U.PORTO
FACULDADE DE MEDICINA DENTÁRIA
UNIVERSIDADE DO PORTO

Master Degree in Dental Medicine

Literature Review

Update on the new polymer infiltrated ceramic network material (PICN)

Fátima Miriam Gonçalves Pereira

Advisor: Prof. Ana Isabel Pereira Portela, DDS, MSc, PhD

Porto, July 2019

U.PORTO

FACULDADE DE MEDICINA DENTÁRIA
UNIVERSIDADE DO PORTO

Fátima Miriam Gonçalves Pereira[1,2]

Update on the new polymer infiltrated ceramic network material (PICN)

Master Degree in Dental Medicine

2018/2019

Scientific Area: Science and Technology of Biomaterials

Dissertation type: Literature Review

Concluded under the supervision of:

Prof. Ana Isabel Pereira Portela, DDS, MSc, PhD[3]

[1]Email: 201406390@fmd.up.pt / fmgp18@gmail.com [2]Mobile phone: 964167953
[3]Assistant Professor at the Faculty of Dental Medicine of University of Porto
Faculty of Dental Medicine of University of Porto
Rua Dr. Manuel Pereira da Silva, 4200-392 Porto

Index

Abstract

Introduction: The polymer infiltrated ceramic network (PICN) represents a hybrid material, developed as an attempt to obtain the ideal restorative material.

Objectives: This review aims to analyse and characterize this new material and, ultimately, define the circumstances in which it should be selected, thus ensuring treatment success and longevity.

Methods: PubMed® search engine was used for the research of full text articles in English, Portuguese and Spanish. There was a preference for studies published within the last 5 years and the bibliographies of relevant articles were used to collect additional articles. The bibliographic review was performed in order to summarize the current knowledge regarding the properties, behaviour and application of this recent dental material and compare its performance with other ceramics and nanoceramic resins available.

Results and Discussion: This literature review was based on 51 articles deemed pertinent to the reviewed subject.

Polymer infiltrated ceramic network materials result from the association of the Young's modulus of resin composites, identical to the dentin, and the aesthetic endurance of the ceramics. A previously sintered ceramic network is infiltrated with a polymeric matrix in order to obtain this material. It represents a computed-aided design and computer-aided manufacturing (CAD-CAM) material indicated for indicated for posterior or implant-supported crowns, onlays/inlays for posterior teeth and veneers. In most studies, this material is compared with ceramics, resin composites and other hybrid materials. Overall, the properties of the polymer infiltrated ceramic network are comparable to nanoceramic resins and lower than lithium disilicate ceramic.

Conclusions: Despite the differences found between polymer infiltrated ceramic network materials and the existing ceramic systems in terms of properties, this new material represents a closest match to human dentin and enamel. The reported characteristics describe a material able to resist the physiological strain brought about by the stomatognathic system without causing excessive wear of the antagonist dentition therefore justifying its selection and clinical application.

Resumo

Introdução: O material híbrido, designado por rede cerâmica infiltrada por polímero (PICN), surge na tentativa de alcançar o material restaurador ideal.

Objetivos: A presente revisão tem como objetivos a análise e caracterização do novo material restaurador, assim como a determinação das circunstâncias em que o mesmo deverá ser selecionado de forma a potenciar o sucesso e longevidade do tratamento.

Materiais e métodos: O motor de busca *PubMed®* foi utilizado para pesquisa de artigos de texto integral, em inglês, português e espanhol. Foi dada preferência a artigos publicados nos últimos 5 anos e as bibliografias de artigos mais relevantes foram usadas para seleção de artigos adicionais. A revisão bibliográfica foi realizada de modo a sumarizar o conhecimento atual sobre as propriedades e aplicação deste recente material, assim como a comparação da sua *performance* com outras cerâmicas e resinas nano cerâmicas disponíveis.

Resultados e Discussão: O presente artigo de revisão bibliográfica baseou-se em 51 artigos considerados pertinentes para o tema em estudo.

A rede cerâmica infiltrada por polímero resulta da associação do módulo de *Young* semelhante ao da dentina, registado nos compósitos à base de resina, e a longevidade estética das cerâmicas. Este material é conseguido através da sinterização de uma rede cerâmica, posteriormente infiltrada por uma matriz polimérica. Trata-se de um material para "*computed-aided design and computer-aided manufacturing"* (tecnologia CAD-CAM) com indicação para coroas posteriores, coroas implanto-suportadas, *onlays/inlays* para dentes posteriores e facetas. Na maioria dos estudos este material é comparado às cerâmicas, resina compostas e outros materiais híbridos. De modo geral, as propriedades do material "rede cerâmica infiltrada por polímero" são comparáveis às das resinas nano cerâmicas e inferiores às cerâmicas de dissilicato de lítio.

Conclusões: Apesar das diferenças encontradas entre as propriedades deste material híbrido e os sistemas cerâmicos existentes, importa destacar a proximidade das suas características com a dentina e esmalte humanos. Estes atributos descrevem um material capaz de resistir às forças e sobrecarga fisiológica por parte do sistema estomatognático sem causar desgaste excessivo na dentição antagonista e justificam a sua seleção e aplicação clínica.

Keywords

Polymer inflitrated ceramic network, PICN, CAD-CAM, Resin infiltrated ceramic, Microstructure, Mechanical properties

Introduction

Restorative dentistry relies on pre-established knowledge and understanding of the wide array of different materials available nowadays. Comprehending each material's composition and underlying properties is, therefore, essential and ensures a successful clinical outcome.(1)

The main purpose of restorative dentistry is the replacement of lost or compromised tooth structure while, ideally, retaining all the attributes of natural dental tissues.(2-4) However, most classes of existing materials differ considerably from enamel and dentin's properties. Gold and amalgam are the best matches to enamel while some cements and highly filled composite resins are the equivalent to dentin.(5) Yet, over the last decade the demands for increasingly aesthetic, biocompatible and long-lasting computed-aided design and computer-aided manufacturing (CAD-CAM) based materials called for different approaches and novel concepts.(6)

Resin composites and ceramics are the current leading choice and preference concerning dental restorations.(2, 7, 8) The properties of resin composites derive from its components: a polymeric organic matrix and inorganic filler particles. The filler particles translate a direct association to Young's modulus and the material's hardness, whereas the monomers that constitute the matrix determine the polymerization shrinkage. Bisphenol A–glycidyl methacrylate (Bis-GMA), urethane dimethacrylate (UDMA), urethane tetramethacrylate (UTMA) and ethoxylated bisphenol A glycol dimethacrylate (Bis-EMA) are amongst the most commonly used.(7, 8) Conversely, ceramics are, for the most part, inorganic materials. The standard composition consists of a crystalline phase and/or glass matrix.(7) Higher crystalline content means stronger yet more opaque ceramics, e.g. zirconia-based and alumina-based ceramics. On the other hand, silica-based ceramics exhibit compelling aesthetics but, in turn, display low resistance to fractures and high susceptibility to slow crack growth. These characteristics expose the limited usage of porcelains in clinical context. (2, 7) This class of materials is chemically stable, biocompatible and features good optical and mechanical properties. Even so, repairs are challenging after the ceramics are applied in the mouth.(2, 9) In comparison, composites are easily repaired and modified, despite presenting overall inferior mechanical properties, biocompatibility and wear resistance than ceramics. (2) Regarding clinical performance, ceramics prevail over direct or indirect resin composites restorations: the difference is exposed in marginal adaptation, anatomical shape, colour matching and wear resistance.(7, 8)

CAD-CAM technology has fundamentally transformed modern dentistry. The latest developments in CAD-CAM processes introduced high-performance materials, refined with advanced compositions and microstructures, as well as novel polymerization modes.(10) These materials are presented as CAD-CAM blocks that are industrially produced, which warrants increased homogeneity, reliability and a smaller number of flaws or pores in the final product. Industrial processes also allow materials with higher filler content, exceptionally effective high-temperature (HT) and/or high-pressure (HP) polymerization modes instead of photopolymerization and the production of blocks devoid of Bis-GMA. The blocks are secondarily milled into aesthetic CAD-CAM processed indirect dental restorations.(6, 10-12) This technology means time-efficient treatments and quality control through the use of safe and stable materials without the variations found in laboratory fabricated restorations. This popular processing system uses two main types of materials: all-ceramic materials or hybrid materials (association of ceramics and resin composite).(6, 13)

The polymer infiltrated ceramic network (PICN) represents a hybrid material, developed as an attempt to obtain the ideal restorative material. The primary objective was the association of the Young's modulus of resin composites, identical to dentin, and the aesthetic endurance of the ceramics.(2, 7, 8, 14) This material consists of two interlocking phases: a previously sintered ceramic network is infiltrated with a polymeric matrix by capillary action.(5, 10) PICN is a CAD-CAM material indicated for posterior or implant-supported crowns, onlays/inlays for posterior teeth and veneers.(8) Previous systems, i.e. the In-Ceram Alumina, were the first interpenetrating network materials commercialized and the basis of the innovative concept behind the use of resin instead of glass for infiltrating porous ceramic structures. The composition of PICN justifies advantageous properties, namely flexibility, rigidity, fracture toughness, reduced brittleness and better machinability. The first PICN was developed by VITA Zahnfabrik and commercialized in 2012.(5, 6, 10, 15, 16)

This review aims to analyse and characterize this new material through an extensive literature revision regarding PICN's mechanical and adhesive properties and, ultimately, define the circumstances in which it should be selected, thus ensuring treatment success and longevity.

Methods

PubMed® search engine was used for the preparation of this paper.

The research was conducted using the following terms: ‘Polymer infiltrated ceramic network’, ‘PICN’, ‘CAD-CAM’, ‘Resin infiltrated ceramic’, ‘Microstructure’, ‘Mechanical properties’, and crossed with additional search terms as needed, as was the case when reviewing the particularities of the material’s properties and application. The research was restricted to full text articles in English, Portuguese and Spanish. There was a preference for studies published within the last 5 years.

To assess the suitability of the articles, a revision by title and abstract was performed, followed by a full text revision. The bibliographies of pertinent articles were used to collect additional articles.

Results and Discussion

This literature review was based on 51 articles deemed pertinent to the reviewed subject. The discussion of said articles will be presented according to their content, attributes and relevance.

Polymer infiltrated ceramic network (PICN)

PICN (VITA Enamic) is an innovative CAD-CAM material consisting of 86 wt.% (75 vol.%) feldspathic ceramic and 14 wt.% (25 vol.%) dimethacrylates (UDMA and triethylene glycol dimethacrylate - TEGDMA), according to its manufacturer VITA Zahnfabrik. The original concept refers back to the 1980s and VITA's In Ceram System.(15) This was the first interpenetrating network dental material indicated for anterior or posterior crowns, two-unit posterior bridges and short span anterior bridges.(5) The all-ceramic system involved the infiltration of a pre-sintered porous alumina structure with glass by capillary action, which resulted in almost entirely dense structures. The main challenge concerning the replacement of glass with resin related to curing shrinkage. The glass-ceramic association pertained to less than 1% differential shrinkage upon cooling whereas the resin's curing shrinkage amounted to approximately 5%, leading up to resin/ceramic-network debonding and subsequent increased opacity on account of interface gaps.(5) According to Swain *et al.*(5), judicious selection of resin, silanation enhanced bonding between the resin and ceramic and high pressure during the curing phase overcame the problems resulting in a dense aesthetically appealing material. High pressure polymerization is the compensating factor concerning the shrinkage stress effects, also averting defects by reducing their number and size.(10) PICN comprises a three-dimensional glass-ceramic scaffold infiltrated with a monomer which is then polymerized. This dental material stands out when compared with classic dispersed-fillers-based materials given the nature of its interconnected phases: the ceramic skeleton allows a superior and effective distribution of stresses in all directions, securing greater resistance.(10) Microstructural qualitative and quantitative analyses showed an overpowering two-phase ceramic network (largely leucite and in less extent zirconia) interconnected with a polymer matrix. A few microcracks were observed between the two. Carbon (C) was the element largely present in the polymer network while silicon (Si), aluminium (Al), sodium (Na) and potassium (K) were reported in the most crystalline phase.(7, 8)

Compositional and microstructural characterization, namely particle size and shape, plays a decisive role in the physical and mechanical properties of any dental material. Moreover, each material's behaviour is heavily dictated by parameters such as density (ρ), Poisson's ratio (ν) and Young's modulus (E).(7, 8)

Numerous studies characterized PICN's properties and compared its performance with other CAD-CAM ceramic or nanoceramic resin systems available. However, most of the findings are diverse and somewhat divisive.

Flexural strength

Coldea *et al*.(17) conducted a three-point flexural strength test and recorded an intrinsic flexural strength of approximately 158,5 and 144,4 MPa for two PICN test materials: higher than feldspathic porcelains (Mark II ~ 137,8 MPa and VM 9 ~ 121,6 MPa) but substantially lower than lithium disilicate ceramic (IPS–e.max CAD ~ 344,0 MPa), glass infiltrated aluminium oxide ceramic (In-Ceram Alumina ~ 402,1 MPa) and yttria stabilized tetragonal zirconia polycrystals (Y-TZP ~ 1358,5 MPa).

In a previous study, Coldea *et al*.(18) concluded that the flexural strength values of PICNs were inversely related to ceramic density.

In the same manner, Albero *et al*.(2), showed that PICN (VITA Enamic ~ 180,9 MPa) registered lower resistance than a lithium disilicate ceramic (IPS–e.max CAD ~ 271,6 MPa), comparable values to a nanoceramic resin (Lava Ultimate ~ 164,3 MPa) and, finally, higher resistance than a feldspathic ceramic (Mark II ~ 137,8 MPa) and a leucite based ceramic (IPS Empress – CAD ~ 146,9 MPa).

Similar studies, however, show PICN to be significantly less resistant than nanoceramic resins.(19-23)

A laboratory study by Kok *et al*.(21) reports higher values of flexural strength for lithium disilicate ceramic (IPS–e.max CAD ~ 301 MPa) and nanoceramic resin (Lava Ultimate ~ 198 MPa) in comparison with PICN (VITA Enamic ~ 131 MPa).

Goujat *et al*.(22) also compared PICN's three-point flexural strength with four other CAD-CAM materials and obtained the following results: composite resin nanoceramic (Cerasmart ~ 216,5 MPa) displayed the highest value, followed by lithium disilicate ceramic (IPS–e.max CAD ~ 210,2 MPa) and nanoceramic resin (Lava Ultimate ~ 172,8 MPa) while PICN (VITA Enamic ~ 148,7 MPa) exhibited the lowest value.

Kurtulmus-Yilmaz *et al*.(23) presented superior flexural strength control values for lithium disilicate ceramic (IPS–e.max CAD~ 218,1 MPa), nanoceramic resins (Lava Ultimate ~ 137,2 MPa and GC Cerasmart ~ 125,9 MPa) than PICN (VITA Enamic ~ 116,4 MPa).

Other studies by Choi *et al*.(20) and Argyrou *et al*.(19), also supported these conclusions: higher values of flexural strength were found in Lava Ultimate, a nanoceramic resin, than in PICN (VITA Enamic).

Table I – Flexural strength (MPa) of human dentin and the PICN material according to the literature.

	Value	**References**
Dentin	212,9±41,9	Plotino *et al*. (as cited in Li *et al*.(24))
PICN (test material 1)	144.44±9.61	Coldea *et al*.(17)
PICN (test material 2)	158,53±7,14	Coldea *et al*.(17)
PICN (VITA Enamic)	180,9±42,2	Albero *et al*.(2)
PICN (VITA Enamic)	131±15	Kok *et al*.(21)
PICN (VITA Enamic)	148,7	Goujat *et al*.(22)
PICN (VITA Enamic)	116,4±9.5	Kurtulmus-Yilmaz *et al*.(23)
PICN (VITA Enamic)	140,1±7,0	Choi *et al*.(20)
PICN (VITA Enamic)	124±8,0	Argyrou *et al*.(19)

PICN showcases a comparable flexural strength to human dentin which justifies its wide clinical application as a material that is able to resist the physiological strain brought about by the stomatognathic system.(18, 24)

Fracture toughness

Della Bonna *et al*.(7) defined fracture toughness (K_{Ic}) as the ability of a material to resist crack propagation and, consequently, catastrophic failure. This property is fundamental when it comes to clinical performance.

The pre-crack-induced-test, labelled single edge V-notched beam (SEVNB), is the recommended test to determine this property given its accuracy, reliability and easy reproduction.(7) This test implies the fabrication of bar-shaped specimens from CAD-CAM blocks, which are secondarily notched (V-notch) and tested under a three-point flexure fixture loaded to fracture.(7)

Swain *et al*.(5), obtained SEVNB fracture toughness values of 1 MPa√m for PICN (VITA Enamic) and 1,51 MPa√m for a PICN test material; 1 and 0,82 MPa√m for feldspathic ceramics (Mark II and VM 9, respectively); 2,37 MPa√m for lithium disilicate ceramic (IPS–e.max CAD); 3,73 MPa√m for glass infiltrated aluminium oxide ceramic (In-Ceram Alumina) and 4,94 MPa√m for Y-TZP.

Goujat *et al*.(22) showed, yet again, PICN'S (VITA Enamic: 1,4 MPa√m) fracture toughness between lithium disilicate ceramic (IPS–e.max CAD: 1,8 MPa√m) and nanoceramic resins (Lava Ultimate: 1,6 MPa√m and Cerasmart: 1,2 MPa√m).

Della Bonna *et al*.(7) obtained a K_{Ic} value of 1,09 for PICN (VITA Enamic).

Overall, PICN materials presented slightly higher fracture toughness than feldspathic porcelains and inferior values when compared with nanoceramic resin, lithium disilicate ceramic, glass infiltrated aluminium oxide ceramic and Y-TZP.

Table II – Fracture toughness (MPa√m) of human dentin, enamel and the PICN material according to the literature.

	Value	**References**
Dentin	3,1	Lucas *et al*. (as cited in Lawn *et al*.(25))
Dentin	3,1	Lawn *et al*.(26)
Enamel	0,7	Lucas *et al*. (as cited in Lawn *et al*.(25))
Enamel	0,8	Lawn *et al*.(26)
PICN (VITA Enamic)	1±0,04	Swain *et al*.(5)
PICN (test material)	1,51±0,11	Swain *et al*.(5)
PICN (VITA Enamic)	1,4	Goujat *et al*.(22)
PICN (VITA Enamic)	1,09±0,05	Della Bonna *et al*.(7)

Weibull modulus

Weibull analysis informs on a ceramic material's resistance, strength and structural reliability.(2, 27) In accordance with Albero *et al*.(2) and previous studies(27, 28), the Weibull modulus indicates the nature, severity and spread of defects: high Weibull modulus values correspond to materials with a very uniform distribution of a lot of homogeneous defects and a smaller strength distribution, while low Weibull modulus values correspond to materials with non-uniform distribution of defects with a highly variable crack length and a wide distribution of strength.

Albero *et al*.(2), reported the lowest Weibull modulus for PICN (VITA Enamic: 4,99) and lithium disilicate ceramic (IPS–e.max CAD:4,91). Leucite based ceramic and feldspathic ceramic (IPS Empress – CAD and Mark II with 8,63 and 8,07, respectively) showed the highest values.

Argyrou *et al*.(19) registered values of 18,27 for PICN (VITA Enamic) and Choi *et al*. listed a 24,1 Weibull modulus for the same material, which imply high structural reliability.

Table III – Weibull modulus of the PICN material according to the literature.

	Value	**References**
PICN (VITA Enamic)	18,27	Argyrou *et al*.(19)
PICN (VITA Enamic)	4,99	Albero *et al*.(2)
PICN (VITA Enamic)	24,1	Choi *et al*.(20)

Hardness

According to Park *et al*.(29) hardness measures a material's resistance to permanent deformation or indentation under contact loading.

Vickers hardness tests based in an indentation method were performed by Goujat *et al*.(22), with the highest value being attributed to lithium disilicate ceramic (IPS–e.max CAD ~ 5,98 GPa) followed by PICN (VITA Enamic ~ 2,35 GPa) and two nanoceramic resins (Lava Ultimate ~ 0,95 GPa and Cerasmart ~ 0,66 GPa).

Albero *et al*.(2) obtained the highest hardness values for lithium disilicate ceramic (IPS–e.max CAD ~ 5,83 GPa), leucite-based ceramic (IPS Empress – CAD ~ 4,60 GPa) and feldspathic ceramic (Mark II ~ 3,46 GPa). PICN (VITA Enamic ~ 1,70 GPa) a nanoceramic resin (Lava Ultimate ~ 1,15 GPa) presented the lowest hardness of all the materials compared in the study.

Xu *et al*.(30) also measured PICN's (VITA Enamic) Vickers Hardness using a Vickers hardness tester (MVK-H2) and compared it with tooth enamel's hardness. The resulting hardness for the hybrid material was 3,35 GPa and 3,70 GPa for enamel.

The PICN material exhibited lower hardness when compared with lithium disilicate ceramic, leucite based ceramic and feldspathic ceramic, hence PICNs are not expected to cause excessive wear of the antagonist dentition.(18)

Table IV – Hardness (GPa) of human dentin, enamel and the PICN material according to the literature.

	Value	References
Dentin	0,6	Lucas *et al*. (as cited in Lawn *et al*.(25))
Enamel	3,5	Lucas *et al*. (as cited in Lawn *et al*.(25))
Enamel	3,70±0,25	Xu *et al*.(30)
PICN (VITA Enamic)	2,35	Goujat *et al*.(22)
PICN (VITA Enamic)	1,70±0,12	Albero *et al*.(2)
PICN (VITA Enamic)	3,35±0,30	Xu *et al*.(30)

The reported hardness values of the PICN material vary between human dentin and enamel.(18)

Elastic constants

‖ Young's modulus (E)

Park *et al*.(29) indicated that the elastic modulus describes a material's resistance to deform elastically and quantifies the ratio between magnitude of stress and corresponding degree of deformation.

The PICN material (VITA Enamic) showed an elastic modulus of 37,95 GPa according with Della Bonna *et al*.(7).

Argyrou *et al*.(19) reported the modulus of elasticity of four different CAD-CAM materials and defined the following ranking: nanoceramic resin (Lava Ultimate: 13,33 GPa) < PICN (VITA Enamic: 27,26 GPa) < leucite reinforced glass-ceramic (IPS Empress CAD:40,78 GPa) < feldspathic ceramic (VITABLOCS TriLuxe forte: 43,01 GPa).

Belli *et al*.(31) explained that the elastic constants are mainly influenced and determined by the matrix phase of the material. As a result, and although PICN and nanoceramic resins have similar compositions, the latter shows a much lower Young's modulus given that polymer is the continuous phase.(1) The difference lies in the internal structure of both materials: while PICN is the polymerized product of a monomer infiltrated porous ceramic scaffold, a nanoceramic resin is the result of the incorporation of ceramic particles by mixing with a resin matrix. In PICN, the continuous ceramic network warrants the material's hardness.(10, 31)

Xu *et al.*(30) also measured the elastic modulus of the PICN material (PICN) using a TriboIndenter, reporting an E of 23,24 GPa.

Table V – Young's modulus (GPa) of human dentin, enamel and the PICN material according to the literature.

	Value	References
Dentin	17,7-21,1	Kinney *et al*. (as cited in Hairul Nizam *et al*.(32))
Dentin	16	Lawn *et al*.(26)
Enamel	90,59±16,13	Willems *et al*. (as cited in Hairul Nizam *et al*.(32))
Enamel	90,08±4,15	Xu *et al*.(30)
PICN (VITA Enamic)	37,95±0,34	Della Bonna *et al*.(7)
PICN (VITA Enamic)	27,26±0,67	Argyrou *et al*.(19)
PICN (VITA Enamic)	23,54±2,44	Xu *et al*.(30)

Considering how the elastic modulus presented by PICN materials closely matches that of human's dentin, a more uniform distribution of stress during mastication is expected.(18, 24)

As per Li *et al*.(24), a high elastic modulus translates in an inferior capability of absorbing stress and, given the modulus discrepancy between restorative material and human teeth, the excess stress concentrates near the interface, resulting in tooth damage during mastication. In this study, the authors report an elastic modulus ranging from 40,2 to 100,5 GPa for an experimental PICN zirconia material sintered at 1,300°C. This closer match to enamel's elastic modulus may result in a more uniform stress distribution during mastication loading preventing tooth cracking.(24)

‖ Poisson's ratio (ν)

The Poisson's ratio translates the relative deformation a material undergoes under mechanical stress.(31)

Della Bonna *et al*.(7) reported a Poisson's ratio of 0.23 for PICN (VITA Enamic).

Choi *et al*.(20) found no significant differences between the ratios of PICN (VITA Enamic: 0,277) e nanoceramic resins (Lava Ultimate: 0,302; Mazic Duro: 0,295 and Cerasmart: 0,306).

Table VI – Poisson's ratio of the PICN material according to the literature.

	Value	References
PICN (VITA Enamic)	0,23	Della Bonna *et al*.(7)
PICN (VITA Enamic)	0,277	Choi *et al*.(20)

Belli *et al*.(31) pointed out that the Poisson's ratio of most dental ceramic ranges between 0,20 and 0,25.

Density

The PICN material (VITA Enamic) showed a density (ρ) of 2,09 g/cm^3 in the study carried out by Della Bonna *et al*.(7)

Belli *et al*.(31) describes consonant results using the method Resonant Beam Technique (RBT) to measure the property: PICN (VITA Enamic) presented a density of approximately 2,13 g/cm^3.

Table VII – Density (g/cm^3) of human dentin, enamel and the PICN material according to the literature.

	Value	References
Dentin (permanent)	2,14	Manly *et al*. (as cited in Lin *et al*.(33))
Enamel (permanent)	2,97	Manly *et al*. (as cited in Lin *et al*.(33))
Enamel	3,02	Wilson *et al*. (as cited in Bajaj *et al*.(34))
PICN (VITA Enamic)	2,09$\pm$0,01	Della Bonna *et al*.(7)
PICN (VITA Enamic)	2,13$\pm$0,015	Belli *et al*.(31)

Edge chipping resistance and milling/ adjustment procedures induced damage/ damage tolerance

Chipping is one of the most predominant causes of failure when it comes to the successful longevity of ceramic restorations.(19, 35, 36) The susceptibility to chipping fracture is due to ceramic's characteristic brittleness.(23)

CAD-CAM milling process might also induce chipping or microcracks which might be responsible for premature clinical fractures.(5, 19, 37) Swain *et al*.(5) defined that a suitable CAD-CAM material is determined by its ability to machine rapidly without chipping and with minimal strength reduction. Milling induced flaws depend on the material's properties, namely elastic modulus, hardness and its brittleness.(37)

Argyrou *et al*.(19) resorted to an edge chipping test to evaluate and compare the resistance of the PICN material and other CAD-CAM dental materials. This test consists in advancing an indenter into a material, deliberately creating chips. The highest edge toughness was reported for leucite reinforced glass-ceramic (IPS Empress CAD: 275 N/mm), followed by feldspathic ceramic (VITABLOCS TriLuxe forte: 179 N/mm) and nanoceramic resin (Lava Ultimate: 169 N/mm). These materials showed no significant differences when evaluated individually. PICN showed the lowest edge chipping resistance out of the materials (VITA Enamic: 120 N/mm).

Coldea *et al*.(17) focused on the strength degradation of two PICN test materials, Y-TZP, feldspathic porcelains (Mark II and VM 9), glass infiltrated aluminium oxide ceramic (In-Ceram Alumina) and lithium disilicate ceramic (IPS–e.max CAD). The indentation strength technique (IS) aims to measure the retained strength of the material after flaw introduction (several Vickers indentations with progressive loads were carried out) and a posterior bending test. Coldea *et al*.(17) concluded that with increasing indentation load, the flexural strength of all tested materials decreased compared to the initial flexural strength. Y-TZP presented the highest strength degradation (81%) at an applied load of 98,07 N, followed by VM 9 (77%), IPS–e.max CAD (72%), Mark II (64%), PICN 1 (62%), In-Ceram Alumina (56%) and PICN 2 (51%). One of the PICN materials tested showed the highest damage tolerance, suggesting that flaws subsequent from mastication or other adjustment procedures will have a lower impact on the material's strength.(8, 17)

Adjustments procedures carried out by clinicians may also incur on material damaging. The duration and pressure applied during grinding or polishing, cooling systems, shape and grit size of the burs and rotations per minute are all critical features concerning adjustments.(37)

Coldea *et al*.(37) analysed the impact of simulated clinical and technical adjustments on the flexural strength of seven dental materials (VITA Enamic, PICN test material, In-Ceram Alumina, VM 9, Mark II, IPS–e.max CAD and Y-TZP) in order to evaluate and compare their damage tolerance after transversal and longitudinal grinding protocols and varying abrasive diamond burs (coarse, medium and extra fine). Out of the seven tested materials Y-TZP exhibited no significant strength reduction upon grinding, contrasting with the remaining materials. The strength degradation after grinding in the longitudinal direction can be summarized in the following order, from least to greatest: VITA Enamic < PICN test material < Mark II < VM 9 < In-Ceram Alumina < IPS–e.max CAD. The order for damage tolerance after grinding in the transversal direction is as follows (from highest to least): PICN test material > VITA Enamic > Mark II > VM 9 > In-Ceram Alumina > IPS–e.max CAD. PICN revealed high damage tolerance, which the authors justify based on the material's microstructure (a mechanism of crack tip bridging and deformation limits the extension of the defect) and low brittleness.

Fatigue resistance and wear behaviour

Swain *et al*.(5) conducted clinical simulation tests in order to compare the fatigue resistance of various dental materials: CAD-CAM fabricated crowns of PICN (VITA Enamic), feldspathic ceramic (Mark II) and lithium disilicate ceramic (IPS–e.max CAD). The crowns were then cemented to resin based composited dies and secondarily subjected to mechanical cycling tests consisting of nominal mouth-motion fatigue (198 N for 1,2 million cycles at 1,6 Hz and simultaneous thermal cycling from 5 to 55◦C for 60s intervals). None of the PICN (VITA Enamic) crowns failed but presented the highest surface wear, 6 lithium disilicate ceramic (IPS–e.max CAD) crowns presented minor cracking and 12 feldspathic ceramic (Mark II) crowns showed significant crack failures, corresponding to simulated 5-year survival rates of 100%, 57,14% and 14,28%, respectively.

El Zhawi *et al*.(15) exposed PICN (VITA Enamic) monolithic crowns cemented to resin based composited dies, to two types of fatigue and wear tests: accelerated sliding-contact mouth-motion step-stress fatigue test in water and long-term sliding-contact mouth-motion fatigue/wear test using a clinically relevant load (200 N) also in water. Out of the 24 crowns tested under accelerated step-stress fatigue (maximum fatigue load of 1700 N) 3 crowns failed due to chipping and bulk fracture. The mouth-motion cyclic loading (frequency of 2 Hz, 200 N, 1,25 million cycles) carried out in this study corresponds to approximately 5 years in the oral cavity. The results showed that none of the PICN (VITA Enamic) crowns fractured or presented significant fatigue damage other than minor wear. Considering that routine chewing ranges between 100–150 N and that extreme tooth loading could reach 1000–1400 N in exceptional situations such as trauma or in bruxer patients, the authors concluded that PICN is a material indicated for crown restorations and highlighted the promising results relating to the treatment of patients with parafunctional activity.

Nishioka *et al*.(38) also carried out laboratorial fatigue tests (monotonic biaxial load-to-failure tests and biaxial fatigue strength tests) with disc-shaped specimens aiming to predict the mechanical behaviour of several restorative dental materials. The PICN (VITA Enamic) material showed higher fatigue resistance than feldspathic ceramic (Mark II) but a substantially lower fatigue strength than high translucence yttrium stabilized tetragonal zirconia polycrystals (Zirconia YZ-HT), lithium disilicate glass-ceramic (IPS–e.max CAD) and zirconia reinforced silicate glass-ceramic (VITA Suprinity).

Homaei *et al*. (as cited in Sieper *et al*.(39)) also reports a lower fatigue resistance for the PICN material than lithium disilicate glass-ceramic, yet describes PICN as a material capable of withstanding normal masticatory forces.

Fracture load – restorations cemented on implant abutments

Kok *et al*.(21) evaluated the risk of fracture of implant-supported restorations, by means of initial load to failure (ILF) testing. Different dental restorative materials based posterior crowns cemented to abutments were, for that effect, subjected to a static loading. The highest ILFs were observed for Y-TZP (Lava Plus: 6065 N) and lithium disilicate glass-ceramic (IPS–e.max CAD: 2788 N). PICN (VITA Enamic) presented an ILF of 2171 N while nanoceramic resin Lava Ultimate (1935 N) had the lowest ILF value among the tested materials. Nonetheless, all tested materials should withstand the physiological forces inherent of the oral cavity.

Baumgart *et al*.(40) assessed PICN (VITA Enamic) bond strength and surface wear after a long-term chewing simulation (1,2 million cycles, 50 N and simultaneous thermo cycling of 5500 cycles with temperatures of 4-56°C for 60s each) equivalent to an *in vivo* load of 5 years. None of the CAD-CAM PICN premolar crowns or implants fractured or loosened during or after the chewing simulation. On the other hand, abrasion of the crowns was macroscopically visible. A limitation of the previous study is the occlusal force applied considering 50 N is, at best, comparable to light biting force.

Bond Strength

The clinical longevity and success of ceramic restorations lies fundamentally on adhesive bonding given that it is essential and determining for the restoration's retention, improving fracture resistance of the tooth-restoration association, defining marginal adaptation and preventing microleakage.(6, 13, 41)

As reported by Rohr *et al*.(13) the typical surface treatment for glass-ceramics is hydrofluoric acid (HF) etching followed by silanization. The HF provides surface roughness and subsequent micromechanical retention while silane creates chemical bonding between the ceramic restoration and the resin composite cement.(13, 42)

PICN's (VITA Enamic) surface treatment method recommended by the manufacturer is etching with conventional 5% HF for 60 seconds.(8)

Rohr *et al*.(13) studied the adhesion mechanism of resin based composite cements to PICN. The shear bond strength of two cements (dual-curing resin cement: RelyX Unicem 2 Automix, self-adhesive resin cement: RelyX Ultimate) was tested after different pretreatments (none, silane, universal adhesive, silane and universal adhesive), increasing 5% HF etching times (0, 15, 30, 60 and 120s) and after 24 hours of water storage at 37ºC. Without etching or a pre-treatment both cements debonded spontaneously from PICN's surface during water storage and the highest shear bond strengths for both cements were achieved when using both silane and universal adhesive (RelyX Unicem 2 Automix: 6,8 MPa, RelyX Ultimate:14,2 MPa). The highest mean shear bond strengths with variable etching duration was achieved after etching for 30 to 60s and pre-treatment association of silane and universal adhesive.

Kömürcüoğlu *et al*.(6) evaluated the effect of different surface treatments on bond strength between dual-curing adhesive resin cement (Variolink N) and different CAD/CAM hybrid restorative materials (VITA Enamic, MARK II, Lava Ultimate and IPS–e.max CAD) using four-point bending strength (FPBS) tests. The highest FPBS values for PICN (VITA Enamic) were found with the combination of sandblasting and universal adhesive (98,06 MPa) along with acid etching (9.5% HF) and universal adhesive (84,00 MPa). Lithium disilicate glass-ceramic (IPS–e.max CAD) and nanoceramic resin (Lava Ultimate) presented the highest values with the combination of acid etching and universal adhesive (100,31 MPa) and sandblasting in addition to universal adhesive (100,19 MPa), respectively. The authors concluded that sandblasting or HF acid etching treatment in combination with a universal adhesive containing MDP (10-Methacryloyloxydecyl dihydrogen phosphate) can be suggested for the adhesive cementation of PICN (VITA Enamic) and nanoceramic resin (Lava Ultimate).

Campos *et al*.(43) compared the micro tensile bond strength between resin cement and hybrid materials after different surface treatments (etching with 10% hydrofluoric acid for 60s, etching with 37% phosphoric acid for 60s and air abrasion with silica-coated alumina particles). All tested specimens were silanized, cemented to composite resin blocks and aged by thermocycling. The non-aged samples showed the higher bond strength values, despite the surface pre-treatment. After the aging process, the HF group was the one showcasing the highest bond strength values and inherently bond stability.

Surface Roughness

The clinical success of dental restorations relies in two other essential features: shade matching and surface roughness. These characteristics are heavily dictated by the applied surface treatment. Surface roughness facilitates microbial plaque formation, especially in areas where the restorative material is in contact with the gingiva.(44)

Özarslan *et al*.(44) performed three different finishing and polishing procedures available for the PICN material (Technical Kit, Clinical Kit, and VITA Enamic Glaze) on specimens of the material in the shade 2M2 and two different translucency levels: high translucent and translucent. The groups with VITA Enamic Glaze showed the highest surface roughness value. In addition, the HT/Clinical Kit group showed perceivable shade alteration after finishing and polishing. Therefore, the authors suggest the use of The Technical Kit in order to attain smoother surfaces and shade matching.(44, 45)

Yu *et al*.(46) analysed PICN specimens (VITA Enamic) before and after immersion (2% acid solution at 37ºC for 4 weeks) in acidic solutions (acetic acid, citric acid and lactic acid) which are fairly common acids in the oral cavity and may be related to accelerated ageing and consequent shortage of the service life of dental restorations. There was a significant increase in surface roughness and a significant decrease in microhardness after the immersion in acidic solution, with lactic acid accountable for the highest roughness reported (from 12,68 to 51,54 nm). Additionally, after immersion the material showcased increasing degrees of surface damage: the acetic acid group showed microcracks between the material's phases, the citric acid group displayed microcracks, defects and pores, and the lactic acid group exhibited aggressive surface degradation (microcracks, pores and potholes). These conclusions are of the utmost importance since the material's wear behaviour (wear resistance) and optical properties, such as long-term colour stability, are also altered by surface roughness.(8, 46)

Biocompatibility

Grenade *et al*.(47) studied PICN's biological properties which are crucial for implant prostheses considering the involvement and direct contact with gingiva and even bone. The authors evaluated and compared the biocompatibility of PICNs with other metallic and ceramic materials used for dental implant prostheses and abutments based on the attachment, proliferation and spreading of human gingival fibroblasts (HGFs). The material must promote the attachment of fibroblasts and keratinocytes, otherwise receding of the biological width occurs, followed by bone resorption and gingival recession, compromising the peri-implant tissues, as well as the aesthetic result. The materials used for the abutment and prosthesis must promote cell adhesion, a critical property for the long-term stability of bone, gingival tissue and implant prostheses.(47, 48) PICN (experimental PICN without TEGDMA or the initiator benzoyl peroxide) and lithium disilicate glass-ceramic showed intermediate results between titanium and zirconia (group with highest cell viability, number and coverage) and the negative control, despite the presence of polymer and their hydrophobicity.(47) Grenade *et al*.(48) carried out a similar study regarding human gingival keratinocytes (HGKs) and reported similar results, with the PICN material showing comparable results to lithium disilicate glass-ceramic. The authors justify the absence of monomer release and indirect cytotoxicity of PICN to its HT-HP polymerization which ensures a high degree of conversion of monomers. Grenade *et al*.(47, 48) suggests further clinical investigation before indicating PICN and lithium disilicate glass-ceramic for transgingival prosthesis components.

Clinical Studies

Spitznagel *et al*.(49) led a prospective clinical study over 5 years in order to evaluate the survival rate and clinical behaviour of CAD/CAM minimally invasive PICN (VITA Enamic) posterior inlays and partial coverage restorations (PCRs). The clinical trial included 47 patients and 103 minimally invasive restorations: 45 inlays and 58 partial coverage restorations. The PICN restorations were first cleaned with 99% isopropanol followed by 4,9% hydrofluoric acid (IPS Ceramic Etching Gel) etching of the intaglio surface for 60s. The pre-treated surface was then rinsed with water, dried, and silane (Monobond S) was applied. After another 60s, the surface was dried and a dual-curing adhesive resin cement (Variolink II) was used for cementation. Spitznagel *et al*.(49) describes the follow-up period of up to 36 months after insertion. During the recall period two partial crowns (23,9 and 28,9 months) and one inlay (19,4 months) failed and had to be replaced due to clinically unacceptable bulk fractures. Four PCRs demonstrated minimal cohesive fractures (chipping) after 11,4/16,3/36,9/38,2 months and were limited to the PICN material. These were clinically acceptable and the minimal defects were corrected with a composite (Tetric EvoCeram). A significant change in surface roughness, marginal adaptation and marginal discoloration was observed over 36 months of service.

Secondary caries did not occur in any of the restorations. After 3 years, the estimated success rate of PICN restorations was 84,8% for inlays and 82,4% for PCRs.

Lu *et al*.(50) evaluated the clinical performance of onlay restorations with PICN (Vita Enamic) and feldspathic ceramic (Mark II) for endodontically treated posterior teeth over 3 years. 93 patients received 101 onlay restorations (PICN: 67 and Mark II: 34). The restorations were etched for 5 minutes with 9.6% hydrofluoric acid (Pulpdent Corp), rinsed and silanated. 5 restorations failed (2 PICN and 3 Mark II restorations) after 12 months due to debonding, ceramic fracture and tooth fracture. The results showed that after 3 years the PICN restorations presented favourable anatomic form, adequate marginal adaptation and colour match. After the 3-year service time, the survival rates were 97,0% and 90,7% for Vita Enamic and Mark II, respectively.

Chirumamilla *et al*.(51) assessed the survival probability and clinical performance of PICN (VITA Enamic) crowns after 2 years of service time. This clinical study involved 35 patients, and 45 crowns cemented by a single operator. 31 crowns were bonded with resin cement and 14 others were cemented with resin modified glass ionomer (RMGI) cement. The crowns were previously sandblasted with 50 µm Al_2O_3 particles for 10 seconds and coated with a layer of ceramic primer (Monobond Plus). No clinical failures occurred after 1 year. At the 2-year recall two restorations failed due to debonding associated with secondary caries (RMGI cemented crown) and extraction of a tooth that displayed a crack before the crown was cemented (the author considered this a failure). The estimated survival rates for VITA Enamic crowns didn't show significant differences between the two cements (96,8% for the resin cement and 92,9% for the RMGI cement).

Conclusions and Perspectives

Aesthetics are crucial today and, by far, a prerequisite regardless of the selected treatment. This imperative often demanded the use of materials with either much higher or lower elastic properties than enamel, such as crystalline ceramics and polymer composite, respectively.

PICNs were introduced with the purpose of finding a middle ground between the properties of ceramics and polymer composites and getting closer to emulating the characteristics and behaviour of natural dental tissues.

Even though most studies reported fairly varied results and methodologies, the properties of PICNs range between resin-based composites and porcelains as well as between enamel and dentin.

Fundamentally, PICN materials combine a lower Young’s modulus and hardness in addition to high resistance to crack growth (substantial R-curve behaviour). This feature is mainly attributed to its unique microstructure: the three-dimensional reinforcement polymeric phase offers a toughening mechanism by bridging the cracks introduced to the ceramic matrix.

The reported characteristics of PICN materials justify their selection and clinical application for successful and safe restorative treatments, however, further clinical studies are required in order to infer about the long-term behaviour of PICNs in comparison with the already pre-established success and longevity of restorations with the classic ceramic-based restorative materials.

References

1. Furtado de Mendonca A, Shahmoradi M, Gouvea CVD, De Souza GM, Ellakwa A. Microstructural and Mechanical Characterization of CAD/CAM Materials for Monolithic Dental Restorations. Journal of prosthodontics : official journal of the American College of Prosthodontists. 2018.
2. Albero A, Pascual A, Camps I, Grau-Benitez M. Comparative characterization of a novel cad-cam polymer-infiltrated-ceramic-network. Journal of clinical and experimental dentistry. 2015;7(4):e495-500.
3. Hao Z, Ma Y, Liu W, Meng Y, Nakamura K, Shen J, *et al*. Influence of low-temperature degradation on the wear characteristics of zirconia against polymer-infiltrated ceramic-network material. The Journal of prosthetic dentistry. 2018;120(4):596-602.
4. Eldafrawy M, Nguyen JF, Mainjot AK, Sadoun MJ. A Functionally Graded PICN Material for Biomimetic CAD-CAM Blocks. Journal of dental research. 2018;97(12):1324-30.
5. Swain MV, Coldea A, Bilkhair A, Guess PC. Interpenetrating network ceramic-resin composite dental restorative materials. Dental materials : official publication of the Academy of Dental Materials. 2016;32(1):34-42.
6. Komurcuoglu MB, Sagirkaya E, Tulga A. Influence of different surface treatments on bond strength of novel CAD/CAM restorative materials to resin cement. The journal of advanced prosthodontics. 2017;9(6):439-46.
7. Della Bona A, Corazza PH, Zhang Y. Characterization of a polymer-infiltrated ceramic-network material. Dental materials : official publication of the Academy of Dental Materials. 2014;30(5):564-9.
8. Facenda JC, Borba M, Corazza PH. A literature review on the new polymer-infiltrated ceramic-network material (PICN). Journal of esthetic and restorative dentistry : official publication of the American Academy of Esthetic Dentistry [*et al*]. 2018;30(4):281-6.
9. Nguyen JF, Ruse D, Phan AC, Sadoun MJ. High-temperature-pressure polymerized resin-infiltrated ceramic networks. Journal of dental research. 2014;93(1):62-7.
10. Mainjot AK, Dupont NM, Oudkerk JC, Dewael TY, Sadoun MJ. From Artisanal to CAD-CAM Blocks: State of the Art of Indirect Composites. Journal of dental research. 2016;95(5):487-95.
11. Choi JW, Song EJ, Shin JH, Jeong TS, Huh JB. In Vitro Investigation of Wear of CAD/CAM Polymeric Materials Against Primary Teeth. Materials (Basel, Switzerland). 2017;10(12).
12. Spitznagel FA, Boldt J, Gierthmuehlen PC. CAD/CAM Ceramic Restorative Materials for Natural Teeth. Journal of dental research. 2018;97(10):1082-91.
13. Rohr N, Flury A, Fischer J. Efficacy of a Universal Adhesive in the Bond Strength of Composite Cements to Polymer-infiltrated Ceramic. The journal of adhesive dentistry. 2017;19(5):417-24.

14. Silva P, Martinelli-Lobo CM, Bottino MA, Melo RM, Valandro LF. Bond strength between a polymer-infiltrated ceramic network and a composite for repair: effect of several ceramic surface treatments. Brazilian oral research. 2018;32:e28.
15. El Zhawi H, Kaizer MR, Chughtai A, Moraes RR, Zhang Y. Polymer infiltrated ceramic network structures for resistance to fatigue fracture and wear. Dental materials : official publication of the Academy of Dental Materials. 2016;32(11):1352-61.
16. Ongun S, Kurtulmus-Yilmaz S, Meric G, Ulusoy M. A Comparative Study on the Mechanical Properties of a Polymer-Infiltrated Ceramic-Network Material Used for the Fabrication of Hybrid Abutment. Materials (Basel, Switzerland). 2018;11(9).
17. Coldea A, Swain MV, Thiel N. In-vitro strength degradation of dental ceramics and novel PICN material by sharp indentation. Journal of the mechanical behavior of biomedical materials. 2013;26:34-42.
18. Coldea A, Swain MV, Thiel N. Mechanical properties of polymer-infiltrated-ceramic-network materials. Dental materials : official publication of the Academy of Dental Materials. 2013;29(4):419-26.
19. Argyrou R, Thompson GA, Cho SH, Berzins DW. Edge chipping resistance and flexural strength of polymer infiltrated ceramic network and resin nanoceramic restorative materials. The Journal of prosthetic dentistry. 2016;116(3):397-403.
20. Choi BJ, Yoon S, Im YW, Lee JH, Jung HJ, Lee HH. Uniaxial/biaxial flexure strengths and elastic properties of resin-composite block materials for CAD/CAM. Dental materials : official publication of the Academy of Dental Materials. 2019;35(2):389-401.
21. de Kok P, Kleverlaan CJ, de Jager N, Kuijs R, Feilzer AJ. Mechanical performance of implant-supported posterior crowns. The Journal of prosthetic dentistry. 2015;114(1):59-66.
22. Goujat A, Abouelleil H, Colon P, Jeannin C, Pradelle N, Seux D, *et al*. Mechanical properties and internal fit of 4 CAD-CAM block materials. The Journal of prosthetic dentistry. 2018;119(3):384-9.
23. Kurtulmus-Yilmaz S, Cengiz E, Ongun S, Karakaya I. The Effect of Surface Treatments on the Mechanical and Optical Behaviors of CAD/CAM Restorative Materials. Journal of prosthodontics : official journal of the American College of Prosthodontists. 2018.
24. Li W, Sun J. Effects of Ceramic Density and Sintering Temperature on the Mechanical Properties of a Novel Polymer-Infiltrated Ceramic-Network Zirconia Dental Restorative (Filling) Material. Medical science monitor : international medical journal of experimental and clinical research. 2018;24:3068-76.
25. Lawn BR, Lee JJ. Analysis of fracture and deformation modes in teeth subjected to occlusal loading. Acta biomaterialia. 2009;5(6):2213-21.
26. Lawn BR, Deng Y, Thompson VP. Use of contact testing in the characterization and design of all-ceramic crownlike layer structures: a review. The Journal of prosthetic dentistry. 2001;86(5):495-510.
27. Gonzaga CC, Cesar PF, Miranda WG, Jr., Yoshimura HN. Slow crack growth and reliability of dental ceramics. Dental materials : official publication of the Academy of Dental Materials. 2011;27(4):394-406.
28. Quinn JB, Quinn GD. A practical and systematic review of Weibull statistics for reporting strengths of dental materials. Dental materials : official publication of the Academy of Dental Materials. 2010;26(2):135-47.

29. Park S, Quinn JB, Romberg E, Arola D. On the brittleness of enamel and selected dental materials. Dental materials : official publication of the Academy of Dental Materials. 2008;24(11):1477-85.
30. Xu Z, Yu P, Arola DD, Min J, Gao S. A comparative study on the wear behavior of a polymer infiltrated ceramic network (PICN) material and tooth enamel. Dental materials : official publication of the Academy of Dental Materials. 2017;33(12):1351-61.
31. Belli R, Wendler M, de Ligny D, Cicconi MR, Petschelt A, Peterlik H, *et al*. Chairside CAD/CAM materials. Part 1: Measurement of elastic constants and microstructural characterization. Dental materials : official publication of the Academy of Dental Materials. 2017;33(1):84-98.
32. Hairul Nizam BR, Lim CT, Chng HK, Yap AU. Nanoindentation study of human premolars subjected to bleaching agent. Journal of biomechanics. 2005;38(11):2204-11.
33. Lin M, Xu F, Lu TJ, Bai BF. A review of heat transfer in human tooth--experimental characterization and mathematical modeling. Dental materials : official publication of the Academy of Dental Materials. 2010;26(6):501-13.
34. Bajaj D, Nazari A, Eidelman N, Arola DD. A comparison of fatigue crack growth in human enamel and hydroxyapatite. Biomaterials. 2008;29(36):4847-54.
35. Petrini M, Ferrante M, Su B. Fabrication and characterization of biomimetic ceramic/polymer composite materials for dental restoration. Dental materials : official publication of the Academy of Dental Materials. 2013;29(4):375-81.
36. Choi S, Yoon HI, Park EJ. Load-bearing capacity of various CAD/CAM monolithic molar crowns under recommended occlusal thickness and reduced occlusal thickness conditions. The journal of advanced prosthodontics. 2017;9(6):423-31.
37. Coldea A, Fischer J, Swain MV, Thiel N. Damage tolerance of indirect restorative materials (including PICN) after simulated bur adjustments. Dental materials : official publication of the Academy of Dental Materials. 2015;31(6):684-94.
38. Nishioka G, Prochnow C, Firmino A, Amaral M, Bottino MA, Valandro LF, *et al*. Fatigue strength of several dental ceramics indicated for CAD-CAM monolithic restorations. Brazilian oral research. 2018;32:e53.
39. Sieper K, Wille S, Kern M. Fracture strength of lithium disilicate crowns compared to polymer-infiltrated ceramic-network and zirconia reinforced lithium silicate crowns. Journal of the mechanical behavior of biomedical materials. 2017;74:342-8.
40. Baumgart P, Kirsten H, Haak R, Olms C. Biomechanical properties of polymer-infiltrated ceramic crowns on one-piece zirconia implants after long-term chewing simulation. International journal of implant dentistry. 2018;4(1):16.
41. Alp G, Subasi MG, Johnston WM, Yilmaz B. Effect of different resin cements and surface treatments on the shear bond strength of ceramic-glass polymer materials. The Journal of prosthetic dentistry. 2018;120(3):454-61.
42. Bello YD, Di Domenico MB, Magro LD, Lise MW, Corazza PH. Bond strength between composite repair and polymer-infiltrated ceramic-network material: Effect of different surface treatments. Journal of esthetic and restorative dentistry : official publication of the American Academy of Esthetic Dentistry [*et al*]. 2018.
43. Campos F, Almeida CS, Rippe MP, de Melo RM, Valandro LF, Bottino MA. Resin Bonding to a Hybrid Ceramic: Effects of Surface Treatments and Aging. Operative dentistry. 2016;41(2):171-8.
44. Ozarslan MM, Buyukkaplan US, Barutcigil C, Arslan M, Turker N, Barutcigil K. Effects of different surface finishing procedures on the change in surface roughness and

color of a polymer infiltrated ceramic network material. The journal of advanced prosthodontics. 2016;8(1):16-20.
45. Buyukkaplan SU, Ozarslan MM, Barutcigil C, Arslan M, Barutcigil K, Yoldan EE. Effects of staining liquids and finishing methods on translucency of a hybrid ceramic material having two different translucency levels. The journal of advanced prosthodontics. 2017;9(5):387-93.
46. Yu P, Xu Z, Arola DD, Min J, Zhao P, Gao S. Effect of acidic agents on the wear behavior of a polymer infiltrated ceramic network (PICN) material. Journal of the mechanical behavior of biomedical materials. 2017;74:154-63.
47. Grenade C, De Pauw-Gillet MC, Gailly P, Vanheusden A, Mainjot A. Biocompatibility of polymer-infiltrated-ceramic-network (PICN) materials with Human Gingival Fibroblasts (HGFs). Dental materials : official publication of the Academy of Dental Materials. 2016;32(9):1152-64.
48. Grenade C, De Pauw-Gillet MC, Pirard C, Bertrand V, Charlier C, Vanheusden A, *et al*. Biocompatibility of polymer-infiltrated-ceramic-network (PICN) materials with Human Gingival Keratinocytes (HGKs). Dental materials : official publication of the Academy of Dental Materials. 2017;33(3):333-43.
49. Spitznagel FA, Scholz KJ, Strub JR, Vach K, Gierthmuehlen PC. Polymer-infiltrated ceramic CAD/CAM inlays and partial coverage restorations: 3-year results of a prospective clinical study over 5 years. Clinical oral investigations. 2018;22(5):1973-83.
50. Lu T, Peng L, Xiong F, Lin XY, Zhang P, Lin ZT, *et al*. A 3-year clinical evaluation of endodontically treated posterior teeth restored with two different materials using the CEREC AC chair-side system. The Journal of prosthetic dentistry. 2018;119(3):363-8.
51. Chirumamilla G, Goldstein CE, Lawson NC. A 2-year Retrospective Clinical study of Enamic Crowns Performed in a Private Practice Setting. Journal of esthetic and restorative dentistry : official publication of the American Academy of Esthetic Dentistry [*et al*]. 2016;28(4):231-7.

Annex I

Parecer - Entrega do trabalho final da Monografia

U.PORTO

FACULDADE DE MEDICINA DENTÁRIA
UNIVERSIDADE DO PORTO

PARECER

Entrega do trabalho final de Monografia

Informo que o trabalho de Monografia desenvolvido pela estudante Fátima Miriam Gonçalves Pereira, com o título *"Update on the new polymer infiltrated ceramic network material (PICN)"* está de acordo com as normas e regras estipuladas pela Faculdade de Medicina Dentária da Universidade do Porto, foi por mim conferido e encontra-se em condições de ser apresentado e defendido em provas públicas.

Porto, 4 de julho de 2019

A Orientadora,

(Professora Doutora Ana Isabel Pereira Portela)

Annex II

Declaração De Autoria Do Trabalho

U.PORTO

FACULDADE DE MEDICINA DENTÁRIA
UNIVERSIDADE DO PORTO

DECLARAÇÃO DE AUTORIA DO TRABALHO

Declaro que o presente trabalho, intitulado: "*Update on the new polymer infiltrated ceramic network material (PICN)*", no âmbito da Monografia de Investigação/Relatório de Atividade Clínica, integrada no Mestrado Integrado em Medicina Dentária da Faculdade de Medicina Dentária da Universidade do Porto, é da minha autoria e todas as fontes foram devidamente referenciadas.

Porto, 4 de julho de 2019

A estudante,

Fátima Miriam Gonçalves Pereira

(Fátima Miriam Gonçalves Pereira)