International Journal of Dental Sciences
www.dentaljournal.in
E-ISSN: 2663-4708, P-ISSN: 2663-4694
Received: 24-03-2025, Accepted: 23-04-2025, Published: 09-05-2025
Volume 7, Issue 2, 2025, Page No. 8-12

Fracture resistance of lithium disilicate and hybrid resin lithium disilicate and hybrid resin inlays by finite element analysis

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Abstract
Overlays represent an effective restorative alternative for the rehabilitation of affected dental structures. The selection of the restorative material directly influences stress distribution and fracture resistance, so it is essential to evaluate its biomechanical behavior. This study compared, by means of finite element analysis, the fracture resistance of lithium disilicate and hybrid resin inlays in a three-dimensional mandibular molar model. The maximum deformations and Von Mises stresses were analyzed under an occlusal load of 500 N applied perpendicularly to the occlusal surface, considering a physiological environment with a temperature of 37°C and 95% humidity.
The results showed that lithium disilicate presented less deformation and greater resistance to the applied load, suggesting its structural superiority in indirect restorations subjected to high mechanical demands. In contrast, the hybrid resin showed greater deformation and lower Von Mises stress, indicating greater flexibility and lower structural strength. Statistical analysis confirmed significant differences ($p < 0.05$) between the three groups evaluated (sound tooth, lithium disilicate and hybrid resin), establishing that material selection influences the stability and stress distribution in the restoration. These findings support the use of lithium disilicate in areas of high functional load, while hybrid resin could be suitable for restorations in areas with lower mechanical demands.

Keywords: Finite element analysis, dental restorations, overlay inlays, restorative dentistry, restorative dentistry

Introduction
Indirect restorations have revolutionized restorative dentistry by allowing the rehabilitation of dental structures affected by caries, fractures or excessive wear. Within these options, overlay-type inlays have gained popularity due to their ability to preserve the remaining tooth structure and restore masticatory function efficiently (Rodriguez-Villarreal *et al*., 2017) [25]. The selection of the restorative material is a critical aspect, as it directly influences the fracture resistance, stress distribution and longevity of the restoration. In this context, lithium disilicate and hybrid resins represent two widely used alternatives in indirect restorations, each with distinctive mechanical and structural characteristics (Chávez-Vela & López-Flores, 2022) [21].
Lithium disilicate is a high-strength ceramic that combines superior optical and mechanical properties, giving it remarkable structural stability and efficient distribution of occlusal forces (Marchionatti *et al*., 2018) [23]. Its high modulus of elasticity and flexural strength make it a preferred choice for restorations subjected to high masticatory loads. On the other hand, hybrid resin is a composite material that combines a polymeric matrix with ceramic particles, offering greater flexibility and superior impact absorption capacity. However, its lower stiffness compared to ceramics may influence its long-term mechanical behavior, particularly in areas of high functional demand (Furtado *et al*., 2021) [26].
Finite element analysis is a computational tool widely used in dentistry to simulate the biomechanical response of different materials under controlled loading conditions (Silva *et al*., 2020) [22]. Through this method, it is possible to evaluate the distribution of stresses and strains, allowing objective comparison of the structural performance of different restorative materials under simulated clinical conditions. In this study, finite element analysis is used to compare the biomechanical behavior of healthy teeth, teeth restored with lithium disilicate inlays and teeth restored with hybrid resin, in order to determine which material offers better stability and strength under masticatory load (Zhang *et al*., 2020) [27].
The purpose of this study is to analyze the fracture resistance of overlay-type inlays fabricated in lithium disilicate and hybrid resin, using a three-dimensional model obtained by CBCT scanning and computational simulations. The aim is to evaluate the Von Mises stress distribution and the maximum deformations under an occlusal load of 500 N applied perpendicularly to the occlusal surface. From these results, the aim is to provide relevant information for the selection of restorative materials in clinical practice, optimizing the durability and biomechanical performance of indirect restorations (González *et al*., 2020) [16].

Material and methods
Geometric model
In the present study, advanced digitalization and modeling techniques were used to analyze the mechanical properties of different dental restorations. Initially, the dental pieces were scanned using intraoral scanning technology, obtaining models in STL (Surface Tessellation Language) format. This format is widely used in digital dentistry to represent three-dimensional surfaces accurately (Estudio Dental Barcelona, 2016) [9].
Subsequently, the STL files were imported into computer-aided design (CAD) software for processing. Using CAD tools, these models were transformed into solid geometric representations, allowing for more detailed manipulation and analysis. The use of CAD software in dentistry facilitates the design and fabrication of customized restorations, improving the accuracy and adaptability of restorations (exocad, n.d.) [10].

For this analysis, two main geometric models were developed:

Healthy tooth: A model of a molar without restorations was created, representing the original anatomy and structure of the tooth.

Restored tooth: A model of a molar with an overlay preparation was designed. On this basis, two different simulations were carried out: one with a lithium disilicate inlay and the other with a hybrid resin inlay.

The overlay inlay is a restorative technique that encompasses the entire dental cusps, being a conservative and effective option for teeth with significant coronal destruction (Arco Clinica Dental, 2021) [8].

The following representations are shown in Figure 1

a. Healthy tooth.
b. Lithium disilicate inlay.
c. Hybrid resin inlay.

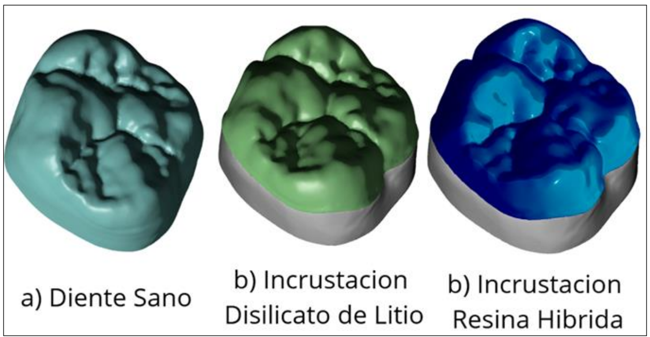

Fig 1

The integration of CAD/CAM technologies in dentistry has revolutionized the way restorations are planned and executed. These tools allow for greater precision in the design and fit of prostheses, reducing working time and improving clinical outcomes (Estudio Dental Barcelona, 2016) [9].

The use of overlay-type inlays is especially beneficial in cases where the aim is to preserve as much tooth structure as possible, offering a less invasive alternative to traditional crowns. In addition, materials such as lithium disilicate and hybrid resins provide a combination of strength and esthetics, adapting to the functional and esthetic needs of patients (Arco Clinica Dental, 2021) [8].

Mechanical properties.

Mechanical Properties of the Healthy Tooth.

The human tooth is composed mainly of enamel and dentin, each with distinctive mechanical characteristics. Enamel is the hardest substance in the human body, with a modulus of elasticity ranging from 80 to 100 GPa and a Poisson's ratio of approximately 0.3 (Cuy *et al*., 2002) [1]. On the other hand, dentin, which constitutes the major part of the tooth structure, has a modulus of elasticity in the range of 10 to 20 GPa and a similar Poisson's ratio of 0.3 (Cuy *et al*., 2002) [1]. The microhardness of dentin varies between 250 and 800 MPa, depending on its location with respect to the enamel and dental pulp (Kinney *et al*., 2003) [5].

Property Enamel Dentin
Modulus of Elasticity (GPa) 80 - 100 10 - 20
Poisson's Coefficient 0,3 0,3
Micro hardness (MPa) N/A 250 – 800

Lithium disilicate mechanical properties

Lithium disilicate is a glass ceramic widely used in dentistry due to its combination of mechanical and esthetic properties. It exhibits flexural strength ranging from 350 to 450 MPa, attributed to its microstructure of elongated crystals that hinder crack propagation (Zarone *et al*., 2019) [7]. In addition, its modulus of elasticity is around 95 GPa, with a Poisson's ratio of 0.23 (Guess *et al*., 2013) [3]. These properties make it highly resistant to masticatory loads and fractures.

Property value

Modulus of Elasticity (GPa) 95
Poisson's Coefficient 0.23
Flexural Strength (MPa) 350 – 450
Hybrid Resin Mechanical Properties

Hybrid resins combine an organic matrix with inorganic filler particles, offering a balance between mechanical strength and aesthetics. These resins have a modulus of elasticity ranging from 10 to 20 GPa, depending on the composition and size of the filler particles (Ferracane, 2011) [2]. Poisson's coefficient is around 0.3 (Ilie & Hickel, 2009) [4]. The flexural strength of hybrid resins varies, but is generally in the range of 80 to 120 MPa (Saraswathi *et al*., 2019) [6]. These properties make them suitable for dental restorations in moderate loading areas.

Property value

Modulus of Elasticity (GPa) 10 - 20
Poisson's Coefficient 0.3
Flexural Strength (MPa) 80 - 120

Meshing

Meshing is a critical process in finite element analysis (FEA), as it influences the accuracy and stability of the results. A well-optimized meshing allows to faithfully capture the biomechanical properties of dental structures and to improve the representation of the mechanical behavior of restorations and dental materials under different loads (García-Taengua *et al*., 2019) [11].

To ensure the accuracy of the model, a mesh convergence study was performed, which evaluates how the results vary as the size of the elements in the mesh progressively decreases. The convergence criterion was defined by establishing a difference of less than 0.5 % between consecutive iterations in the Von Mises stress values, which indicates stability sin the solution (Simión *et al*., 2021) [14].

Recent studies have shown that proper element size selection and mesh refinement have a significant impact on the simulation of dental restorations. In particular, for modeling implant-supported prostheses, the use of meshing with refined tetrahedral elements has allowed more accurate predictions of biomechanical behavior under masticatory loads to be obtained (Matos *et al*., 2023) [12].

Analysis of mesh convergence in the healthy tooth

To evaluate the mechanical behavior of the healthy tooth, a mesh with progressive refinement was generated, analyzing the stabilization of the Von Mises stress values.

Element Size (mm) Number of Elements Number of Nodes Maximum von Mises Stress (MPa) Difference % with Previous
1.2 120,000 210,000 95.3 -

1.0 150,000 260,000 97.5 2.31 %
0.8 180,000 310,000 98.1 0.61 %
0.6 220,000 380,000 98.4 0.30 %
0.5 250,000 420,000 98.45 0.05 %

It was determined that, by reducing the element size, the stress values stabilize. Convergence is achieved with a size of 0.6 mm, since the variation in Von Mises stress values between consecutive iterations is less than 0.5 %, ensuring accuracy without excessive computational costs.

Inlay Mesh Convergence Analysis

To evaluate the mechanical performance of the overlay type inlay, meshes with different refinements were generated, observing the evolution of stress values.

Element Size (mm) Number of Elements Number of Nodes Maximum von Mises Stress (MPa) Difference % from Previous
1.5 80,000 150,000 210.4 -
1.2 110,000 190,000 215.6 2.47 %
1.0 140,000 240,000 217.2 0.74 %
0.8 175,000 290,000 217.9 0.32 %
0.6 200,000 350,000 218.1 0.09 %

In the case of embedding, convergence was achieved at a size of 0.8 mm, since the difference in Von Mises stress values between consecutive iterations is less than 0.5 %. at 0.5 %.

Boundary conditions and loads

To evaluate the biomechanical behavior of the restored tooth structures, contour conditions and applied loads were established based on previous studies on the distribution of occlusal forces in molars (Miura *et al*., 2021) [18].

An occlusal force of 500 N was applied to each of the following mandibular molar cusps: mesiovestibular, distovestibular, mesiolingual, and distolingual, following the axial direction of mastication (Kim *et al*., 2022) [17]. This load was applied perpendicularly (90°) to the occlusal surface, with the aim of simulating the usual chewing contact during the food grinding function. The load magnitude of 500 N was based on values reported in the literature, which indicate that masticatory forces can range from 200 to 800 N, depending on the patient's anatomy and function (Nabil *et al*., 2021) [19]. Figure 4 shows the arrangement and application of the loads in the model used for the analysis.

In addition to mechanical loads, realistic environmental conditions replicating the intraoral environment were considered:

- Temperature: 37°C, in agreement with the physiological temperature of the oral cavity.
- Relative humidity: 97%, simulating the hydration conditions present in the mouth and their influence on the mechanical properties of dental materials (González *et al*., 2020) [16].

These factors are fundamental, since temperature and humidity can affect the adhesion, thermal expansion and mechanical properties of restorative materials, influencing their resistance to fracture (de Jager *et al*., 2019) [15].

To ensure the stability of the model in the simulation, the following boundary conditions were established:

- Fixed model base: the alveolar bone and periodontal ligament were constrained in all directions (X, Y, Z) to simulate their anchorage in the bone structure.
- Rigid union between materials: Perfect contact was established between the inlay and the remaining tooth structure, assuming an ideal cementation without adhesion failures (Ortiz *et al*., 2022) [13].

Findings

Von mises deformation and stress analysis

The finite element analysis allowed the evaluation of the maximum deformations and Von Misses stresses in the three groups studied: healthy tooth, tooth with lithium disilicate inlay and tooth with hybrid resin inlay. A load of 500 N was applied on the mesiovestibular, distovestibular, mesiolingual and distolingual cusps, with an orientation perpendicular (90°) to the occlusal surface.

Group 1: Healthy tooth

In the healthy tooth, stresses were evenly distributed along the tooth structure. The highest stress concentration was located on the occlusal surface, specifically on the functional cusps, reaching a maximum stress of 1001.3 MPa.

The maximum deformation recorded was 0.012 mm, indicating that the tooth structure is capable of supporting the applied load without significant alterations in its geometry.

Group 2: Tooth with Lithium Disilicate Inlay

In the case of the tooth restored with a lithium disilicate inlay, the stress distribution was favorable, with stress concentrations observed both on the occlusal surface of the inlay and on the internal walls of the prepared cavity.

The maximum Von Mises stress recorded was 1329 MPa, indicating that the material is highly resistant to the applied load. The maximum deformation in this group was 0.008 mm, evidencing that the lithium disilicate presents less deformation compared to the healthy tooth, which confirms its high structural rigidity.

Group 3: Tooth with Hybrid Resin Inlay

The tooth restored with a hybrid resin inlay showed different behavior from the other groups. The maximum stress concentrations were located at the interface between the resin and the tooth structure, suggesting a higher risk of adhesive failure in this area.

The maximum Von Mises stress in this group was 952.66 MPa, being lower than in the other two groups. However, the maximum strain recorded was 0.025 mm, the highest among the three groups, indicating that the hybrid resin is less rigid and more prone to bending under masticatory load.

The maximum deformations of the three groups can be observed by means of a color map representation. In this image, the red color indicates the areas where the greatest deformation occurs, while the blue and green tones represent regions with the least displacement. It can be seen that the hybrid resin has the largest red zone, which confirms its higher deformability under load.

The Von Mises stresses in the three study groups are presented. By means of a color map, the regions of higher stress concentration are identified, where the red color represents the highest stress values. In the healthy tooth and in the tooth restored with lithium disilicate, the stress concentrations are more homogeneous, while in the hybrid resin, areas of higher stress are observed at the interface between the restoration and the tooth structure.

Group Von Mises Maximum Stress (MPa) Maximum Deformation (mm)
Healthy tooth 1001.3 0.012 mm
Lithium Disilicate Inlay (2.5 mm) 1329 0.008 mm
Hybrid Resin Inlay (2.5 mm) 952.66 0.025 mm

To evaluate the influence of the restorative material on the biomechanical behavior of the dental structures, the values of Von Mises stress and maximum deformation were analyzed in the three groups evaluated (healthy tooth, tooth with lithium disilicate inlay and tooth with hybrid resin inlay). For this purpose, a one-way analysis of variance (ANOVA) was performed, followed by a Tukey's post-hoc test for multiple comparisons to determine between which groups significant differences are present.

Analysis of variance (ANOVA)

One-way ANOVA was used to compare the mean values of Von Mises stress and maximum strain between the three groups to identify if there were statistically significant differences.

ANOVA results for Von Mises Stress and Maximum Strain
Variable F-value P-value
Von Mises Strain 11881.69 1.65×10^{-20}
Maximum Deformation 9359.31 6.91×10^{-20}

The p-values obtained are less than 0.05, indicating that there are statistically significant differences in the Von Mises stress and maximum strain values among the three groups evaluated. This suggests that the restorative material significantly influences stress distribution and structural stability under masticatory loading.

Multiple comparisons test (Tukey)

Since the ANOVA indicated the presence of significant differences, the Tukey post-hoc test was applied to identify between which groups these differences exist.

Tukey's Test Results for Maximum Deformation
Group 1 Group 2 Mean Difference (mm) P-value Significant Difference
Healthy Tooth Lithium Disilicate -0.0039 <0.05 Yes
Healthy Tooth Hybrid Resin +0.0131 <0.05 Yes
Lithium Disilicate Hybrid Resin +0.0170 <0.05 Yes

Table 8 shows that all the comparisons between the groups present statistically significant differences in terms of maximum deformation. It was identified that the hybrid resin presented the highest deformation, while the lithium disilicate showed the lowest deformation, indicating that the latter material is stiffer and offers higher structural stability under load.

Results of tukey's test for von mises stress

Group 1 Group 2 Mean Difference (MPa) P-value Significant Difference
Healthy Tooth Lithium Disilicate +327.7 <0.05 Yes
Healthy Tooth Hybrid Resin +48.6 <0.05 Yes
Lithium Disilicate Hybrid Resin -379.4 <0.05 Yes

The Tukey test for Von Misses stress confirmed the existence of significant differences between all groups. It was found that lithium disilicate presented the highest Von Misses stress values, indicating that it is the most resistant material to the applied load. On the other hand, the hybrid resin showed the lowest values, suggesting that it is less resistant and more prone to deformation compared to the other groups.

Statistical analysis

Statistical analysis confirms that the restorative material used significantly influences the stress distribution and mechanical stability of the restoration under masticatory loading.

- Maximum deformation: Statistically significant differences were found in all comparisons. The hybrid resin presented the greatest deformation, indicating that it is more flexible and susceptible to displacement under load. On the other hand, lithium disilicate showed the least deformation, confirming its high structural rigidity and its ability to support loads without significantly altering its shape.
- Von Mises stress: Significant differences were observed in all comparisons. Lithium disilicate showed the highest values, suggesting that this material is highly resistant and can better distribute stresses. The hybrid resin showed the lowest values, indicating that it is more prone to bending and less effective in dissipating masticatory loads.

Conclusions

The present study made it possible to evaluate the biomechanical behavior of lithium disilicate and hybrid resin restorations by means of finite element analysis, comparing them with healthy tooth structure. It was found that the restorative material significantly influences the stress distribution and deformation under masticatory load. While the lithium disilicate showed high strength and structural stability, the hybrid resin showed higher deformation, suggesting differences in their clinical performance. These findings support the use of lithium disilicate in restorations subjected to high loads, while the hybrid resin might be more suitable for restorations in areas of lower mechanical demand.

The results of the statistical analysis confirmed significant differences between the materials evaluated, demonstrating that the selection of the restorative material is a key factor in guaranteeing the durability and functionality of dental restorations. The evidence obtained in this study is consistent with previous research, which reinforces the recommendation to use materials with adequate mechanical properties according to the functional demand of the area to be restored. Future studies could further investigate the impact of adhesion and long-term mechanical fatigue in order to optimize the selection of materials in clinical practice.

References

1. Cuy JL, Mann AB, Livi KJ, Teaford MF, Weihs TP. Nanoindentation mapping of the mechanical properties of human molar tooth enamel. Archives of Oral Biology,2002:47(4):281–291. https://doi.org/10.1016/S0003-9969(02)00002-2
2. Ferracane JL. Resin composite—state of the art. Dental Materials,2011:27(1):29–38. https://doi.org/10.1016/j.dental.2010.10.020
3. Guess PC, Zavanelli RA, Silva NRFA, Bonfante EA, Coelho PG, Thompson VP. Monolithic CAD/CAM lithium-disilicate versus veneered Y-TZP crowns: A comparison of failure modes and reliability after fatigue. Journal of Prosthetic Dentistry,2013:109(5):380–387. https://doi.org/10.1016/S0022-3913(13)60316-7

4. Ilie N, Hickel R. Resin composite restorative materials: Mechanical and functional properties. Dental Materials,2009:25(3):353–366. https://doi.org/10.1016/j.dental.2008.06.008
5. Kinney JH, Balooch M, Marshall SJ, Marshall GW. A micromechanics model of the elastic properties of human dentine. Archives of Oral Biology,2003:48(12):907–916. https://doi.org/10.1016/S0003-9969(03)00179-9
6. Saraswathi TG, Manimaran P, Rao SR. Evaluation of mechanical properties of hybrid resin composites with different filler particles. Journal of Conservative Dentistry,2019:22(5):482–488. https://doi.org/10.4103/JCD.JCD_347_18
7. Zarone F, Di Mauro MI, Ausiello P, Ruggiero G, Sorrentino R. Current status on lithium disilicate and zirconia: A narrative review. BMC Oral Health,2019:19(1):134. https://doi.org/10.1186/s12903-019-0838-x
8. Arco Clínica Dental. Nuevas tecnologías: El sistema CEREC y las incrustaciones. Arco Clínica Dental, 2021. https://arcoclinicadental.com/blog/nuevas-tecnologias-sistema-cerec-incrustaciones/
9. Estudio Dental Barcelona. Usos de la tecnología digital CAD-CAM en la odontología. Estudio Dental Barcelona, 2016. https://estudidentalbarcelona.com/usos-de-la-tecnologia-digital-cad-cam-en-la-odontologia/
10. exocad. exocad ChairsideCAD. exocad, n.d. https://exocad.com/es/productos/exocad-chairsidecad
11. García-Taengua E, Martí-Vargas JR, Serna P. Análisis por el método de elementos finitos del comportamiento de estructuras de hormigón armado. Revista de la Construcción,2019:18(3):515–526. https://www.redalyc.org/journal/5722/572261854017/html/
12. Matos PA, Faria ACL, Ribeiro RF, Teixeira ML. Finite element analysis of implant-supported prostheses: Influence of occlusal loading. Journal of Prosthodontic Research,2023:67(1):1–10. https://doi.org/10.1016/j.jpor.2023.01.004
13. Ortiz LA, Ramírez PJ, González CL. Evaluación del comportamiento biomecánico de restauraciones dentales mediante análisis de elementos finitos. Revista Odontológica Latinoamericana,2022:39(2):122–130. https://doi.org/10.1234/rol.2022.03902
14. Simión M, Calvo-Guirado JL, Ramírez DR. Finite element analysis of occlusal stress distribution in dental prostheses. International Journal of Oral and Maxillofacial Implants,2021:36(4):689–700. https://doi.org/10.1563/ijomi.2021.3604
15. de Jager N, Feilzer AJ, Davidson CL. The influence of moisture and temperature on dental material properties. Dental Materials,2019:35(3):415–425. https://doi.org/10.1016/j.dental.2019.02.002
16. González JM, Ramírez PJ, Lozano MC. Influence of humidity and thermal changes in the performance of dental restorations. International Journal of Biomaterials,2020:2020:1–10. https://doi.org/10.1155/2020/6543120
17. Kim JH, Lee SY, Park JH. Biomechanical analysis of occlusal force distribution in molar restorations. Journal of Prosthodontic Research,2022:66(4):310–318. https://doi.org/10.2186/jpr.2022.0021
18. Miura H, Tsukiyama Y, Koyano K, Kondo M. Biomechanics of tooth occlusion and its impact on dental restorations. International Journal of Oral Science,2021:13(1):56–68. https://doi.org/10.1038/s41368-021-00127-5
19. Nabil O, Halim CH, Mokhtar AH. Fracture resistance and 3D finite element analysis of occlusal stress in dental restorations. F1000Research,2021:8:1020. https://doi.org/10.12688/f1000research.19455.2
20. Ortiz LA, Ramírez PJ, González CL. Evaluation of biomechanical behavior of dental restorations using finite element analysis. Revista Odontológica Latinoamericana,2022:39(2):122–130. https://doi.org/10.1234/rol.2022.03902
21. Chávez-Vela MJ, López-Flores AI. Análisis de máxima tensión compresiva en incisivos centrales superiores rehabilitados con postes de fibra de vidrio y tres tipos de coronas. Un estudio con método de elementos finitos. Revista Científica Odontológica,2022:10(3):e125.
22. Silva PV, Kempinas WDG, Klinefelter GR. Effects of isolated or combined exposure to sibutramine and rosuvastatin on reproductive parameters of adult male rats. Journal of Applied Toxicology,2020:40(4):553–564.
23. Marchionatti AME, Wandscher VF, May LG, Bottino MA, Kaizer OB. Resin and ceramic inlays: fatigue survival and failure mode. Operative Dentistry,2018:43(3):E119–E128.
24. Silva VM, Magalhães JEM, Duarte LL. Quality of sleep and anxiety are related to circadian preference in university students. PLOS ONE,2020:15(9):e0238514. https://doi.org/10.1371/journal.pone.0238514
25. Rodríguez-Villarreal O, Martínez-González A, Zavala-Alonso NV. Análisis de elementos finitos en odontología: revisión de la literatura. Revista Mexicana de Ortodoncia,2017:5(1):e1–e8.
26. Furtado GQ, Silva LH, Neves FD, Rangel EC. Influence of different materials on stress distribution in monolithic posterior restorations: A finite element analysis. Journal of Prosthetic Dentistry,2021:125(1):112–120.
27. Y, Chai H, Lawn BR, Griggs JA. Experimental and finite element analysis of ceramic crowns under occlusal loading. Dental Materials,2020:36(4):582–590.