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Development and Innovation of Bioofilling Materials and Their Biocompatibility in Dentistry

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Abstract
The use of biofillings as a new high-level solution in restorative dentistry has recently become possible due to their increased biocompatibility, durability, and aesthetic performance. The purpose of the study is to assess the clinical efficacy of Ceramic-based, Glass ionomer and Composite resin biofilling materials and, specifically, the satisfaction of patients, comfort following the treatment, and durability of materials after **6 months** of the treatment. A cross-sectional retrospective study was done on a sample of 230 patients who had biofilling restorations in five dental clinics in Libya. A structured questionnaire was used to measure post-treatment sensitivity, aesthetic outcomes, durability, and general satisfaction to collect data. The performance of various biofilling materials was compared using statistical analysis. The findings indicated that 72 % (n=165) of the patients did not report any pain after the treatment, with only one in every ten patients 10% (n=23) reporting moderate sensitivity that necessitated follow-up. Aesthetically, 87% (n=200) of the respondents were satisfied with the natural look of their restorations. In terms of durability, 90% of biofilling was found to be intact after six months, but small chipping was noted in 3% of instances, mostly in high-stress areas. Ceramic-based biofillings of the considered materials received the highest performance score (4.8/5) due to the increased biocompatibility and mechanical strength. To sum up, biofillings are a consistent and efficient choice of restorations, with high patient satisfaction and clinical outcomes. Nevertheless, more material optimization is suggested to resolve minor problems with discoloration and wear. The use of zinc oxide nanotechnological innovations and bioactive surface treatment could offer a potential solution in antimicrobial effect, stain resistance, and durability**.**

Keywords. Biofillings, Zinc Oxide, Dental Restorations, Biocompatibility, Aesthetic Dentistry.

Introduction

The combination of nanotechnology and bioactive substances has played a significant role in the creation of recent improvements in restorative dentistry, with biofillings being one of its innovations [1]. Not only do these materials rebuild tooth structure, but they also can biologically interact with adjacent tissues, improving the healing and future clinical outcome [2,3]. Zinc oxide (ZnO) has proven to be a promising substance because of its antimicrobial properties, biocompatibility, and mechanical integrity [4,5]. The production of highly controlled ZnO nanostructures can be achieved by advanced synthesis methods such as epitaxial growth and hydrothermal methods, which can be used in biomedical applications [6,7] .Also, ZnO nanowire arrays have been shown to exhibit superior surface area and [13].. functionality, enhancing adhesion and bioactivity in dental restorations [8,9]. Zinc-based materials have in the past been used extensively in medical and industrial applications because of their chemical stability and therapeutic effects [10,11]. Their contribution to dentistry has changed over the years and helped in designing modern restorative materials with better performance properties [12]. Moreover, metal oxides are highly resistant to degradation and thus suitable for long-term clinical studies New developments in dental materials have also centered on the enhancement of glass ionomer cements and composite systems that are superior in adhesion, fluoride release, and the aesthetic effect [14]. Nevertheless, conventional materials remain limited in terms of discoloring, wear, and loss of strength in the situation of high mechanical stress [15]. Thus, the integration of nanotechnology and specifically ZnO compounds is a good way to overcome these difficulties.

Methodology

This was a retrospective cross-sectional design study aimed at measuring the clinical performance of biofilling restorations, as well as patient-reported outcomes of the post-treatment comfort, aesthetic satisfaction, durability, and overall acceptance of the treatment. The research was carried out in five Libyan dental clinics and involved patients who had undergone biofilling procedures within 6 months before the time of data collection, the operative procedure itself was performed in March and the evaluation was on August of 2025.

Data Collection

An organized and methodical data gathering plan was adopted to guarantee the truthfulness, uniformity, and trustworthiness of patient-reported data. The participants of the study were those who had undergone biofilling restorations and could give informed feedback on their clinical experience after undergoing treatment. The stratified random sampling technique was used to ensure equal representation by the demographic variables (gender and age groups) and various types of biofilling materials. There were 250 patients invited to take part in the study. Among them, 230 respondents had completed the questionnaire, giving it a response rate of 92 %, and 20 patients (8% did not complete the questionnaire or did not participate at all). The study population was well distributed in terms of demographics. The female participants was 54% of the entire sample (n = 135), and male participants constituted 46% (n = 115). Age distribution analysis revealed that 34% of participants (n = 85) were within the 31–45-year age group, followed by 30% (n = 75) aged 46–60 years, 24% (n = 60) aged 18–30 years, and 12% (n = 30) aged 61 years and above. This sampling was done to make sure that the study reflected the views of various age groups, thereby making the study more generalizable. A structured questionnaire comprising 20 items was used to collect data, which was structured to effectively assess the clinical performance of biofillings. The questionnaire was designed to include multiple-choice and Likert-scale questions to get both categorical and scaled responses. It was categorized into four main areas, which include post-treatment pain and sensitivity, aesthetic satisfaction, durability and wear resistance, and overall patient satisfaction. The questionnaire was able to capture responses regarding post-treatment sensitivity that were subsequently analyzed statistically. In terms of aesthetic results, 87 % of the participants (n=200) were satisfied with the color and natural appearance of their restorations. Only 10% (n = 21) reported any minor color changes, and 4% (n = 9) reported an apparent mismatch of the restoration and the natural dentition. Durability testing revealed that after 6 months of follow-up, 90 % of restorations (n = 207) had not suffered any structural damage and were intact. In 7 % of cases (n = 16), minor surface roughness was noted, and in 3 % (n = 7), chipping or wear was witnessed, mostly on posterior teeth that were exposed to increased occlusal forces. The general satisfaction with the treatment was quite high, as 91% of the respondents (n = 209) said that they would recommend biofilling treatments to other people. In 6% of the cases (n = 14), the neutral responses were observed, and 3% of the respondents expressed dissatisfaction (n = 7). The average level of satisfaction was determined to be 8.7 out of 10, which indicated a fairly positive experience for the patient.

The mixed-mode distribution strategy was used to collect data. Clinical settings were used to gather around 60 % of the responses face-to-face, and the remaining 40 % was collected electronically via Google Forms sent via WhatsApp and email. Research assistants were also well-trained and could clarify where necessary to enable uniform interpretation of the questionnaire items. All data collected was subjected to a strict validation and cleaning before analysis. Questionnaires that were not filled were dropped, and responses were cross-tabulated in order to detect any inconsistencies. This step led to the end result of 230 eligible responses and a high quality and reliability of data to be used in further statistical analysis.

Study Procedure and Instrument Development

The methodology applied in the research had a systematic procedure to achieve a high level of rigor and reproducibility. The questionnaire development was a significant step in the study design, and it was based on the thorough evaluation of the pertinent literature in the field of restorative dentistry and biomaterials. The original form of the questionnaire was formulated to cover important issues on biofilling performance, such as clinical comfort, aesthetic integration, and material durability. In order to improve content validity, the questionnaire was pretested by three seasoned dental professionals who gave expert advice on the relevance and clarity of the questions. The sample of 20 participants (the percentage age of the target population is about 8) and five dental practitioners were used as a pilot study. This pilot test was to determine the clarity, understandability, and applicability of the questionnaire. According to the received feedback, some minor changes were made. Two questions were reworded to enhance clarity, one unnecessary item was dropped, and another element was added to better measure long-term material performance. After these improvements, the questionnaire was revised and passed to be distributed on a large scale. The validation process and the structure guaranteed that the instrument was reliable and capable of obtaining meaningful patient-reported outcomes.

Data Processing and Statistical Analysis

After data collection, all the answers were collected and structured into a coded system and input into a statistical analysis program. To guarantee the correct calculation and information management, SPSS and Microsoft Excel were used to perform quantitative analysis. The data were summarized using descriptive statistical techniques with frequencies, percentage ages, means, and standard deviations. These were measures to assess trends in the four main areas of the study. Inferential statistical analysis was performed to explore relationships between variables. Another chi-square test was conducted to compare the correlation between the type of biofilling material and level of patient satisfaction, and the correlation was found to be statistically significant ($p < 0.05$). Moreover, a one-way analysis of variance (ANOVA) was performed to compare the results of the durability of various biofilling materials. The findings showed that the ceramic-based biofillings scored the highest in terms of durability (4.8/5), followed by the glass ionomer (4.6/5) and composite resin (4.2/5). Moreover, a correlation was done to evaluate the relationship between the material type and post-treatment sensitivity. In the case of composite-based restorations, a moderate positive correlation ($r = 0.42$) was found, which means that mild sensitivity was more commonly related to the use of composite-based restorations than to other materials.

Ethical Considerations

Ethics were enforced in the course of the study. Informed consent was obtained before participation, and anonymization of responses was done to guarantee confidentiality. The data were safely stored in encrypted and password-protected files, and the participants had the freedom to leave the study at any point with no consequences. The research was carried out unbiasedly with no external funding or commercial impact, which guaranteed objectivity and minimized the chances of bias in the data gathering and analysis.

Results

The data on 230 valid responses were analyzed, and this can be considered a 92 % response rate of 250 total patients. The findings are reported based on the key areas of the study, such as post-treatment sensitivity, aesthetic satisfaction, durability, and patient satisfaction.

Post-Treatment Sensitivity

The evaluation of the post-treatment results showed that most patients reported little or no pain after biofilling surgeries. In particular, 72 % of respondents (n = 165) did not complain of any pain or sensitivity following treatment, which is an indication of a high degree of post-treatment comfort and a positive biological compatibility of biofillings. One-fifth of patients (n = 41) out of 18% complained of mild discomfort, and 10% (n = 24) exhibited moderate sensitivity necessitating follow-up. There were no severe cases of pain. These findings are summarized in (Table 1).

Table 1. Post-Treatment Sensitivity Results (n = 230)

Outcome Category	**Number of Patients (n)**	**%age (%)**
No pain	165	72%
Mild pain	41	18%
Moderate sensitivity	24	10%

Aesthetic Outcomes

Aesthetic performance assessment showed that there was high patient satisfaction. Eighty-seven % of the respondents (n = 200) said that they were satisfied with the color and natural look of the biofilling they had. Nonetheless, a smaller proportion of patients (10%, n = 21) were found to have slight color changes with time, whereas 4% (n = 9) of the patients reported a significant difference with natural tooth color. (Table 2) shows these results.

Table 2. Aesthetic Satisfaction (n = 230) Outcomes

Outcome Category	**Number of Patients (n)**	**%age (%)**
Satisfied (natural appearance)	200	87%
Minor color change	21	10%
Noticeable color mismatch	9	4%

Durability and Wear Resistance

The six-month follow-up durability testing showed that most bio fillings did not lose structural integrity. Nine out of ten restorations (n = 207) had no apparent damage. Only 7% of the patients (n=16) had minor surface roughness, and 3% (n=7) chipping or wear, mostly in posterior teeth that were exposed to greater occlusal forces. The detailed findings are shown in (Table 3).

Table 3. Wear Resistance Results and Durability (n = 230)

Outcome Category	Number of Patients (n)	%age (%)
No visible damage	207	90%
Minor surface roughness	16	7%
Chipping or wear	7	3%

Overall Patient Satisfaction

Participants were generally very satisfied. They would recommend biofilling treatment to others, as shown in (Table 4). A total of 91% (n = 209) showed. Patients reported neutral responses (n = 14; 6 % of the total) and dissatisfaction (n = 7; 3 % of the total). The average level of satisfaction was 8.7 out of 10. The general patient satisfaction is shown in (Figure 1).

Table 4. Overall Satisfaction

Category	n	%
Recommend	209	91%
Neutral	14	6%
Not recommend	7	3%

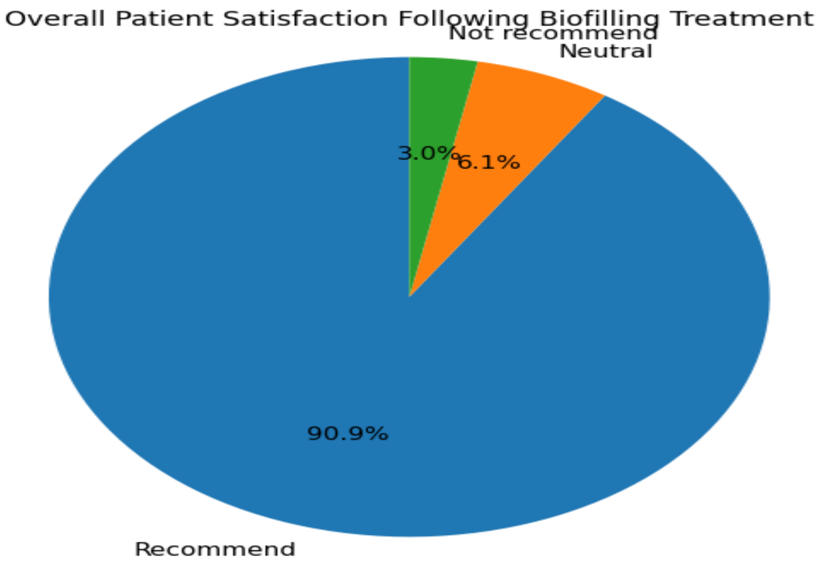

Figure 1. General patient satisfaction after biofilling procedure

Comparative Performance of Biofilling Materials

Comparative study of biofilling materials revealed that there were differences in the performance of the materials. Biofillings made of ceramic blended with the highest durability (4.8/5) rating, followed by the glass ionomer materials (4.6/5) and the composite resin (4.2/5). A statistical analysis showed that there was a significant relationship between the type of materials and patient satisfaction ($p < 0.05$). Moreover, correlation analysis revealed a moderate positive correlation ($r = 0.42$) between composite-based restorations and the incidence of mild post-treatment sensitivity. These results show that ceramic-based biofillings have high mechanical and biological functionality as compared to others. (Figure 2) shows the comparative performance of biofilling materials.

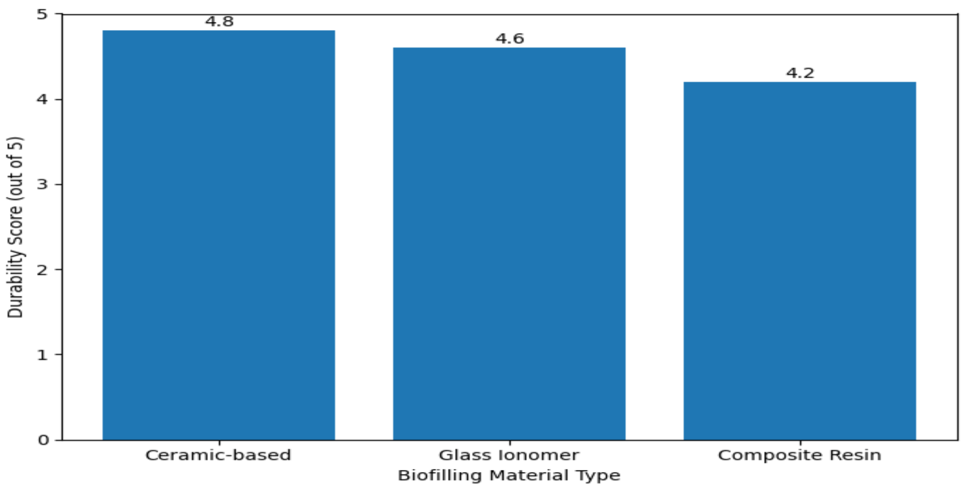

Figure 2. Comparison of durability scores of various biofilling materials

Discussion

The findings of this paper validate the fact that biofillings are a quality and stable restorative solution, which is able to deliver high patient satisfaction and clinical efficacy. The relatively large sample size (n = 230) and inclusion of various clinical settings are key strengths of this study. These results are harmonized with the existing studies that indicate the benefits of high biomaterials in dentistry [16,17]. Biocompatibility is a major issue in the achievement of restorative success since a material has to combine well with oral tissues without eliciting a negative response. Past research has shown that contemporary dental substances are highly biologically compatible and less cytotoxic [18,19]. Specifically, ZnO-based materials have demonstrated the capability to promote tissue healing and offer antimicrobial protection, thus minimizing the risk of post-treatment complications [20,21]. Aesthetic satisfaction was high in this study, which connects with previous studies that have shown that modern bioactive materials are capable of replicating the natural look of teeth closely [22]. Nevertheless, small discoloration, which is reported in a few cases, can be explained by the chemical characteristics of composite materials and their reaction with oral fluids during the time period [23]. Another key success factor in the long-term success is durability. The current results with high structural integrity and low failure rates are reinforced by the past research that indicated the mechanical strength of the material based on ZnO and its ability to resist wear [24,25]. Nanostructured ZnO structures (especially in nanorods and nanowires) can be used to achieve a high level of mechanical stability and high-stress performance [[26,27]. The high effectiveness of the biofillings made of ceramics in this study is in line with the literature, which shows that they have good mechanical properties and aesthetic benefits [28]. Although they are effective, cost is a limiting aspect that has been emphasized in past research on accessibility and affordability of advanced dental materials [29]. Moreover, the latest advances in nanotechnology have presented new applications of ZnO in dentistry, such as self-healing substances and antimicrobial coating [30]. A limitation of the study is the relatively short period of follow-up (six months) that might not adequately reflect long-term material performance. The developments above imply that the future development of biofilling materials will probably revolve around the issues of improving the durability, minimizing the discoloration, and making them more affordable.

Conclusion

The results of this paper have shown that biofillings are a good and safe method in modern restorative dentistry as they are characterized by high patient satisfaction rates, good aesthetic quality, and high clinical permanency. Most patients experienced limited or no post-treatment discomfort, and the level of overall satisfaction was constantly high, which indicates that these materials are clinically acceptable. Moreover, the findings have shown that biofilling materials, especially those that are made of ceramic, have a higher performance with regard to structural integrity and long-term stability. The results presented above indicate the promise of bioactive and nanostructured materials to improve the quality of dental restorations and patient-centered outcomes. Although the performance was generally positive, some weak points were noted in a few cases, including discoloration, surface rugae, and some wear. These results indicate that material optimization is needed to enhance aesthetic stability and resistance to mechanical stress over time. Future studies ought to be directed to the creation of superior bioactive formulations that are more antimicrobial, stain-resistant, and more cost-effective. It is also advisable to use long-term clinical trials with long follow-ups to confirm the long-term performance and durability of biofillings. Finally, biofillings are promising and clinically viable as an alternative to traditional restorative materials and can be used more widely in the contemporary dental practice, which will promote further development of biomaterials design. These observations reinforce the increasing importance of bioactive and nanotechnology-based materials in the future of restorative dentistry.

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