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Comparison of fracture resistance for CAD/CAM overlay restorations made of different ceramic materials and designs

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Aim: To evaluate the fracture resistance and failure mode of complete crown and different designs of overlay restorations fabricated from different CAD/CAM ceramic materials. **Methods:** Ninety upper premolars were randomly divided into nine groups (n=10/group) according to ceramic material and restoration design into: **LD4**: Lithium disilicate overlay with margin located 4millimeter (mm) above the Cementoenamel junction (CEJ). **LD2**: Lithium disilicate overlay with margin located 2mm above the CEJ. **LD-F:** Lithium disilicate crown. **ZLS4**: Zirconia-reinforced lithium silicate overlay with margin located 4mm above the CEJ. **ZLS2:** Zirconia-reinforced lithium silicate overlay with margin located 4mm above the CEJ. **ZLS-F**: Zirconia-reinforced lithium silicate crown. **HC4**: Hybrid ceramic overlay with margin located 4mm above the CEJ. **HC2**: Hybrid ceramic overlay with margin located 2mm above the CEJ. **HC-F**: Hybrid ceramic crown. The ceramic restorations were fabricated according to the manufacturer instruction and cemented to the prepared tooth surfaces. Universal testing machine was used to evaluate the fracture resistance at cross head speed of1mm/min until failure. The obtained results were statistically analyzed using One-way ANOVA test at 0.05 level of significance and failure mode were evaluated. **Results:** There was a significant difference (p=0.00) between the restoration designs of the same ceramic material, with a higher fracture resistance for the overlay restoration design with 4mm above the CEJ. Also, there was a significant difference (p=0.00) between the restoration materials with the same restoration design. The failure mode was mainly of type III. **Conclusion:** Minimal invasive restorations like overlay restorations can be used as an alternative for the full crown restorations. Keeping the finish line coronary as possible during indirect restoration preparation increases the fracture resistance of the tooth. The Type III fracture of the tested samples can probably be attributed to the high modulus of elasticity of the used materials.

Keywords: Denture, overlay. Ceramics. Flexural strength.

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Introduction

Nowadays, minimally invasive dentistry has participated in a significant part of modern restorative dentistry. The advancement and development of adhesive techniques, materials, ceramics with higher strength and new CAD/CAM techniques[1] has changed the interest from traditional, mechanical retained restorations to a conservative, biomimetic, biological and adhesive type[2], additionally, extending the applications and indications of tooth-colored partial coverage prosthesis. These indirect restorations that may be divided into inlays (cusps are not covered), only 1 cusp is covered) and overlays (all cusps are covered) are invented to permit maximal preservation of natural dental structure by preparing the finish line as supragingivally as possible in comparison with the traditional, more destructive full coverage restorations[3,4].

Partial and full coverage crown prosthesis can be used for the treatment of erosion, tooth wear, occlusal abrasion, cracked tooth syndrome, noncarious misaligned teeth[4], and for restoring the vertical dimension[2].The full coverage crowns are the conventional treatment means for oral rehabilitation. However, by using this treatment means, additional removal of dental structures that have already been weakened by abrasion, wear and other intrinsic factors is required. Therefore, novel restoration designs have been introduced in the branch of conservative dentistry such as overlays. These partial coverage restorations are considered a proper treatment option in such clinical cases[4].

These novel restorations have become a standard treatment option for minimal coronal destruction in posterior teeth. According to the location of the finish line of the tooth preparation, the overlay preparations vary in its designs that tend to be kept supragingivally as possible so to conserve more dental structure[1].

Throughout the last four decades, the technology of computer-aided design and computer-aided manufacturing (CAD-CAM) has played an extending role in general dentistry, allowing the restorations to be designed and fabricated by mechanized, computer-assisted technologies. As this technology has gained a lot of popularity, recent materials have been invented to be used for milling restorations using CAD-CAM processing devices[5].

With CAD/CAM technology in dentistry, the reality of producing CAD/CAM high strength ceramic restorations has become true and its use in dental clinics has become more popular[4].

One of the factors that increases the longevity of a conservative restoration is its proper fracture resistance[6]. Therefore, when taking into account the long-term viability of a dental material for producing restorations, it is important to check its fracture resistance[5]. In addition, various materials have different physical and structural properties and, consequently, do not react similarly to occlusal stresses, forces and thermal changes[7].

Unfortunately, there is little research available evaluating the fracture resistance of different overlay restoration designs with margins located in different coronal positions relative to the gingival level and additionally fabricated from different CAD/CAM ceramic materials. Therefore, the aim of this study was to evaluate the fracture resistance of complete crown and two different designs of overlay restorations with margins located 2 and 4 mm above the gingival level and fabricated from three different CAD/CAM ceramic materials. The first null hypotheses were that the restoration designs with different locations of finish line level will resist similar fracture load. The second hypothesis was that different CAD/CAM ceramic materials would provide the same fracture resistance for each restoration design.

Materials and Methods

Specimens preparation

The study was approved by the "Research Ethics Committee of Mosul University/ College of Dentistry under record reference numbers (UoM.Dent. 23/8). Ninety human maxillary premolars of the same size that had been extracted for periodontal or orthodontic purposes were used. The buccopalatal and mesiodistal dimensions of each tooth were measured by a digital caliper. For the purpose of standardization of tooth dimensions, 0.5 mm difference was considered acceptable for each measurement[6].

The teeth were checked under x10 magnification in the absence of any defect, caries or restoration. Then they were cleaned utilizing a hand scaler to remove any attached soft tissue and calculus followed by polishing with fluoride free pumice. Finally, the samples were submerged in 0.1% thymol solution at room temperature (25±5) until the experimental time[8,9].

All teeth were embedded 2mm below the cementoenamel junction (CEJ) [8] in self-curing acrylic resin (Veracril, Colombia) mixed according to the manufacturer's instructions and poured into moulds[9].

In order of standardization, all the teeth were prepared by a single operator one group at a time using a high-speed electric handpiece (~200,000rpm) with air and water cooling utilizing diamond flat-end taper burs. The teeth were prepared as follows: ((1) an overlay preparation with 1.5 mm occlusal thickness and 1.0 mm chamfer located 2 mm above the CEJ (Figure 1B), and (2) an overlay preparation with 1.5 mm occlusal thickness and 1.0 mm chamfer located 4 mm above the CEJ (Figure 1C) (3) a crown preparatiom with 1.5 mm occlusal thickness and 1.0 mm chamfer located at the CEJ (Figure 1A). After completion of preparation, the teeth were scanned with an intraoral scanner (Primescan, Dentsply Sirona, Charlotte, NC) and the restorations were designed with digital software (CEREC, Dentsply Sirona).

Ceramic material

Three different CAD/CAM ceramic materials were tested in this study: Lithium disilicate (IPS E.max CAD; Ivoclar; Vivadent, Schaan, Liechtenstein), Zirconia reinforced lithium silicate (Celtra Duo; Dentsply Sirona; Bensheim, Germany), and hybrid ceramic (Vita Enamic; Vita Zahnfabrik, Bad Säckingen, Germany). All restorations were fabricated using a computer-aided design/computer-aided manufacturing (CAD/CAM) milling machine and were finished and glazed according to the manufacturers' instructions[6] (Figure 1).

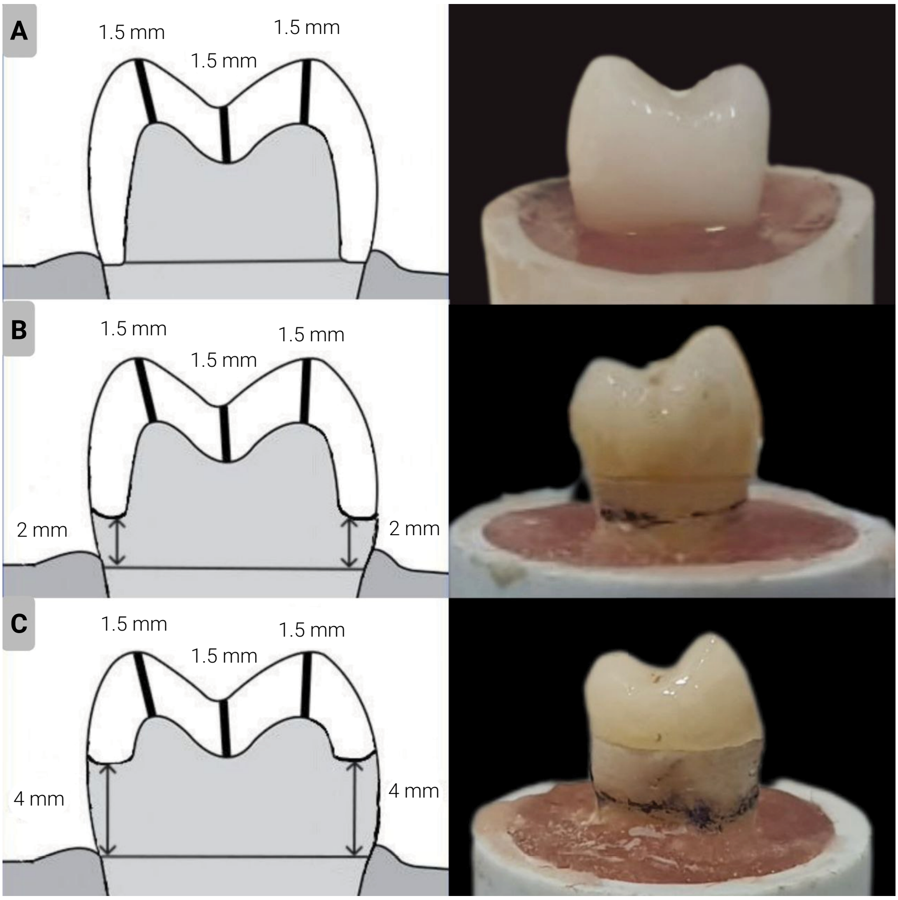

Figure 1. Schematic drawing of the three different preparation designs with images of the restorations (A): Full coverage crown with margin located at the CEJ; (B) : Overlay restoration with margin located 2 mm above the CEJ; and (C) Overlay restorations with margin located 4 mm above the CEJ.

Study design and specimen grouping

The ninety teeth were randomly divided into three groups (n=30) according to the ceramic material. Each of these groups were further subdivided into three groups (n=10) according to the restoration design as follows:

LD 4:Lithium disilicate overlay with margin located 4 mm above the CEJ.

LD 2:Lithium disilicate overlay with margin located 2 mm above the CEJ.

LD-F: Lithium disilicates full crown.

ZLS 4: Zirconia reinforced lithium silicate overlay with margin located 4 mm above the CEJ.

ZLS 2: Zirconia reinforced lithium silicate overlay with margin located 4 mm above the CEJ.

ZLS-F: Zirconia reinforced lithium silicate full crown.

HC 4: Hybrid ceramic overlay with margin located 4 mm above the CEJ.

HC 2: Hybrid ceramic overlay with margin located 2 mm above the CEJ.

HC-F: Hybrid ceramic full crown.

Cementing the restorations

The prepared tooth surfaces were dried and etched by applying 37% phosphoric acid to the enamel for 15 seconds (s.), then were thoroughly rinsed with water for 30 s, and were air dried. A tooth primer was applied and allowed to dry for 30 s, followed by the application of resin cement (Panavia V5, Kuraray Noritake Dental Inc., Tokyo, Japan) [9].

The intaglio surfaces of the restorations were etched with4.9%hydrofluoric acid (IPS Ceramic etching gel®, Ivoclar,Vivadent, Schann, Lichtenstein) for 20s. for zirconia reinforced lithium silicate and lithium disilicate ceramic[4] and for 60s. for Vita Enamic hybrid ceramic[10] then thoroughly rinsed with water for 30s., followed by air-drying. The etched surfaces were then treated with Monobond Plus® (Ivoclar,-Vivadent, Schann, Lichtenstein) for 60s. and were allowed to air dry[4] .Rely X U200® (3M, ESPE) self-adhesive resin cement was used according to the manufacturer's instructions and applied on the intaglio surface of the restorations, which were then seated with finger pressure on the prepared teeth. An initial cure of 1 s. on each surface of the restoration with LED curing light was applied in order to remove excess cement. Afterward, the final cure of the cement was performed for 20 s. on each surface of the restoration[9].

The finished cemented samples were submerged in distal water and incubated at 37°C for 1 week prior to the fracture resistance measurement[6].

Experimental procedure

Fracture resistance measurement

The fracture resistance of the samples was measured by a universal testing machine (Gester,Gester, International Co.,China). The samples were secured on a steel jig and subjected to load that was applied by a round-end stainless steel bar with 6 mm diameter at a crosshead speed of 1 mm/min. The load was applied to the center of the line connecting the buccal and lingual cusps until fracture (Figure 2) [4,8]. The fracture resistance values were recorded in Newton and statistically analyzed.

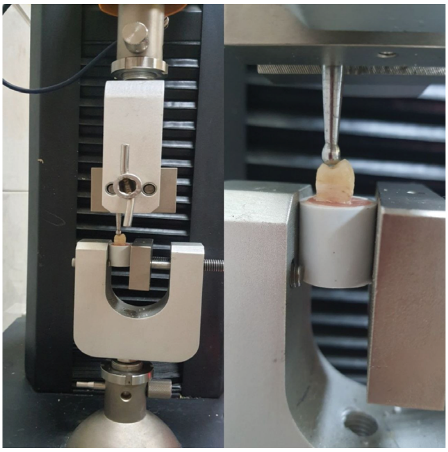

Figure 2. Universal testing machine loaded with specimen

Failure mode determination

The failure mode of the samples was determined by nacked eye and by using stereoscope (Optica microscope, Italy) x10 magnification[8]. The mode of failure was categorized according to the modified Burke's classification: Type I: Fracture within the restoration . Type II: Fracture of the restoration and dentin. Type III: Fracture of the restoration and tooth structure reaching beyond the dentin and involving pulpal tissue[9].

Statistical analysis

The statistical analyses were accomplished utilizing the statistical packages for SPSS 25.0 for Windows (SPSS Inc., Chicago, IL, USA). The normality of the distribution of data was estimated with Kolmogorov- Smirnov and Shapiro test. A one-way ANOVA test was applied to compare the different restoration designs and materials. Duncan's post-hoc test was used for multiple comparisons to determine the significance of differences between the groups. Statistical significance was established at $P<0.05$.

Results

Descriptive statistics and one-way ANOVA tests for the study groups are shown in table (1). It was found that the highest FR was for ZLS 4 (2411.6 N) and the lowest FR for HC-F (983 N).

There was a significant difference between the restoration designs of the same ceramic material, with a higher FR for the overlay restoration design with 4mm above the CEJ. Also, there was a significant difference between the restoration materials with the same restoration design.

The mode of failure of the samples in the study groups were mainly of type III as seen in table (2). Representative images of the mode of failure are seen in figure (3).

Table 1. Descriptive statistics and one-way ANOVA tests for fracture resistance (N) of the study groups.

Groups	Minimum	Maximum	Mean	Std. Deviation	F	Sig.
LD 4	1630.00	1819.00	1747.9000[A]	53.39049	182.936	0.000
LD 2	1387.00	1506.00	1432.3000[a]	34.54482		
LD-F	1369.00	1498.00	1428.4000[a]	38.32667		
ZLS 4	2310.00	2497.00	2411.6000[B]	57.94480	438.475	0.000
ZLS 2	2165.00	2310.00	2237.7000[B]	45.80890		
ZLS-F	1694.00	1841.00	1757.6000[B]	48.93351		
HC 4	1350.00	1591.00	1498.7000[C]	76.72324	91.725	0.000
HC 2	1223.00	1433.00	1350.9000[C]	61.73321		
HC-F	810.00	1171.00	983.0000[C]	115.62199		
LD4/ZLS4/ HC 4					552.306	0.000
LD2/ZLS2/HC 2					1014.890	0.000
LD-F/ZLS-F /HC-F					263.105	0.000

The same lowercase letter in the same vertical column indicates no significant difference (p>0.05). The same uppercase letter in the same individual vertical row indicates a significant difference (p>0.05).

Table 2. Frequency distribution of failure modes types.

Groups	Type I	Type II	Type III
LD 4	0 (10%)	1 (10%)	9 (10%)
LD 2	1 (10%)	2 (10%)	7 (70%)
LD-F	1 (10%)	0 (10%)	9 (90%)
ZLS 4	0 (10%)	1 (10%)	9 (90%)
ZLS 2	1 (10%)	1 (10%)	8 (80%)
ZLS-F	1 (10%)	0 (10%)	9 (90%)
HC 4	0 (10%)	2 (20%)	8 (80%)
HC 2	1 (10%)	1 (10%)	8 (80%)
HC-F	1 (10%)	1 (10%)	8 (90%)

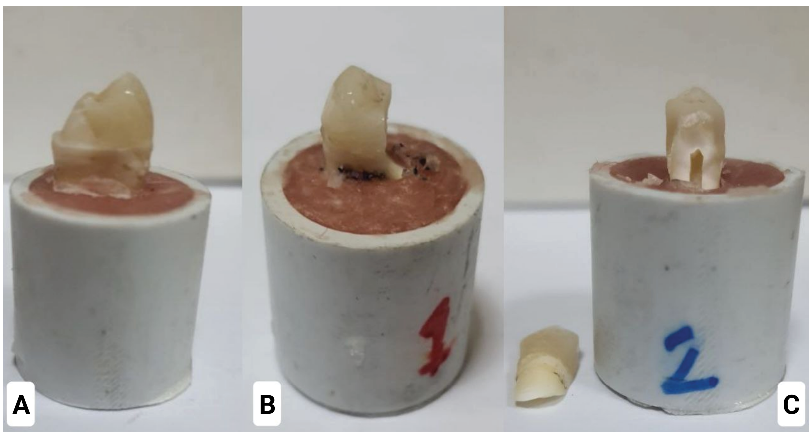

Figure 3. Modified Burke's classification. A: Type I ; B: Type II ; C: Type III .

Discussion

The development and evolution of physical and mechanical properties in restorative materials and the improvement of adhesive cementation has led to the evolution of minimally invasive preparations, that allow the preservation of significant amounts of tooth structure and thus maximal reinforcement of the remaining dental structure[11] . In this study, indirect restorations were cemented with an adhesive technique that uses resin cement, as etching and adhesive cementation of the overlay and crown restorations are known to reinforce the dental and ceramic structures and therefore enhance its fracture resistance[12]. The standard recommended thickness by the manufacturer for posterior partial coverage ceramic restorations was (1.5 mm) [13], therefore we used this occlusal thickness in our study.

The first null hypothesis was rejected, as the different preparation designs differ in their fracture resistance. Higher FR was for the minimal preparation design in which the finish line was 4 mm above the CEJ. This was true for all the tested ceramic materials. These results were in agreement with other studies[4,14]. Jurado et al.[4] (2022) who tested the fracture resistance of Leucite reinforced the cad cam full and partial coverage crown and found that the Rosetta BM partial coverage crowns had a higher fracture resistance. Meanwhile, Huang et al.[14] (2020) studied the fracture strength of four different occlusal veneers compared with the conventional full crown restoration and observed that the different occlusal veneers possess higher fracture resistance than the full crown. These results were unexpected, as one might think that the partial coverage crowns to be weaker than the full ones. Therefore, one can suggest that there is no need to remove excess tooth structure to fabricate a strong restoration especially in those teeth that are already weakened by excessive loss of tooth structure. In addition, it has been shown that the biting forces are evenly distributed across the tooth with overlay restorations[9]. The maintenance and preservation of tooth structure at the periphery of the overlay preparation aids deformation resistance, as the enamel-dentin complex disperse forces and therefore increases the resistance to fracture. While in full coverage restoration, the preparation design is below the line of maximum contour, the amount of the enamel- dentin complex is decreased, the dentin's ability to prevent crack propagation is weaker and therefore decreases the resistance to deformation[2].

In agreement, Luekiatpaisarn and Leevailoj[15] (2018) concluded during their study on lithium disilicate (LS) onlays and crowns that the larger the degree of tooth preparation, the weaker the remaining tooth structure and therefore the lower its fracture resistance. Comba et al.[16] (2022) stated that overlay preparation seems to be a valid alternative to the traditional full crown and that LS is more resistant than Vita Enamic.

Yoshinari and Dérand[17] (1994) reported that the highest masticatory forces in the posterior molar region ranged between 200-540 N. However, in patients with bruxism these forces can reach up to more than 800 N[18]. In our study, the fracture resistance of all the study groups was higher than the reported maximum masticatory forces. In addition, Sirous et al.[19] (2022) stated that occlusal veneers possess higher fracture resistance than the normal range of human masticatory force; therefore, aggressive unconservative preparation to increase the fracture resistance is not recommended, and therefore, the preparation can be minimally invasive as proved in our study.

According to the results of our study, different materials possess different fracture resistance for the same restoration design. Therefore, the second null hypotheses was also rejected This may be influenced by the differences in the crystalline and micro structure of the different materials which lead to development of varying physical and mechanical properties[4,5,20].This was in agreement with Abo El-Farag and Elnawawy[21] (2019) who studied the fracture resistance and mode of failure of onlays made of three different materials with different preparation designs and observed statistically significant differences between them. García-Engra et al.[22] (2020) studied the fracture resistance and fracture patterns of 4 different CAD-CAM materials in fabrication of partial posterior restorations and concluded that their strength depended on their composition, ceramic materials being stronger than hybrid materials. In the agreement, Elassy et al.[23] (2023) concluded different fracture resistance between lithium disilicate and hybrid ceramic occlusal overlay.

However, studies confirmed by Abdel Sadek et al.[24] (2021) and Hany and Taymour[25] (2017) observed no significant differences between the tested materials. The reason for the different results may be due to a difference in the preparation design of the indirect partial restoration.

In the current study, the highest fracture resistance was for zirconia reinforced lithium silicate ceramic material compared to the other tested material. This was in agreement with Jassim and Majeed[20] (2018), Preis et al.[26] (2015) and Schwindling et al.[27] (2017). This can be explained due to the integration of highly-dispersed and completely-dissolved submicron-sized zirconia grains within the glassy matrix of CELTRA Duo which is believed to increase both the fracture toughness and flexural strength when compared to IPS e.max CAD. However, the modulus of elasticity of zirconia reinforced lithium silicate is (70 GPa) when compared with that of Lithium disilicate (95 GPa), this indicates that there will be higher stress accumulation in the crowns fabricated from Lithium disilicate[20]. While the lowest fracture resistance was for hybrid ceramic (Vita Enamic). This could be explained by its relatively low mechanical properties that include a low fracture toughness of (1.5 MPa m1/2) and low flexural strength (150-160 MPa)[28]. In addition, the hybrid nature of this material could also be a factor, as it is composed of interconnected networks of ceramic and polymer, that conducts various rates of ablation for ceramic and polymer during the polishing and grinding procedures, that may lead to microcracks in the network boundaries, and therefore to a reduction in its mechanical properties[20]. In addition, in this type of material, failure can be started from any fragile point of microstructure, like the polymer in a polymer infiltrated ceramic[20,29].

Static load of failure provoked splitting the crowns from the central fossa through the tooth buccolingually below CEJ. This is a typical failure mode for monolithic restorations split by a hard intender wedged between the premolar cusps[30,31]. In this study, the majority of the samples observed catastrophic fracture Type III with slightly higher rates of Lithium disilicate and zirconia reinforced lithium silicate. This can probably be attributed to the higher modulus of elasticity of these materials, which results in tooth fractures under lower forces and in a shorter time than those of hybrid ceramic[32].

The limitations of the present study are inherent to the in vitro design, where only controlled variables are considered. We focused on different overlay preparation designs in premolars, and in future further studies studying the fractured behavior of other teeth is suggested. Cyclic fatigue tests with thermal stress to reproduce the clinical condition of the oral cavity are also suggested.

In conclusion, minimal invasive restorations like overlay restoration can be used as an alternative for fully covered crown restorations. Keeping the finish line coronary as possible during indirect restoration preparation increases the fracture resistance of the tooth, as higher fracture resistance was found for the overlay restoration design with 4mm above the CEJ. In addition, different ceramic materials possess different fracture resistance for the same restoration design with the highest fracture resistance for Zirconia reinforced lithium silicate. In terms of failure modes, the catastrophic fracture Type III of the tested samples can probably be attributed to the high modulus of elasticity of the used materials.

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Conflict of Interest

The authors have no conflict of interest to disclose.

Data availability

Datasets related to this article will be available to the corresponding author upon request.

Author Contribution

Sarah Ihsan Al-Araji: Conception and Design of the Study, Methodology, Data Analysis, Statistical analysis, Interpretation, Writing the Draft, Review and Editing. **Mohammed Riyadh Abdulateef:** Methodology, Data Analysis, Statistical analysis, Interpretation, Writing the Draft, Review and Editing.

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