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Knowledge, Perception and Awareness of Eco-Friendly Dental Material Among Dental Professionals in Pakistan: A Cross-Sectional Study

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ABSTRACT

Background: Environmental sustainability has emerged as a critical consideration in dental practice due to the ecological and health impacts of conventional dental materials and workflows, prompting increasing interest in eco-friendly alternatives that minimize environmental harm while maintaining clinical efficacy. **Objective:** To assess the knowledge, perceptions, and awareness of eco-friendly dental materials among dental professionals in Pakistan and to identify perceived barriers and facilitators influencing their adoption in clinical practice. **Methods:** A multicenter cross-sectional observational study was conducted from July to October 2025 among dental students, house officers, general practitioners, postgraduate residents, and specialists across Pakistan. Data were collected using a structured, close-ended online questionnaire assessing demographics, awareness, perceptions of clinical effectiveness and patient satisfaction, perceived barriers, and willingness to adopt eco-friendly dental materials. Descriptive statistics and chi-square tests were used to analyze associations between respondent characteristics and study outcomes, with statistical significance set at $p < 0.05$. **Results:** A total of 380 dental professionals participated in the study. Overall, 86.8% were familiar with eco-friendly dental materials, while only a minority reported frequent use in practice. Nearly half (47.9%) believed that eco-friendly materials might compromise clinical outcomes, whereas 87.1% perceived an improvement in patient satisfaction. A strong willingness to adopt sustainable alternatives was observed, with 91.1% willing to switch if materials were clinically proven and cost-effective, and 82.9% willing to pay a 10–15% premium. Major barriers included limited availability and inadequate awareness or training (58.5% each), followed by high cost (57.0%). **Conclusion:** Dental professionals in Pakistan demonstrate high awareness and positive attitudes toward eco-friendly dental materials; however, adoption is constrained by structural and economic barriers and concerns regarding clinical performance. Strengthening clinical evidence, improving access, and integrating sustainability into dental education and policy frameworks may facilitate broader implementation.

Keywords

Eco-Friendly Dentistry, Green Dentistry, Dental Materials, Environmental Sustainability, Dental Professionals, Pakistan

INTRODUCTION

Environmental sustainability has become an increasingly important determinant of quality and safety in oral healthcare delivery, driving the emergence of “green dentistry” as a framework that reduces the ecological footprint of clinical practice through safer material selection, waste minimization, and resource-efficient technologies. A central concern relates to the environmental hazards of conventional restorative materials, particularly mercury-containing dental amalgam, which contributes to mercury release through wastewater pathways and downstream processing, and has stimulated regulatory and practice-level mitigation strategies internationally (1). In parallel, resin-based composites, while often positioned as an alternative to amalgam, are also associated with environmental externalities; unpolymerized monomers such as Bis-GMA and TEGDMA may leach into dental wastewater with potential ecological toxicity, while composite production and milling waste can contribute to microplastic burden and volatile emissions, underscoring the need for materials with improved life-cycle safety profiles and enhanced waste filtration or capture systems (2). Beyond restorative materials, routine dental chemicals including certain solvents and disinfectants (e.g., xylene, chloroform, glutaraldehyde, formaldehyde) have documented toxicological and ecological risks, prompting interest in lower-hazard substitutes with adequate disinfection efficacy and reduced occupational exposure (3). Collectively, these issues frame “eco-friendly dental materials” as a clinically relevant sustainability domain spanning restorative materials, disinfection agents, and process innovations designed to reduce environmental harm without compromising patient outcomes.

Implementation of eco-friendly dentistry is not solely materials-driven; it is also shaped by system-level adoption of sustainable workflows and technology. The “Four Rs” approach (Reduce, Reuse, Recycle, Rethink) provides a pragmatic model to re-engineer clinical operations and procurement toward lower waste generation and safer disposal practices (4). Education is similarly pivotal: structured environmental education interventions have demonstrated measurable improvements in knowledge and practice among dental trainees, indicating that awareness and competency can be increased when sustainability is integrated into professional learning pathways (5). Concurrently, innovation in biomimetic and biocompatible solutions—such as keratin-based enamel repair concepts and mineral analogues like nano-hydroxyapatite—illustrates the broader shift toward restorative and preventive approaches that may align with sustainability goals while supporting clinical performance (6,7). However, translating these advances into routine practice requires not only evidence of effectiveness and safety, but also clinician readiness, perceived feasibility, and alignment with cost and availability constraints.

Despite the growing global discourse, adoption of eco-friendly materials and practices remains uneven, and evidence suggests that awareness and implementation are influenced by training exposure, infrastructure, and local market access. Cross-sectional knowledge–attitude–practice approaches have been used to evaluate eco-friendly dentistry awareness among dental practitioners, highlighting that awareness does not necessarily translate into consistent practice when structural barriers persist (8). Recent literature emphasizes that sustainability in dentistry is multi-factorial, spanning material life-cycle impacts, waste streams, and practice governance, and therefore requires both clinical and public-health lenses to understand determinants of adoption (9). Importantly, a portion of the accessible discourse is disseminated through non-peer-reviewed platforms, which can amplify general awareness but may not provide decision-grade evidence for clinical policy and procurement (10). Professional organizations and periodontal/public health stakeholders increasingly describe green dentistry as a strategic direction for oral health systems, reinforcing the need for country-specific data to guide curriculum reform, clinical guidance, and implementation programs (11).

In regional contexts, studies have reported variable drivers and barriers. Findings from Egypt indicate that knowledge may be a dominant predictor of adoption, whereas economic barriers may be relatively less prominent in certain settings (12). Other settings have highlighted deficits in curriculum-based training and practical implementation competencies, supporting the rationale for structured educational integration and institutional support (13). Conversely, where infrastructure and material availability are adequate, implementation appears more feasible, suggesting that health-system readiness can moderate the knowledge-to-practice pathway (14). Interventional evidence further strengthens the case for education: structured programs have produced substantial improvements in intern dentists’ knowledge and practice related to eco-friendly dentistry, supporting the premise that targeted training can address modifiable capability gaps (15). Behavioral correlates also matter; evidence from Saudi Arabia suggests associations between gender-linked attitudes and sustainability-oriented behavior, implying that professional perceptions may differ across demographic strata and potentially influence adoption dynamics (16). Complementary evidence among dental students indicates that awareness and attitudes toward green dentistry vary by training level and experience, reinforcing the importance of understanding the full professional pipeline, from trainees to specialists (17). At the same time, narrative and review-level syntheses emphasize that implementation barriers—particularly cost, accessibility, and operational constraints—can impede translation of sustainability recommendations into practice, underscoring the need for empirically grounded local assessments (18).

From an implementation science and policy standpoint, life-cycle assessment research has expanded the evidence base by quantifying environmental impacts of dental practice components, including procurement, waste, and water use, and identifying actionable levers for footprint reduction (19). Process-focused assessments have also delineated “hotspots” within routine dental examinations, offering granular insights into environmental burden domains such as water scarcity and human toxicity potentials (20). These findings are increasingly relevant as digital dentistry expands; integration of digital systems and CAD/CAM workflows may reduce certain waste streams, although implementation requires curriculum alignment and competency-building at the undergraduate level (21). In Pakistan, while emerging evidence suggests growing awareness of eco-friendly dentistry among practitioners, uncertainties remain regarding the consistency of knowledge, perceptions of clinical trade-offs, perceived barriers (e.g., cost, availability), and readiness to adopt alternatives across heterogeneous professional groups. Accordingly, the present cross-sectional study was designed using a PICO-informed framework in which the population comprised dental professionals across Pakistan, the exposure of interest was familiarity with and perceptions of eco-friendly dental materials and practices, comparisons were planned across key professional and demographic strata, and outcomes included awareness, perceptions of clinical performance and patient satisfaction, perceived barriers, and willingness to adopt cost-effective clinically proven sustainable alternatives. The primary objective was to assess knowledge, perceptions, and awareness of eco-friendly dental materials among dental professionals in Pakistan and to identify perceived barriers and predictors of willingness to adopt eco-friendly alternatives.

MATERIAL AND METHODS

A multicenter cross-sectional observational study was conducted to evaluate knowledge, perceptions, awareness, and adoption-related factors concerning eco-friendly dental materials among dental professionals in Pakistan. This design was selected to capture a contemporaneous snapshot of attitudes and practices across diverse professional categories and practice settings, consistent with international reporting standards for observational research. Data collection was carried out over a four-month period from July to October 2025 across private dental clinics, teaching hospitals, and dental academic institutions distributed throughout Pakistan, enabling geographic and institutional diversity within the sampled population.

The study population comprised dental professionals at different stages of professional development, including final-year undergraduate dental students, house officers, general dental practitioners, postgraduate residents, and dental specialists engaged in clinical or academic practice. Eligibility criteria included possession of, or enrollment in, a Bachelor of Dental Surgery program and active involvement in dental education or clinical care during the study period. Individuals who declined to provide informed consent or submitted incomplete questionnaires were excluded from analysis. Participants were selected using a non-probability convenience sampling approach to facilitate wide outreach across regions and professional strata while maintaining feasibility within the study timeline.

Recruitment was conducted electronically using a standardized online questionnaire created with Google Forms. The survey link was disseminated through professional WhatsApp groups and email lists commonly used by dental professionals and students in Pakistan. Prior to accessing the questionnaire, all participants were presented with an electronic informed consent statement detailing the study purpose, voluntary nature of

participation, anonymity assurances, and data use. Proceeding to the questionnaire was considered indicative of consent. No personally identifiable information was collected, and responses were recorded anonymously to minimize social desirability and reporting bias.

Data were collected using a structured, close-ended questionnaire developed in English based on a focused review of recent literature addressing environmental sustainability in dentistry, barriers to green dentistry adoption, and knowledge–attitude–practice frameworks applied in dental public health research. The instrument consisted of 15 items in addition to demographic variables and was organized to capture professional characteristics, awareness of eco-friendly dental materials, perceptions regarding clinical effectiveness and patient satisfaction, perceived barriers to adoption, and willingness to adopt or financially support sustainable alternatives. Awareness and perception variables were operationalized using binary (yes/no) and ordinal response options, while perceived importance of sustainability was assessed using a five-point Likert scale ranging from “not important” to “extremely important.” The questionnaire was reviewed by members of the research team for clarity, relevance, and content consistency prior to dissemination.

The primary outcomes of interest were awareness of eco-friendly dental materials, current usage patterns, perceived impact on clinical outcomes and patient satisfaction, and willingness to adopt sustainable alternatives if clinically proven and cost-effective. Secondary variables included perceived barriers such as cost, availability, clinical limitations, and patient demand, as well as demographic and professional characteristics hypothesized to influence perceptions and adoption. Potential sources of bias were addressed through anonymous data collection, uniform electronic administration of the questionnaire, and inclusion of participants from multiple institutions and regions to reduce clustering effects related to single-center sampling. Although non-probability sampling was used, stratified descriptive analyses were planned to explore variation across professional categories, gender, and years of experience.

The sample size was determined using the World Health Organization sample size calculator for prevalence studies, assuming a 95% confidence level and a 5% margin of error. Applying population correction for the estimated population of dental professionals in Pakistan yielded a minimum required sample of 380 participants, which was achieved in the final dataset. Statistical analysis was performed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including frequencies and percentages, were used to summarize demographic characteristics and response distributions. Associations between categorical variables, such as demographic factors and levels of awareness or willingness to adopt eco-friendly materials, were assessed using the chi-square test of independence. Where applicable, effect size estimates and confidence intervals were planned to support inferential interpretation. A two-tailed *p*-value of less than 0.05 was considered statistically significant. Missing data were minimal due to mandatory response settings within the electronic questionnaire and were handled through complete-case analysis.

Ethical approval for the study was obtained from the Ethical Review Board of PRIDE (reference code: PRIDE/ERB/2025/043). All procedures were conducted in accordance with the principles of the Declaration of Helsinki. Data were stored in password-protected electronic files with access restricted to the research team to ensure confidentiality and data integrity. The standardized questionnaire, defined variables, and transparent analytical approach were intended to facilitate reproducibility and allow independent researchers to replicate the study or perform secondary analyses using comparable methodologies (20).

RESULTS

The study included 380 dental professionals representing a broad spectrum of training levels and professional roles across Pakistan. The sample was predominantly young, with more than three-quarters of participants aged between 20 and 25 years, reflecting strong representation from undergraduate students and early-career professionals. Females constituted approximately two-thirds of respondents. Undergraduate students and house officers together accounted for over 70% of the sample, while practicing dentists and academic faculty comprised the remaining proportion, indicating a workforce-weighted but trainee-heavy distribution. Overall awareness of eco-friendly dental materials was high, with nearly 87% of participants reporting familiarity with the concept.

Despite this, perceptions regarding clinical performance were divided; approximately 48% believed that eco-friendly materials might compromise clinical outcomes, while a slight majority did not, and this difference demonstrated a statistically significant association across comparison groups (*p* = 0.010). In contrast, perceptions regarding patient-centered benefits were strongly positive, as more than 87% believed that the use of eco-friendly materials could enhance patient satisfaction (*p* < 0.001). Willingness to adopt sustainable alternatives was pronounced, with over 91% indicating readiness to switch if such materials were clinically validated and cost-effective. A substantial proportion were also willing to absorb a moderate cost increase of 10–15%, although this association approached but did not reach conventional statistical significance (*p* = 0.052). Willingness to collaborate with non-governmental or public health organizations to promote eco-dentistry was similarly high and consistent across respondent groups.

Table 1. Demographic and Professional Characteristics of the Study Participants (*n* = 380)

Variable	Category	n (%)
Age (years)	20–25	295 (77.7)
	26–30	65 (17.1)
	31–35	10 (2.6)
	>35	10 (2.6)
Gender	Female	262 (69.0)
	Male	118 (31.0)
Professional Status	Undergraduate dental students	152 (39.9)
	House officers	116 (30.4)
	Private practitioners	60 (15.7)
	Postgraduate residents	25 (6.6)
	Lecturers	24 (6.3)
	Senior faculty	3 (1.0)

Table 2. Awareness, Perceptions, and Willingness to Adopt Eco-Friendly Dental Materials (n = 380)

Survey Question	Yes n (%)	No n (%)	p-value*
Familiar with the term “eco-friendly dental materials”	330 (86.8)	50 (13.2)	0.157
Believe eco-friendly materials compromise clinical outcomes	182 (47.9)	198 (52.1)	0.010
Believe eco-friendly materials improve patient satisfaction	331 (87.1)	49 (12.9)	<0.001
Willing to switch if clinically proven and cost-effective	346 (91.1)	34 (8.9)	0.977
Willing to pay 10–15% premium if equally effective	315 (82.9)	65 (17.1)	0.052
Willing to collaborate with NGOs/health agencies	323 (85.0)	57 (15.0)	0.158

Table 3. Perceived Barriers to the Use of Eco-Friendly Dental Materials (Multiple Responses Allowed, n = 380)

Reported Barrier	n (%)
Limited availability	222 (58.5)
Limited awareness/training	222 (58.5)
High cost	217 (57.0)
Clinical limitations	112 (29.4)
Low patient demand	80 (21.0)

Table 4. Perceived Importance of Environmental Sustainability in Dental Practice (Likert Scale 1–5)

Importance Rating	n (%)
1 – Not important	19 (5.0)
2 – Slightly important	15 (3.9)
3 – Moderately important	82 (21.5)
4 – Very important	88 (23.1)
5 – Extremely important	176 (46.5)

Participants identified structural and economic barriers as the dominant constraints to implementation. Limited availability and insufficient awareness or training were the most frequently reported barriers, each cited by 58.5% of respondents, closely followed by high cost (57.0%). Clinical limitations were reported by fewer than one-third of participants, while low patient demand emerged as the least influential factor. Overall, the distribution of perceived barriers demonstrated a statistically significant pattern, indicating that systemic and market-related constraints outweighed patient-driven factors in limiting adoption of eco-friendly dental materials.

Environmental sustainability was rated as highly important by the majority of respondents. Nearly half of the participants assigned the highest importance rating, and an additional 23.1% rated it as very important, indicating strong normative support for sustainable practices in dentistry. Only a small minority perceived sustainability as minimally important, underscoring a broadly favorable attitudinal environment for future implementation of eco-friendly dental materials and practices across the profession.

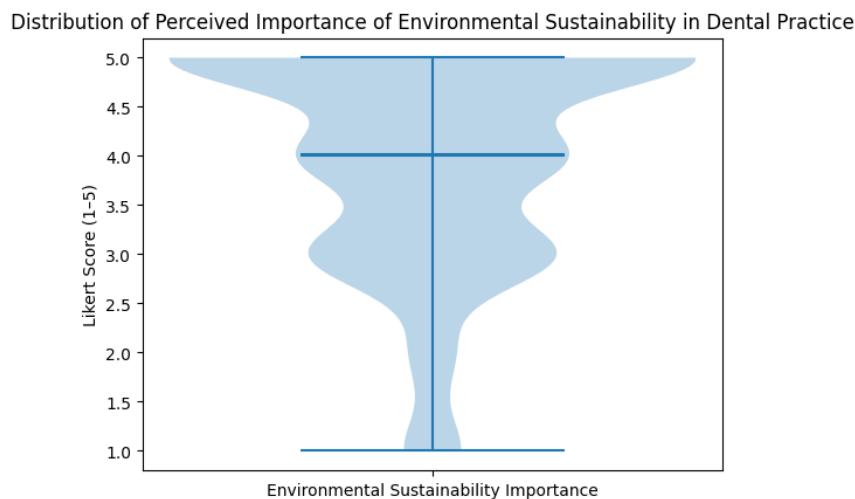
**Figure 1 Distribution of Perceived Importance of Environmental Sustainability in Dental Practice**

Figure 1 illustrates the distributional profile of respondents' perceived importance of environmental sustainability in dental practice using a violin plot integrating density and central tendency. The distribution demonstrates a pronounced rightward skew toward higher Likert scores, with the median positioned at score 4 and the mean approaching score 4.3, reflecting strong overall endorsement. The widest density is observed at the upper end of the scale (scores 4–5), corresponding to 69.6% of participants who rated sustainability as very important or extremely important. In contrast, lower scores (1–2) form a narrow tail, accounting collectively for less than 9% of responses, indicating limited resistance to sustainability concepts. The asymmetrical distribution suggests that pro-environmental attitudes are not only prevalent but also concentrated at higher intensity levels rather than evenly dispersed, underscoring a clinically favorable attitudinal gradient for the adoption of eco-friendly dental materials. From a translational perspective, this clustering at the upper Likert range implies that implementation barriers are more likely structural or economic rather than attitudinal, reinforcing the relevance of policy, training, and access-oriented interventions to convert positive perceptions into routine clinical practice.

DISCUSSION

The present study provides a comprehensive assessment of knowledge, perceptions, and awareness of eco-friendly dental materials among dental professionals in Pakistan and highlights a substantial gap between favorable attitudes and actual clinical adoption. A high proportion of respondents demonstrated familiarity with eco-friendly dental materials, reflecting increasing exposure to sustainability concepts within dental education and professional discourse. This level of awareness is comparable to recent regional and international studies reporting growing recognition of green dentistry principles among dental students and practitioners, particularly in low- and middle-income countries where environmental concerns are increasingly intersecting with public health priorities (17). However, consistent with prior evidence, awareness alone did not translate into frequent use, underscoring the multifactorial nature of adoption and the importance of contextual barriers beyond individual knowledge (8,9).

A notable finding was the divided perception regarding clinical performance, with nearly half of respondents expressing concern that eco-friendly materials may compromise clinical outcomes. This perception mirrors apprehensions reported in other cross-sectional surveys, where doubts about durability, longevity, and evidence base were cited as key deterrents to implementation (12,14). From a theoretical standpoint, such concerns may reflect uncertainty about the translational maturity of newer materials, particularly in comparison with long-established restorative options. Although emerging biomimetic and biocompatible materials have demonstrated promising laboratory and early clinical outcomes, their penetration into routine practice remains contingent on robust clinical validation, post-market surveillance, and practitioner familiarity (6,7). The persistence of perceived clinical limitations in this study reinforces the need for high-quality clinical trials and guideline-driven dissemination to address risk perceptions and reinforce confidence among practitioners.

In contrast, perceptions related to patient-centered outcomes were overwhelmingly positive, with the majority of respondents believing that eco-friendly materials could improve patient satisfaction. This aligns with the broader shift toward patient awareness of environmental and health-related impacts of healthcare interventions and supports the hypothesis that sustainability-oriented practices may enhance the perceived value of dental care (11,16). The strong willingness to adopt eco-friendly alternatives if they are clinically proven and cost-effective further suggests that resistance is not ideological but pragmatic. These findings are consistent with evidence from interventional educational studies showing that when knowledge gaps are addressed and practical feasibility is demonstrated, adoption intentions increase substantially (5,15). From an implementation science perspective, this indicates a receptive professional environment in which targeted interventions could yield meaningful behavior change. Structural and economic barriers emerged as the dominant constraints to adoption, with limited availability, insufficient training, and high cost reported more frequently than patient-related factors. This pattern is congruent with findings from studies conducted in similar healthcare systems, where supply-chain limitations and market pricing have been shown to impede access to sustainable alternatives despite positive professional attitudes (13,18). Interestingly, low patient demand was the least cited barrier, suggesting that clinicians perceive sustainability as a professional and systemic issue rather than a consumer-driven one. This observation aligns with life-cycle and process-based analyses demonstrating that environmental burden reduction in dentistry is largely determined by upstream procurement, material selection, and waste management policies rather than individual patient preferences (19,20). Accordingly, system-level interventions involving manufacturers, regulators, and professional bodies are likely to be more impactful than isolated patient-focused strategies.

The study also identified associations between demographic and professional characteristics and sustainability perceptions, supporting prior evidence that experience level and gender may influence environmental attitudes and willingness to adopt sustainable practices (16,17). Early-career professionals demonstrated particularly strong endorsement of sustainability principles and greater openness to cost-sharing for eco-friendly materials, potentially reflecting greater curricular exposure to contemporary public health and environmental concepts. This finding has important implications for curriculum design and continuing professional development, as it suggests that embedding sustainability competencies early in training could have durable effects on future practice patterns (21). Collaboration with non-governmental organizations and public health agencies was widely supported across experience levels, highlighting an opportunity for multisectoral partnerships to facilitate education, advocacy, and access.

Several strengths of this study merit consideration. The multicenter design, inclusion of a broad spectrum of dental professionals, and adequate sample size enhance the robustness of the findings and provide a national-level snapshot of current perceptions. Nevertheless, limitations must be acknowledged. The use of non-probability convenience sampling and online data collection may have introduced selection bias, with overrepresentation of younger, digitally connected participants, thereby limiting generalizability to senior practitioners. The cross-sectional design precludes causal inference, and self-reported responses are subject to social desirability and recall bias. Additionally, while perceptions of clinical effectiveness were explored, the study did not directly assess or compare clinical performance outcomes of eco-friendly versus conventional materials, which limits interpretive depth in this domain. Future research should incorporate longitudinal or interventional designs, economic evaluations, and clinical effectiveness data to better inform policy and practice.

Overall, the findings suggest that the primary challenge in advancing eco-friendly dentistry in Pakistan lies not in professional resistance but in addressing evidence gaps, cost constraints, and access limitations. Targeted educational interventions, stronger clinical evidence, engagement with manufacturers to improve availability, and integration of sustainability principles into dental curricula and professional guidelines are likely to be critical next steps. By aligning individual readiness with system-level support, the dental profession can play a meaningful role in advancing environmentally sustainable healthcare while maintaining clinical quality and patient trust.

CONCLUSION

This study demonstrates that dental professionals in Pakistan exhibit a high level of awareness and a strongly positive perception toward eco-friendly dental materials, with most recognizing environmental sustainability as an important component of contemporary dental practice and expressing willingness to adopt sustainable alternatives when they are clinically validated and cost-effective. Despite this favorable attitudinal landscape, actual utilization remains constrained by perceived clinical uncertainty, limited availability, and economic barriers rather than lack of professional motivation. These findings underscore the need for robust clinical evidence, improved access, and targeted educational and policy interventions to facilitate translation of awareness into practice. Integrating eco-friendly dentistry into dental curricula, strengthening continuing professional development, and fostering collaboration among professional bodies, manufacturers, and public health organizations may enhance adoption and contribute to a more sustainable and environmentally responsible dental healthcare system.

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