 800 N in bruxism behavior.[21, 22] The 4 mm-build-up, and endocrown restorations started to fail at 800 N while all short build up did not show fracture before 1200 N. Those results suggest that it may be possible using all three types of RNC restorations with self-adhesive cementation for ETM with extensive loss of coronal structure even under high loads requirements. It is noteworthy to compare the performance of those restored non-vital teeth with that of crowned vital molars from another study by the same author in strictly identical conditions, 1.5-mm RNC crowns with self-adhesive cementation.[16] Simulated fatigue survival of the crowned vital teeth was 80% (53-87% in the present study) and average load-to-failure of survived specimens was 3,122 N (2,606 -2,969 N in the present study). This indicates that the restorative modalities proposed for ETM in the present study may allow approaching the performance of vital teeth despite the absence of ferrule effect.

There is evidence that the use of posts does not influence the performance of restored ETM.[3, 5, 20] In addition, the placement of a post is always associated to a risk of perforation and cracking of the root. Therefore, no posts were used in the present study. No-post endocrown restorations allow for maximum tooth structure preservation, reduce the requirement for macro retentive geometry, provide an efficient and esthetic outcome and seem viable clinically.[23-25] From a clinical perspective, the endocrown design seems to have practical advantages over restorations with a core build-up, it is cheaper, takes less time to complete and there is no composite resin shrinkage associated to this technique. The endocrown is also a useful option when there is simply no occlusal clearance (extra-short clinical crowns). On the other hand, there are advantages of using an adhesive composite resin core build-up when possible. The build-up is preceded by the use of a dentin adhesive system that safely seals the dentin. It reduces the thickness of the overlaying restoration, allowing for a more efficient light polymerization during cementation. It is know that even for dual-polymerization cements, the light-polymerization component is determinant for obtaining an acceptable degree of conversion.[26-28] In view of the present results, small composite resin build-ups should be preferred. They also induce less polymerization shrinkage than large ones and they are useful to provide enhanced geometry, to remove undercuts from the endodontic preparation and to facilitate provisionalization (by stabilization) when necessary.

Failure modes tended to be more favorable with the 2-mm build-up or no build-up (just cohesive failures). Only one endocrown failed with a small subgingival margin dentin chipping, which was still considered reparable because it would be feasible to smoothen this margin or, in the worst case scenario, use periodontal surgery or the margin elevation technique. [29] Small superficial chipping of the RNC material around the contact points was frequently observed. Because there was no effect on the integrity of the restoration and stable occlusal contacts were maintained, the fatigue machine did not stop. From a clinical perspective, those defects would be easily corrected and polished, since Lava Ultimate proved extremely polishable, which is another advantage of the RNC material.

Further research should explore the use of different core-build-ups (such as auto-cure composite resins), restorative materials and adhesive luting procedures. Even though more flexible materials seem to be indicated to restore those severely-broken-down ETM, rather than traditional porcelain, [10-13] the use of ceramics with stronger mechanical properties, such as lithium disilicate may be a potential alternative.

CONCLUSION

Within the limitations of this in vitro study, it can be concluded that there is no influence of the build-up design on the performance of endodontically treated molars restored with resin nano ceramic CAD/CAM full crowns placed with self-adhesive resin cement. All restoration designs survived the normal range of masticatory forces. Failure mode tended to be more favorable with the 2-mm build-up or no build-up (endocrown). The endocrown has many practical advantages (simpler, quicker, more economic) while the use of a small composite resin build-up maybe useful to provide enhanced geometry, to remove undercuts from the endodontic preparation and to facilitate provisionalization when necessary.

REFERENCES

1. Belli S, Cobankara FK, Eraslan O, Eskitascioglu G & Karbhari V (2006) The effect of fiber insertion on fracture resistance of endodontically treated molars with MOD cavity and reattached fractured lingual cusps *Journal of Biomedical Materials Research. Part B, Applied Biomaterials.* **79(1)** 35-41.

2. Tidmarsh BG (1976) Restoration of endodontically treated posterior teeth *Journal of Endodontic* **2(12)** 374-375.
3. Salameh Z, Ounsi HF, Aboushelib MN, Al-Hamdan R, Sadig W & Ferrari M (2010) Effect of different onlay systems on fracture resistance and failure pattern of endodontically treated mandibular molars restored with and without glass fiber posts *American Journal of Dentistry* **23(2)** 81-86.
4. Salameh Z, Sorrentino R, Papacchini F, Ounsi HF, Tashkandi E, Goracci C & Ferrari M (2006) Fracture resistance and failure patterns of endodontically treated mandibular molars restored using resin composite with or without translucent glass fiber posts *Journal of Endodontic* **32(8**) 752-755.
5. Krejci I, Mueller E & Lutz F (1994) Effects of thermocycling and occlusal force on adhesive composite crowns *Journal of Dental Research* **73(6)** 1228-1232.
6. Assif D & Gorfil C (1994) Biomechanical considerations in restoring endodontically treated teeth *The Journal of Prosthetic Dentistry* **71(6)** 565-567.
7. Lima AF, Spazzin AO, Galafassi D, Correr-Sobrinho L & Carlini-Junior B (2010) Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth *Journal of Applied Oral Science* **18(4)** 360-363.
8. Salameh Z, Sorrentino R, Papacchini F, Ounsi HF, Tashkandi E, Goracci C & Ferrari M (2006) Fracture resistance and failure patterns of endodontically treated mandibular molars restored using resin composite with or without translucent glass fiber posts *Journal of Endodontia* **32(8)** 752-755.
9. Fokkinga WA, Le Bell AM, Kreulen CM, Lassila LV, Vallittu PK & Creugers NH (2005) Ex vivo fracture resistance of direct resin composite complete crowns with and without posts on maxillary premolars *International Endodontic Journal* **38(4)** 230-237.
10. Pissis P (1995) Fabrication of a metal-free ceramic restoration utilizing the monobloc technique *Practical Periodontics and Aesthetic Dentistry* **7(5)** 83-94.
11. Magne P (2010) Virtual prototyping of adhesively restored, endodontically treated molars *Journal of Prosthetic Dentistry* **103(6)** 343-351.
12. Jiang W, Bo H, Yongchun G & LongXing N (2010) Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis *Journal of Prosthetic Dentistry* **103(1)** 6-12.

13. Magne P & Knezevic A (2009) Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars *Quintessence International* **40(9)** 729-737.
14. Magne P & Knezevic A (2009) Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars *Quintessence International* **40(2)** 125-133.
15. Kelly JR (1999) Clinically relevant approach to failure testing of all-ceramic restorations *Journal of Prosthetic Dentistry* **81(6)** 652-661.
16. Schlichting LH, Maia HP, Baratieri LN & Magne P (2011) Novel-design ultra-thin CAD/CAM composite resin and ceramic occlusal veneers for the treatment of severe dental erosion *Journal of Prosthetic Dentistry* **105(4)** 217-226.
17. Carvalho AO, Bruzi G, Maia HP, Giannini M & Magne P (2012) Fatigue Resistance of CAD/CAM Fabricated Full---Coverage Crowns [abstract #p07] *Academy Dental Materials Meeting*.
18. Sakaguchi RL, Douglas WH, DeLong R & Pintado MR (1986) The wear of a posterior composite in an artificial mouth: a clinical correlation *Dental Materials* **2(6)** 235-240.
19. Kelly JR, Rungruanganunt P, Hunter B & Vailati F (2010) Development of a clinically validated bulk failure test for ceramic crowns *Journal of Prosthetic Dentistry* **104(4)** 228-238.
20. Karl M & Kelly JR (2009) Influence of loading frequency on implant failure under cyclic fatigue conditions *Dental Materials* **25(11)** 1426-1432.
21. Biacchi GR & Basting RT (2012) Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns *Operative Dentistry* **37(2)** 130-136.
22. Kampe T (1987) Function and dysfunction of the masticatory system in individuals with intact and restored dentitions. A clinical, psychological and physiological study *Swedish Dental Journal. Supplement* **42** 1-68.
23. Kiliaridis S, Kjellberg H, Wenneberg B & Engstrom C (1993) The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study *Acta Odontologica Scandinavica* **51(5)** 323-331.
24. Lander E & Dietschi D (2008) Endocrowns: a clinical report *Quintessence International* **39(2)** 99-106.

25. Bindl A & Mormann WH (1999) Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results *Journal of Adhesive Dentistry* **1(3)** 255-265.
26. Bindl A, Richter B & Mormann WH (2005) Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry *The International Journal of Prosthodontics* **18(3)** 219-224.
27. Darr AH & Jacobsen PH (1995) Conversion of dual cure luting cements *Journal of Oral Rehabilitation* **22(1)** 43-47.
28. Besek M, Mormann WH, Persi C & Lutz F (1995) [The curing of composites under Cerec inlays] *Schweizer Monatsschrift für Zahnmedizin* **105(9)** 1123-1128.
29. Arrais CA, Giannini M & Rueggeberg FA (2009) Kinetic analysis of monomer conversion in auto- and dual-polymerizing modes of commercial resin luting cements *Journal of Prosthetic Dentistry* **101(2)** 128-136.
30. Magne P & Spreafico RC (2012) Deep Margin Elevation: A Paradigm Shift *American Journal of Esthetic Dentistry* **(2)** 86-96.

LEGENDS:

Figure 1. Restorative techniques: (A) Group I, (B) Group II and (C) Group III.

Figure 2. Life table survival distributions by materials at each load step (n=15).

Figure 3. Photographs of crown (RNC) and antagonist (resin hemi-sphere) wear. A- Crown before Fatigue Test; B- Arrow - Wear of crowns after Fatigue Test; C- Arrow - Wear of the Z100 composite resin hemi-sphere after Fatigue Test.

Table 1. Failure mode during Fatigue Testing.

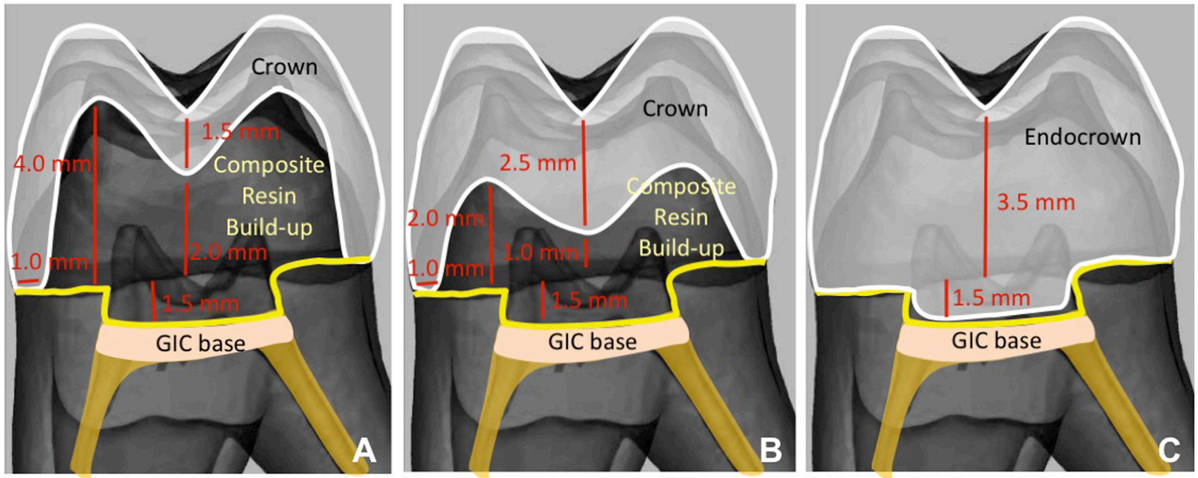


Figure 1.

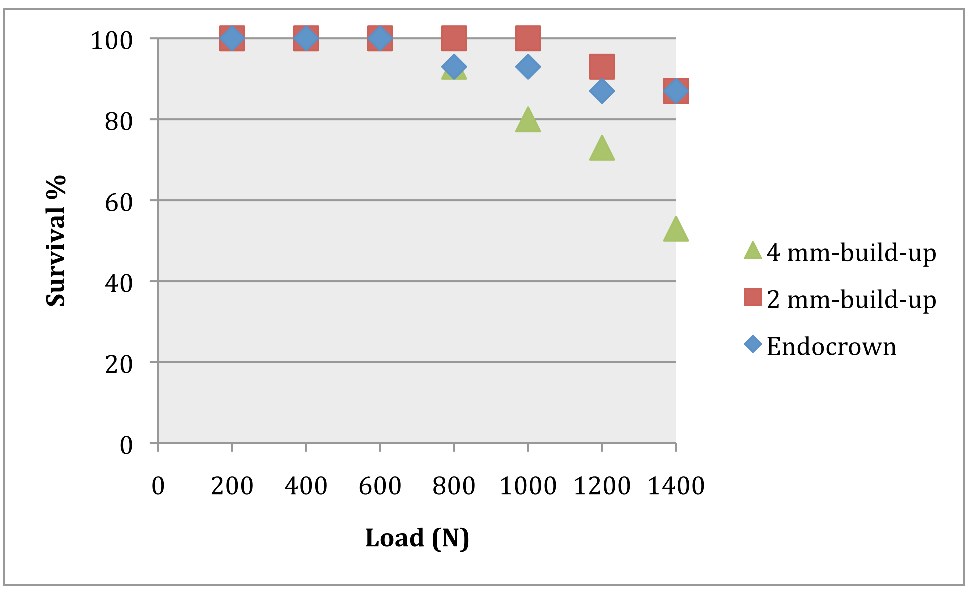


Figure 2.

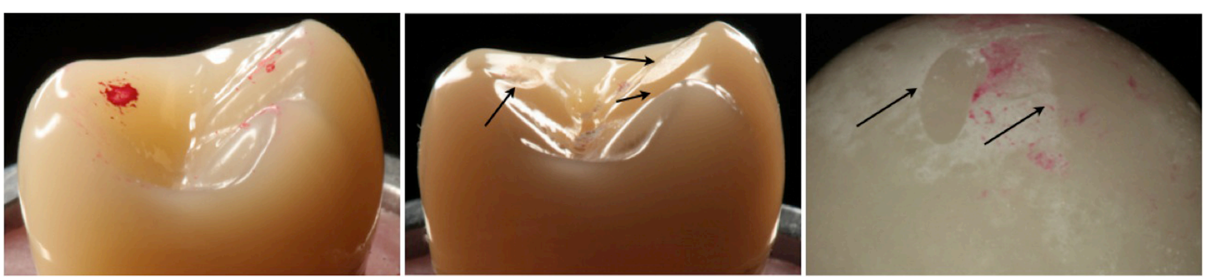


Figure 3.

Table 1.

	Reparable				Not reparable
	Cohesive failure at crown	Cohesive failure at crown and build up + Adhesive failure at dentin margin	Adhesive failure between crown and build up + Adhesive failure at dentin margin	Cohesive failure at crown and build up + Dentin chip	Catastrophic failure
Endocrown	1	-	-	1	-
2 mm-Build-up	2	-	-	-	-
4 mm- Build-up	1	3	1	-	2

Acknowledgments

This study was supported by CNPq 20092/2011-6, CAPES 3110/2010 and CAPES 4979/11-7. The authors thank 3M ESPE, St Paul, Minn, for providing Lava Ultimate blocks, Rely X Unicem 2 Automix, Filtek Z100.

CAPÍTULO 4 [1]

Influence of no-ferrule and no-post build-up design on the resistance of endodontically-treated molars restored with lithium disilicate CAD/CAM crowns

Running Title: The resistance of endodontically-treated molars restored with lithium disilicate CAD/CAM crowns

Magne P[1], Carvalho AO[2], Bruzi G[3], Anderson RE[4], Maia HP[5], Giannini M[6]

[1] Don and Sybil Harrington Professor of Esthetic Dentistry, Restorative Sciences, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA.
[2] PhD Student, Department of Restorative Dentistry, Dental Material Division, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.
[3] PhD Student, Department of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil.
[4] DMD, Endodontics Department, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA
[5] DDS, MS, PhD, Professor of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianópolis, Santa Catarina, Brazil.
[6] Associate Professor, Department of Restorative Dentistry, Piracicaba Dental School, State University of Campinas, Piracicaba, SP, Brazil.

Corresponding Author

Dr. Pascal Magne

UNIVERSITY OF SOUTHERN CALIFORNIA

Division of Restorative Sciences

School of Dentistry – Oral Health Center

3151 S. Hoover St

Los Angeles, CA 90089-7792

Phone (213) 740-4239

Fax (213) 821-5324

[1] Artigo formatado de acordo com as normas da revista *Operative Dentistry*.

Clinical Relevance Statement:

Lithium disilicate CAD/CAM crowns with or without composite resin build-up exceeded all expectations to restore endodontically treated molars with extensive loss of coronal structure and no ferrule effect. The use of composite resin build-up with 2 mm high provided the highest loads to failure and good fatigue resistance, which can be indicated in cases of high occlusal loading.

ABSTRACT

Objectives: To assess the influence of adhesive core build-up designs (4-mm build-up, 2-mm build-up and no build-up/endocrown) on the fatigue resistance and failure mode of endodontically treated molar teeth restored with lithium disilicate CAD/CAM complete crowns placed with self-adhesive cement.

Materials and Methods: Forty-five extracted molars were decoronated at the level of CEJ and endodontically-treated. Specimens received different Filtek Z100 adhesive core build-ups (4-mm build-up; 2-mm build up; and no build-up, endocrown preparation) and were restored with Cerec 3 CAD/CAM lithium disilicate (LD) crowns (IPS e.max CAD). The intaglio surfaces of restorations (n=15) were conditioned by hydrofluoric acid etching and silane and prepared teeth were treated with airborne-particle abrasion, followed by cementation with RelyX Unicem 2 Automix. Specimens were then subjected to cyclic isometric loading at 10Hz, beginning with a load of 200 N (x 5000 cycles), followed by stages of 400, 600, 800, 1000, 1200, and 1400 N at a maximum of 30,000 cycles each. Specimens were loaded until failure or to a maximum of 185,000 cycles. The chewing cycle was simulated by an isometric contraction (load control) applied through a 10 mm-diameter composite resin hemi-sphere (Filtek Z100). Survived specimens were axially loaded until failure or to a maximum load of 4,500 N (crosshead speed 0.5 mm/min). The failure mode was assessed, “catastrophic” (tooth/root fracture that would require tooth extraction), or “reparable” fracture (cohesive or cohesive/adhesive fracture of restoration only). Groups were compared using the life table survival analysis (Log rank test at P=.05). Survived specimens were loaded to failure and compared with one-way ANOVA. Previously published data from the same authors about resin nano ceramic complete crowns using the same experimental set-up were included for comparison.

Results: The survival rate after the fatigue test for 4-mm, 2-mm and no build-up (endocrown) were 100%, 93% and 100% respectively and were not statistically different (only one specimen failed with a 2-mm build-up under a crown that cohesively fractured at 1,400 N). Post-fatigue load to failure averaged 3181 N with large build-ups (15 specimens), 3759 N for 2-mm build-ups (12 specimens) and 3265 N for endocrowns (14 specimens). Short build-ups were associated to higher loads to failure than endocrowns and large build-ups but no differences between large build-ups and endocrowns were found ($p<.05$.) One endocrown and two 2 mm build-up restorations survived the load to failure test (at 4500 N). There were only catastrophic fractures after the load to failure test. The survival of LD crowns was higher than identical designs resin nano ceramic crowns (RNC) from a previous study ($P=.002$). At the load to failure, LD was also superior to RNC for endocrowns and on 2 mm build-ups.

Conclusions: There was an influence of the build-up design on the performance of endodontically treated molars restored with lithium disilicate CAD/CAM complete crowns placed with self-adhesive resin cement. Short build-ups (2 mm) were associated to higher loads to failure than endocrown and large build-up (4 mm) but all restoration designs survived far beyond the normal range of masticatory forces.
Key words: Crown, endocrown, build-up, self-adhesive cement, CAD/CAM, fatigue resistance, lithium disilicate, endodontically treated molar.

INTRODUCTION

Long-term success of endodontic treatment is highly dependent on the restorative treatment that follows. [1] There is wide general agreement that the "ferrule effect" is a critical element in the performance of crowned endodontically-treated molars (ETM). [2, 3] In dentistry, the ferrule refers to the cervical tooth structure that provides retention and resistance form to the restoration and protects it against fracture. However, in cases of absence of any ferrule, there is no consensus about the optimal build-up design required to rehabilitate these ETM with extensive loss of coronal structure. Although the insertion of a post does not strengthen or reinforce ETM, it is frequently used to retain coronal build up materials, which in turn is used to retain a restoration.

With advances in the mechanical properties of composite resins and bond strength of dentin adhesive resins, it is logical to question whether these materials can be used to develop an "internal" adhesive ferrule effect without a post. Usually, molars have a substantial amount of dentin (including the pulp chamber) available for bonding. In addition to substituting the pulp ceiling, the composite resin core build-up allows to remove retentions from the endodontic preparation and control the restoration thickness. A different strategy to restore ETM is the endocrown restoration. [4, 5] This alternative approach utilizes the surface available inside the pulp chamber and restores both the core and the crown as one component. There is little information about the clinical quality of endocrowns generated with the CEREC system, however, it appears to be feasible and at an acceptable level. [6, 7] Nowadays, both composite resin and ceramic materials can be used in the CAD/CAM technique. In vitro and in vivo research [8-10] tends to favor composite resin blocks over porcelain ones, especially when restoring ETM. Additional CAD/CAM materials have emerged such as resin nano ceramics (RNC) and lithium disilicates (LD). Previous conclusions about CAD/CAM porcelain blocks may not apply to all ceramics materials. Therefore, the biomechanical behavior of those materials as well as the most appropriate restorative strategy (core-buildup vs. endocrown) must be investigated to ensure appropriate clinical use.

The aim of this study was to evaluate the influence of a 4-mm build-up, a 2-mm build-up or no build-up (endocrown) on the mechanical performance and failure mode of ETM restored with lithium disilicate CAD/CAM complete crowns placed with self-adhesive resin cement. The null hypotheses were that (1) there is no significant difference in the fatigue resistance and failure mode of ETM among the three different build-up designs tested in this in vitro study, and (2) the fatigue resistance of these restorations would not be influenced by the restorative material (RNC vs. lithium disilicate). Data regarding Lava Ultimate RNC, previously published by the same authors using an identical experimental set-up, were used to test this second hypothesis.

MATERIAL AND METHODS

Once approval was obtained from both the Ethical Committee of the Piracicaba Dental School (Campinas State University) and the University of Southern California Review Board, forty-five freshly extracted, sound human maxillary molars stored in solution saturated with thymol were used. Teeth were mounted in a special positioning device with acrylic resin (Palapress; Heraeus Kulzer, Armonk, NY, USA) embedding the root up to 3.0 mm below the cementoenamel junction (CEJ).

Tooth preparation

A standardized tooth preparation was applied to all specimens. The intact crowns were removed by a horizontal section 1 mm above the CEJ using a diamond saw (Isomet, Buehler Ltd., Lake Bluff, IL, USA), under water lubrication. A standard access opening was prepared to simulate root canal treatment in each tooth. Teeth were accessed using slow speed round and GK269 burs to de-roof the pulp chamber and smoothen the internal walls. Canals were located and patency achieved using #10k files (Dentsply Tulsa Dental, Johnson City, TN, USA). Coronal flare was created using Gates #3 (Dentsply) and canals were chemomechanically debrided using 04 rotary files (Protaper Niti Rotary, Dentsply) and NaOCl (5.25%) to within 3 mm of the apex. A final rinse with water was performed and canals were dried using paper points. Warm vertical obturation of the canals was then performed using gutta percha to the orifice level and condensed. An additional horizontal reduction of 1.0 mm was obtained (flat preparation following the CEJ, no ferrule) with the aid of a coarse round diamond bur (Brasseler, Savannah, GA, USA). Finally, a 1.0-1.5 mm – thick glass-ionomer barrier (Ketac Molar, 3M ESPE, St. Paul, MN, USA) was applied to the base of the pulp chamber.

The teeth were randomly divided into three groups according to the different restorative technique (n = 15):

- Group I – large build-up (4-mm height from CEJ at cusp tips, 2-mm height from CEJ at central groove) + complete crown restorations (1.5-mm thick) (Figure 1A);
- Group II – Short build-up (2-mm height from CEJ at cusp tips, 1-mm height from CEJ at central groove) + complete crown restorations (2.5-3.5 mm thick) (Figure 1B);
- Group III - Endocrown restoration (ca. 5-5.5-mm thickness) (Figure 1C).

Build-ups for groups I and II were made using Optibond FL adhesive system (Kerr Corp., Orange, CA, USA) and Filtek Z100 composite resin (3M ESPE) placed in 1.5-mm increments polymerized for 20 s each at 1,000 mW/cm^2 (Valo, Ultradent Products, Inc., South Jordan, UT, USA).

Design and manufacturing of restorations

The molars were restored using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany). The specimens were fitted with a crown or endocrown of standardized thickness and occlusal anatomy (third maxillary molar, Lee Culp Youth database). Using the Crown Master Mode and the Design Tools of the Cerec software (v. 3.6, Sirona Dental Systems), the occlusal surface was moved and rotated in order to make parallel the cusp tips and the preparation surface as well as to align the central groove. All restorations were milled in lithium disilicate ceramic IPS e.max CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein) using Endo mode with the sprue located at the lingual surface, then polished mechanically with a diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler) and glazed with IPS e.max CAD Cristall/Glaze (Ivoclar Vivadent) according to the manufacturer's instructions. The lithium disilicate crowns require crystallization firing. Thus, after milling and glazed, IPS e.max CAD ceramic crowns were fired in a ceramic furnace (Austromat 624; DEKEMA Dental-Keramiköfen GmgH, Freilassing, Germany) following the manufacturer's instructions.

Crown placement

All crowns were cemented with a dual-cure self-adhesive resin cement (RelyX Unicem 2 Automix cement, 3M ESPE). Before cementation, each crown was fitted on its respective tooth to check its marginal adaptation and steam cleaned. The inner surface of IPS e.max CAD crowns were cleaned in a steam cleaner and etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) for 20 s, rinsed, cleaned in ultrasonic bath in distilled water for 1 minute and then silanized (RelyX Ceramic Primer, 3M ESPE, Seefeld, Germany) according to the manufacturer's instructions. The prepared teeth were sandblasted with 27 µm - aluminum oxide, rinsed and dried. The cement was applied to the inner surface of the crowns, which were then seated on the tooth with an approximate pressure of 70 N. Cement excesses were removed after a brief light exposure (approximately 2 seconds) with a LED light (Valo, Ultradent Products) and followed by light polymerized for 20 seconds on each surface. Air-blocking barrier (KY Jelly; Johnson & Johnson Inc., Montreal, QC, Canada) was used to cover all margins and additional polymerization was carried out for 20 seconds per surface. The margins were finished and polished with diamond ceramic polisher (CeramiPro Dialite W16DM; Brasseler), polishing brush (soft bristle brush) with diamond paste (Diamord Twist SCL, Premier, EC Representative: MDSS GmbH * Schiffgraben, Hannover, Germany) and buff with a muslin rag wheel.

Testing

1) Fatigue testing

Each specimen was stored in distilled water at room temperature for at least 24 hours following adhesive restoration placement. Masticatory forces were then simulated with an artificial mouth using closed-loop servo hydraulics (Mini Bionix II; MTS Systems, Eden Prairie, MN, USA). Each specimen was placed into the load chamber and situated with a positioning device (sliding table). The chewing cycle was simulated by an isometric contraction (load control) applied through a composite resin hemi-sphere (Filtek Z100, 3M ESPE) with a diameter of 10.0 mm. Because of the standardized occlusal anatomy, all specimens could be adjusted (through the positioning device) in the same reproducible position with the hemi-sphere contacting the mesio-buccal, disto-buccal and palatal cusps (tripod contact). The load chamber was filled with distilled water to submerge the sample during testing. Cyclic load was applied at a frequency of 10 Hz, starting with a load of 200 N for 5,000 cycles (pre-conditioning phase to guarantee predictable positioning of the hemi-sphere with the specimen), followed by stages of 400, 600, 800, 1,000, 1,200 and 1,400 N at a maximum of 30,000 cycles each. Samples were loaded until fracture or to a maximum of 185,000 cycles. The number of endured cycles and failure mode were recorded. Following a two-examiner agreement under optical microscope, a distinction was made between “catastrophic” failure (crown/root fracture that would require tooth extraction), or “reparable” failure (cohesive or cohesive/adhesive failure).

2) Load-to-failure testing of survived specimen

After the fatigue test, survived specimens were axially loaded until failure or to a maximum load of 4,500 N with a 10-mm composite resin hemi-sphere. The hemi-sphere had the same three-point occlusal contacts as in the fatigue test. The crosshead speed was 0.5mm/min. The maximum post-fatigue load before failure was recorded in Newtons and mean values were calculated per group. After load tests, the specimens were analyzed for one of the three failure modes as in the fatigue test.

Statistical analysis

The fatigue resistance of the three groups was compared using the life table survival analysis. At each time interval (defined by each load step), the number of specimens starting the interval intact and the number of specimens fracturing during the interval were counted, allowing the calculation of survival probability (%) at each interval.

The post-fatigue load-to-failure resistance of the survived specimens was compared using one-way ANOVA (data tested normal) and the Tukey HSD test for posthoc analyses. For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, V. 11.0.1; MedCalc Software, Mariakerke, Belgium).

Supplementary data from a previous study about same design RNC crowns by the same authors in strictly identical experimental conditions were combined to the present data for additional computation and comparison (life table survival analysis and 2-way ANOVA).

RESULTS

The survival rate after the fatigue test for ETM with 4-mm, 2-mm build-ups and endocrowns were 100% (15 samples), 93% (14 samples) and 100% (15 samples), respectively, and no statistical differences in survival were found among them (p=.98) (Figure 4). There was only one failure during the fatigue test (specimen with 2 mm-build-up that fractured cohesively - crown and build-up - at 1400 N). All specimens demonstrated limited wear of the crown material (mainly glaze) but marked concave wear facet on the resin hemi-sphere antagonist (Figure 5).

Post-fatigue load to failure averaged 3181 N with large build-ups (15 specimens), 3759 N for 2 mm-build-ups (12 specimens) and 3265 N for endocrowns (14 specimens). One way ANOVA revealed the higher load to failure resistance of 2 mm-build-ups (2 mm high) compared to the large build-up and endocrown designs (p=.02), but no differences between large build-up and endocrown was found. One endocrown and two 2 mm-build-up restorations survived the load to failure test at 4,500N. Failure mode analysis showed that all of specimens after load-to-failure test exhibited non-restorable catastrophic fractures.

Additional comparisons were made to compare IPS e.max CAD and Lava Ultimate crowns for each build-up design. Previously published data regarding Lava Ultimate RNC (Fig. 6 – same authors using an identical experimental set-up), were used to test the second null hypothesis (Table 1). It demonstrated higher fatigue resistance of the IPS e.max CAD crowns (p=.002) compared to RNC after fatigue test. Two-way ANOVA (Table 2) demonstrated a significant effect of both the material (LD > RNC) and the build-up on the load to failure. Post-hoc comparisons also revealed the superiority of LD for endocrowns and on 2 mm-build-ups.

DISCUSSION

In the present study, the influence of three build-up designs and restorative material on the fracture resistance of ETM with extensive loss of coronal structure and no ferrule effect was evaluated. The load-to-failure of fatigued 2 mm build-up restorations was higher compared to those with a large build-up and to endocrown (no build up design) restorations. Thus, the first null hypotheses, which states that no significant difference in the fatigue resistance and failure mode of ETM among the three different designs tested in this "*in vitro*" study was partially rejected, since the fatigue test alone did not demonstrate significant differences, neither did the failure mode. The restorative material (lithium disilicate vs RNC) (combined data with previously published work by the same authors using a similar experimental set-up) significantly affected the fatigue resistance. Consequently, the second null hypothesis of the present study is rejected.

The present testing method allows a physiologic representation of mastication by servohydraulic control system. [11] It uses a stepped load protocol, which is a compromise between the traditional time-consuming low-load/high-cycle fatigue test and the conventional load to failure (maybe relevant in trauma situations). Although it is not possible to make a direct clinical correlation about the significance of the load range used in this study, Sakaguchi et al., [12] correlated 250,000 cycles at only 13.6 N with one year of clinical service, using a similar machine. Given the extreme range of load in the present study, the accelerated life cycle of the restored tooth may certainly have been simulated. Careful tooth selection and the CAD/CAM Cerec machine were used in this study to standardize the dimensions and anatomy of occlusal surfaces of all specimens. The load was applied simultaneously at buccal and palatal cusps by a composite resin spherical antagonistic [9, 13] to generate cuspal flexure and stresses that challenged the coronal integrity. [14-16] It was intentional not to use posts in the present study because minimally invasive approaches were studied. Placing a post often involves removing more tooth structure, weakening the tooth and taking additional risks of root fractures and/or root perforations. [17] Furthermore, it is well known that post do not bond well to buildup materials. In addition, omission of the post opens the possibility to use the endocrown restorations, which may even present greater fracture strength than the conventional crowns supported on posts and filling cores. [4]

Overall, this study demonstrated that, even though no differences in fatigue survival were found among the three types of LD crowns, the load to failure test of the fatigued restorations with a 2 mm build-up showed the best results. All restorations survived far beyond maximum masticatory human forces, one endocrown and two 2 mm build-up restorations even survived the load to failure test at 4,500 N. The use of endocrown restorations presents the advantage of simplicity. On the other hand, 2 mm-build-up, besides providing the best fracture resistance, helps removing possible retentions from the endodontic preparation, offers some kind of positive geometry (will facilitate seating of the restoration), decreases restoration thickness, allowing the blue light pass through the indirect restoration to polymerize the underline resin cement. [18] The 4 mm buildup certainly provides even better provisional stabilization, however, this is at the cost of polymerization shrinkage due to the large amount of composite resin.

Alike the present work, there were no differences in survival rates of RNC crowns in a previous study [19] with the same three types of build-ups. RNC crowns, even though also surviving far beyond maximum human masticatory forces, did not perform as well as LD crowns in the present study. After the fatigue test, it was observed the build-up design could influence the load-to-failure resistance of restored ETM with LD. Short build-up performed better than endocrowns and 4 mm build-ups. The explanation may lie in the fact that in the 2 mm build-up, the restoration is still relatively thick, providing additional resistance and the build-up itself acts as a bonded connector (Optibond FL included) with the tooth. Conversely, the combination of those two elements is missing in the 4 mm build-up (well bonded but thinner restoration) and the endocrown (thick restoration but lack of bonding because of the self-adhesive cement).

When using the endocrown or the 2 mm build up, LD proved superior to RNC in load-to-failure. The large amount of LD material for those designs seems to be the determinant factor. In presence of the large Z100 build-up, this difference disappears as the main coronal volume is represented by the build-up material. Similarly, LD and RNC crowns yielded identical result on simulated vital teeth because the main coronal volume was represented by dentin.

Loaded restorations and resin hemi-sphere antagonists showed well defined wear facets, which is in support of the clinical relevance and validity of this simulation. It is always more realistic to simulate tooth contacts through wear facets distributing the load without reaching the compressive limit of the tissues or restorative materials. [13] Wear facets were predominant on the antagonistic (resin hemi-sphere) compared to the DL restoration itself. This trend was opposite when testing RNC, which displayed well defined wear facets but did not induce much wear of the antagonistic load hemi-sphere.

Considering the results of this *in vitro* simulated fatigue study on no-ferrule and no-post complete crowns, further research could be carried out to confirm that the use of a post is not required. However, is difficult to envision how another restorative strategy could yield better results than those obtained with lithium dissilicate ceramics without ferrule nor posts.

CONCLUSION

It can be concluded that there was influence of the build-up design on the performance of lithium disilicate CAD/CAM complete crowns placed with self-adhesive cement, even though all three build-up designs exceeded all expectations. The use of a 2 mm build-ups was the most robust approach and not only yielded higher loads to failure than endocrown and large build-ups, but may also be useful to provide enhanced geometry, to remove undercuts from the endodontic preparation and to facilitate provisionalization.

REFERENCES

1. Ree M & Schwartz RS (2010) The endo-restorative interface: current concepts *Dental Clinics of North America* **54(2)** 345-374.
2. Zicari F, Van Meerbeek B, Scotti R & Naert I (2012) Effect of ferrule and post placement on fracture resistance of endodontically treated teeth after fatigue loading *Journal of Dentistry*. [Epub ahead of print]
3. Lima AF, Spazzin AO, Galafassi D, Correr-Sobrinho L & Carlini-Junior B (2010) Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth *Journal of Applied Oral Science* **18(4)** 360-363.
4. Biacchi GR & Basting RT (2012) Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns *Operative Dentistry* **37(2)** 130-136.
5. Pissis P (1995) Fabrication of a metal-free ceramic restoration utilizing the monobloc technique *Practical Periodontics and Aesthetic Dentistry* **7(5)** 83-94.
6. Lin CL, Chang YH & Pai CA (2011) Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation *Dental Materials* **27(5)** 431-438.
7. Lin CL, Chang YH, Chang CY, Pai CA & Huang SF (2010) Finite element and Weibull analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolar *European Journal of Oral Sciences* **118(1)** 87-93.
8. Magne P & Knezevic A (2009) Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars *Quintessence International* **40(2)** 125-133.

9. Magne P & Knezevic A (2009) Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars *Quintessence International* **40(9)** 729-737.
10. Fasbinder DJ (2002) Restorative material options for CAD/CAM restorations *Compendium of Continuing Education in Dentistry* **23(10)** 911-916, 918, 920 passim; quiz 924.
11. DeLong R & Douglas WH (1991) An artificial oral environment for testing dental materials *IEEE Transactions on Bio-medical Engineering* **38(4)** 339-345.
12. Sakaguchi RL, Douglas WH, DeLong R & Pintado MR (1986) The wear of a posterior composite in an artificial mouth: a clinical correlation *Dental Materials* **2(6)** 235-240.
13. Kelly JR (1999) Clinically relevant approach to failure testing of all-ceramic restorations *Journal of Prosthetic Dentistry* **81(6)** 652-661.
14. DeLong R, Sakaguchi RL, Douglas WH & Pintado MR (1985) The wear of dental amalgam in an artificial mouth: a clinical correlation *Dental Materials* **1(6)** 238-242.
15. DeLong R, Douglas WH, Sakaguchi RL & Pintado MR (1986) The wear of dental porcelain in an artificial mouth *Dental Materials* **2(5)** 214-219.
16. Magne P (2007) Efficient 3D finite element analysis of dental restorative procedures using micro-CT data *Dental Materials* **23(5)** 539-548.
17. Kishen A (2006) Mechanisms and risk factors for fracture predilection in endodontically treated teeth *Endodontic Topic* **13** 57-83.
18. Arrais CA, Giannini M & Rueggeberg FA (2009) Kinetic analysis of monomer conversion in auto- and dual-polymerizing modes of commercial resin luting cements *Journal of Prosthetic Dentistry* **101(2)** 128-136.
19. Carvalho AO, Bruzi G, Maia HP, Giannini M & Magne P (2013) Influence of no-ferrule and no-post build-up design on the fatigue resistance of endodontically treated molars restored with resin nano ceramic CAD/CAM crowns. No prelo.

LEGENDS:

Figure 1. Restorative techniques: (A) Group I, (B) Group II and (C) Group III.

Figure 2. Life table survival distributions by restorative technique at each load step in the present study (n=15).

Figure 3. Photographs of crown (IPS e.max CAD) and antagonist (resin hemi-sphere) wear. A- Crown before Fatigue Test; B- Arrow - Wear of crowns after Fatigue Test; C- Wear of the Z100 composite resin hemi-sphere after Fatigue Test.

Figure 4. Life table survival distributions by restorative technique at each load step in the previous study (n=15).

Table 1. Pairwise post hoc comparisons including previous data.

Table 2. Two-way ANOVA comparing RNC and LD load-to-failure.

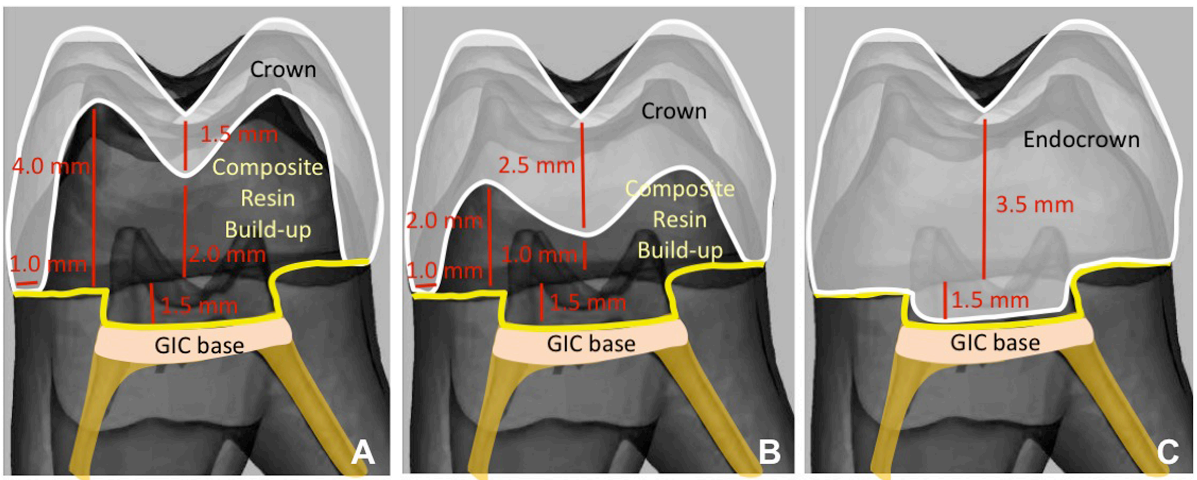


Figure 1.

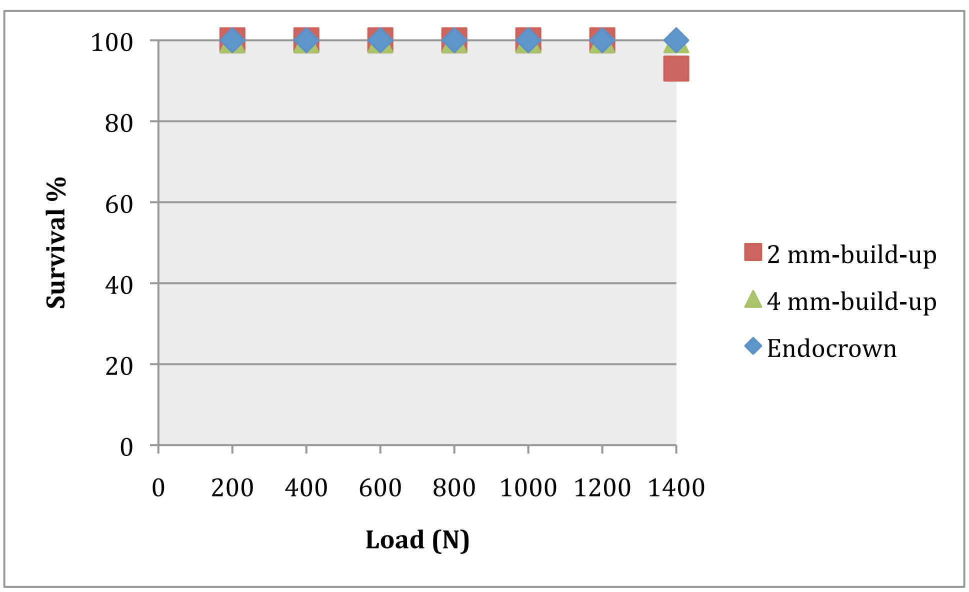


Figure 2.

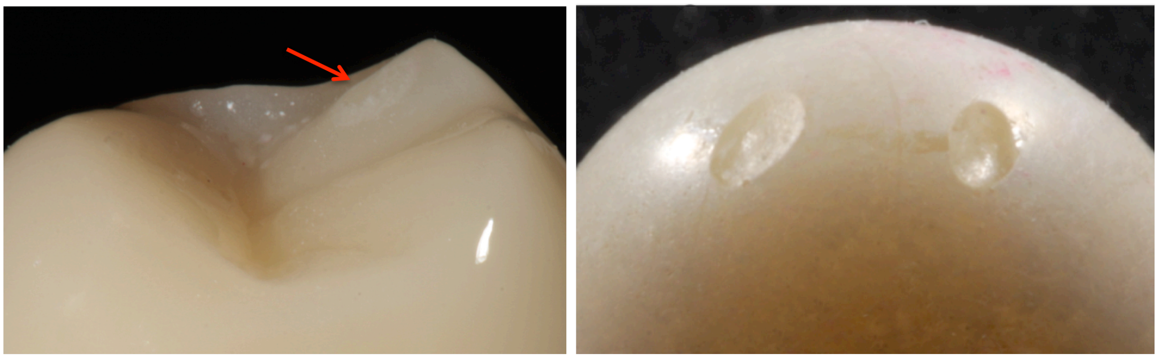


Figure 3.

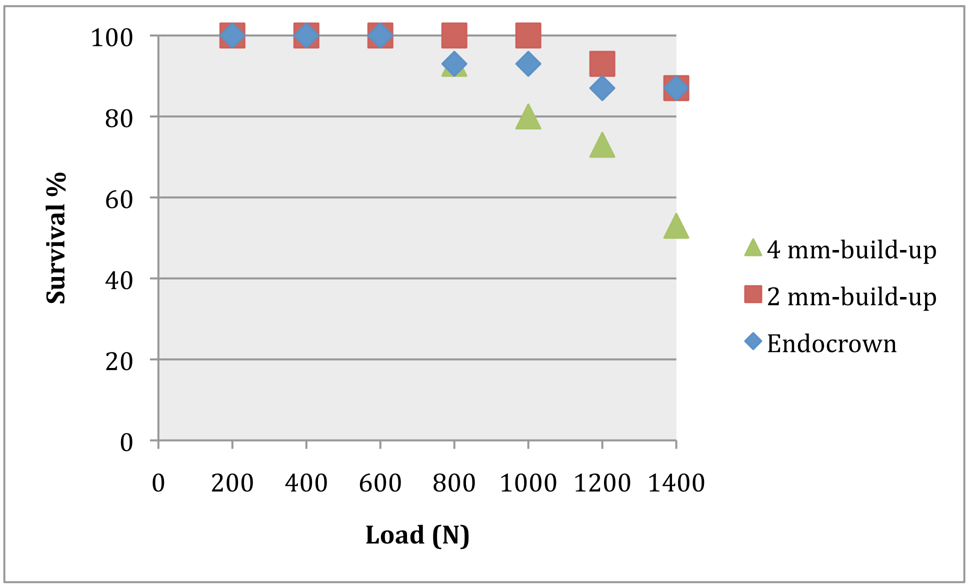


Figure 4.

Table 1.

	LD Endocrown	LD 2 mm Build-up	LD 4 mm Build-up	RNC Endocrown	RNC 2 mm Build-up	RNC 4 mm Build-up
LD Endocrown		.98	.98	.002 (pooled data)		
LD 2 mm Build-up	<.05		.98			
LD 4 mm Build-up	> .05	<.05				
RNC Endocrown	<.05				.06	.06
RNC 2 mm Build-up		<.05		.34		.06
RNC 4 mm Build-up			>.05	.34	.34	

Bold square - Results in the present study: Shaded squares - fatigue post hocs tests (Log rank test) / Clear squares – Load to failure post hoc tests (Tukey HSD).
Double-line square: Results in the previous study. Shaded square - fatigue post hoc tests (Log rank test) / Clear square – Load to failure results.
Dashed squares: Additional computation including previous data. Shaded square - fatigue test results between LD and RNC (pooled data)/ Clear square – Load to failure posthoc tests (Scheffe test).

Table 2.

Source	Sum of Squares	DF	Mean Square	F	P
Material	6966629.997	1	6966629.997	21.780	<0.001
Build-up	2031639.223	2	1015819.612	3.176	0.048
var1*var2	1359571.087	2	679785.543	2.125	0.127
Residual	23029854.065	72	319859.084		

Acknowledgments

This study was supported by CNPq 20092/2011-6, CAPES 3110/2010 and CAPES 4979/11-7. The authors thank 3M ESPE, St Paul, Minn, for providing RelyX Unicem 2 Automix, Filtek Z100 and RelyX Ceramic Primer.

CAPÍTULO 5 [1]

Simulated Fatigue Resistance of Vital vs. Endodontically-treated Molars Restored with CAD/CAM crowns

Carvalho AO[1], Bruzi G[2], Maia HP[3] , Giannini M[4], Magne P[5].

[1]PhD Student, Department of Restorative Dentistry, Dental Materials Division, Piracicaba School of Dentistry, Campinas State University, Piracicaba, SP, Brazil.

[2]PhD Student, Department of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil.

[3]DDS, MS, PhD, Professor of Operative Dentistry, Federal University of Santa Catarina (UFSC), Florianopolis, SC, Brazil.

[4]Associate Professor, Department of Restorative Dentistry, Piracicaba School of Dentistry, Campinas State University, Piracicaba, SP, Brazil.

[5]Don and Sybil Harrington Professor of Esthetic Dentistry, Restorative Sciences, Ostrow School of Dentistry, University of Southern California, Los Angeles, California, USA.

Corresponding Author
Dr. Pascal Magne
UNIVERSITY OF SOUTHERN CALIFORNIA
Division of Restorative Sciences
School of Dentistry – Oral Health Center
3151 S. Hoover St
Los Angeles, CA 90089-7792
Phone (213) 740-4239
Fax (213) 821-5324

[1] Este artigo será um *Short Communication.*

SHORT ABSTRACT

Data from three simulated fatigue studies about the resistance of vital and nonvital molars restored with lithium disilicate (LD) or resin nano ceramic (RNC) CAD/CAM complete crowns were combined. Each study was carried out in strictly identical conditions and by the same operators and authors (200-1,400N staircase-loading applied to extracted molars simulating 1.5mm-thick complete crowns). Vital and nonvital teeth were restored with RNC Lava Ultimate crowns and LD e.max crowns. Nonvital teeth had extensive loss of coronal structure and no ferrule effect (included composite resin build-ups). All crowns survived until the 800N-step of accelerated fatigue. RNC and LD crowns on vital teeth and LD crowns on nonvital teeth were not statistically different. Neither were RNC crowns on vital and nonvital teeth.
Key words: Crown, CAD/CAM, fatigue resistance, lithium disilicate, resin nano ceramic, vital teeth, endodontically treated molar.

INTRODUCTION

Endodontic treatment generally results in a reduction in stiffness and fracture resistance of teeth (1-3). It can be explained by the structural defect generated by dental caries, endodontic access and root canal preparation. To reduce fracture susceptibility of teeth with extensive loss of coronal structure and no ferule effect, restoration with a composite resin core build-up and a crown have been recommended (4, 5). Nevertheless, there is a lack of information about the appropriate restorative material and its influence on the biomechanical behavior of teeth with extensive loss of coronal structure when they are compared to their vital equivalents. Therefore, the purpose of this study was to assess the influence of endodontic treatment on the mechanical performance of molar restored with lithium disilicate (LD) or resin nano ceramic (RNC) CAD/CAM complete crowns. The null hypothesis was that no difference on the performance of the different restorative materials used to restore vital and non-vital teeth would be found.

MATERIAL AND METHODS

Data from three previous studies were combined in order to carry out additional computations and statistical analysis. Each study was carried out in strictly identical conditions and by the same operators and authors. Altogether, thirty extracted molars were prepared for a complete crown restoration and another 30 molars were decoronated at the level of CEJ, endodontically-treated, and received a composite resin core and a complete crown (no ferrule effect).

In nonvital teeth, a 1.0-1.5 mm – thick glass-ionomer barrier (Ketac Molar, 3M ESPE, St. Paul, MN, USA) was applied to the base of the pulp chamber and Optibond FL adhesive system (Kerr Corp., Orange, CA, USA) with Filtek Z100 (3M ESPE, St. Paul, MN, USA) composite resin were used for the core build-up (4-mm height from CEJ at cusp tips, 2-mm height from CEJ at central groove). For vital and non-vital teeth with core build up, the tooth preparation design included an axial reduction of 1.5 mm with a circular chamfer size of 1.0 mm following CEJ and 6° convergence angle between tooth axis and lateral walls.

Crowns were obtained using the Cerec 3 CAD/CAM system (Sirona Dental Systems GmbH, Bensheim, Germany) and featured standardized thickness (1.5 mm at the central grove, a maximum of 2.0 mm at the cusp). They were milled either in RNC Lava Ultimate blocks (3M ESPE, St. Paul, MN, USA) or IPS e.max CAD blocks (Ivoclar Vivadent, Berufsbildung *Schaan,* Schaan, Liechtenstein) and finished following the manufacturer's instructions.

All crowns were cemented with a dual-curing self-adhesive resin cement (RelyX Unicem 2 Automix). LD crowns were etched with 5% hydrofluoric acid (IPS Ceramic etching gel, Ivoclar Vivadent) for 20 s, rinsed, cleaned in ultrasonic bath in distilled water for 1 minute and then silanized (RelyX Ceramic Primer, 3M ESPE, Seefeld, Germany) according to the manufacturer's instructions. RNC crowns were cleaned in a steam cleaner, sandblasted with 50 µm – aluminum oxide (Danville, San Ramon, CA, USA), rinsed and cleaned in ultrasonic bath in distilled water for 1 minute. The tooth preparations were sandblasted with 27 µm - aluminum oxide, rinsed and dried.

Mastication was simulated by an isometric contraction (load control) applied through a 10.0 mm-composite resin hemi-sphere (Filtek Z100) at a frequency of 10 Hz, starting with a load of 200 N for 5,000 cycles followed by stages of 400, 600, 800, 1,000, 1,200 and 1,400 N at a maximum of 30,000 cycles each. Samples were loaded while submerged in distilled water until fracture or to a maximum of 185,000 cycles. After the fatigue test, survived specimens were axially loaded until failure or to a maximum load of 4,500 N with the same 10-mm composite resin hemi-sphere.

The fatigue resistance of the four groups was compared using the life table survival analysis. The influence of the restorative material on the fracture strength (load step at which failure occurred) was analyzed by using the Log-rank test at a significance level of .05. Differences were localized using pairwise post hoc comparisons with the same test at a significance level of .016 (Bonferroni correction for 3 comparisons).

The post-fatigue load-to-failure resistance of the survived specimens was compared using two-way ANOVA (data tested normal). For all statistical analyses, the level of significance was set at 95%. The data were analyzed with statistical software (MedCalc, V. 11.0.1; MedCalc Software, Mariakerke, Belgium).

RESULTS

All specimens survived the fatigue test until the 800 N-step. The survival rate after the fatigue test for vital RNC, vital LD, non-vital RNC and non-vital LD were 93%, 80%, 53% and 100%, respectively (Figure 1). Vital RNC, vital LD and non-vital LD crowns did not differ from each other but vital and non-vital LD far exceeded that of non-vital RNC (p=.004) while vital and nonvital RNC were not different (p=.1). Post-fatigue load-to-failure ranged among 3122N (RNC, 12 samples), 3237N (LD, 14 specimens), 2969 N (non-vital RNC, 8 specimens) and 3266 N (non-vital LD, 15 specimens). Two-way ANOVA revealed that there were no statistically difference among the four groups for post-fatigue load-to-failure analysis (Table 1).

DISCUSSION

The null hypothesis of this study was partially rejected because the crown material had no influence on the fatigue resistance of vital teeth, but performed differently on nonvital teeth. Neither the material nor the vitality had an effect on the load-to-failure test after fatigue.

On nonvital teeth, LD crowns outperformed RNC crowns during the fatigue test. The latter, however, had similar performances on vital and nonvital teeth. Those results have to be placed in the perspective that all restorations survived beyond maximum masticatory human forces and that no difference was found after the load-to-failure test. Therefore, it cannot be stated that RNC crowns are contraindicated for nonvital teeth, especially knowing that there was no ferrule effect and that many clinical situations would still provide a ferrule. The superiority of LD crowns in fatigued nonvital teeth can be explained by the more tooth-like structure obtained by the combination of LD, simulating a "super" enamel in terms of elastic modulus and flexural strength covering the Z100 build-up with a dentin-like damping behavior.

In spite of different flexural strength, similar performance of RNC and LD crowns used on vital teeth can be explained by taking into account the elastic modulus of the material (LD – 95 GPa, RNC 12.77 GPa). The work of fracture (6), which is the energy required to create a new surface in a propagating flaw, is inversely related to the elastic modulus of the material. In other word, the similarity of LD and RNC may be explained by the ratio between strength and elastic modulus (both lower for RNC compared to LD). For similar performance, the use of RNC crowns on vital teeth present major clinical and practical advantages compared to LD (mill time, mill bur usage, polishability, simplicity of delivery and reparability)(7).

Further researches are needed to analyze other popular CAD/CAM blocks and luting procedures, such as the use of dentin bonding agents and light curing composite resins or conventional dual-cure resin cements instead of self-adhesive resin cements.

CONCLUSION

Endodontic treatment did not influence the fatigue resistance of molars restored with LD CAD/CAM complete crowns but decreased the performance of RNC crowns. Those results have to be placed in the perspective that all restorations survived beyond maximum masticatory human forces and that no difference was found after the load-to-failure test.

AKNOWLEDGEMENTS

This study was supported by CNPq 20092/2011-6, CAPES 3110/2010 and CAPES 4979/11-7. The authors thank 3M ESPE, St Paul, Minn, for providing Lava Ultimate blocks, RelyX Unicem 2 Automix, Filtek Z100 and RelyX Ceramic Primer.

REFERENCES

1. Hannig C, Westphal C, Becker K, Attin T. Fracture resistance of endodontically treated maxillary premolars restored with CAD/CAM ceramic inlays. *Journal of Prosthetic Dentistry* 2005 Oct;**94**(4):342-9.
2. Jiang W, Bo H, Yongchun G, LongXing N. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. *Journal of Prosthetic Dentistry* 2010 Jan;**103**(1):6-12.
3. Reeh ES, Messer HH, Douglas WH. Reduction in tooth stiffness as a result of endodontic and restorative procedures. *Journal of Endodontic* 1989 Nov;**15**(11):512-6.
4. Carvalho AO, Bruzi G, Maia HP, Giannini M, Magne P. Influence of no-ferrule and no-post build-up design on the fatigue resistance of endodontically treated molars restored with resin nano ceramic CAD/CAM crowns. Piracicaba: FOP/UNICAMP; No prelo 2013.
5. Magne P, Carvalho AO, Bruzi G, Maia HP, Giannini M. Influence of no-ferrule and no-post build-up design on the resistance of endodontically-treated molars restored with lithium disilicate CAD/CAM crowns. Piracicaba: FOP/UNICAMP; No prelo 2013.
6. Kobashigawa A, Magne P, Schlichting L. Correlation of Fatigue Resistance to Mechanical Properties of CAD-CAM Blocks [abstract #1170] *IADR / AADR /CADR 89th General Session and Exhibition* 2011.
7. Carvalho AO, Bruzi G, Maia HP, Giannini M, Magne P. Fatigue Resistance of CAD/CAM Fabricated Full---Coverage Crowns [abstract #p07]. *Academy Dental Materials Meeting* 2012.

Table 1. Pairwise post hoc comparisons.

	Vital RNC	Vital LD	Non-vital RNC	Non-vital LD	Vital RNC	Vital LD	Non-vital RNC	Non-vital LD
Vital RNC		.28	.10	.07		>.05	>.05	
Vital LD			.001	.32				>.05
Non-vital RNC				.003				>.05
Non-vital LD								

Bold square - fatigue post hoc tests (Log rank test). Shaded squares – Material comparison. Clear squares plus underline – comparison on the effect of vitality loss.
Dashed square – Load to failure posthoc tests (Anova two-way). Shaded squares – Material comparison. Clear squares – comparison on the effect of vitality loss.

LEGENDS:

Figure 1. Life table survival distributions by materials and vitality of the teeth at each load step at the fatigue test (n=15).

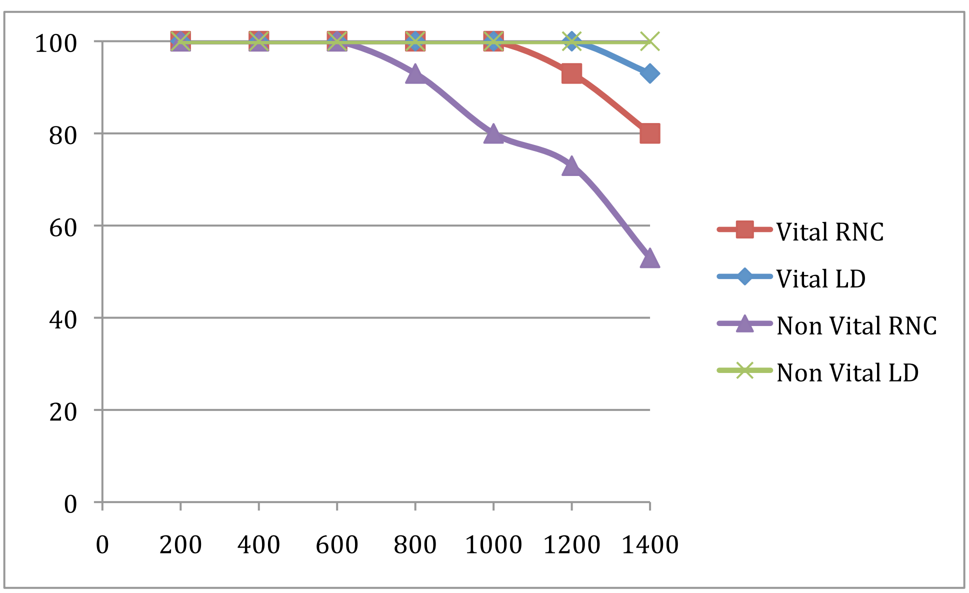


Figure 1.

CONSIDERAÇÕES GERAIS

Com o avanço da Odontologia Adesiva, e o progresso da Odontologia Minimamente Invasiva, o uso de coroas restauradoras está sendo superado por opções mais conservadoras como facetas*, inlays, onlay* ou *overlays* (29). No entanto, existem situações em que as coroas restauradoras ainda são bastante utilizadas, como por exemplo, quando há necessidade de substituição de uma coroa pré-existente ou em situações de dentes tratados endodonticamente extensamente destruídos.

Novos materiais combinados com um recente sistema de fabricação assistido pelo computador (Sistema CAD/CAM) estão disponíveis para a confecção destas coroas e a sua durabilidade mecânica é um requerimento importante. Informações quanto ao desempenho mecânico dos blocos CAD/CAM representa um tópico relevante e atual da Odontologia Restauradora. Assim, o presente estudo avaliou a resistência à fadiga, a resistência à fratura, o modo de falha e o desgaste provocado pelo antagonista de diferentes *designs* de coroas CAD/CAM fabricadas em cerâmica feldspática, dissilicato de lítio ou resina nano cerâmica cimentadas com cimento resinoso auto-adesivo utilizadas para restaurar molares tratados endodonticamente ou não.

O teste de resistência a fadiga *in vitro* dos materiais dentários são frequentemente realizados submetendo-se uma amostra em barra a um carregamento cíclico flexural de 3 ou 4 pontos . No entanto, sabe-se que a performance de uma barra isolada de um material restaurador pode não predizer o seu comportamento clínico (30). Desta forma, com o intuito de se padronizar o estudo e aproximar-se de uma situação clínica real, dentes naturais foram selecionados, a superfície oclusal e a espessura das restaurações foram padronizadas pelo sistema CAD/CAM (31) e um mesmo protocolo de carga foi aplicado em todas as amostras. Com o uso do sistema CAD/CAM algumas variáveis como habilidade do técnico em prótese e alguns passos envolvidos no processo de fabricação não existem. Como em estudos anteriores (30, 32), o uso de uma esfera de resina composta foi preferida ao uso de uma esfera de aço para simular o dente antagonista, pois a menor tenacidade e menor resistência ao desgaste das resinas compostas permitem uma simulação mais realística das áreas de contato entre o dente restaurado e o esmalte do dente antagonista (33). O ligamento periodontal não foi simulado porque os materiais (elastómeros e silicones) geralmente utilizados para esta finalidade, mostram uma acelerada degradação que desequilibra o sistema.

O teste utilizado permite uma representação fisiológica da mastigação por um controle de sistema hidráulico. Apesar de não ser possível fazer uma correlação clínica direta entre o presente protocolo de envelhecimento e um suposto tempo de função mastigatória clínica, este teste classifica-se entre o teste de resistência à fratura, o qual utiliza uma carga única muito alta por um curto tempo, não sendo relevante clinicamente, com exceção em situações de trauma, e o teste tradicional de resistência à fadiga, o qual utiliza cargas baixas por um longo tempo/milhões de ciclos torna o teste "tempo-consumista". Sakaguchi et al. (1986), (34) utilizando uma máquina similar correlacionou 250.000 ciclos submetidos a uma força de 13.6 N com um ano de vida de uma restauração submetida a forças mastigatórias. Assim, o protocolo de aplicação de carga utilizado pode ser chamado de fadiga acelerada, pois apesar de ter sido utilizados no máximo 185.000 ciclos, foram utilizados cargas progressivas muito além de 13.6 N (de 200N a 1400N). Um outro elemento notório do atual estudo é que o teste de resistência à fratura foi utilizado apenas após as amostras terem sido submetidas a um estresse mecânico. Correlacionando o protocolo utilizado mais uma vez com uma real situação clínica.

Todas as coroas foram fixadas com um cimento resinoso auto-adesivo (Rely X Unicem 2 Automix / 3M ESPE). Este sistema foi escolhido por possuir polimerização dual sendo indicado tanto para as coroas ultra-finas quanto as de maior espessura, reduzindo assim uma nova variável no estudo. Além disso, este cimento é bastante apreciado pelos clínicos por possuir um procedimento de cimentação simplificado, devido a eliminação da necessidade do pré-tratamento da estrutura dental.

A taxa de sobrevida das coroas com 1.5 – 2.0 mm de espessura, fabricadas em RNC e LD não diferiram entre si e tiveram uma performance mecânica superior ao das cerâmicas feldspáticas. O desempenho inferior das cerâmicas feldpáticas está de acordo com vários autores (8, 11, 32, 35, 36) e correlaciona-se com sua menor resistência flexural comparado aos outros dois materiais. No entanto, coroas com 0.7 mm de espessura confeccionadas com os mesmos três materiais tiveram comportamento mecânico similares entre si. A resistência à fadiga das coroas fabricadas em RNC e DL diminuiu com a diminuição da espessura do material, enquanto que não houve diferença estatística para as coroas fabricadas em cerâmica feldspática nas duas espessuras estudadas. Estes resultados requerem uma cuidadosa interpretação. As forças mastigatórias normais variam de 50 a 250N e em situações de parafunções de 500 a 800 N (37, 38). Assim, apesar das coroas em cerâmica feldspática não terem sido influenciadas estatisticamente pela espessura do material, quando confeccionadas em 0.7 mm de espessura começaram a apresentar falhas quando submetidas a cargas inferiores (600 N) àquelas apresentadas pelas coroas fabricadas em DL e RNC (800 N). Dessa forma, pode-se concluir que quando submetidas a elevadas cargas, sugere-se a indicação de coroas de molares fabricadas em DL ou RNC.

Como dentes tratados endodonticamente inerentemente são mais susceptíveis às fraturas radiculares e/ou coronárias que dentes vitais, para a confecção de coroas sobre molares extensamente destruídos sem qualquer efeito de férula foram selecionados apenas o DL e a RNC. Intencionalmente não foram utilizados pinos intra-radiculares pois além de tornar possível utilizar-se as restaurações endocrown, pretendeu-se estudar apenas técnicas minimamente invasivas. A colocação de pino envolve a remoção de mais estrutura dental, enfraquecendo o dente e até mesmo correndo o risco de provocar algum tipo de perfuração ou fratura da raiz (24).

As restaurações, tanto em RNC quanto em DL, com os três diferentes formatos de núcleo de preenchimento (4 mm, 2 mm de altura, ou sem núcleo de preenchimento) propostos sobreviveram além da máxima força mastigatória humana sugerindo-se que é possível utilizar-se os três tipos de *designs* com coroas em RNC ou DL. No entanto, apesar da performance mecânica das coroas em RNC não terem sofrido influencia do design do núcleo, as coroas em DL tiveram uma melhor performance quando foi utilizado o núcleo de preenchimento com 2 mm de altura. Nota-se que além da altura do núcleo de preenchimento ajudar na remoção de retenções provenientes do tratamento endodôntico, oferece uma geometria positiva, que facilita a confecção de provisórios, diminui a espessura da restauração para permitir que a luz azul passe através da restauração para efetiva polimerização do cimento resinoso (39). Além disso, eles não sofrem tanto efeito da contração de polimerização, quanto um núcleo com grande quantidade de resina.

Quando foi comparado coroas com a mesma espessura fabricadas com RNC ou DL sobre dentes vitais e não-vitais observou-se que o tratamento endodôntico não influenciou na resistência à fadiga de molares restaurados com DL ou RNC. No entanto, apesar de não haver diferença estatística entre as coroas em DL e RNC utilizadas sobre dentes vitais, as coroas em DL tiveram uma melhor performance mecânica do que as coroas em RNC sobre os dentes não vitais. Isto pode ser explicado pela combinação do DL, simulando um “super”esmalte em termos de módulo de elasticidade e resistência a flexão, cobrindo o núcleo de preenchimento em resina Z100, o qual age como “dentina artificial”.

No estudo, em geral, as coroas fabricadas em RNC demonstraram provocar um menor desgaste ao antagonista do que as coroas fabricadas em dissilicato de lítio ou cerâmica feldspática. Facetas de desgaste puderam ser vistas nos pontos de contato das coroas em RNC, enquanto estes desgaste raramente foram vistos sobre as coroas em DL ou FEL. Estes achados estão em acordo com os resultados de Kunzelman et al. (2001) (9), os quais mostraram que os materiais à base de resina composta sofrem desgaste protegendo o dente natural antagonista. Dessa forma especula-se que a resistência ao desgaste das RNC é menor do que o da resina composta Z100. O que pode ser explicado pela maior quantidade de matriz resinosa e consequentemente menor quantidade de carga inorgânica das RNC.

Pesquisas adicionais são necessárias para analisar outros blocos de CAD/CAM, outros materiais usados para a confecção de núcleos de preenchimento, assim como, outros procedimentos de cimentação tais como o uso de um cimento resinoso tradicional ou uma resina composta aquecida (40, 41).

CONCLUSÃO

Dentro das limitações dos cinco capítulos pode-se concluir que:

1- Coroas CAD/CAM com espessuras de 1.5 – 2.0 mm, fabricadas em dissilicato de lítio ou RNC tiveram performance mecânica significantemente maior do que aquelas fabricadas em cerâmica feldspática. Todas as falhas durante o teste de fadiga foram restauráveis enquanto que após o teste de resistência à fratura todas as falhas foram catastróficas. As coroas fabricadas em RNC induziram menor desgaste aparente ao antagonista do que aquelas fabricadas em dissilicato de lítio ou cerâmica feldspática. Quanto a performance mecânica similar, a RNC possui vantagens práticas e clínicas comparado ao dissilicato de lítio (menor tempo de fresagem, menor desgaste das brocas, simplicidade no tratamento da superfície, facilmente polido e reparado).

2- Não houve diferença na resistência à fadiga entre coroas CAD/CAM de molares com espessuras de 0.7 mm fabricadas em cerâmica feldspática, dissilicato de lítio ou RNC. Todas as falhas durante o teste de fadiga foram restauráveis. As coroas CAD/CAM com espessura de 1.5 - 2.0 mm fabricadas em dissilicato de lítio ou RNC tiveram maior taxa de sobrevida do que aquelas com espessura de 0.7 mm. A espessura das coroas fabricadas em cerâmica feldspática não influenciou na resistência à fadiga. No entanto, pôde-se confirmar que o uso de coroas CAD/CAM com espessura reduzida (0.7 mm) é viável quando se deseja preservar estrutura dental intacta (como em casos de erosões severas ou substituição de restaurações como coroas metálicas ou em ouro) pois todas as restaurações, independente da espessura (com exceção das coroas FEL com espessura de 0.7 mm) sobreviveram além da máxima força mastigatória humana.

3- O *design* do núcleo de preenchimento não influenciou na performance dos molares tratados endodonticamente restaurados com coroas CAD/CAM fabricadas em RNC. O modo da falha foi mais favorável para as restaurações *endocrown* e com núcleo de preenchimento com altura de 2 mm. As restaurações *endocrown* possuem vantagens práticas como, simplicidade no manuseio, rapidez e menor custo enquanto que o uso de pequenos núcleos de preenchimento podem fornecem um aumento da geometria, remover retenções do preparo endodôntico e facilitar a utilização de provisórios quando necessário.

4- O *design* do núcleo de preenchimento utilizado sob coroas CAD/CAM fabricadas em dissilicato de lítio não influenciou na resistência à fadiga e nem no modo de falha das restaurações. No entanto, na resistência à fratura, núcleos de preenchimento com 2 mm de altura tiveram desempenho superior àqueles com 4 mm de altura ou com nenhum núcleo de preenchimento (*endocrown*) apesar de todas as restaurações terem superado todas as expectativas. O uso do núcleo de preenchimento de 2 mm de altura além de ter sido a técnica mais resistente, também é uma técnica útil para remover retenções e facilitar na confecção do provisório.

5- O tratamento endodôntico não influenciou na resistência à fadiga de molares restaurados com coroas CAD/CAM fabricadas em dissilicato de lítio mas influenciou na performance das coroas fabricadas em RNC. No entanto, todas as restaurações sobreviveram além das forças humanas mastigatórias. Quanto a resistência à fratura o tratamento endodôntico não influenciou no desempenho das coroas CAD/CAM fabricadas em dissilicato de lítio ou RNC.

REFERÊNCIAS

1. Fasbinder DJ. Materials for chairside CAD/CAM restorations. *Compend Contin Educ Dent* 2010 Nov-Dec;**31**(9):702-4, 6, 8-9.

2. Fasbinder DJ. Restorative material options for CAD/CAM restorations. *Compend Contin Educ Dent* 2002 Oct;**23**(10):911-6, 8, 20 passim; quiz 24.

3. Tsitrou EA, Helvatjoglu-Antoniades M, van Noort R. A preliminary evaluation of the structural integrity and fracture mode of minimally prepared resin bonded CAD/CAM crowns. *J Dent* 2009 Jan;**38**(1):16-22.

4. Fasbinder DJ, Dennison JB, Heys D, Neiva G. A clinical evaluation of chairside lithium disilicate CAD/CAM crowns: a two-year report. *J Am Dent Assoc* 2010 Jun;**141 Suppl 2**:10S-4S.

5. Reich S, Fischer S, Sobotta B, Klapper HU, Gozdowski S. A preliminary study on the short-term efficacy of chairside computer-aided design/computer-assisted manufacturing-generated posterior lithium disilicate crowns. *Int J Prosthodont* 2010 May-Jun;**23**(3):214-6.

6. Stawarczyk B, Sener B, Trottmann A, Roos M, Ozcan M, Hammerle CH. Discoloration of manually fabricated resins and industrially fabricated CAD/CAM blocks <I>versus</I> glass-ceramic: Effect of storage media, duration, and subsequent polishing. *Dent Mater J* 2012;**31**(3):377-83.

7. Brunton PA, Cattell P, Burke FJ, Wilson NH. Fracture resistance of teeth restored with onlays of three contemporary tooth-colored resin-bonded restorative materials. *J Prosthet Dent* 1999 Aug;**82**(2):167-71.

8. Attia A, Abdelaziz KM, Freitag S, Kern M. Fracture load of composite resin and feldspathic all-ceramic CAD/CAM crowns. *J Prosthet Dent* 2006 Feb;**95**(2):117-23.

9. Kunzelmann KH, Jelen B, Mehl A, Hickel R. Wear evaluation of MZ100 compared to ceramic CAD/CAM materials. *Int J Comput Dent* 2001 Jul;**4**(3):171-84.

10. Park S, Quinn JB, Romberg E, Arola D. On the brittleness of enamel and selected dental materials. *Dent Mater* 2008 Nov;**24**(11):1477-85.

11. Magne P, Knezevic A. Simulated fatigue resistance of composite resin versus porcelain CAD/CAM overlay restorations on endodontically treated molars. *Quintessence Int* 2009 Feb;**40**(2):125-33.

12. Magne P, Perakis N, Belser UC, Krejci I. Stress distribution of inlay-anchored adhesive fixed partial dentures: a finite element analysis of the influence of restorative materials and abutment preparation design. *J Prosthet Dent* 2002 May;**87**(5):516-27.

13. Kopperud SE, Tveit AB, Gaarden T, Sandvik L, Espelid I. Longevity of posterior dental restorations and reasons for failure. *Eur J Oral Sci* 2012 Dec;**120**(6):539-48.

14. Ferracane JL. Resin composite--state of the art. *Dent Mater* 2011 Jan;**27**(1):29-38.

15. Belli S, Cobankara FK, Eraslan O, Eskitascioglu G, Karbhari V. The effect of fiber insertion on fracture resistance of endodontically treated molars with MOD cavity and reattached fractured lingual cusps. *J Biomed Mater Res B Appl Biomater* 2006 Oct;**79**(1):35-41.

16. Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. *J Prosthet Dent* 2005 Oct;**94**(4):321-9.

17. Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). *Quintessence Int* 2008 Feb;**39**(2):117-29.

18. Ma PS, Nicholls JI, Junge T, Phillips KM. Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. *J Prosthet Dent* 2009 Oct;**102**(4):229-34.

19. Salameh Z, Ounsi HF, Aboushelib MN, Al-Hamdan R, Sadig W, Ferrari M. Effect of different onlay systems on fracture resistance and failure pattern of endodontically treated mandibular molars restored with and without glass fiber posts. *Am J Dent* 2010 Apr;**23**(2):81-6.

20. Salameh Z, Sorrentino R, Papacchini F, Ounsi HF, Tashkandi E, Goracci C, et al. Fracture resistance and failure patterns of endodontically treated mandibular molars restored using resin composite with or without translucent glass fiber posts. *J Endod* 2006 Aug;**32**(8):752-5.

21. Lima AF, Spazzin AO, Galafassi D, Correr-Sobrinho L, Carlini-Junior B. Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. *J Appl Oral Sci* 2010 Jul-Aug;**18**(4):360-3.

22. Fokkinga WA, Le Bell AM, Kreulen CM, Lassila LV, Vallittu PK, Creugers NH. Ex vivo fracture resistance of direct resin composite complete crowns with and without posts on maxillary premolars. *Int Endod J* 2005 Apr;**38**(4):230-7.

23. Scotti N, Coero Borga FA, Alovisi M, Rota R, Pasqualini D, Berutti E. Is fracture resistance of endodontically treated mandibular molars restored with indirect onlay composite restorations influenced by fibre post insertion? *J Dent* Oct;**40**(10):814-20.

24. Kishen A. Mechanisms and risk factors for fracture predilection in endodontically treated teeth. *Endodontic Topic* 2006;**13**:57-83.

25. Juloski J, Radovic I, Goracci C, Vulicevic ZR, Ferrari M. Ferrule effect: a literature review. *J Endod* 2012 Jan;**38**(1):11-9.

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

27. 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. *J Prosthet Dent* 2008 Oct;**100**(4):264-73.

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

29. Magne P. Composite resins and bonded porcelain: the postamalgam era? *J Calif Dent Assoc* 2006 Feb;**34**(2):135-47.

30. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. *J Prosthet Dent* 1999 Jun;**81**(6):652-61.

31. Chitmongkolsuk S, Heydecke G, Stappert C, Strub JR. Fracture strength of all-ceramic lithium disilicate and porcelain-fused-to-metal bridges for molar replacement after dynamic loading. *Eur J Prosthodont Restor Dent* 2002 Mar;**10**(1):15-22.

32. Magne P, Knezevic A. Influence of overlay restorative materials and load cusps on the fatigue resistance of endodontically treated molars. *Quintessence Int* 2009 Oct;**40**(9):729-37.

33. Schlichting LH, Maia HP, Baratieri LN, Magne P. Novel-design ultra-thin CAD/CAM composite resin and ceramic occlusal veneers for the treatment of severe dental erosion. *J Prosthet Dent* 2011 Apr;**105**(4):217-26.

34. Sakaguchi RL, Douglas WH, DeLong R, Pintado MR. The wear of a posterior composite in an artificial mouth: a clinical correlation. *Dent Mater* 1986 Dec;**2**(6):235-40.

35. Kassem AS, Atta O, El-Mowafy O. Fatigue resistance and microleakage of CAD/CAM ceramic and composite molar crowns. *J Prosthodont* 2012 Jan;**21**(1):28-32.

36. Chen HY, Hickel R, Setcos JC, Kunzelmann KH. Effects of surface finish and fatigue testing on the fracture strength of CAD-CAM and pressed-ceramic crowns. *J Prosthet Dent* 1999 Oct;**82**(4):468-75.

37. Kampe T. Function and dysfunction of the masticatory system in individuals with intact and restored dentitions. A clinical, psychological and physiological study. *Swed Dent J Suppl* 1987;**42**:1-68.

38. Kiliaridis S, Kjellberg H, Wenneberg B, Engstrom C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. *Acta Odontol Scand* 1993 Oct;**51**(5):323-31.

39. Arrais CA, Giannini M, Rueggeberg FA. Kinetic analysis of monomer conversion in auto- and dual-polymerizing modes of commercial resin luting cements. *J Prosthet Dent* 2009 Feb;**101**(2):128-36.

40. Daronch M, Rueggeberg FA, De Goes MF. Monomer conversion of pre-heated composite. *J Dent Res* 2005 Jul;**84**(7):663-7.

41. Mundim FM, Garcia Lda F, Cruvinel DR, Lima FA, Bachmann L, Pires-de-Souza Fde C. Color stability, opacity and degree of conversion of pre-heated composites. *J Dent* Jul 2010; **39 Suppl 1**:e25-9.

ANEXO 1

Submission Confirmation

De: **JPD** (JPD@georgiahealth.edu)
Enviada: quarta-feira, 5 de dezembro de 2012 01:55:09
Para: aoc1981@hotmail.com

Dear Dr. Adriana Carvalho,

We have received your article "Fatigue Resistance of CAD/CAM Complete Crowns with a Simplified Cementation Process" for consideration for publication in The Journal of Prosthetic Dentistry.

Your manuscript will be given a reference number once an editor has been assigned.

To track the status of your paper, please do the following:

1. Go to this URL: http://ees.elsevier.com/jpd/

2. Enter the login details.
Your username is: aoc1981@hotmail.com
If you need to retrieve password details, please go to:
http://ees.elsevier.com/JPD/automail_query.asp.

3. Click [Author Login]
This takes you to the Author Main Menu.

4. Click [Submissions Being Processed]

Thank you for submitting your work to this journal.

Kind regards,

Elsevier Editorial System
The Journal of Prosthetic Dentistry

****
Please note that the editorial process varies considerably from journal to journal. To view a sample editorial process, please click here:
http://ees.elsevier.com/eeshelp/sample_editorial_process.pdf

For further assistance, please visit our customer support site at http://help.elsevier.com/app/answers/list/p/7923. Here you can search for solutions on a range of topics, find answers to frequently asked questions and learn more about EES via interactive tutorials. You will also find our 24/7 support contact details should you need any further assistance from one of our customer support representatives.

ANEXO 2

13-004-L Manuscript received - Operative Dentistry

De: **editor@jopdent.org**
Enviada: quinta-feira, 3 de janeiro de 2013 16:35:01
Para: magne@usc.edu
Cc: aoc1981@hotmail.com; kikaodonto@yahoo.com.br; robertandersondmd@gmail.com; hpmaia@ccs.ufsc.br; giannini@fop.unicamp.br; aoc1981@fop.unicamp.br

Dear Dr. Magne,

On January 3, 2013, I received your manuscript entitled "Influence of no-ferrule and no-post build-up design on the fatigue resistance of endodontically treated molars restored with resin nano ceramic CAD/CAM crowns." by Adriana Carvalho, Greciana Bruzi, Robert Anderson, Hamilton Maia, Marcelo Giannini, and Pascal Magne.

Your manuscript has been assigned the Paper #: 13-004-L.

You may check on the status of this manuscript by visiting your author home page at http://jopdent.allentrack.net.

Thank you for submitting your work to Operative Dentistry.

Sincerely,

Kevin Matis
Editorial Assistant
Operative Dentistry

ANEXO 3

COMITÊ DE ÉTICA EM PESQUISA
FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa **"Avaliação da união de sistemas restauradores em superfícies dentinárias planificadas e em preparos cavitários"**, protocolo nº 146/2010, dos pesquisadores Adriana Oliveira Carvalho e Marcelo Giannini, satisfaz as exigências do Conselho Nacional de Saúde - Ministério da Saúde para as pesquisas em seres humanos e foi aprovado por este comitê em 15/12/2010.

The Ethics Committee in Research of the School of Dentistry of Piracicaba - State University of Campinas, certify that the project **"Bond strength evaluation of restorative systems bonding to flattened dentin surfaces and in cavity preparations"**, register number 146/2010, of Adriana Oliveira Carvalho and Marcelo Giannini, comply with the recommendations of the National Health Council - Ministry of Health of Brazil for research in human subjects and therefore was approved by this committee at 12/15/2010.

Prof. Dr. Pablo Agustin Vargas
Secretário
CEP/FOP/UNICAMP

Prof. Dr. Jacks Jorge Junior
Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição.
Notice: The title of the project appears as provided by the authors, without editing.

ANEXO 4

Study Approval Notice Sent

De: **istar@istar.usc.edu**
Enviada: quarta-feira, 23 de maio de 2012 22:04:44
Para: aoc1981@hotmail.com

University of Southern California | Childrens Hospital Los Angeles

Proposal #HS-12-00278

University of Southern California Health Sciences Campus
Institutional Review Board
LAC+USC Medical Center, General Hospital Suite 4700
1200 North State Street, Los Angeles, CA 90033
(323) 223-2340 phone
(323) 224-8389 fax
irb@usc.edu

Date: May 23, 2012, 03:04pm
To: Pascal Magne , PhD
RESTORATIVE SCIENCES (DIVISION 4)

From: Health Sciences Institutional Review Board
General Hospital, Suite 4700
1200 North State Street
Los Angeles, CA 90033
(323) 223-2340

TITLE OF PROPOSAL:
Influence of build-up design and restorative material on the fatigue resistance of endodontically treated teeth restored with full coverage CAD/CAM crowns (Influence of build-up design and restorative material on the fatigue resistance of endodontically treated teeth restored with full coverage crowns)

Action Date: **5/23/2012** Action Taken: **Approve**

Committee: Institutional Review Board Chairman

Note:

Your iStar application and attachments were reviewed by the expedited mechanism on May 23, 2012.

The project was APPROVED.

The materials submitted and considered for review of this project included:
1. iStar application dated 5/21/12
2. Methods and Procedures
3. Approval Letter from the Ethics Committee in Research of the School of Dentistry of Piracicaba - State University of Campinas (Brazil), dated 12/15/10

The National Institutes of Health (NIH) and the Office for Human Research Protections (OHRP) do not consider research involving ONLY coded private information or specimens to involve human subjects as defined under 45 CFR 46.102(f) if the following conditions are BOTH met: the private information or specimens were not collected specifically for the currently proposed research project through an interaction or intervention with living individuals and the investigator(s) cannot readily ascertain the identity of the individual(s) to whom the coded private information or specimens pertain because the key to decipher the code is destroyed before the research begins.

Based on the information submitted for review, this study is not human subjects research. If research is conducted, a separate IRB approval must be obtained.

This review and opinion is based only on the information provided to the IRB Office and is not valid if the proposed project is not exactly as described, or if additional information (including grants, contracts or other information) have been withheld.

This project is not subject to requirements for continuing review.

Attachments: