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EXPERIMENTAL AND CLINICAL EVALUATION OF METHODS FOR IMPROVING THE FIXATION OF FIXED PROSTHODONTIC CONSTRUCTIONS MADE OF ZIRCONIUM DIOXIDE

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Abstract: The widespread adoption of zirconium dioxide in restorative dentistry is driven by its superior biocompatibility and aesthetic properties, yet its chemical inertness poses significant challenges for reliable adhesive cementation. This article presents a comprehensive study conducted at the Department of Orthopedic Stomatology of Andijan State Medical Institute, aiming to establish an optimal fixation protocol for zirconia-based fixed prostheses. Utilizing the IMRAD framework, the research investigates the efficacy of various surface treatment methods, including air-particle abrasion with aluminum oxide and the application of 10-MDP containing primers, both in vitro and in vivo. The laboratory phase evaluated the shear bond strength of zirconia specimens bonded to dentin analogs, while the clinical phase monitored the retention and marginal integrity of crowns cemented in patients over an eighteen-month period. The results indicate that a combined protocol of mechanical surface roughening and chemical priming significantly enhances bond strength and clinical survival rates compared to conventional cementation methods. The study concludes that the integration of tribochemical surface treatments is essential for the long-term success of zirconia restorations.

Keywords: zirconium dioxide, adhesive cementation, shear bond strength, surface treatment, 10-MDP primer, air-particle abrasion, prosthodontics.

ЭКСПЕРИМЕНТАЛЬНАЯ И КЛИНИЧЕСКАЯ ОЦЕНКА МЕТОДОВ УЛУЧШЕНИЯ ФИКСАЦИИ НЕСЪЕМНЫХ ОРТОПЕДИЧЕСКИХ КОНСТРУКЦИЙ ИЗ ДИОКСИДА ЦИРКОНИЯ

Аннотация: Широкое внедрение диоксида циркония в восстановительную стоматологию обусловлено его превосходной биосовместимостью и эстетическими свойствами, однако его химическая инертность создает серьезные проблемы для надежной адгезивной фиксации. В данной статье представлено комплексное исследование, проведенное на кафедре ортопедической стоматологии Андижанского государственного медицинского института, целью которого является создание оптимального протокола фиксации несъемных протезов на основе диоксида циркония. Используя структуру IMRAD, в работе исследуется эффективность различных методов обработки поверхности, включая пескоструйную обработку оксидом алюминия и применение праймеров, содержащих 10-MDP, как in vitro, так и in vivo. Лабораторная фаза оценивала прочность соединения на сдвиг образцов циркония, приклеенных к аналогам дентина, в то время как клиническая фаза отслеживала ретенцию и краевую целостность коронок, зафиксированных у пациентов в течение восемнадцати месяцев. Результаты показывают, что комбинированный протокол механического придания шероховатости поверхности и химического праймирования значительно повышает прочность соединения и показатели клинической выживаемости по сравнению с традиционными методами цементирования. Исследование делает вывод, что интеграция трибохимических методов обработки поверхности необходима для долгосрочного успеха реставраций из диоксида циркония.

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Ключевые слова: диоксид циркония, адгезивная фиксация, прочность на сдвиг, обработка поверхности, праймер 10-MDP, пескоструйная обработка, ортопедическая стоматология.

SIRKONIY DIOKSIDIDAN TAYYORLANGAN OLINMAYDIGAN ORTOPEDIK KONSTRUKSIYALARNING FIKSATSIYASINI YAXSHILASH USULLARINI EKSPERIMENTAL VA KLINIK BAHOLASH

Annotatsiya: Sirkoniy dioksidining tiklash stomatologiyasida keng joriy etilishi uning yuqori biosigmimliligi va estetik xususiyatlari bilan bog‘liq bo‘lib, ammo uning kimyoviy jihatdan inertligi ishonchli adgeziv sementlashda jiddiy muammolarni keltirib chiqaradi. Ushbu maqolada Andijon davlat tibbiyot institutining Ortopedik stomatologiya kafedrasida o‘tkazilgan, sirkoniy asosli olinmaydigan protezlarni fiksatsiya qilishning optimal protokolini ishlab chiqishga qaratilgan keng qamrovli tadqiqot natijalari keltirilgan. IMRAD tuzilmasiga asoslangan ushbu ish alyuminiy oksidi bilan qumlash va 10-MDP saqlovchi praymerlarni qo‘llash kabi turli sirtni qayta ishlash usullarining samaradorligini ham in vitro, ham in vivo sharoitda o‘rganadi. Laboratoriya bosqichida dentin analoglariga yopishtirilgan sirkoniy namunalarining siljishga chidamlilik kuchi baholandi, klinik bosqichda esa o‘n sakkiz oy davomida bemorlarda sementlangan tojlar retentsiyasi va qirra butunligi kuzatildi. Natijalar shuni ko‘rsatadiki, sirtni mexanik g‘adir-budir qilish va kimyoviy praymerlashning kombinatsiyalangan protokoli an’anaviy sementlash usullariga nisbatan bog‘lanish kuchi va klinik saqlanib qolish ko‘rsatkichlarini sezilarli darajada oshiradi. Tadqiqot shunday xulosa qiladiki, tribokimyoviy sirtni qayta ishlash usullarini integratsiya qilish sirkoniy restavratsiyalarining uzoq muddatli muvaffaqiyati uchun zarurdir.

Kalit so‘zlar: sirkoniy dioksidi, adgeziv sementlash, siljishga chidamlilik kuchi, sirtni qayta ishlash, 10-MDP praymeri, qumlash, ortopedik stomatologiya.

INTRODUCTION

The advent of zirconium dioxide (zirconia) ceramics has revolutionized modern orthopedic stomatology by providing a material that combines the high fracture toughness of metals with the esthetic appeal of ceramics. Unlike silica-based glass ceramics, which can be easily etched with hydrofluoric acid to create a micro-retentive surface, zirconia is a dense, crystalline oxide ceramic that is acid-resistant and chemically inert. This inherent lack of glassy phase presents a significant clinical challenge regarding fixation. Traditional protocols relying on glass-ionomer cements often result in decementation, particularly in preparations with compromised retention form, such as short clinical crowns or excessive convergence angles.

The failure of the adhesive interface in zirconia restorations is not merely an inconvenience but a complication that compromises the biological integrity of the abutment tooth and incurs financial and psychological costs for the patient. Consequently, the establishment of a reliable bonding protocol is a priority for prosthodontists. Current literature suggests a multifaceted approach involving surface modification to increase roughness and chemical activation to facilitate covalent bonding with resin cements. However, there remains a lack of consensus regarding the specific combination of mechanical and chemical treatments that yields the most durable bond under clinical conditions in the Central Asian region.

At the Department of Orthopedic Stomatology of Andijan State Medical Institute, clinical observations indicated a higher-than-expected rate of debonding in zirconia fixed partial dentures when cemented with conventional protocols designed for metal-ceramics. This prompted an investigation into advanced fixation strategies. The primary objective of this study is to experimentally and clinically evaluate methods for improving the adhesion of zirconia. The

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hypothesis posits that a synergistic protocol involving air-particle abrasion (sandblasting) followed by the application of a primer containing 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) will provide superior retention compared to standard methods.

This article details a systematic study designed to validate this hypothesis. By correlating laboratory shear bond strength data with clinical survival rates, the research aims to provide a scientifically grounded, practical algorithm for the cementation of zirconia prostheses that can be implemented by practitioners to enhance treatment longevity.

METHODS

The study followed a rigorous experimental design comprising two distinct phases: a laboratory in vitro investigation and a prospective clinical trial. The entire protocol was reviewed and approved by the Scientific Council and Ethics Committee of Andijan State Medical Institute.

Laboratory Phase Methodology The in vitro component utilized sixty presintered zirconia blocks (3Y-TZP), which were sintered according to the manufacturer's thermal cycle. These specimens were embedded in acrylic resin to facilitate handling and testing. The zirconia surfaces were polished to a standard roughness using 600-grit silicon carbide paper to ensure baseline uniformity. The specimens were then randomly divided into three experimental groups of twenty. Group A (Control) received no surface treatment other than alcohol cleaning. Group B (Mechanical) underwent air-particle abrasion using 50-micron aluminum oxide particles at a pressure of 2 bar for fifteen seconds. Group C (Combined) received the same air-particle abrasion followed by the application of a universal primer containing 10-MDP monomer. Composite cylinders were bonded to these treated surfaces using a dual-cure resin cement. Following thermocycling (5000 cycles between 5 and 55 degrees Celsius) to simulate oral aging, the shear bond strength was measured using a universal testing machine until fracture.

Clinical Phase Methodology The clinical phase recruited forty-five patients requiring single crowns or three-unit fixed partial dentures in the posterior region. A total of sixty abutment teeth were prepared with a standardized chamfer finish line. The patients were divided into groups matching the laboratory protocols, with the exception of the control group which used standard glass-ionomer cementation as a clinical baseline comparison. The experimental clinical groups utilized the combined sandblasting and MDP-primer protocol with resin cement. The inclusion criteria required teeth with vital pulps or successful endodontic treatment and adequate periodontal health.

Fixation Protocol For the clinical experimental group, the internal surface of the zirconia restoration was sandblasted chairside using a portable micro-etcher with 30-micron aluminum oxide particles. The surface was then cleaned ultrasonically in alcohol to remove loose particles. An MDP-containing primer was applied and allowed to dry for the manufacturer-specified time before applying the dual-cure resin cement. Isolation was maintained using cotton rolls and saliva ejectors to prevent moisture contamination during the bonding procedure.

Evaluation Criteria Clinical evaluation was performed at baseline, six months, twelve months, and eighteen months. The primary outcome measure was retention (survival of the restoration without debonding). Secondary outcomes included marginal integrity and marginal discoloration, assessed according to the United States Public Health Service (USPHS) criteria. Gingival health was also monitored to ensure that the adhesive residue did not cause inflammation.

Statistical Analysis Laboratory bond strength data were analyzed using one-way ANOVA and Tukey's post-hoc tests to determine statistical significance between groups. Clinical survival data were analyzed using Kaplan-Meier survival curves. A p-value of less than 0.05 was considered statistically significant for all analyses.

RESULTS

The study yielded compelling data that highlights the critical role of surface treatment in

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zirconia adhesion.

Laboratory Findings The in vitro shear bond strength testing revealed statistically significant differences among the three groups. Group A (Control), which relied solely on the inherent adhesion of the cement to untreated zirconia, demonstrated the lowest bond strength values, averaging 4.5 Megapascals. This value is generally considered insufficient for clinical retention against masticatory forces. Group B (Mechanical) showed a substantial improvement, with mean bond strength increasing to 12.8 Megapascals. The creation of micro-retentive grooves via sandblasting significantly increased the surface area available for bonding. Group C (Combined), which utilized both sandblasting and the MDP primer, achieved the highest bond strength, averaging 26.4 Megapascals. The failure mode analysis for Group C predominantly showed cohesive failure within the cement layer or mixed failure, whereas Group A exhibited almost exclusive adhesive failure at the zirconia-cement interface. This indicates that the chemical bond formed by the MDP monomer is crucial for achieving high-strength adhesion.

Clinical Findings: Retention Rates Over the eighteen-month observation period, the clinical performance mirrored the laboratory results. In the group cemented with standard glass-ionomer cement without surface treatment, three debonding events were recorded, representing a failure rate of approximately 15 percent. In contrast, the experimental group utilizing the combined sandblasting and MDP-primer protocol experienced zero debonding events. The survival rate for the experimental protocol was 100 percent at the eighteen-month interval.

Clinical Findings: Marginal Integrity The assessment of marginal integrity revealed superior results for the resin-bonded group. The USPHS evaluation showed that 95 percent of restorations in the experimental group maintained "Alpha" ratings for marginal adaptation, meaning there was no detectable gap or catch with a dental explorer. The control group showed a higher incidence of "Bravo" ratings, indicating slight marginal discrepancies that were clinically acceptable but less ideal. This suggests that the strong adhesive bond helps to seal the margin against microleakage, which is often a precursor to secondary caries and cement dissolution.

Gingival Health Gingival health scores were comparable between the groups, provided that excess cement was meticulously removed. However, the resin cement used in the experimental group required more careful cleanup techniques compared to the glass-ionomer cement, which is easier to remove in a gel state. This highlights that while the adhesive protocol offers better retention, it demands a higher level of operator skill to prevent iatrogenic gingival irritation from residual cement.

DISCUSSION

The findings from the Department of Orthopedic Stomatology at Andijan State Medical Institute underscore the necessity of moving away from "cementation" towards "bonding" when dealing with zirconia restorations.

The Mechanism of Adhesion The dramatic increase in bond strength observed in the combined group can be attributed to the dual mechanism of adhesion. Air-particle abrasion removes the organic contaminants from the zirconia surface and creates a micro-rough topography. This increases surface energy and wettability. However, roughness alone is insufficient because zirconia is hydrophobic. The 10-MDP monomer serves as a bifunctional coupling agent. One end of the molecule contains a phosphate group that bonds chemically to the zirconium oxide surface, while the other end contains a methacrylate group that copolymerizes with the resin cement. This chemical bridge is what provides the durability of the bond observed in Group C.

Clinical Implications of Sandblasting There has been some debate in the literature regarding the potential for sandblasting to induce micro-cracks in zirconia, which could weaken the restoration. However, our study utilized mild sandblasting parameters (50 microns at 2 bar), which have been shown to be safe for the phase transformation toughening mechanism of zirconia. The clinical success without fracture suggests that this protocol does not compromise

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the structural integrity of the crown while providing necessary retention. It is crucial for practitioners to avoid high pressures (above 4 bar) which could indeed be detrimental.

Comparison with Glass-Ionomer Cements While glass-ionomer cements are convenient and moisture-tolerant, the results of this study suggest they should be reserved for retentive preparations where the geometry of the tooth provides the primary resistance form. For non-retentive preparations, short clinical crowns, or cantilever designs, the adhesive protocol utilizing MDP primers is not optional but mandatory. The adhesive bond compensates for the lack of mechanical friction.

The Importance of Cleaning An important methodological note discussed in the study is the cleaning of the zirconia after try-in. Saliva contamination significantly reduces bond strength because the phosphate proteins in saliva compete with the phosphate groups in the MDP primer for binding sites on the zirconia. Therefore, the protocol emphasized in this study—sandblasting after try-in or using a specialized cleaning solution (like Ivoclean)—is critical. Simply rinsing with water is ineffective.

CONCLUSION

The experimental and clinical evaluation conducted at Andijan State Medical Institute leads to definitive conclusions regarding the fixation of zirconia prostheses.

Firstly, the traditional methods of cementation used for metal-ceramic or cast metal crowns are insufficient for optimizing the retention of zirconium dioxide restorations. The chemical inertness of the material requires a specific surface treatment strategy to ensure long-term clinical success.

Secondly, the combination of mechanical surface modification via air-particle abrasion (sandblasting) and chemical activation using an MDP-containing primer yields the highest shear bond strength values in laboratory testing. This combined protocol is significantly superior to either method used in isolation.

Thirdly, clinical evidence supports the laboratory findings, demonstrating that restorations cemented with the combined adhesive protocol exhibit higher survival rates, better marginal integrity, and resistance to debonding over an eighteen-month period.

Therefore, it is recommended that the standard of care for the fixation of zirconia-based fixed prosthodontics should include chairside air-particle abrasion followed by the application of an MDP-based primer or a universal adhesive containing MDP. This protocol provides a predictable, durable bond that enhances the quality of orthopedic treatment and patient satisfaction.

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