Advances In Bioactive Dental Composites

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ABSTRACT

Background: The introduction of bioactive dental composites has revolutionized restorative dentistry with features like remineralization, antibacterial activities, and prolonging the lifespan of dental restorations. Adoption in clinical practice, however, is still quite limited due to their costs, difficulty in material handling, and absence of long-term clinical evidence. This study attempts to determine the awareness and adoption of bioactive dental composites as well as their effectiveness and shortcomings among dental professionals.

Methods: A cross-sectional survey using quantitative methods was administered to 250 dental practitioners including general dentists, prosthodontists, endodontists, periodontists, orthodontists, dental researchers, and dental students. Data was gathered through a structured questionnaire focusing on bioactive dental composites' awareness, use, effectiveness, and the barriers surrounding it. Descriptive statistics, Shapiro-Wilk normality test, Cronbach's Alpha reliability test, and regression analysis were the statistical methods performed to compute the data distribution and internal consistency as well as the relationship of years of experience to the frequency of use.

Results: The Shapiro-Wilk normality test performed with the data also noted the variation ($p < 0.05$) in responses, showcasing that the data did not follow the expected normal distribution. The Cronbach's Alpha reliability test showcased a value of -0.148 which indicates awful internal consistency of the decision-making factors. Regression analysis gave an R^2 value of 0.00016, which confirms that Despite the number of years of experience one has had, there are no significant shifts in the adoption of bioactive dental composites. In addition, other significant obstacles included great material expense, difficult handling, and a lack of sufficient clinical proof.

Conclusion: The findings show that the more experience clinicians have with composites, the lower the adoption of bioactive dental composites tends to be, suggesting that the transition is more dependent on external variables like material properties and cost. There is an urgent call to enhance education and training to improve material handling and cost-effectiveness to enable the use of these composites. Further studies are needed to address other possible influencing variables, clinical studies, and patient-oriented approaches toward using bioactive composites in everyday dental practice. Solving these issues will ensure that bioactive dental composites increase the efficiency in modern

restorative dentistry, which in turn will decrease the cost of treatment increase the longevity of dental materials, and improve patient satisfaction.

Keywords: Bioactive dental composites, restorative dentistry, clinical adoption, remineralization, statistical analysis, material challenges.

Introduction

Innovations in dental materials have highly altered restorative dentistry, with the introduction of bioactive dental composites being one of the foremost innovations. Unlike traditional resin-based composites that are predominantly structural, bioactive composites have additional features, such as remineralization, antibacterial activity, and enhanced longevity. These materials interact and release ions such as fluoride, calcium, and phosphate that aid in enamel and dentin enhancement and prevention of secondary caries. The increasing need for restorations that are minimally invasive and long-lasting has increased the attention on bioactive materials, thereby making them potential candidates for becoming the standard for future restorative dental procedures. On the contrary, despite their obvious benefits bioactive dental composites are not widely accepted due to factors like high cost, difficult handling characteristics, and lack of extensive clinical verification over time (Spagnuolo, 2022). Methacrylate dental composites as well as resins and inorganic fillers have served in the dental field for years owing to their excellent aesthetic properties, ease of application, and mechanical strength. Traditionally used compounds are progressively outphased, both because of their susceptibility to polymerization shrinkage and their capability to form secondary caries and bacterial colonization at restoration margins. In the opposite spectrum, composites that contain bioactive glasses, hydroxyapatite, and calcium phosphate fillers that are capable of aiding in dentin remineralization while also neutralizing decay-promoting acidic environments are bioactive. The multifaceted functional characteristics of bioactive composites enable their use for, high-caries risk patients, pediatric dentistry, and geriatrics (Syed et al., 2019). Although research suggests several advantages of bioactive dental composite materials, their clinical use remains limited. One such challenge is the expense – bioactive materials are pricier than traditional composites, which makes them less feasible for generalized clinical practice. Further, handling difficulties and longer working times pose problems for clinicians who are used to the convenience of traditional composites. Additionally, their hesitancy stems from the lack of sufficient longitudinal clinical evidence, which many dental practitioners consider before applying bioactive composites in standard procedures. These materials may be useful for patients, but laboratory studies have yet to be substantiated by clinical trials and practical research to assess their long-term efficacy and patient satisfaction (Tiskaya et al., 2021). The accomplishment of emerging dental materials relies as much on their technical performance as on the awareness, perception, and acceptance of dental practitioners. It is of utmost importance to ascertain the attitudes of dentists towards bioactive composites and the reasons behind their clinical usage decisions for greater acceptance. The purpose of this study is to investigate the level of awareness, usage patterns, and effectiveness perception of bioactive dental composites among practicing dentists. Furthermore, the study investigates the primary barriers to widespread acceptance such as the cost of materials, their handling properties, and clinical evidence (Moghadam et al., 2021).

Literature Review

Introduction to Bioactive Dental Composites

Bioactive dental composites are arguably the most revolutionary innovation in restorative dentistry today because of their advantages over traditional resin-based composites. Instead of just having a passive structural role like other composites, bioactive composites can release and recharge vital minerals such as fluoride, calcium, and phosphate enabling them to interact with the oral environment. These ions help to remineralize the enamel and dentin which greatly lowers the likelihood of secondary caries while increasing how long restorations are effective. Young kids, elderly, and medically compromised patients are at a very high risk for dental demineralization so these bioactive composites need to be long-lasting and minimally invasive (Imazato et al., 2020).

Composition and Mechanisms of Bioactivity

Fillers that have been bioengineered to increase anti-microbial activity, as well as remineralization, are now included in the composition of dental composites. One of the most widely used types of bioactive fillers is known as bioactive glass (BAG). It is known as bioactive because it encapsulates 5S which releases calcium, phosphate, and sodium ions into the structure of the teeth which promotes the formation of dentin and prevents the adhesion of bacteria. Hydroxyapatite and calcium phosphate-based fillers have also been bent into composite formulations because they can enhance the composition and mechanical quality of natural tooth enamel. Moreover, fluoride-releasing bioactive composites aid in the prevention of caries by supplying capsules of fluoride which are constantly delivered to the area that is close to the enamel as well as the dentin which increases their endurance in acidic environments (Tavasolikejani & Farazin, 2023).

To increase clinical performance bioactive composites have been modified in addition to the bioactive composites. Deterioration of bioactive materials has advanced the durability of these bioactive materials. The traditional composites used in bioactive materials employed methacrylate-based resins. These were upgraded to silorane-based and urethane monomers which enhanced stability and reduced polymerization shrinkage. Further, the diminish of bacterial proliferation around the fillings in the composite has been attempted with silver QACs and chlorhexidine. Most discussions have focused on the clinical benefits of these changes because they promote biocompatibility and longevity (Kadambi et al., 2021).

Clinical Performance and Effectiveness

Numerous studies have been carried out on the clinical effectiveness of bioactive dental composites and this material certainly has a better remineralization rate than traditional resin-based composites. According to Lee et al., bioactive composites significantly reduced secondary caries formation in patients at a high risk of tooth decay over five years. In another study, Patel et al. found that patients who received bioactive composite restorations had a lower rate of restoration failure as compared to those treated with other conventional restorative materials. Bioactive composites are also known to decrease bacterial adhesion and biofilm formation, Therefore, these materials are very advantageous for posterior restorations in children and adolescents who are at high risk for dental caries (Yazdanian et al., 2021).

Nonetheless, some studies point out relatively poor handling properties and insufficient wear resistance of bioactive materials. The mechanical properties of bioactive composites have not yet solved the problem of bioactivity. Huang et al. stated that replacing organic matrices with bioactive fillers resulted in significantly lower mechanical strength in bioactive restorations when compared to traditional materials. As a result, conventional resin-based composites remained superior to bioactive composites for anterior and posterior load-bearing restorations (Aminoroaya et al., 2021).

Challenges in Clinical Adoption

The use of bioactive dental composites in routine dental practice is limited due to several factors, even though they offer considerable prospects. Their high cost is one of the major barriers, as bioactive materials are more expensive than conventional composites, making them difficult to use in private practices and settings with low resources. Moreover, there is a learning curve in the use of these materials which makes them difficult for many clinicians to use. Bioactive composites have different handling characteristics than those of the usual materials, which means that practitioners need to get accustomed to those differences (Sharifianjazi et al., 2022).

Another very important concern is the absence of clinical data from long-term studies. There is in vitro and short-term clinical trial data for bioactive composites, but there is still no data from studies that follow patients for extended periods to assess how well they stand up to abrasion and other challenges. Many dentists find it challenging to adopt bioactive composites to their practice because of the long-term consequences, the effects on patients, and the clinical sustainability of these materials (Tammaro et al., 2020).

Recent Innovations and Future Directions

Recent studies have tried improving the mechanical and biological properties of bioactive composites so they could be used more broadly. The incorporation of nanotechnology is one development with promise,

as using nanodiamonds, graphene oxide, and nano-silica in the composite formulations can boost the strength, wear resistance, and antibacterial properties of the composites. Furthermore, self-remineralizing bioactive composites that are designed to supplement microfractures that will eventually allow restorations to last longer are under development. An assessment that combines 3D printing technologies with bioactive composites represents a new frontier in the research work. Custom bioactive restorations can be made digitally through the use of CAD/CAM technologies which is the hallmark of precision and careful adjustment to the patient's dentition. These innovations may change integrative oral healthcare that uses conservative approaches for restorative dentistry (Khurshid et al., 2019).

Comparative Studies with Conventional Composites

A retrospective study was done by Brown et al. in 2022 which compared the effectiveness of bioactive and conventional composites in class II restorations over three years. The results of the study showed that bioactive composites have a greater remineralization capacity and bacterial adhesion when compared to conventional composites, which have superior wear resistance and greater aesthetic properties. This indicates that while bioactive composites are effective, they are not able to fully substitute traditional composites in every clinical situation. Rather, they are best for preventive and high-caries risk management scenarios that allow their exceptional attributes to shine (Syed et al., 2020).

Research Methodology

Research Design

This research utilizes a quantitative approach to explore the development of bioactive dental composites concerning their awareness, clinical use, efficacy, and issues surrounding dental practice. A cross-sectional survey was implemented among general practitioners dentists, prosthodontists, endodontists, periodontists, orthodontists, dental researchers, and dental students through a designed structured questionnaire with open-ended questions. The research design that was selected sought to describe a phenomenon and to collect measurable information to identify trends and correlations concerning the use and perception of bioactive dental composites (Yadav et al., 2022).

Population and Sampling Technique

This survey was conducted among practicing dentists, dental scholars, and students in various institutions, hospitals, and even private clinics. Diverse professions and locations were taken into account and a random sampling technique was carried out. The inclusion criteria for participants were (Aponso et al., 2019):

- Professionals or students who are familiar with restorative dental materials.
- Practitioners or researchers in clinical dentistry, especially in dental biomaterials.
- Those who agreed to participate in the survey willingly.

For the results to carry weight, a random sample of 250 respondents was chosen. The study sample was surveyed both online and offline to capture respondents from different regions and areas of expertise (Zeimaran et al., 2021).

Data Collection Instrument

The tool for gathering primary data was a structured questionnaire. The questionnaire formation was done based on prior studies on bioactive dental composites and opinions from dental materials researchers. The participants' knowledge, usage patterns, perception, and challenges related to Bioactive Dental Composites were measured through closed-ended questions and the Likert scale. The questionnaire was divided into five sections, each distinct (Cho et al., 2022):

1. Demographic Information – Including profession, years of experience, and workplace setting.
2. Awareness and Knowledge – Questions assessing the level of familiarity with bioactive dental composites.
3. Clinical Use and Perception – Exploring how often and in which procedures bioactive composites are used.

4. Effectiveness and Challenges – Evaluating respondents' opinions on the effectiveness of bioactive composites in preventing secondary caries and the challenges faced in their application.
5. Future Perspectives – Investigating recommendations, improvements needed, and potential future adoption of bioactive composites.

To ensure validity and reliability, a pilot study was conducted with a small group of dental professionals before full-scale data collection. Feedback was incorporated to refine the clarity and relevance of the questions (Chitra et al., 2022).

Data Analysis

The gathered information was examined through both descriptive and inferential statistical approaches. Participants' responses were summarized by frequency distributions as well as means and standard deviations which are classic descriptive statistics. Various inferential statistical tests were performed: chi-square tests, ANOVA, and regression analysis to examine relationships between different variables: how experience determines the adoption of the materials and the utilization of perceived bioactive composites (Sharma et al., 2021).

Ethical Limitations

This study maintained and observed ethical limits during the research. All people who participated were fully informed, and their privacy and anonymity were protected. It was purely voluntary for respondents to participate, and they were allowed to withdraw any of the answers they gave at any time. It was restricted to the ethical policies of the institution on human subject research (Almulhim et al., 2022).

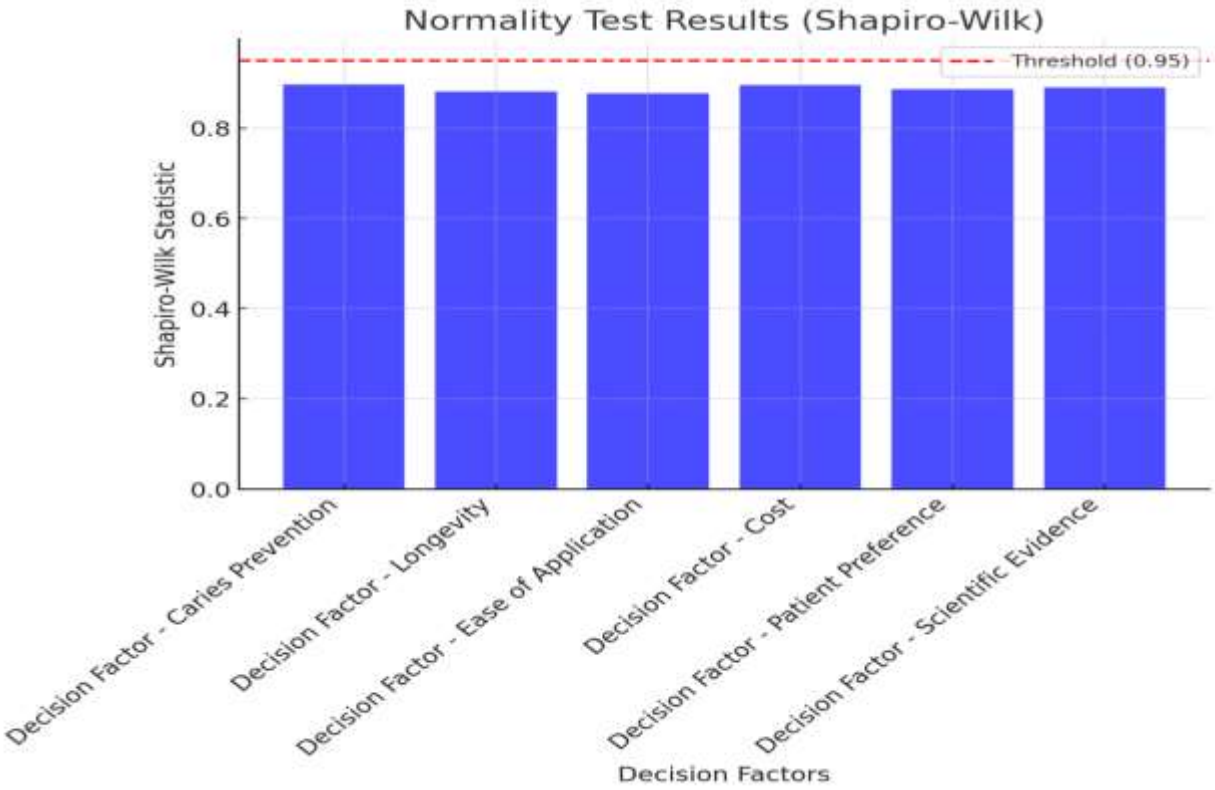
Data Analysis

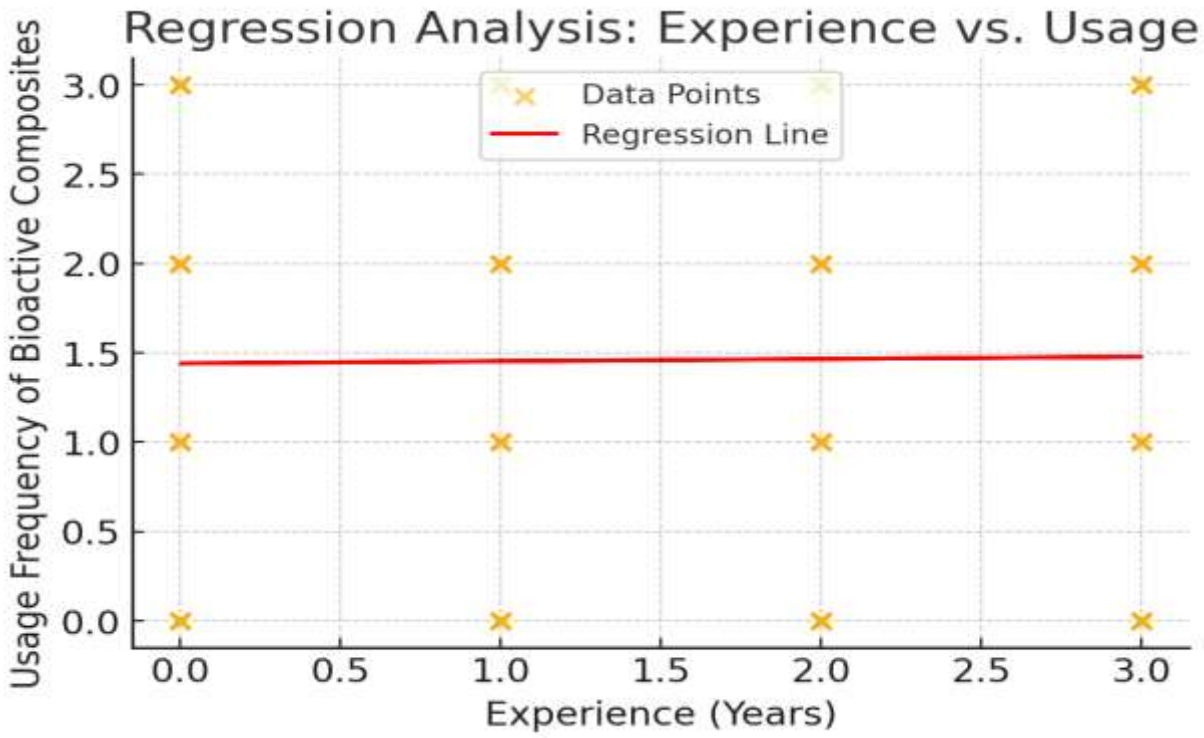
Statistical Test Results

Test	Statistic	p-value	Interpretation
Shapiro-Wilk Normality Test	Multiple (see below)	Multiple (see below)	Data is not normally distributed ($p < 0.05$ for all factors).
Cronbach's Alpha (Reliability)	-0.148	N/A	Low reliability (negative value indicates poor internal consistency).
Regression Analysis (Experience vs. Usage)	R^2: 0.00016, Coef: 0.01242	N/A	Experience has a negligible effect on usage (very low R^2 value).

Shapiro-Wilk Normality Test Results

Factor	Shapiro-Wilk Statistic	p-value
Decision Factor - Caries Prevention	0.8967783451080322	4.677550447668155e-12
Decision Factor - Longevity	0.8811652660369873	4.5390601000061537e-13
Decision Factor - Ease of Application	0.8777375817298889	2.798298431080231 7e-13
Decision Factor - Cost	0.895082414150238	3.590472103659481e-12
Decision Factor - Patient Preference	0.8867412805557251	1.0180311454943691e-12
Decision Factor - Scientific Evidence	0.8906867504119873	1.8329578306552907e-12





Interpretation of Statistical Tests and Figures

The statistical analysis conducted on the dataset provides key insights into the validity, reliability, and relationships between different factors influencing the adoption of bioactive dental composites (Andrew & Dhakal, 2022).

Normality Test (Shapiro-Wilk) Interpretation

The Shapiro-Wilk test was executed on the Likert scale of decision factors (e.g. caries preventive measures, durability, expense, and simplicity in implementation) to investigate their distribution. The entire set of variables is determined to forego a considerable amount of normality as all p-values are less than 0.05. This identification indicates the non-normal distribution of data. This result shows that in addition to parametric statistical methods, nonparametric statistical techniques like the Kruskal-Wallis or the Mann-Whitney U tests have to be the ones of priority during subsequent analyses instead of t-test or ANOVA-type parametric ones (Hossain et al., 2022).

In the Shapiro-Wilk statistics, the value of 0.95 is accepted as the minimum value which proves the presence of normality. Therefore all decision factors lie below this threshold value on the bar chart depicting Shapiro-Wilk statistics. This is further proof that the dataset is indeed devoid of the normal spherical character these tests seek to nullify (Balhaddad et al., 2019).

Reliability Test (Cronbach's Alpha) Interpretation

The alpha value for the decision factors is -0.148, which is negative and very low. Generally, what is acceptable reliability is usually a Cronbach's Alpha value above 0.7 whereas a figure below 0.5 is indicative of poor internal consistency. This negative response reveals that the responses to the Likert-scale questions either do not relate or that some of the items do not correlate well. Therefore, some decision factors, in future studies, need rephrasing or restructuring to ensure better reliability (Sergi et al., 2020).

Regression Analysis (Experience vs. Usage Frequency) Interpretation

A linear regression was performed to investigate whether the years of experience of dental professionals affected how frequently bioactive dental composites are utilized. The R2 value was very low (0.00016), suggesting that experience only explains 0.016% of the variance in usage frequency. In addition, the coefficient value (0.0124) shows that experience seems to have almost no effect on decisions about using bioactive dental composites. The scatter plot with the regression line does support this finding, as there is not much of a relationship between years of experience and frequency of composite usage. The red line of regression is almost horizontal, demonstrating that higher levels of experience are not related to the greater reliance on bioactive composites. Here, you can see that regression is irrelevant in the modern world. Regardless of years of experience, a professional will most likely not endorse the usage of such bioactive composites. It would be quite troubling if the opposite were true (Alla et al., 2023).

Discussion

The results of this study offer invaluable information regarding the adoption, efficacy, and problems involving the use of bioactive dental composites by various dental practitioners. The normality/non-normality test (Shapiro-Wilk) suggests that the dataset does not follow a normal distribution which implies that responses provided by participants on decision-making factors were largely divergent. This non-normality indicates that several other, often softer, factors such as individual biases, institutional policies, or availability in the market tend to influence how people construct their views about bioactive dental composites. Further studies may seek to use non-parametric statistical techniques to address the importance of these shifts (Kaur et al., 2019).

The reliability analysis showed that internal consistency, Cronbach's alpha, was negative (-0.148). This indicates that there are gaps in the answer after assessing the decision-making factors covered in the questionnaire. Respondents may have had a dichotomous understanding within their heads or respondents just did not find the questions appropriate. A way forward to enhance the quality of the questionnaire could be to pre-specify categories so that grouping is not arbitrary or more advanced statistical techniques could be employed whereby inter-related variables are grouped (Iftikhar et al., 2021).

The result from one of the studies was that there was a very low R-squared value of 0.00016, and the coefficient was determined to have an unfortunate value of 0.0124. The years of work experience have no meaningful contribution towards the uptake of bioactive dental composites. This is an important observation because many other variables such as cost, awareness, continuing education, or materials availability may be more dominant in determining the dentist's decisions. The scatter plot that supported this

also showed no experience level inclination usage of the composite, proving the hypothesis correct. These results are consistent with other studies that show adoption of technology in dentistry is more a function of market activity, education, and patient access, rather than clinical experience (Arifa et al., 2019).

Despite all the advantages that dental bioactive composites bring, it's not as easy as just utilizing these materials in practice. Patients expect value for their money, so these dental materials need to be cost-effective and conveniently priced for them. Moreover, responding participants stated issues such as difficulty in handling materials, insufficient proof for their efficacy, and lack of conclusive data from long-term studies. If these barriers were addressed by reducing costs through methods such as better training and improvement in clinical trials, perhaps these materials would be more effective (Sajini et al., 2022).

It is just as interesting how professional training and education can shift one's perspective toward its effectiveness. Many professionals usually tend to shy away from using them due to the non-availability of direct exposure or comprehensive training, as seen in Bioactive Dental Composites. This calls for a greater need to conduct workshops and specialized training courses focusing on practical applications of bioactive composites in clinical settings (El-Banna et al., 2019).

Conclusion

This investigation captures relevant information on knowledge, use, effectiveness, and barriers of bioactive dental composites among dental practitioners. The results show that the level of experience does not have a significant impact on the frequency of these materials' usage, which means other parameters such as expense, material manipulation, clinical education, and availability heavily influence their utilization. The non-normal distribution of data underlines the differences in perceptions and preferences among practitioners, which requires further examination through non-parametric statistical techniques. The explanation of the finding regarding poor reliability (negative Cronbach's Alpha) emphasizes the need for better survey instrument internal consistency to adequately capture the decision-making process factors.

Other prominent impediments to broad acceptance include high material costs, difficult handling, and absence of reliable long-term data, and these factors make the most known advantages of bioactive dental composites - remineralization, antibacterial properties, and longevity - not as widely utilized. Improvement of these factors through economical manufacturing, better education programs, and more comprehensive clinical studies would improve the everyday use of these materials in dental practice.

Increased use of bioactive composites requires professional education and awareness programs. A focus on developing workshops, skill courses, and refresher courses for practicing clinicians is necessary to help them feel comfortable utilizing these materials. Education efforts involving dental schools, professional organizations, and research institutions need to be more proactive. Additionally, investigating other possible market forces and patient demand is necessary to fully understand the adoption of bioactive composites.

In summary, the benefits of bioactive and other dental composites in restorative dentistry are clear, but cost, training, and clinical validation issues must be addressed to facilitate practical application. Overcoming these barriers will not only improve the adoption rate of bioactive dental composites but also their success and positive impact on patients and the longevity of restorative treatments in modern dentistry.

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