RESEARCH

Evaluation of Fracture Strength of Different CAD/CAM Veneers That are Manufactured For Zirconia Cores

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ABSTRACT

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Background: The purpose of this study was to evaluate the fracture resistance of zirconia crowns veneered with CAD/CAM fabricated veneers by using simple and anatomic core designs with different veneering materials and procedures.

Methods: A total of 100 zirconia frameworks were fabricated with an anatomic core design or simple core design. The frameworks were then divided into five subgroups according to the following veneering procedures: Control (layering), cemented CAD/CAM fabricated feldspathic veneer, cemented CAD/CAM fabricated lithium disilicate veneer, fused CAD/CAM fabricated feldspathic veneer, and fused CAD/CAM fabricated lithium disilicate veneer. Next, 250000 cycles were applied with an occlusal load of 50 N at 1.6 Hz in a chewing simulator, and a thermal cycle was applied during loading (5°C to 50°C every 60 s). The crowns were then subjected to a single load failure test by using a universal test machine.

Results: Statistical analyses between the groups showed significant differences (F= 23.296; p<0,001). The lowest fracture resistance values were observed in fused feldspathic CAD/CAM veneers with an anatomic core design (470.63 N). The highest fracture resistance was obtained in cemented lithium disilicate CAD/CAM veneers with a simple core design (2075.06 N).

Conclusion: Within the limitations of this study, it can be said that the use of CAD/CAM fabricated veneers can be an alternative to layering when their advantages are considered.

KEYWORDS

Dental CAD/CAM, Zirconia Crowns, Core Design, Fracture Strength, Veneering

ÖZ

Zirkonya Çekirdekler İçin Üretilen Farklı CAD/CAM Kaplamaların Kırılma Mukavemetinin Değerlendirilmesi

Amaç: Bu çalışmanın amacı, farklı veneer materyalleri ve işlemleri ile hazırlanmış basit ve anatomik kor tasarımları kullanarak kaplanmış zirkonya altyapılı kronların kırılma direncini değerlendirmektir.

Gereç ve Yöntemler: Anatomik bir çekirdek tasarımı veya basit bir çekirdek tasarımı ile toplam 100 zirkonya kron altyapısı üretildi. Bu kor altyapılar daha sonra aşağıdaki veneerleme prosedürlerine göre beş alt gruba ayrıldı: Kontrol (katmanlama), simante CAD/CAM fabrikasyon feldspatik veneer, simante CAD/CAM fabrikasyon lityum disilikat veneer, porselenle kaynaştırılmış CAD/CAM fabrikasyon feldspatik veneer ve porselenle kaynaştırılmış CAD/CAM fabrikasyon lityum disilikat kaplama. Daha sonra, bir çiğneme simülatöründe 1,6 Hz'de 50 N'luk bir oklüzal yük ile 250000 döngü uygulandı ve yükleme sırasında bir termal döngü uygulandı (her 60 saniyede bir 5°C ila 50°C). Kronlar daha sonra evrensel bir test makinesi kullanılarak kırma testine tabi tutuldu.

Bulgular: Gruplar arasında istatistiksel analizler önemli farklılıklar gösterdi (F= 23.296; p<0,001). En düşük kırılma direnci değerleri, anatomik çekirdek tasarımlı (470.63 N) porselenle kaynaştırılmış feldspatik CAD/CAM kaplamalarda gözlendi. En yüksek kırılma direnci, basit bir çekirdek tasarımına (2075.06 N) sahip simante lityum disilikat CAD/CAM kaplamalarda elde edildi.

Sonuç: Bu çalışmanın sınırlamaları dahilinde, avantajları düşünüldüğünde CAD/CAM fabrikasyon veneerleme tekniklerinin kullanımının katmanlamaya alternatif olabileceği söylenebilir.

ANAHTAR KELİMELER

Zirkonya Kron, Altyapı Tasarımı, Dental CAD/CAM, Kırılma Dayanımı, Veneering

INTRODUCTION

Metal-ceramic restorations have been widely used for fixed partial dentures and have been seen as a reliable treatment option since the early 1960s.[1] More recently, zirconia core material has become an appropriate alternative to metal substructures.[2]

Zirconia can serve as a core material because of its biocompatibility, wear resistance, flexural strength and fracture toughness.[3] Phase transformation and crack propagation prevention mechanisms of zirconia offer new treatment options as well.[4] Fabrication of extensive multi-unit restorations has become possible with the introduction of zirconia ceramics.[5] However, adhesive and cohesive failure of the veneer is relatively higher in zirconia-based restorations than with metal-ceramic ones; veneer failures can necessitate the replacement of the restorations especially when they affect dental function and aesthetics.[6]

Fracture or chipping of the veneering ceramic is stated as being the most crucial and frequent problem for zirconia-based ceramics.[2,7] Fracture of all-ceramic restorations seems to occur due to microcracks as a result of occlusal contacts, fatigue or wear.[8] Also, material-related factors such as veneering method[8], core design[8,9] and the mechanical properties of the veneering ceramic[9] may affect the clinical success of zirconia-based restorations.

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Conventional layering procedures can cause chipping or fracture of the veneer because of porosities occurring in the veneer structure during layering. Thermal expansion mismatch between the core and veneering material is another factor that can cause chipping.[7] For a strong bond between core and veneer, the thermal expansion coefficient of the materials should be close.[10] Layering methods usually include several firings.[11] Zirconia has a low thermal conductivity, so firing temperatures and cooling rates are important to prevent stress development within the veneer ceramic, which may cause chipping.[12] Low thermal conductivity of zirconia leads to unfavorable temperature distributions and internal stress development in the veneer ceramic during firing and cooling.[13]

CAD/CAM fabricated high-strength zirconia cores and CAD/CAM fabricated veneer combinations were introduced as a new procedure to fabricate veneered all-ceramic restorations.[5,14] Veneer and core can be combined with glass-ceramic powder by only one firing.[5,14–18] Another way to combine veneer and core is by using resin cement, which does not have any firing requirements.[15,19,20] It has been suggested that CAD/CAM fabrication improves the mechanical characteristics of the veneer ceramic and industrially produced veneers have fewer flaws than layered ones.[21]

Core veneer thickness ratio and veneering material properties affect the strength of veneered restorations.[22] The optimizing framework design has been shown to be an important factor in reducing chipping of the veneer ceramic. The structural integrity of the veneer ceramic and framework support for the veneer ceramic are the main issues of zirconia-based ceramics.[23] CAD software options were not able to fabricate anatomically reduced core designs, which resulted in thicker ceramic layers without cusp support. However, it has become possible to fabricate anatomically cut back-core designs with modern CAD/CAM systems.[14] Computer simulations can be carried out to optimize connector dimensions and location as well as provide an adequate thickness of the framework and marginal design in the CAD phase.[24]

The veneering ceramic is the weakest part of zirconia-based restorations.[15] Improvement in the strength of the veneering porcelain could reduce chipping. It has been shown that high-strength heat-pressed ceramics have better fracture resistance than traditional ceramics.[25] To increase the fracture resistance of the all-ceramic restorations, use of lithium disilicate ceramics is suggested instead of feldspathic ceramics, since these have better mechanical properties.[21]

Although there are studies evaluating effect of varying parameters on the veneered zirconia restorations in posterior region[6,8,9,14,15,19-24] the existing data is still limited. One of the most important parameters that will determine the survive of zirconia crowns in the oral environment is the bonding and fracture strengths of the veneers on the veneers on the core. Therefore, influencing clinical preferences according to the results of the present study reveals the clinical implication of this study. The aim of this study was to evaluate the fracture strength of zirconia-based single-crown restorations using feldspathic or lithium disilicate CAD/CAM fabricated veneers with two core designs (simple core, anatomical core). Zirconia cores were connected to CAD/CAM fabricated veneers by resin cement or low-fusing porcelain. The null hypothesis of this study was that the veneering method, core design, and veneering material would not affect the fracture strength of zirconia-based all-ceramic crowns.

MATERIALS AND METHODS

An anatomically designed maxillary first premolar (Phantom Frasaco, Frasaco GmbH) made of hard thermosetting plastic material was prepared with a 1 mm wide chamfer finish line and circular and occlusal anatomical reduction of 1.5–2 mm. Sharpnesses and undercuts were eliminated.

Digital impressions were performed with the CEREC Omnicam system (Sirona Dental Systems GmbH). Multilayered designs were performed with either the simple or anatomic core design shown below. The thickness of the die spacer was 80 μm.

A.Simple core: A uniform core was designed with a 0.5 mm thickness (Fig. 1A).

B.Anatomic core: Core was anatomically reduced 1 mm from the finished crown dimension. A core with variable thickness between 0.5–1 mm was obtained while veneer thickness was fixed at 1 mm (Fig. 1B).

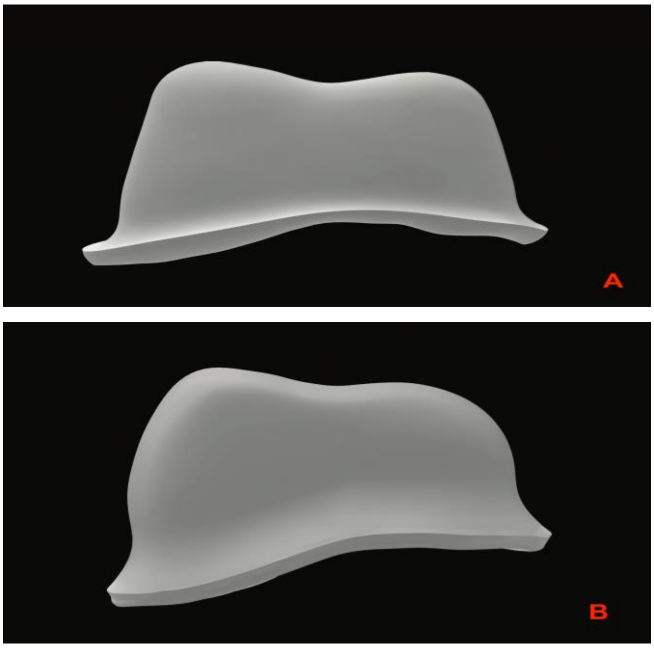

Figure 1

Core design for multilayered Zirconia crowns. **A)** Simple core, **B)** Anatomic core

50 simple and 50 anatomic cores; in total, 100 cores with were milled from yttria-stabilized pre-sintered zirconium oxide blocks (InCoris ZI, Sirona Dental Systems GmbH; Cerec In Lab MC XL, Sirona Dental Systems). The zirconia specimens were sintered in the sintering oven (Sirona in Fire HTC, Sirona Dental Systems GmbH) according to the manufacturer's instructions. Following sintering, cores were checked for flaws using light microscopy (Leica MZ12, Leica Microsystem Inc.) and sandblasted with 50 μm aluminum oxide particles (BEGO Korox) with 2 bar pressure from a 10 mm distance from the core surface for 15 seconds. Ultrasonic cleaning was applied for 5 minutes with distilled water (Whaledent, BIOSONIC, Coltene/Whaladent Inc.).

Specimens in each core group were divided into five subgroups according to the veneering procedure and material used (n=10) (Fig. 2).

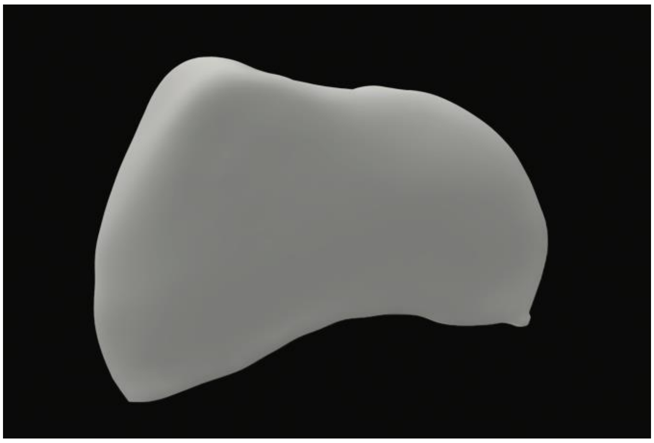

Figure 2

Veneer design for Zirconia cores.

1. Layering was applied as control group. Fluorapatite ceramic (IPS e.max Ceram, Ivoclar Vivadent) was performed by an experienced technician to minimize operator-sourced mistakes. Dentin and enamel firing was applied with 400°C stand-by temperature with 90°C/minute heating rate to 650 °C, then 20°C/minute heating rate to 730°C (for 2 minutes before cooling started). Glaze firing was applied 450°C stand-by temperature with 90°C/minute heating rate to 725 °C for 1 minute before cooling started.
2. CAD/CAM fabricated feldspathic veneer (CEREC Blocs; Sirona Dental Systems GmbH) cemented to zirconia core (Panavia V5, Kuraray Noritake Dental Inc.).
3. CAD/CAM fabricated lithium disilicate veneer (IPS e.max CAD, Ivoclar-Vivadent AG) cemented to zirconia core.
4. CAD/CAM fabricated feldspathic veneer (Cerec Blocs) fused to zirconia core with fluorapatite ceramic (IPS e.max Ceram, Ivoclar Vivadent). Fusion ceramic was fired with 400°C stand-by temperature with 90°C/minute heating rate to 650°C, then 20°C/minute heating rate to 730°C (for 2 minutes then 20°C/minute heating rate to 730°C (for 2 minutes before cooling started).
5. CAD/CAM lithium disilicate veneer (IPS e.max CAD) fused to zirconia core fluorapatite ceramic (IPS e.max Ceram).

The core with veneer were designed together (InLab 16, Dentsply Sirona). Additional scanning of the core was not performed for veneer design. The final form of all crowns was the same to provide standardization. First, a simple core was designed with 0.5 mm thickness and a veneer was designed with a average total restoration thickness of 2 mm. The milled simple core and veneer complex was scanned with the CEREC Omnicam system. The scanned crown was used as a biogeneric copy to design the crowns with an anatomical core exactly in the same contour and shape as the simple core crowns. A silicone mold was prepared from digitally fabricated crowns for fabricating layered crowns.

After controlling the adaptation of core and CAD/CAM fabricated veneers, these were connected by fluorapatite fusion ceramic or resin cement. Fusion ceramic or resin cement was applied with the help of a vibrator (Vibroboy SL, Bego). Veneers were seated on the zirconia core with finger pressure and excess cement, or fusion ceramic was removed with the help of a hand instrument. Fusion ceramic fired while resin cement was light-cured from the buccal, lingual, mesial, distal, and occlusal aspects for 20 seconds.

Thermomechanical aging was applied to the specimens in a chewing simulator (MOD Dental Chewing Simulator, Esetron). Acrylic resin (Ortocryl, Dentaurum) dies were prepared to fix the crowns onto the chewing simulator. Sphere-shaped tips (stainless steel, 5 mm diameter) were used as antagonists for standardized simulation. A total of 250000 cycles were applied with an occlusal load of 50 N at 1.6 Hz, and thermal cycling was applied during loading (5°C to 50°C every 60 s).

The crowns were then subjected to a single load failure test by using a universal test machine (Instron, Instron Corp., Canton MA). The force was applied with a stainless-steel tip with a three-point contact between the tip and the occlusal surface of the crown at a 1 mm/min crosshead speed until fracture. The force was delivered vertically at the center of the occlusal surface.

All statistical analyses were performed using Opensource R Statistical Software. The normality of the data was analyzed by Kolmogorov-Smirnov test. The data showed normal distribution. A one-way ANOVA was used to analyze the presence of significant differences between the groups. Post hoc comparisons between treatments were made via the multiple comparison Bonferroni test.

RESULTS

Statistical analyses between the groups showed significant differences ($F = 23.296$, $p<0.001$). The mean, maximum and minimum fracture strength values and statistical differences between the groups are shown in Table 1.

GROUPS	FRACTURE STRENGTH	Maximum Load	Minimum Load
A1	1719.58± (441.91)^{E}	2399.40	1306.70
B1	1592.12 ± (258.11) ^{DE}	1878.25	1086.12
A2	1596.06 ± (404.46)^{DE}	2127.27	1031.28
B2	1306.87 ± (250.92)^{CD}	1686.42	1028.47
A3	2075.06± (293.07)^{F}	2468.47	1764.21
B3	1751.83±(245.51)^{E}	2152.65	1452.12
A4	800.83± (266.21)^{B}	1251.95	375.88
B4	470.63± (228.02)^{A}	225.34	883.48
A5	1637.41± (276.04)^{E}	2092.02	1450.9
B5	1252.33± (387.33)^{C}	1838.5	732.46

** The superscript letters indicate the statistical differences. Different letters represent the differences between test groups.*

The lowest fracture resistance values were observed in fused feldspathic CAD/CAM veneers with anatomic core design (470.63 N) (Group B4). The highest fracture resistance was obtained in cemented lithium disilicate CAD/CAM veneers with simple core design (2075.06 N) (Group A3). Groups A1 and B1 showed statistically similar results. Groups B2 and B5 (anatomic cores with cemented feldspathic and fused lithium disilicate veneers) showed statistically similar fracture strength values. Groups B1, A2, and B2 (especially anatomic core with cemented feldspathic core and simple cor with layering technique) showed statistically similar results. Groups A1, B1, A2, B3, and A5 showed statistically similar fracture strength values. Additionally, Groups A4 and B4 (fused feldspathic veneer groups) showed the lowest and statistically different values.

The simple and anatomical core designs showed statistically similar fracture strength in layered samples. Simple and anatomic core designs showed similar fracture strength in cemented CAD/CAM fabricated feldspathic veneers.

Simple core design showed statistically higher fracture strength than anatomic ones in fused CAD/CAM fabricated veneers. The fused Lithium disilicate CAD/CAM fabricated veneers showed higher fracture strength than fused feldspathic CAD/CAM fabricated veneers with both of the core designs.

DISCUSSION

Roughening the zirconia surface improves the bond strength by micromechanical interlocking.[26] Sandblasting was applied when fabricating the crowns in this study as it is an ordinary procedure; the crowns used for this study were fabricated as intended for clinical use.

The crowns used in this study had the same form and dimensions to provide standardization. The layered crowns were prepared using a silicone mold. The CAD/CAM fabricated crowns were designed with CAD/CAM as a biogeneric copy. The cores and veneers were designed and fabricated together without additional scanning of the core to design the veneer as in previous studies.[15,27] This can be considered as an important advantage of this study. The fabrication procedure provided standardization as well as time-saving benefits.

Residual stresses can occur during sintering and cooling processes as a result of the thermal expansion mismatch between the zirconia and the veneer ceramic, as well as tempering stresses.[28] An increase in firing cycles is reported to decrease the bond strength between the veneer ceramic and zirconia core.[29]

With CAD/CAM fabricated veneers the need to match the thermal expansion coefficient of the core and veneer ceramic is reduced.[28] Industrially fabricated blocks without porosities are used and also a perfect adaptation of the restoration is provided by CAD/CAM systems.[17,30]

Finally, CAD/CAM fabricated veneers can reduce the time for fabrication of the restoration and reduce surface flaws compared to conventional fabrication processes.[31] It is reported in previous studies[18,31-33] that usage of CAD/CAM fabricated veneers provides higher bond strength at the zirconia veneer interface.

When each core design is evaluated in itself, cemented and fused feldspathic veneers and fused lithium disilicate veneers showed lower fracture resistance than layered ones. Only cemented lithium disilicate veneers showed higher fracture resistance compared to layered ones. According to these results, it can be concluded that usage of cemented lithium disilicate CAD/CAM fabricated veneers would be a promising alternative to conventional layering. This result can be explained via the better mechanical properties of the lithium disilicate ceramics and the reinforcement effect of the resin cement under ceramic structures. A thin layer of resin cement can provide an internal barrier to crack propagation across and between the layers at the interface thus preventing delamination.[29]

Schmitter et al.[6] reported a higher initial fracture resistance for CAD/CAM fabricated lithium disilicate veneer fused to an anatomical zirconia core compared to layering. They concluded that CAD/CAM fabricated veneers were more resistant to aging. In this study, fracture resistance was evaluated only following aging; the results were different from Schmitter et al. Layered crowns showed higher fracture resistance than fused lithium disilicate veneers with anatomic core design. None of the layered crowns failed during chewing simulation.

Beuer et al.[27] reported higher mechanical stability with CAD/CAM fabricated lithium disilicate veneers fused to a simple zirconia core than layered or pressed veneers.

a simple zirconia core than layered or pressed veneers. Choi et al.[14] reported higher resistance for CAD/CAM fabricated glass-ceramic veneers fused to a simple zirconia core compared to layered veneers. The results of this study are not inconsistent. Layered veneers showed higher fracture resistance in this study. Possible reasons for this are that 48 hours of water storage was applied instead of chewing simulation in both studies and that they also used an experimental low-fusing ceramic to connect the zirconia core and the veneer ceramic.

Kanat et al.[17] found no significant difference between the fracture resistance of CAD/CAM lithium disilicate veneers fused to an anatomical zirconia core and layered veneers. In contrast, layering showed higher fracture load in this study. The aging procedure used in the present study included mechanical and thermal aging while Kanat et al. applied only 48 hours of humidity storage and no mechanical aging.

Previous studies have reported that CAD/CAM fabricated feldspathic veneers cemented to anatomical zirconia core showed lower fracture loads compared to layered ones.[15,19] The results of this study are similar. Lower fracture resistance was observed in feldspathic veneers cemented to anatomical zirconia core.

Cementing veneer ceramic to the zirconia core can produce residual stresses due to the shrinkage of the resin cement; however, these stresses are expected to be unimportant compared to thermally induced stresses associated with conventional layering.[28]

Schmitter et al.[21] found that fused CAD/CAM fabricated lithium disilicate veneers showed higher fracture resistance than cemented ones following chewing simulation. The anatomic core design was used in the study. They mentioned that both cemented and fused veneers showed clinically acceptable fracture strength. The results of the present study did not show the same: cemented lithium disilicate veneers with anatomical core design showed higher fracture resistance than fused ones.

Nossair et al.[19] evaluated various veneering methods in customized implant abutments. They reported that cemented CAD/CAM fabricated lithium disilicate veneers showed higher fracture resistance than fused or layered ones; the resin layer acted as a resilient cushion under the brittle veneer. In this study, cemented lithium disilicate veneers with anatomical design showed statistically similar results to layering while cemented lithium disilicate veneers with simple core showed statistically higher results.

The occlusal load is separated into two components directed at the fossa or the equator. Therefore, framework support is necessary to allow an effective shift of the stress distribution from the veneer to the core material.[22] Frameworks with an anatomical design

core material.[22] Frameworks with an anatomical design are reported to increase the restoration strength in previous studies.[8,9,15,22] This is explained with the uniform thickness of the veneering ceramic through CAD-control of manufacture.[17,34]

It was stated in previous studies that anatomic core design is advantageous.[17,22] The results of this study are not similar. No statistically significant difference was observed in layered or cemented feldspathic veneers between anatomical and simple core designs. Higher results were observed with simple core design in cemented lithium disilicate veneers, fused lithium disilicate veneers and fused feldspathic veneers. This can be explained by the increased ceramic thickness of the simple core design. The thicker ceramic layer may have compensated for the mechanical advantages of the anatomical core.

The flexural strength and fracture toughness of bi-layered restorations depend on the veneer layer when the crack originates from the veneer surface.[35] In order to reduce chipping, more resistant veneering material may be used instead of feldspathic porcelain.[36] Lithium disilicate glass-ceramic has been recommended as an alternative veneering material for zirconia-based restorations.[37] Zaher et al.[38] reported that CAD/CAM fabricated lithium disilicate veneers showed higher bond strength to zirconia core compared to layering. The results of the present study are similar. The cemented or fused veneers with the same core design showed higher fracture loads than feldspathic veneers when lithium disilicate veneer was used.

Restorations are subjected to mechanical and thermal fatigue and moisture in the oral environment, which induce deformations and internal stresses within the materials and at the interface between the materials. To simulate cycling in ceramics, an aqueous environment is essential, as water can chemically act at crack tips and affect the strength of the ceramics.[1] Here, thermomechanical loading was applied to the specimens to simulate the oral environment.

Acrylic dies were used to fix the crowns during thermomechanical aging and test procedure instead of natural teeth. The usage of acrylic dies was preferred in this study to provide standardized support for restorations. The use of natural teeth instead of dies would require the preparation of 100 teeth, which would be very difficult to prepare to achieve a similar form. Different preparations could lead to different core and veneer designs, which would affect the results more than the usage of metal dies. Also, Schmitter et al.[21] reported the die material has only a minor importance.

CONCLUSIONS

Within the limitations of this study, it can be said that the use of CAD/CAM fabricated veneers can be an alternative to layering when its advantages are considered. However recent literature is very limited. The existing literature includes various parameters that make it difficult to analyze and make a definitive conclusion. Thus, further studies are needed.

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