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ASSESSMENT OF FRACTURE RESISTANCE OF IMPLANT-SUPPORTED FIXED PARTIAL PROSTHESES CONSTRUCTED OF TWO DIFFERENT MATERIALS WITH DIFFERENT PONTIC DESIGNS

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ABSTRACT

Objective: The aim of this study is to evaluate the effect of different pontic framework designs, constructed from two different materials: monolithic zirconia and Polyether ether ketone (PEEK), on the fracture resistance of implant supported fixed partial prosthesis.

Material and Methods: The study conducted assess the effect of pontic design on the fracture resistance of a four units implant supported fixed partial denture; the pontic constructed replaces the second premolar and first molar with two different designs: modified ridge lap and sanitary designs. A total of forty implants were used in this research; the implants are embedded in poly-urethane foam blocks (20 pounds per cubic foot (20 PCF)) to resemble supporting bone structure. Specimens are divided according to material of construction into two groups, monolithic zirconia group (n=10) and PEEK group (n=10). Then, the specimens are sub-divided into two subgroups according to pontic design modified ridge lap group (n=5) and sanitary group (n=5). All specimens are subjected to loading test in a computerized universal testing machine until fracture occurs.

Results: According to statistical results, there is a significant difference between the zirconia and PEEK in different pontic designs. The monolithic Zirconia displayed higher results the PEEK upon testing $p \leq 0.05$. All the tested materials were within the acceptable range for functioning under mastication.

Conclusions: Zirconia and PEEK are materials of choice when designing a long span bridges due to their high fracture strength values. Aside from the pontic design, the restorative material has a great impact on the fracture resistance, behavior of the material and stress distribution.

KEY WORDS: zirconia, PEEK, pontic, polyurethan, fracture resistance.

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INTRODUCTION

The aim of contemporary dentistry is to restore the normal shape, functionality, comfort, aesthetics, speech, and overall health of the stomatognathic system. However, it gets harder to accomplish this goal with conventional treatment regimens when more teeth have lost. (1)

Dental implants gained all the attention as a common treatment approach in dentistry there for, more researches had been conducted to provide advancement in implant designs, materials, and treatment approaches. Currently, a variety of implant types are accessible for use in the rehabilitation of various clinical conditions.

Today, the term "dental implantology" refers to the process of securing alloplastic material into the jaws to support and retain prosthetic teeth replacements. (2)

Depending on the alveolar bone and overall health of the patient, dental implants have been used for oral rehabilitation of either entire or partial edentulous arches to replace lost teeth. (3,4)

Dental implants can be used in the replacement of single or multiple missed teeth, using single or multiple individual units, fixed partial dentures, removable dentures or to support or retain complete dentures. Esthetics is an ever-growing part of dentistry today. Implants can provide a function and esthetic way to restore the area back to function in conservative manner without preparing adjacent teeth. (5,6)

Recently, prosthetic treatment for tooth loss can be handled with all-ceramic restorations rather than metal-ceramic ones, which had challenges with appearance and functionality. (7,8)

With the development of high resistant oxide ceramics, all-ceramic restorations are also utilized in the fabrication of big restorations in the posterior area. zirconia (zirconium dioxide, $ZrO2$) has been particularly popular and is currently a widely utilized material in all-ceramic restorations. From mechanical to physio-chemical to aesthetic qualities, zirconia offers nearly all the benefits of dental materials in a single component (color close to that of teeth, good durability and elasticity, no static electric load on the surface). (9,10)

Polyether ether ketone (PEEK), the most recent dental inventory, has superior qualities when compared to current materials. Peek belongs to the PAEK (poly-aryl-ether-ketone) polymer family, which is characterized by its strong mechanical qualities and great temperature stability, reaching temperatures beyond 300 °C. (11)

Y.C. Huang et al., (12) claimed that when teeth are missing from the oral cavity, dental bridges are a prosthetic method of restoring oral function. The abutment retainer, connector, and pontic are its three constituent components. This structure's resultant force on the fixed bridge must not result in any pathological alterations and must fall within the abutment retainer's permitted physiological range.

Fracture toughness is the capacity of a material to disperse fracture energy around the tip of a propagating crack. Brittle ceramics have a lower fracture toughness than ductile metals since there isn't any plastic deformation prior to fracture. Many ceramics have extremely high strengths, but because of their comparatively low fracture toughness, they are seldom ever used in practical applications. This suggests that fracture toughness is still the primary factor restricting the usage of ceramics. Zirconia's hardness can reach levels of approximately 10 $MPa.m^{½}$, more than twice as high as high-density alumina, despite never reaching the level of metals. Although never attaining the level of metals, can reach values of about 10 $MPa•m^{½}$, which is more than twice as high as for high-density alumina. As mentioned earlier. (13,14)

When compared to other dental ceramics, Y-TZP's flexural strength (900–1400 MPa) is superior and significantly higher than the yield strength of metallic alloys used in dentistry. [15]

Using a monolithic three-unit implant-supported prosthesis, Marini et al. [16] investigated the fatigue performance zirconia polycrystals, they concluded that the zirconia bridges showed a high fracture strength of 1654 N.

The dental industry is constantly looking for improved materials that can address the shortcomings of the ones that are now available. PEEK, the most recent dental inventory, is said to have superior qualities when compared to current materials. [17]

Schwitalla et al., [18] claimed that PEEK according to documented data, physical characteristics include an elastic modulus of 3.6 GPa, which is comparable to cortical bone. Due to its radiolucency, PEEK exhibits less artefacts in magnetic resonance imaging and has a flexural strength of 140–170 Mpa, making it extremely rigid.

Polyetheretherketone, or PEEK, is the most widely used thermoplastic in the PAEK family in dentistry, according to Papathanasiou et al. [19] claimed that PEEK can be utilized in digital prosthodontics. possessing outstanding mechanical qualities, strong wear resistance, X-ray translucency, chemical stability, polish ability, and biocompatibility. PEEK has been reported to be appropriate for many applications including as implant abutments, occlusal splints, intra-radicular posts, interim restorations, and frameworks for both fixed and removable dental prostheses.

D. Dede et al [20] stated that Polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) are high performance polymers of the PAEK family that have been used to fabricate interim implant abutments, overdenture attachments including clasps, bar patrices for removable dental prostheses, and frameworks for fixed dental prostheses (FDPs). They exhibit good dimensional stability, appropriate stress distribution, high chemical resistance, good resistance to wear, high tensile strength, fatigue strength and fracture resistance, as well as high biocompatibility and an elastic modulus like that of bone.

Soldatovic et al., [21] stated that every four units PEEK FDP supported by an implant displayed a fracture load greater than the maximal occlusal forces in the posterior area. The long-term durability of implant-supported four units PEEK FDPs is significantly influenced by the veneering procedure. The long-term viability of bi-layered structures can be increased by choosing the right veneering technique.

Stein, [22] stated that four pontic designs are available: hygienic, ridge lap, modified ridge lap, and ovate pontic, according to research on the pontic residual ridge relationship. To reduce or eliminate contact between the pontic and mucosa, hygienic and modified ridge lap designs were devised. Although these types of prostheses are easily cleaned, their insufficient tissue contact makes them inappropriate for use in aesthetic situations. But even though the ridge lap design can look good enough, maintaining good oral hygiene is made more difficult by its vast concave tissue surface.

Ozgur et al., [23] studied the effect of pontic framework design on the fracture resistance of implant supported all ceramic partial denture and concluded that, If the pontic design is altered, the characteristic stress pattern can be optimized to improve the survival time of implant-supported all-ceramic bridges.

Feldmann et al., [24] stated that rigid foam blocks are considered a viable substitute for human cadaver bone. They also stated that, bone drilling is a crucial stage in many surgical procedures, including pre-drilling for screw placement or external fixator insertion, and bone fracture repair with metallic implants. Therefore, they conducted an experimental investigation to compare the effects of heat on polyurethane bone foam and bovine bone, and they found that the outcomes were nearly same in both cases.

When evaluating the effects of drilling temperature on synthetic polyurethane bone foam, natural bone is not as effective as alternative polyurethane bone foam in overcoming complex, anisotropic biological tissue that contains both organic and inorganic components. [25]

The objective of current study was assessing the effect of pontic design on fracture resistance of implant supported fixed partial denture. The null hypothesis that the pontic design has no effect on fracture resistance.

MATERIAL AND METHODS

The study is conducted to assess the fracture resistance of four units implant supported fixed partial denture replacing missing second premolar and first molar with two different pontic designs, modified ridge lap and sanitary designs and from two different materials, monolithic zirconia (KATANA Zirconia, KURARAY NORITAKE, Japan) and PEEK (breCAM.BioHPP blanks, GmbH & Co.KG). Forty implants (oxy implant, piesse line, Biomec s.r.l., colico LC, Italy) utilized in this study and anchored in polyurethane rigid foam (20 PCF, solid rigid polyure- thane foam, Sawbones, USA).

Preparation of the polyurethane test blocks:

Solid rigid polyurethane test blocks were used as substitute test medium for human bone resembling D2 as this type more common type after tooth loss according to Yamaguchi Y. et al. [25] and Berglundh T. et.al. [26]. Testing model of 2 cm buccolingually, 5 cm in mesiodistally, and 4.5 cm occluso-apically were obtained using an electric saw. (Fig 1)

Implants Installation

The implants installed centered in the polyurethan block with a space between the two implants of 22 mm to accommodate the planned restorations. A pilot key with a diameter of 2 mm was used first and make a pilot hole into the block specimen using a digital torque meter hand piece (800 rpm). Then sequential drilling carried out, using specific keys corresponding to the drills size (2.5; 3.3; 3.5; 3.8) to reach a diameter of 4 mm for implant installation using a digital torque meter hand piece (1000 rpm). The torque adjusted for 35 Ncm, and the ending of the implant insertion was executed manually with the aid of the surgical torque wrench according to the manufacture's recommendations and x-ray was taken for confirmation (Fig 2). each abutment was inserted to its corresponding implant using screwdriver and secured in its position using torque wrench according to the manufacture's recommendations. [35,36]

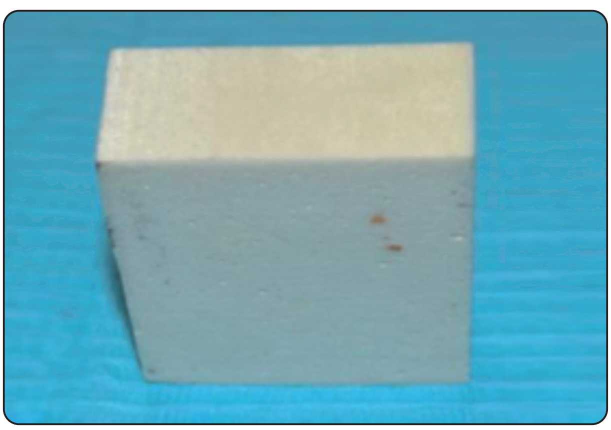

Fig. (1) Polyurethan Block for Implant Drilling.

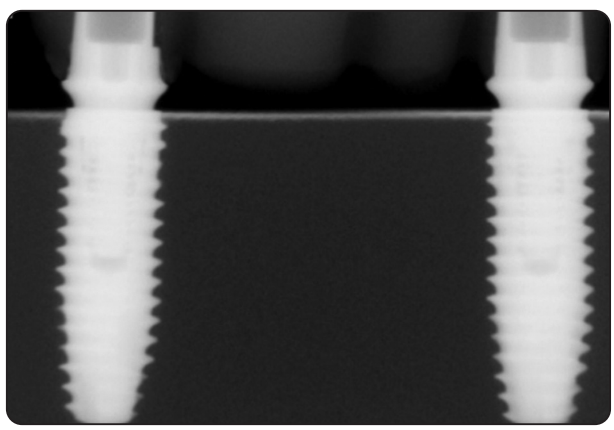

Fig. (2) X-ray of The Implants After Insertion.

Construction of bridge Restorations

Preparing model for optical impression:

To improve the quality of the optical imaging obtained on the in-Lab system, the abutments were coated with optical reflection media spray (Sirona CEREC Opti spray). then fixed to a designated tray so that the scanner (Sirona InEos X5) could take a complete digital picture of the block and implant scan bodies (oxy implant, ODS Cad, Biomec s.r.l., colico LC, Italy).

Acquiring the optical impression:

Along the abutment's long axis, which is perpendicular to the plane of the scanner lens, the optical imaging of the abutment was recorded. The model was scanned from top to bottom from a variety of angles, and the combined results of all these scans were used to create the final image. the impression was captured digitally and later turned into an animated picture for further designing of the final restoration.

Construction of implant bridges:

The final bridges constructed using Cad software system (CEREC inLab Design Software, Dentsply Sirona, Germany) to create the full anatomical FPDs in compliance with the specifications given by the producer of each material, full anatomical FPDs were produced from monolithic zirconia and PEEK. With the help of Exocad, the abutment margins were defined, the insertion axis of the design was corrected for the path of insertion, and the bridges were designed to the following parameters:

The premolar had a mesial-distal width of 8 mm and 10 mm for the molars. The buccal-lingual dimension of the teeth was 8 mm. Simplified occlusal surface and a minimum wall thickness of 1.5 mm. The connector is 16 mm^2 according to the manufacture. To assist the passive fit of the crown over the abutment, luting cement spacing tolerance of 80 microns was achieved. [30]

The pontic was designed into two designs one is modified ridge lap design that is shaped arch-away between the two connectors which surrounds the ridge in the form of a saddle (Fig 3) and the second one was sanitary design with a 2-3 mm gap exists between the tissue surface of the pontic and the polyurethan surface (Fig 4).

Completely shaped bridges were created by incorporating, deleting, and adjusting choices in the CAD part.

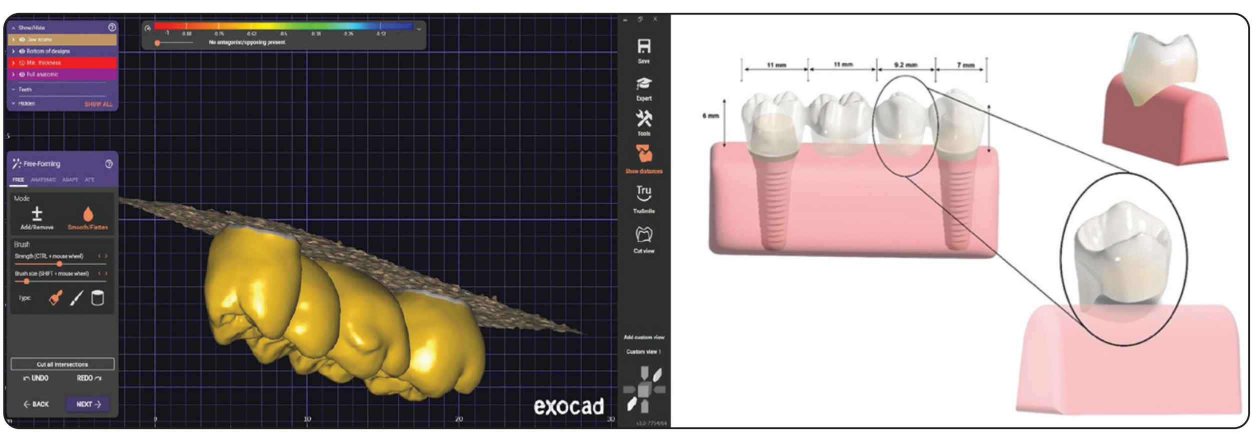

Fig. (3) Illustration of modified ridge lab design.

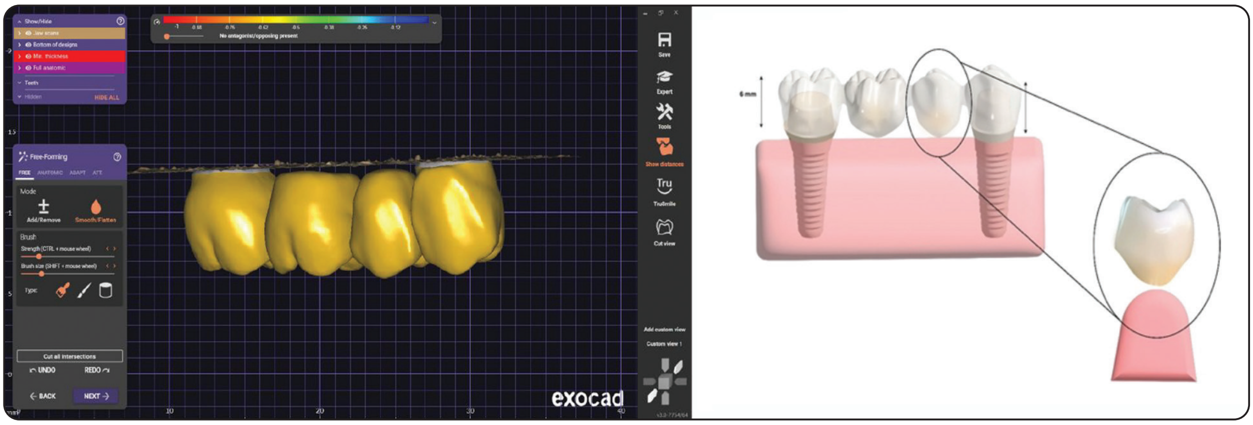

Fig. (4) Illustration of sanitary design.

Cementation of the crowns on their respective abutments:

Before cementation, the bridges were inspected to make sure they fit properly on the matching abutments.

Zirconia bridges internal surface was sand blasted using 30m alumina oxide then rinsed and dried. After that, the internal surface coated with zirconia primer (z-prime- Bisco, Shaumborg, USA) that supports chemical adhesion of cements to the zirconia restorations.

Peek bridges internal surface was sand blasted using 30m alumina oxide then rinsed and dried. After that, the internal surface coated with silane coupling agent (Porcelain Primer Silane Coupling Agent, Bisco, Inc.)

A dual cure resin cement (paracore, coltene, whaledent, altstatten, Switzerland) was used in accordance with the manufacturer's recommendations. In order to prevent elastic rebound and crown dislodgment, each crown was first cemented to its corresponding abutments using finger pressure. After that, the specimens were all subjected to a static loading device that weighed 2.0 kg for five minutes to standardize the thickness of the luting cement. An explorer was used to remove any extra cement.

Testing of the specimens:

All specimens subjected to loading test in a computerized universal testing machine until fracture occurs (Fig 5). A static compressive load was applied vertically to the central fossa with a crosshead speed of 1 mm/min. A 0.5-mm-thick tin foil was used to equalize the stress distribution. [31] The fracture resistance records had been determined and statistically analyzed.

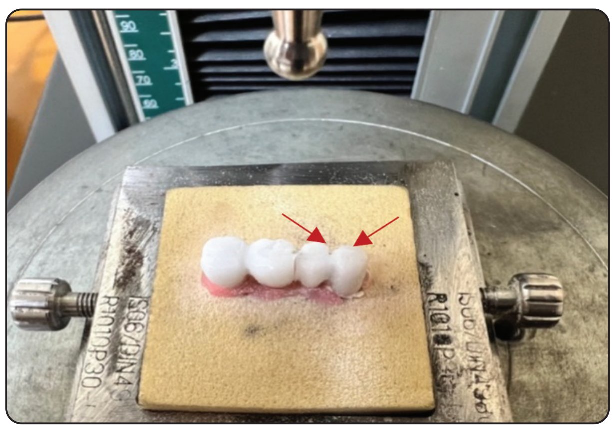

Fig (5) Illustration of The Fracture after loading.

RESULTS

All pontic designs with the two different material monolithic zirconia and PEEK are subjected to fracture resistance test utilizing a universal testing machine, with all fracture data collected and statistically analyzed.

From the data collected from testing and statistical analysis all designs and material are fall within the acceptable range of fracture resistance, with minor variations in strength as zirconia as a material showed a superior result over PEEK material.

From the statistical results there is no significant difference between the modified ridge lap design and sanitary design in zirconia group, showed in table (1) and no significant difference between the two designs in the PEEK group as P ^{3} 0.05, showed in table (2).

TABLE (1) Comparison between different designs in zirconia group.

	M.R.L	Sanitary	ANOVA	P value
Zirconia				
Range	1423.9-1426.2	1422.0-1425.7	1.05	0.6525
Mean	1424.9	1424.0		N.S.
SD	0.8	1.3		

P was significant if ≤ 0.05 ***N.S. = Not significant***

TABLE (2) Comparison between different designs in PEEK group.

	M.R.L	Sanitary	ANOVA	P value
PEEK				
Range	1195.0-1197.0	1187.9-1193.7	12.59	0.980
Mean	1195.8	1190.5		N.S.
SD	0.6	2.1		

P was significant if ≤ 0.05 ***N.S. = Not significant***

From the statistical results there is significant difference between the zirconia sanitary design group and PEEK sanitary design group as zirconia crowns showed a higher strength, P £0.05 as zirconia crowns showed a higher strength upon test (mean=1424±1.3) while PEEK (mean=1190.5±2.1). showed in table (1) figure (6).

TABLE (3) Comparison between zirconium group and PEEK group in sanitary design.

	Zirconia	PEEK	t-test	P value
Sanitary				
Range	1422.0-1425.7	1187.9-1193.7	12.59	0.001*
Mean	1424.0	1190.5		
SD	1.3	2.1		

P was significant if ≤ 0.05 ***N.S. = Not significant***

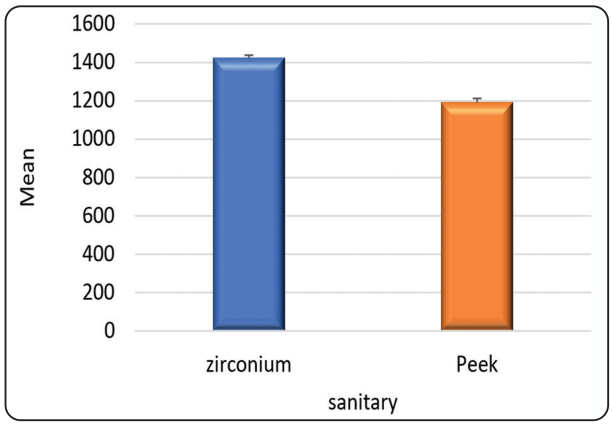

Fig. (6) Comparison between zirconium group and PEEK group in sanitary design.

From the statistical results there is significant difference between the zirconia modified ridge lap design group and PEEK modified ridge lap design group P £0.05 as zirconia crowns showed a higher strength upon test (mean=1424.9±0.8) while PEEK (mean=1195.89±0.6) showed in table (2) figure (7).

TABLE (4) Comparison between zirconium and Peek group in modified ridge lap design.

	Zirconium	PEEK	t-test	P value
M.R.L				
Range	1423.9-1426.2	1195.0-1197.0	12.60	0.001*
Mean	1424.9	1195.8		
SD	0.8	0.6		

P was significant if ≤ 0.05 **** = significant difference***

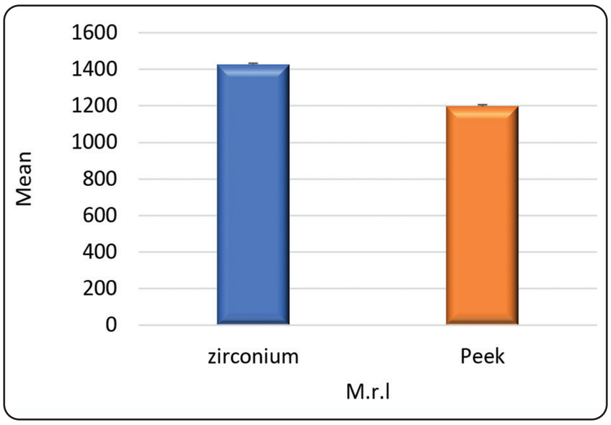

Fig. (7) Comparison between zirconium and Peek group in modified ridge lap design.

DISCUSSION

Zirconia and PEEK are considered alternative materials of metal porcelain in the construction of implant supported fixed prosthesis. This in vitro study evaluated the effect of change in pontic design on fracture resistance of long span posterior bridge supported by two implants, fabricated from two different materials, monolithic zirconium and PEEK.

With the advent of CAD/CAM technology and increased demand for metal-free prostheses, yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) has been used as an alternative to metal in dental treatments [(31)].

Zirconia's hardness can reach levels of approximately 10 MPa•m¬, more than twice as high as high-density alumina, despite never reaching the level of metals there for use of zirconia allows framework masking and presents a similar survival rate to metal. [(17)] While a metal framework presents an elastic modulus that ranges between 100 and 200 GPa, PEEK presents approximately 4 GPa [(32)].

The present study showed that the material type also influences fracture resistance (P<.05).

From the results in this study the mean fracture resistance for the PEEK group showed lower resistance than Zirconia group as shown in tables 3 and 4, but all larger than normal human bite, human bite forces range between (285.0 and 462.3 N) for men, and (253.9 - 445.8 N) for women as mentioned in Marini et al., [(24)], stimmelmayr et al., [(33)] Takaki et al., [(34)] and Gehrke et al., [(35)] It also showed that there is no significant difference between the two designs fabricated from the same material as shown in table 1 and 2 as P ³ 0.05.

In this study monolithic zirconia showed higher fracture resistance than PEEK where modified ridge lap (mean=1424.9±0.8) and PEEK (mean=1195.89±0.6). The sanitary design in monolithic zirconia (mean=1424±1.3) and PEEK (mean=1190.5±2.1).

The present study revealed that the shape of pontic has no significant influence the clinical performance of a restoration while tha material used have a great influence on fracture resistance and that was against Inan et al., [(22)] Tsumita et al., [(35)] and Kokubo, et al., [(36)] whom reported that pontic design have a great influence on fracture resistance of the restoration despite of the restorative material.

Although the restorative material could play an important role in the mechanical behavior of implant-supported prostheses, other factors in addition to the fracture resistance could be occlusion, occlusal force, abutment angulation, restorative configuration, implant splinting, and implant-abutment connection type should be considered in selecting and evaluating restorative systems. [(35)]

The fractures evolving the connector basis (region of tensile stress) and the occlusal surface in contact with the load application (region of compressive stress) as declared by DeHoff et al.,[(37)]. This pattern is in agreement with previous studies Amelya et al., 2019 [(38)], Onodera et al., 2011[(39)] and points out for the relevance of the connector characteristic on the resistance of this type of prosthesis. Considering fracture origin, the literature traditionally shows that crack starts and propagate at the lower part of connector (region of tensile stress concentration) for fixed all-ceramic bridges as mentioned by Amelya et al., [(38)], Onodera et al., [(39)], Luft et al., [(40)].

CONCLUSIONS

Under the limitations of this study, several conclusions could be detected:

1. Zirconia and PEEK are material of choice when planning for long span bridges for their high fracture strength values.
2. The restorative material used have influence on fracture resistance and behavior of the material to function under masticatory forces with a little effect when changing in pontic designs.
3. The fracture resistance of the zirconia group was significantly greater than that of the PEEK group.

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