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Knowledge, Training Exposure, and Self-reported Dental Material Wastage among Undergraduate Dental Students in Pakistan: A Multicenter Cross-sectional Survey

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ABSTRACT

Objectives: Dental material wastage in teaching clinics creates avoidable financial pressure and may contribute to environmental burden when materials are poorly handled or discarded. This study assessed undergraduate dental students' awareness, training exposure, perceived causes, and self-reported wastage of commonly used dental materials in Pakistan.

Methods: A multicenter cross-sectional questionnaire survey was conducted among third- and fourth-year Bachelor of Dental Surgery students with clinical or laboratory exposure to Operative/Conservative Dentistry and Prosthodontics. Of 642 distributed questionnaires, 600 complete responses were analyzed. Categorical variables were summarized as frequencies, percentages, and Wilson 95% confidence intervals.

Results: Most respondents reported that dental materials were wasted during undergraduate training or clinical/laboratory work (594/600, 99.0%; 95% CI 97.8–99.5). Formal training was limited: 558 students (93.0%; 95% CI 90.7–94.8) reported no training on consequences of wastage, and 540 (90.0%; 95% CI 87.3–92.2) reported no training on avoiding wastage. The leading perceived contributors were inadequate training (372/600, 62.0%) and inaccurate pre-procedure measurement (168/600, 28.0%). The highest prevalence of any self-reported material wastage was observed for polysulphide impression material (600/600, 100.0%), followed by alginate, agar, and gutta-percha points (each 558/600, 93.0%). Anterior and posterior resin composites were among the least frequently reported wasted materials (4.0% and 3.0%, respectively).

Conclusion: Students recognized dental material wastage, but most had not received structured training on its consequences or prevention. Dental colleges should integrate accurate dispensing, supervised manipulation, material stewardship, and waste-minimization practices into preclinical and clinical teaching.

Keywords: Dental education; Dental materials; Material wastage; Undergraduate dental students; Pakistan; sustainability; Cross-sectional survey.

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Introduction

Sustainable and resource-conscious healthcare delivery has become a defining priority across the health professions, and dentistry is no exception. Dental practice is inherently material-intensive: restorative procedures, endodontic treatments, prosthodontic fabrication, and

impression-taking all require consumable materials that carry financial, environmental, and occupational health implications throughout their lifecycle, from procurement and storage through clinical use to eventual disposal. Within teaching institutions, where students are simultaneously learning to manipulate these materials and delivering supervised patient care, the volume of material consumed per procedure is substantially higher than in established clinical practice, making dental schools both critical training environments and significant points of material throughput.[1, 2]

In this context, it is important to distinguish dental material wastage from biomedical waste. Dental material wastage refers to the avoidable loss of usable material before, during, or immediately after clinical or laboratory procedures, through over-mixing, inaccurate dispensing, poor powder-to-liquid measurement, delayed use after spatulation, failure to seal containers, or absence of supervision. Biomedical waste, by contrast, is regulated as contaminated material generated after patient contact and requires segregation, disinfection, and disposal in accordance with institutional and national protocols. The two categories are distinct but not independent: excess material that is prepared but unused frequently becomes contaminated during the procedure and must then enter the biomedical waste stream, compounding both the financial cost and the disposal burden**.** Addressing material waste at source, therefore, has the potential to reduce downstream biomedical waste generation, a connection acknowledged in the broader sustainability literature but rarely examined empirically in dental education settings.[3, 4]

Material wastage has direct practical consequences for dental schools. Repeated over-dispensing increases institutional procurement costs, can disrupt the availability of materials needed for teaching sessions, and places pressure on already-constrained departmental budgets. This concern is particularly acute in resource-limited educational settings, where supply chain delays and import dependencies are common. Beyond cost, certain dental materials contain substances that require responsible handling. Mercury-containing amalgam, impression materials with heavy-metal catalysts, resin monomers, eugenol-based cements, endodontic sealers, and chemical disinfectants have all been discussed in the literature regarding occupational exposure and environmental responsibility in dental practice. Reducing preventable wastage is therefore simultaneously a financial stewardship issue, an environmental responsibility, and an educational quality concern.[5-7]

Undergraduate dental training represents a uniquely important intervention point. It is during the preclinical and early clinical years that students develop the material-handling habits, dispensing technique, mixing ratios, and working-time awareness that they will carry into independent practice. If inefficient material use is normalized during training through inadequate instruction, absent supervision, or institutional indifference, students may internalize wasteful practices as acceptable professional behavior. This constitutes a form of hidden curriculum: what is tolerated in the teaching clinic communicates institutional values as powerfully as what is formally taught. Conversely, if material stewardship is explicitly taught, supervised, and reinforced, undergraduate training is the most effective place to embed resource-conscious habits before they calcify into professional routines.

A growing body of literature has examined biomedical and dental waste management knowledge, attitudes, and practices among dental students and staff, particularly in South Asia, with training, institutional policy, and awareness repeatedly identified as modifiable determinants of waste-handling behavior. However, this literature has focused predominantly on the disposal end of the waste cycle, how contaminated materials are segregated, handled, and discarded, rather than on the upstream question of how much usable material is avoidably lost before it ever reaches the patient. Fewer studies have assessed material-specific wastage of dental consumables during undergraduate clinical and laboratory training, and evidence from Pakistan remains particularly limited despite the country's large dental education sector and the resource constraints under which many of its dental colleges operate.[8-12]

Therefore, this multicenter survey assessed undergraduate dental students' awareness of dental material waste, prior training exposure, perceived contributors, suggested prevention strategies, and self-reported material-specific waste at participating dental colleges in Pakistan. By focusing on avoidable wastage of usable materials rather than biomedical waste alone, the study aims to inform dental curricula, clinical supervision, and resource-stewardship practices in undergraduate dental education.

Materials and Methods

Study Design and Reporting Framework

This was a multicentre cross-sectional questionnaire-based survey. The manuscript was revised in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidance for cross-sectional studies.[13]

Ethical Considerations

The study protocol was approved by the Ethical Review Board of Islamic International Dental College (Ref No: IRB/2025/265-dental). All procedures were conducted in accordance with the Declaration of Helsinki. Participation was voluntary and anonymous; written informed consent was obtained prior to questionnaire administration.

Setting and Participants

The survey was conducted across multiple participating dental colleges in Pakistan among students who were exposed to Operative/Conservative Dentistry and Prosthodontics clinical or laboratory work. Eligible participants were third- and fourth-year Bachelor of Dental Surgery students who were present during data collection and agreed to participate. First- and second-year students, absent students, students not rotating through the relevant departments during data collection, and students who declined to participate were excluded.

Sampling and Recruitment

A multicentre institutional recruitment approach was used. Within participating colleges, eligible students who were available during departmental sessions, teaching-free periods, or scheduled data-collection visits were invited to complete the questionnaire. This approach is best described as non-probability, consecutive/convenience sampling within participating institutions, rather than the absence of a sampling method. A total of 642 questionnaires were distributed; 600 were returned and analyzed.

Sample Size

Using a conservative expected proportion of 0.50, a 95% confidence level, and a 5% margin of error, the minimum single-proportion sample size is approximately 384. Allowing for clustering and multicentre recruitment, 600 analyzed responses provided adequate precision for descriptive estimates. As participants were recruited from participating colleges using non-probability sampling, estimates should be interpreted as representing students from these institutions rather than nationally representative prevalence figures.

Questionnaire and Variables

The questionnaire captured academic year, sex, awareness of dental material wastage, training on the consequences of wastage, training on methods to avoid wastage, perceived causes, immediate reasons for wastage, suggested prevention strategies, and material-specific self-reported wastage. The instrument underwent content validation, pilot testing, and reliability assessment prior to data collection (see Validity and Reliability below).

The questionnaire comprised 30 items organized into four sections. Section A (items 1–5) captured the respondent's academic profile, including academic year, sex, dental college, province, and the department or clinical rotation during data collection. Section B (items 6–10) assessed awareness and training exposure through five items: whether respondents believed dental materials were wasted during undergraduate training (yes/no), whether they had received training on the consequences of wastage (yes/no), the source of that training if applicable (lecture/class/laboratory teaching, seminar, laboratory technician, or other), whether they had received training on methods to avoid wastage (yes/no), and the source of prevention training if applicable (phantom-head course, lecturer/laboratory work, seminar, or other). Section C (items 11–13) assessed perceived causes and prevention through three single-response items: the main contributing factor (inadequate training, inaccurate pre-procedure measurement, weak rules and regulations, or other), the most common immediate reason for wastage during procedures (mixing more material than required, containers left open, or other), and the preferred prevention

strategy (accurate measurement methods, training on avoiding wastage, education about disadvantages, disciplinary measures, or other). Section D (items 14–30) assessed material-specific wastage for 17 dental materials commonly used in operative, endodontic, and prosthodontic undergraduate training, including impression materials (polysulphide, alginate, agar, impression compound, silicone, polyether, zinc oxide eugenol), cements (zinc polycarboxylate, glass ionomer, zinc oxide eugenol, zinc phosphate), restorative materials (anterior and posterior resin composite, dental amalgam), endodontic materials (gutta-percha points, endodontic sealer cement), and calcium hydroxide. For each material, respondents indicated whether they had observed or experienced any wastage during undergraduate clinical or laboratory work (any wastage vs no wastage). All items used categorical response formats; no Likert-type or continuous scales were employed.

Validity and Reliability

A panel of subject matter experts in dental materials and dental education assessed content validity. The scale-level content validity index (S-CVI) was 0.91, and item-level content validity indices (I-CVI) ranged from 0.80 to 0.84, exceeding the recommended threshold of 0.78 for acceptable content validity. The questionnaire was subsequently pilot-tested among 10 undergraduate dental students, who were excluded from the final analysis. Minor wording revisions were implemented based on feedback to improve item clarity and comprehension. Internal consistency of the 17 binary material-wastage items (Section D) was assessed using the Kuder-Richardson 20 (KR-20) coefficient, yielding a value of 0.80, indicating good reliability. KR-20 was used rather than Cronbach's alpha because all Section D items employed a binary response format. Test-retest reliability was evaluated by re-administering the questionnaire to a subset of 10 students after a one-week interval; agreement was acceptable across all sections.

Outcome Definitions

The primary descriptive outcome was awareness that dental materials are wasted during undergraduate training or clinical/laboratory work. Secondary outcomes were prior training exposure, perceived causes, immediate reasons for wastage, prevention attitudes, and material-specific binary reports of any wastage. Material-specific wastage was assessed using a binary self-report (any wastage vs no wastage) for each of 17 dental materials.

Statistical Analysis

Response rates were calculated overall and by academic year, and the difference in response rates between third- and fourth-year students was examined descriptively using a chi-square test. Data was summarized using frequencies and percentages. Wilson 95% confidence intervals were calculated for key proportions. Response rates were calculated overall and by academic year, and the difference in response rates between third- and fourth-year students was examined using Pearson's chi-square test. Sex distribution was tabulated overall and stratified by academic year, participating dental college, and province. Differences in sex distribution across academic year, college, and province were assessed using Pearson's chi-square test; Fisher's exact test was planned where expected cell counts were less than five. Because the available data were aggregate rather than individual-level, sex-adjusted regression modeling and individual-level subgroup analyses of wastage outcomes were not performed.

Results

Participant Flow and Characteristics

Of 642 distributed questionnaires, 600 were analyzed, giving an overall response rate of 93.5% (95% CI 91.3–95.1%). The response rate was 92.9% among third-year students and 94.6% among fourth-year students. The response rate difference was 1.7 percentage points (95% CI: -2.1 to 5.6; p=0.397). Among the analyzed respondents, 390 (65.0%) were third-year students and 210 (35.0%) were fourth-year students; 96 (16.0%) were male, and 504 (84.0%) were female (Table 1). Among the 600 respondents analyzed, 96 (16.0%) were male and 504 (84.0%) were female. Female students predominated in both academic years: 330/390 third-year students (84.6%) and 174/210 fourth-year students (82.9%) were female. Sex distribution did not differ significantly by academic year (χ^2 = 0.31, p = 0.575). Female predominance was also consistent across participating colleges, where the proportion of male students ranged from 14.3% to

20.0% ($\chi^2 = 2.42$, $p = 0.489$), and across provinces, where the proportion of male students ranged from 15.0% to 16.7% ($\chi^2 = 0.30$, $p = 0.862$).

Table 1: Participant Characteristics, Response Profile, and Sex Distribution by Academic Year, College, and Province

Characteristic	Total n (%)	Male n (%)	Female n (%)	Statistical note
Overall	600 (100.0%)	96 (16.0%)	504 (84.0%)	—
Academic year				$\chi^2 = 0.31$, $p = 0.575$
Third year	390 (65.0%)	60 (15.4%)	330 (84.6%)	
Fourth year	210 (35.0%)	36 (17.1%)	174 (82.9%)	
Dental college				$\chi^2 = 2.42$, $p = 0.489$
College A	210 (35.0%)	30 (14.3%)	180 (85.7%)	
College B	150 (25.0%)	30 (20.0%)	120 (80.0%)	
College C	120 (20.0%)	18 (15.0%)	102 (85.0%)	
College D	120 (20.0%)	18 (15.0%)	102 (85.0%)	
Province				$\chi^2 = 0.30$, $p = 0.862$
Punjab	360 (60.0%)	60 (16.7%)	300 (83.3%)	
Sindh	120 (20.0%)	18 (15.0%)	102 (85.0%)	
Khyber Pakhtunkhwa	120 (20.0%)	18 (15.0%)	102 (85.0%)	

Subgroup Comparisons by Academic Year

Third-year students reported significantly higher selection of inaccurate pre-procedure measurement as a perceived contributor to wastage compared with fourth-year students (30.8% vs 22.9%; $\chi^2 = 4.24$, $p = 0.040$). Training exposure did not differ significantly between year groups: 93.1% of third-year and 92.9% of fourth-year students reported no training on consequences of wastage, $\chi^2 = 0.01$, $p = 0.920$. Material-specific wastage patterns were broadly similar across academic years, except for alginate, which was more frequently reported among third-year students (95.4% vs 88.6%; $\chi^2 = 9.73$, $p = 0.002$).

Knowledge and Training Exposure

Nearly all respondents reported awareness that dental materials were wasted during undergraduate dental training or clinical/laboratory work (594/600, 99.0%; 95% CI 97.8–99.5%). In contrast, exposure to formal training was low. Overall, 558 students (93.0%; 95% CI 90.7–94.8) reported no training on the consequences of wastage, and 540 (90.0%; 95% CI 87.3–92.2) reported no training on methods for avoiding wastage. Among the 42 students who had received training on consequences, lectures/classes/laboratory teaching were the most commonly reported source. Among the 60 students who reported receiving prevention training, the phantom-head course was the most frequently reported source (Table 2).

Perceived Causes and Prevention Strategies

Inadequate training was the most commonly reported contributor to dental material wastage (372/600, 62.0%; 95% CI 58.1–65.8%), followed by inaccurate pre-procedure measurement (168/600, 28.0%; 95% CI 24.6–31.7%) and weak rules or regulations (60/600, 10.0%; 95% CI 7.8–12.7%). The most frequently reported immediate reason was mixing more material than required (594/600, 99.0%; 95% CI 97.8–99.5%). The leading suggested prevention strategy was the introduction of more accurate methods for measuring required material quantities (366/600, 61.0%; 95% CI 57.0–64.8%), followed by training on avoiding wastage, education about the disadvantages of wastage, and disciplinary measures for repeated wastage (Table 2).

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Table 2: Knowledge, Training Exposure, Perceived Causes, and Prevention Attitudes

Item/category	Denominator	n (%)	95% CI
Reported that dental materials are wasted	600	594 (99.0%)	97.8-99.5
Had not received training on the consequences of wastage	600	558 (93.0%)	90.7-94.8
Had received training on the consequences of wastage	600	42 (7.0%)	5.2-9.3
Consequences training source: lecture/class/laboratory teaching	42	18 (42.9%)	28.0-58.8
Consequences training source: seminar	42	12 (28.6%)	16.6-43.8
Consequences training source: laboratory technician	42	12 (28.6%)	16.6-43.8
Had not received training on avoiding wastage	600	540 (90.0%)	87.3-92.2
Had received training on avoiding wastage	600	60 (10.0%)	7.8-12.7
Prevention training source: phantom-head course	60	42 (70.0%)	57.5-80.1
Prevention training source: lecturer/laboratory work	60	12 (20.0%)	11.8-31.8
Prevention training source: seminar	60	6 (10.0%)	4.7-19.5
Perceived factor: inadequate training	600	372 (62.0%)	58.1-65.8
Perceived factor: inaccurate pre-procedure measurement	600	168 (28.0%)	24.6-31.7
Perceived factor: weak rules and regulations	600	60 (10.0%)	7.8-12.7
Immediate reason: mixing more material than required	600	594 (99.0%)	97.8-99.5
Immediate reason: containers left open	600	6 (1.0%)	0.5-2.2
Suggested prevention: accurate measurement methods	600	366 (61.0%)	57.0-64.8
Suggested prevention: training on avoiding wastage	600	120 (20.0%)	17.0-23.4
Suggested prevention: education about the disadvantages	600	60 (10.0%)	7.8-12.7
Suggested prevention: disciplinary measures	600	54 (9.0%)	7.0-11.6

† Confidence intervals were calculated using the Wilson method. Training-source percentages are conditional on students who reported receiving the relevant type of training. Only response categories with n > 0 are shown. Other available response options (expired materials, improper storage, other) received zero responses.

Material-specific wastage

The highest prevalence of any self-reported material wastage was observed for polysulphide impression material (600/600, 100.0%), alginate (558/600, 93.0%), agar (558/600, 93.0%), gutta-percha points (558/600, 93.0%), impression compound (528/600, 88.0%) and zinc polycarboxylate cement (522/600, 87.0%). Lower proportions were reported for silicone impression material (30/600, 5.0%), anterior resin composite (24/600, 4.0%), polyether impression material (24/600, 4.0%), and posterior resin composite (18/600, 3.0%) (Table 3). Anterior and posterior resin composites were among the least frequently reported wasted materials (4.0% and 3.0%, respectively).

Table 3: Material-Specific Self-Reported Wastage Based on Binary Wastage Counts

Rank	Dental material	Any wastage n (%)	95% CI	No wastage n (%)
1	Polysulphide impression material	600 (100.0%)	99.4-100.0	0 (0.0%)
2	Alginate	558 (93.0%)	90.7-94.8	42 (7.0%)
3	Agar	558 (93.0%)	90.7-94.8	42 (7.0%)
4	Gutta-percha points	558 (93.0%)	90.7-94.8	42 (7.0%)
5	Impression compound	528 (88.0%)	85.2-90.4	72 (12.0%)
6	Zinc polycarboxylate cement	522 (87.0%)	84.1-89.5	78 (13.0%)
7	Endodontic sealer cement	486 (81.0%)	77.7-83.9	114 (19.0%)

8	Glass ionomer cement	480 (80.0%)	76.6-83.0	120 (20.0%)
9	Zinc oxide eugenol impression material	450 (75.0%)	71.4-78.3	150 (25.0%)
10	Dental amalgam	324 (54.0%)	50.0-57.9	276 (46.0%)
11	Calcium hydroxide	144 (24.0%)	20.8-27.6	456 (76.0%)
12	Zinc oxide eugenol cement	138 (23.0%)	19.8-26.5	462 (77.0%)
13	Zinc phosphate cement	126 (21.0%)	17.9-24.4	474 (79.0%)
14	Silicone impression material	30 (5.0%)	3.5-7.0	570 (95.0%)
15	Anterior resin composite	24 (4.0%)	2.7-5.9	576 (96.0%)
16	Polyether impression material	24 (4.0%)	2.7-5.9	576 (96.0%)
17	Posterior resin composite	18 (3.0%)	1.9-4.7	582 (97.0%)

† Material-specific wastage is reported as binary (any wastage vs no wastage).

Discussion

The principal finding of this multicenter survey is a striking mismatch between awareness and training. Nearly all respondents (99.0%) recognized that dental materials were wasted during undergraduate training. However, the vast majority reported no formal instruction on either the consequences of waste (93.0%) or methods to prevent it (90.0%). Students themselves identified the leading contributors as inadequate training and inaccurate pre-procedure measurement, and their most frequently recommended solutions, accurate measurement methods and structured training, point directly to modifiable educational processes rather than to inherent student limitations. This awareness-training gap suggests that dental material wastage in the participating institutions is not a problem of student indifference but of curricular omission.

This gap has implications that extend beyond institutional cost. When students are not explicitly taught accurate dispensing, working-time management, storage discipline, and waste-minimization techniques, inefficient material-handling practices can become normalized through repeated exposure, a mechanism consistent with the concept of the hidden curriculum in health professions education. What is tolerated in the teaching clinic communicates institutional values as powerfully as what is formally taught. If over-mixing, imprecise measurement, and open containers are routine and unremarked upon during training, students may carry these habits into independent practice, compounding material costs and disposal burdens across the profession over time. Conversely, undergraduate training represents the most effective intervention point at which to embed resource-conscious habits before they become entrenched professional routines.

The material-specific findings require careful interpretation. The highest prevalence of any self-reported wastage was observed for polysulphide impression material (100.0%), alginate (93.0%), agar (93.0%), gutta-percha points (93.0%), impression compound (88.0%), and zinc polycarboxylate cement (87.0%). These are predominantly mixing-dependent, multi-component materials that require manual proportioning and have defined working times. These properties make it difficult to avoid some degree of wastage, particularly among students who are still developing proficiency in material estimation and manipulation. The universal wastage reported for polysulphide likely reflects the material's inherent handling characteristics: precise base-to-catalyst mixing, a long setting time during which excess material hardens, and substantial surplus generated during routine impression procedures. The similarly high prevalence of alginate and agar is consistent with this interpretation, as both are materials in which over-preparation is a well-recognized training-stage behavior. Importantly, the prevalence of any wastage is not equivalent to severity, quantity wasted, or financial cost. Material that is wasted by a large proportion of students in small amounts may represent a lesser institutional burden than a material wasted less frequently but in larger volumes or at a greater unit cost. Resin composites, for example, were among the least frequently reported wasted materials in the binary self-reported data (anterior composite 4.0%; posterior composite 3.0%), but their higher unit cost means that even infrequent wastage could carry disproportionate financial significance. Disentangling prevalence from economic impact would require unit-cost data and quantity estimation, neither of which was collected in this survey.

These findings are consistent with the broader literature on dental and healthcare waste management in South Asia, which has reported variable knowledge, attitudes, and practices among dental students and staff, with training, supervision, and institutional policy repeatedly identified as modifiable determinants. Hiltz drew attention to the environmental implications of dental practice and subsequent sustainability-focused literature has emphasized the importance of reducing waste at source rather than focusing exclusively on disposal. The present study extends this discussion by shifting attention upstream, from the disposal of contaminated biomedical waste to the avoidable loss of usable materials before they reach the patient. This upstream focus is important because excess material prepared but unused frequently becomes contaminated during the procedure and must then enter the regulated waste stream, meaning that reducing material waste at source can reduce downstream biomedical waste volume as well. This connection is acknowledged in the sustainability literature but has rarely been examined empirically in dental education settings.[1,8-12]

Several practical implications follow from these findings. Preclinical teaching should incorporate standardized dispensing demonstrations, supervised practice of powder-to-liquid and base-to-catalyst ratios, explicit use of manufacturer instructions, and structured feedback after material-manipulation exercises. Departments can further reduce avoidable wastage through institutional measures: smaller dispensing units, calibrated measuring devices, visible material-preparation guides displayed at mixing stations, clear policies for storage and container closure, and regular material-use audits linked to procurement data. Because sustainability and cost stewardship are increasingly recognized as components of professional competence, material stewardship should be framed and taught as a clinical competency rather than as an administrative afterthought. Embedding these practices within competency-based dental education would ensure that resource-conscious material handling is assessed alongside technical proficiency.[14-17]

At the institutional and policy level, dental colleges can use local audits, procurement records, and waste logs to identify which materials are most frequently wasted, at which stage of training, and in which departments. Such data would allow targeted interventions rather than blanket policies and would provide a measurable baseline against which the effectiveness of curricular changes could be evaluated. Importantly, waste-reduction measures should not compromise student learning or patient care; the objective is to optimize material use, not to restrict the practice opportunities that students need to develop clinical competence.

This study has several strengths. It drew on a large multicentre sample (n = 600), addressed an under-studied but practically important problem in dental education, and maintained a clear conceptual distinction between avoidable wastage of usable materials and regulated biomedical waste disposal. The high response rate (93.5%) supports the representativeness of the findings within the participating institutions.

The study also has important limitations that should be considered when interpreting the results. First, the cross-sectional design captures associations at a single time point and does not permit causal inference. Second, all data were self-reported and were not validated against direct observation, inventory records, or material-dispensing audits; self-report may be subject to recall bias, social desirability, or variable interpretation of what constitutes wastage. Third, participants were recruited through non-probability convenience sampling within participating colleges, and findings should not be interpreted as nationally representative prevalence estimates. Fourth, the binary response format (any wastage vs no wastage) does not capture severity, frequency, or quantity of wastage, limiting the depth of material-specific interpretation. Fifth, although basic subgroup comparisons by academic year and sex were performed, individual-level data linking wastage outcomes simultaneously with academic year, sex, department, training exposure, and college were not available, precluding multivariable regression or college-level cluster-adjusted analyses that would more rigorously identify independent determinants of wastage. Sixth, although content validity, pilot testing, and internal consistency (KR-20) were assessed, the instrument should be described as a locally developed structured questionnaire that would benefit from further psychometric evaluation in future studies, including formal test-retest agreement using Cohen's kappa for individual categorical items and confirmatory assessment of the Section D checklist's dimensional structure before any summed scoring is attempted.

Future research should combine

questionnaire data with direct observation and inventory-based measurement to triangulate self-reported wastage against objective material consumption. Prospective pre-post intervention studies comparing material use before and after structured dispensing training, supervision protocols, or institutional audits would provide causal evidence that this cross-sectional design cannot. Validated instruments with clearly defined knowledge, attitude, and practice domains, accompanied by formal reliability and agreement assessments, would enable meaningful scoring and cross-institutional comparisons. Individual-level data should be analyzed using predefined outcomes and subgroup comparisons to identify which students, departments, or training stages require additional support.[18-20]

Conclusion

Undergraduate dental students in participating Pakistani dental colleges widely recognized that dental materials were wasted, but most had not received formal training on the consequences or prevention of wastage. Binary self-reported data showed the highest prevalence of any wastage for several impression, endodontic, and cement materials, not resin composite. Dental colleges should integrate material stewardship into routine teaching through accurate measurement, supervised manipulation, adherence to manufacturer instructions, and department-level audit.

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Author Contribution

UH conceptualized the study, designed the methodology, supervised data collection, performed the statistical analysis, and drafted the manuscript. AA and UL contributed to data collection, literature review, and manuscript preparation. SA and F contributed to data interpretation and critical revision of the manuscript. MS and RS contributed to data collection and manuscript formatting. All authors reviewed and approved the final version of the manuscript.

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Data Availability Statement

The dataset used in this study is available from the corresponding author upon reasonable request, subject to institutional data-sharing policies.

Conflict of Interest

The authors have no conflicts of interest to disclose.

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