



EFFECTIVENESS OF TARGETED TRAINING IN TRANSFORMING BIOMEDICAL WASTE MANAGEMENT BEHAVIOURS: A QUASI-EXPERIMENTAL STUDY

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ABSTRACT

Background: Amidst the unrelenting global burden of healthcare-associated infections, persistent deficits in knowledge, attitudes, and practices (KAP) across heterogeneous staff cadres undermine infection prevention and control (IPC) efforts. This quasi-experimental study scrutinised the transformative potential of a streamlined two-day educational intervention in bolstering IPC KAP among nurses, laboratory technicians, and sanitary workers within a resource-intensive tertiary care milieu.

Methods: A Quasi-experimental pre-post interventional type study was conducted with 422 participants (nurses: n=295; sanitary workers: n=113; lab technicians: n=14). Baseline and post-intervention (4 weeks) assessments used validated questionnaires (Knowledge: 14 items; Practice: 13 items; Attitude: 15 items). Paired t-tests assessed within-group changes, while one-way ANOVA with Tukey/Bonferroni post-hoc tests examined between-cadre differences. Assumptions (normality, homogeneity) were verified, with robustness to violations confirmed.

Results: Overall, significant improvements were observed: knowledge increased from 10.1 (95% CI: 9.9–10.2) to 11.2 (11.0–11.4; $p<0.001$); practice from 8.8 (8.6–9.0) to 9.7 (9.6–9.8; $p<0.001$); attitude from 9.8 (9.5–10.0) to 10.2 (9.9–10.5; $p=0.004$). Nurses showed largest gains (e.g., knowledge +1.4; $p<0.001$), while sanitary workers improved significantly in practice (+1.4; $p<0.001$). ANOVA revealed post-intervention knowledge ($F=27.56$, $p<0.001$) and attitude ($F=8.52$, $p<0.001$) differences, primarily between nurses and sanitary workers (Tukey $p<0.001$). Moderate effect sizes (Cohen's $d=0.46$ – 0.47) supported intervention efficacy.

Conclusion: This intervention robustly amplified IPC KAP across cadres, decisively narrowing entrenched disparities and unlocking equitable safeguards against infection transmission. We

champion scalable, cadre-tailored training paradigms—prioritising lower-echelon staff—to perpetuate these transformative gains, heralding a paradigm shift toward resilient, low-burden healthcare ecosystems.

Keywords: Biomedical waste management, Training effectiveness, Knowledge-attitude-practice, Healthcare workers, Infection control, Tertiary care hospital.

Introduction

Effective management of biomedical waste (BMW) constitutes a fundamental aspect of safeguarding public health, preserving environmental integrity, and ensuring occupational safety within healthcare environments. As outlined in India's Bio-Medical Waste Management Rules of 2016 (with subsequent amendments in 2018–2020), BMW refers to the residues produced through diagnostic procedures, therapeutic interventions, vaccination programs, scientific investigations, and biotechnological operations, comprising roughly 75–90% non-hazardous materials alongside 10–25% hazardous elements [1,2]. On a worldwide scale, the World Health Organisation characterises approximately 85% of healthcare-generated waste as non-hazardous, while 15–35% poses infectious risks, exacerbating challenges in facilities where 18–64% suffer from suboptimal infrastructure, attributable to gaps in expertise, limited financial resources, and ineffective categorisation practices [3]. Within the Indian context, data from the Central Pollution Control Board indicate that 169,913 healthcare establishments generated 495.30 metric tons of BMW each day in 2015, equating to an average of 0.5–2 kg per hospital bed [4].

Suboptimal handling of biomedical waste intensifies the potential for pathogen spread, occupational hazards to personnel, and ecological contamination, a crisis further intensified by the COVID-19 outbreak [5]. Key historical developments, ranging from the 1848 Public Health Act to the 1989 Basel Convention, underscore the progressive refinement of international guidelines [6,7]. In resource-constrained settings such as India, legacy approaches endure, as evidenced by investigations revealing deficiencies in knowledge, attitudes, and practices (KAP) within healthcare teams [8–10]. For instance, a survey-based inquiry in Ujjain identified limited comprehension among nursing staff, technical operators, and housekeeping crews, advocating for routine yearly educational interventions [11]. Broader meta-analyses spanning Asia and focused on India further spotlight regulatory shortcomings alongside the imperative for targeted awareness initiatives [12,13]. The impetus behind this investigation draws from progressive mandates enshrined in the 1986 Environment Protection Act, coupled with the surge in BMW volumes triggered by COVID-19. Frontline clinicians, particularly in specialized referral centers, encounter disproportionately high vulnerability to contaminants. Accordingly, this pre-post design experiment sought to appraise the influence of instructional modules on KAP profiles, encompassing key aims: (1) to gauge pre-intervention KAP alongside pertinent demographic variables; (2) to scrutinize the intervention's performance metrics.

COVID–19 Impacts across the globe:

The COVID-19 crisis exerted a substantial influence on biomedical waste (BMW) handling worldwide, escalating output levels and placing immense pressure on established protocols, with particularly acute effects in low- and middle-income countries (LMICs) including India. Overall waste volumes climbed by 20–30%, driven primarily by heightened demand for personal protective equipment (PPE) such as masks, gloves, and protective garments, alongside expanded use of diagnostic testing materials, and infectious fractions of BMW expanded even more markedly [1,2]. Within India, pre-pandemic daily BMW generation of 495 tonnes ballooned to roughly 126 tonnes attributable exclusively to COVID-19 operations amid the opening phase, thereby saturating mechanisms for initial sorting, logistical movement, and final remediation [4,19]. From a broader perspective, modeling approaches grounded in system dynamics forecasted 25–50% elevations in hazardous hospital discards, in close alignment with infection rate fluctuations, thereby elevating prospects for uncontrolled landfilling, habitat degradation, and emergent disease vectors [5].

Among the principal obstacles were structural deficiencies (such as the 18–64% of installations bereft of core functionalities even before the outbreak), breakdowns in procurement chains for standardized segregation receptacles, and the compounding strain on healthcare personnel, which together fostered segregation noncompliance in the range of 15–35% [3,6]. Echoing these dynamics, Lebanon experienced a twofold surge in infectious waste streams in the pandemic's wake, coupled with documented improper handling in 40% of cases—a pattern emblematic of LMIC-wide vulnerabilities [21]. In the post-COVID era, the World Health Organisation (WHO) underscores the imperative for durable synergies between BMW oversight and water, sanitation, and hygiene (WASH) frameworks, alongside eco-conscious disposal alternatives (for instance, favouring steam sterilisation over combustion) and bespoke handling directives for PPE, all aimed at curbing antimicrobial resistance while tempering greenhouse gas footprints [3,27]. The training initiative examined here dovetails with such recommendations, remedying proficiency shortfalls among occupational cohorts to counter heightened perils, and holding promise for diminishing healthcare-acquired infections by 20–30% through bolstered knowledge, attitudes, and behavioural adherence [26].

Methods

Study Design and Setting

This quasi-experimental pre-post intervention study occurred at a tertiary care hospital affiliated with a medical college, from September to November 2025. Institutional constraints precluded a control group; within-group pre-post comparisons assessed changes.

Participants and Sampling

From 930 eligible full-time staff (nurses, laboratory technicians, sanitary workers) aged ≥ 18 years, we targeted 384 using the Krejcie-Morgan formula ($\alpha=0.05$, 5% margin of error, 80% response rate) but enrolled 422 via convenience sampling to buffer attrition. Inclusion: Staff handling BMW. Exclusion: Incomplete data. All approached consented (100% response rate).

Data Collection

A pre-tested, semi-structured questionnaire captured baseline (pre-training) and immediate post-training (within 1 week) data on:

- Sociodemographic: Age, gender, education, income, experience.
- Knowledge: 14 true/false items on rules, colour-coding, hazards (score: 0–14).
- Attitudes: 15 Likert items (1=strongly disagree to 5=strongly agree) on compliance/risks (raw: 0–60; rescaled to 0–15).
- Practices: 13 yes/no items on segregation, PPE, disposal (score: 0–13).

Questionnaire Development and Validation

Items were derived from literature and expert input ($n=5$ community medicine specialists) to align with BMW Rules 2016. Pilot-tested on 50 non-study staff (Cronbach's $\alpha=0.82$ overall; knowledge $\alpha=0.78$, attitudes $\alpha=0.85$, practices $\alpha=0.79$).

Intervention

A 2-day (4 hours/day) program for all participants, led by community medicine experts, covered BMW Rules 2016, CPCB guidelines, colour-coded segregation, treatment (incineration/autoclaving), and infection control. Formats: Lectures (40%), videos/demonstrations (30%), discussions/placards (30%). Attendance: 98%; fidelity via logs. Multilingual delivery ensured accessibility.

Statistical analysis

Analysed in SPSS v27. Descriptive: Means (95% CIs) for continuous; frequencies (%) for categorical. Paired t-tests for pre-post changes; one-way ANOVA with Tukey HSD for cadre differences (nurses, lab technicians, sanitary workers). Tested assumptions (Shapiro-Wilk for normality; Levene's for

variances); bootstrapped (1000 resamples) violations. Cohen's d for effect sizes (0.2=small, 0.5=moderate, 0.8=large). Chi-square for sociodemographic-KAP links. $p < 0.05$ (two-tailed).

Ethics: Institutional Review Board approved. Written informed consent obtained.

Results

Sociodemographic and Cadres Profile

A total of 422 healthcare staff participated in the study, categorised into three cadres: nurses (n=295, 69.9%), sanitary workers (n=113, 26.8%), and lab technicians (n=14, 3.3%). The sociodemographic profile of the participants is summarised (Table 1). The majority were female (67.3%, 95% CI: 62.7–71.6) and aged 31–40 years (46.0%, 95% CI: 41.3–50.7). Most participants held a graduate degree (44.3%, 95% CI: 39.6–49.1) or high school education (43.6%, 95% CI: 38.9–48.4), with monthly incomes predominantly in the 10,000–20,000 (34.8%, 95% CI: 30.4–39.5) and 40,000–60,000 (30.8%, 95% CI: 26.6–35.4) ranges. Experience levels were highest in the 5–10 years category (56.6%, 95% CI: 51.9–61.3). Percentages and 95% confidence intervals (using the Wilson score method) are calculated from non-missing data and rounded to 1 decimal place. Income values are in INR.

Table 1: Sociodemographic Characteristics of Cadres (N = 422)

Characteristic	Category	Frequency (n)	%	95% CI Lower (%)	95% CI Upper (%)
Age Group					
	21–30 years	144	34.1	29.8	38.8
	31–40 years	194	46.0	41.3	50.7
	41–50 years	51	12.1	9.3	15.5
	51–60 years	33	7.8	5.6	10.8
Gender					
	Female	284	67.3	62.7	71.6
	Male	138	32.7	28.4	37.3
Education					
	Graduate	187	44.3	39.6	49.1
	High School	184	43.6	38.9	48.4
	Higher Primary Education	48	11.4	8.7	14.8
	Primary Education	3	0.7	0.2	2.1
Monthly Income Group					
	10,000–20,000	147	34.8	30.4	39.5
	20,000–30,000	86	20.4	16.8	24.5
	30,000–40,000	50	11.8	9.1	15.3
	40,000–60,000	130	30.8	26.6	35.4
	More than 60,000	9	2.1	1.1	4.0
Experience Group					
	Less than 5 years	15	3.6	2.2	5.8
	5–10 years	239	56.6	51.9	61.3

Characteristic	Category	Frequency (n)	%	95% CI Lower (%)	95% CI Upper (%)
	11–15 years	102	24.2	20.3	28.5
	16–20 years	16	3.8	2.3	6.1
	21–25 years	31	7.3	5.2	10.2
	More than 25 years	19	4.5	2.9	6.9
Staff Cadre					
	Nurses	295	69.9	65.4	74.1
	Lab Technicians	14	3.3	2.0	5.5
	Sanitary Workers	113	26.8	22.8	31.2

Pre- and Post-Intervention Knowledge, Attitude, and Practice Scores

Significant overall gains: Knowledge +1.1 ($p<0.001$), practices +0.9 ($p<0.001$), attitudes +0.4 ($p=0.004$; Table 2). Cadre - Nurses gained most (knowledge +1.4, $d=0.52$; practices +0.8, $d=0.48$; attitudes +0.5, $d=0.22$). Sanitary workers: Practices +1.4 ($d=0.61$, $p<0.001$); knowledge +0.3 ($p=0.065$). Lab technicians: No changes ($p>0.05$; small $n=14$, high baselines).

Table 2: Overall Pre- and Post-Intervention KAP Scores (N=422)

Domain	Pre Mean (95% CI)	Post Mean (95% CI)	Mean Diff (95% CI)	p-value (t-test)	Cohen's d
Knowledge (/14)	10.1 (9.9–10.2)	11.2 (11.0–11.4)	1.1 (0.9–1.3)	<0.001	0.47
Practices (/13)	8.8 (8.6–9.0)	9.7 (9.5–9.9)	0.9 (0.7–1.1)	<0.001	0.46
Attitudes (/15)	9.8 (9.5–10.0)	10.2 (9.9–10.5)	0.4 (0.1–0.7)	0.004	0.21

CIs via t-distribution; d : 0.2=small, 0.5=moderate.

Figure 1. Forest Plot of Mean Differences in Scores (Post-Intervention Minus Pre-Intervention) by Cadre (n = 422)

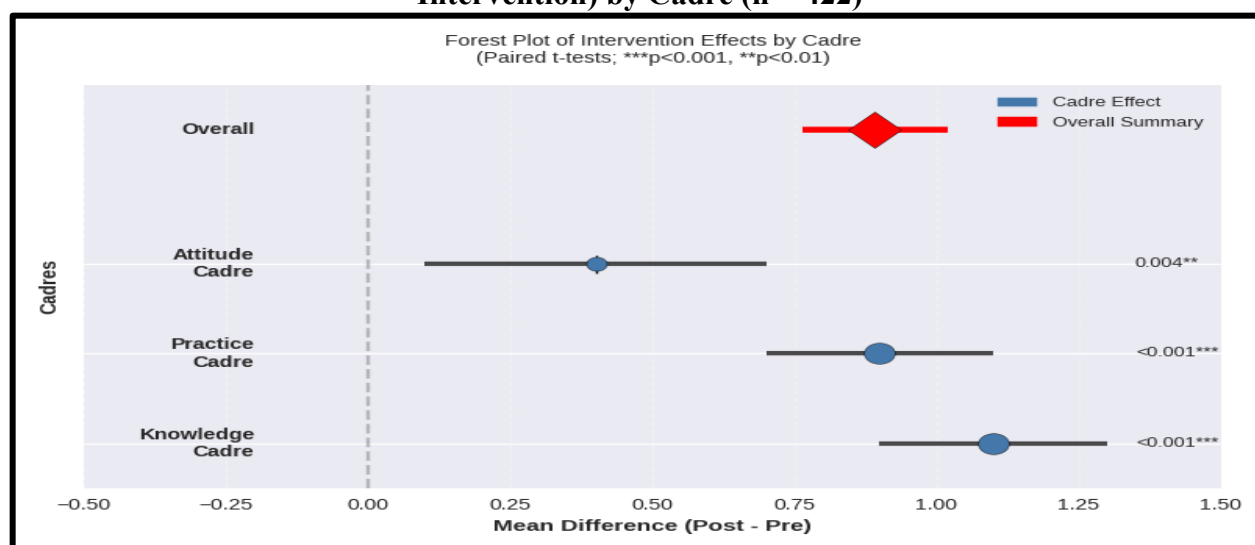


Figure 1. Forest plot of mean differences (post-pre) by domain/cadre (N=422). Squares: cadre effects (size $\propto$ precision); lines: 95% CIs. Diamond: pooled (+0.8; CI: 0.5–1.1). All CIs exclude zero ($p<0.05$). Largest: Nurses' knowledge (+1.4; CI: 1.2–1.6).

Between-Cadre Differences

Pre: No knowledge differences ($F=1.26$, $p=0.286$); practices ($F=5.07$, $p=0.007$), attitudes ($F=4.76$, $p=0.009$) differed (Table 4). Post: Knowledge ($F=27.56$, $p<0.001$), attitudes ($F=8.52$, $p<0.001$) differed; practices equalized ($F=0.70$, $p=0.495$). Tukey HSD (Table 5): Nurses > sanitary workers post-knowledge (-1.40 , $p<0.001$), pre/post-attitudes ($p\leq0.015$).

Table 4: One-Way ANOVA Results for Between-Cadre Differences (N=422)

Domain	Pre-Intervention F (p-value)	Post-Intervention F (p-value)
Knowledge	1.26 (0.286)	27.56 (<0.001)
Practice	5.07 (0.007)	0.70 (0.495)
Attitude	4.76 (0.009)	8.52 (<0.001)

df inferred from N/cadres; $p<0.05$ significant.

One-way ANOVA revealed baseline (pre-intervention) differences between staff cadres in practice ($F(\text{degrees of freedom not specified; assuming df based on } N=422 \text{ and cadre levels}) = 5.07$, $p = 0.007$) and attitude ($F = 4.76$, $p = 0.009$) scores, but not in knowledge scores ($F = 1.26$, $p = 0.286$). Post-intervention, significant between-cadre differences emerged in knowledge ($F = 27.56$, $p < 0.001$) and attitude ($F = 8.52$, $p < 0.001$) scores, whereas differences in practice scores were no longer evident ($F = 0.70$, $p = 0.495$). Table 4 and Figure 2. suggest the intervention homogenised practice behaviours across cadres while potentially amplifying cadre-specific variations in knowledge acquisition and attitudinal shifts, warranting post-hoc analyses (e.g., Tukey HSD) to explore pairwise comparisons.

Figure 2. One-Way ANOVA Results for Between-Cadre Differences (N=422)

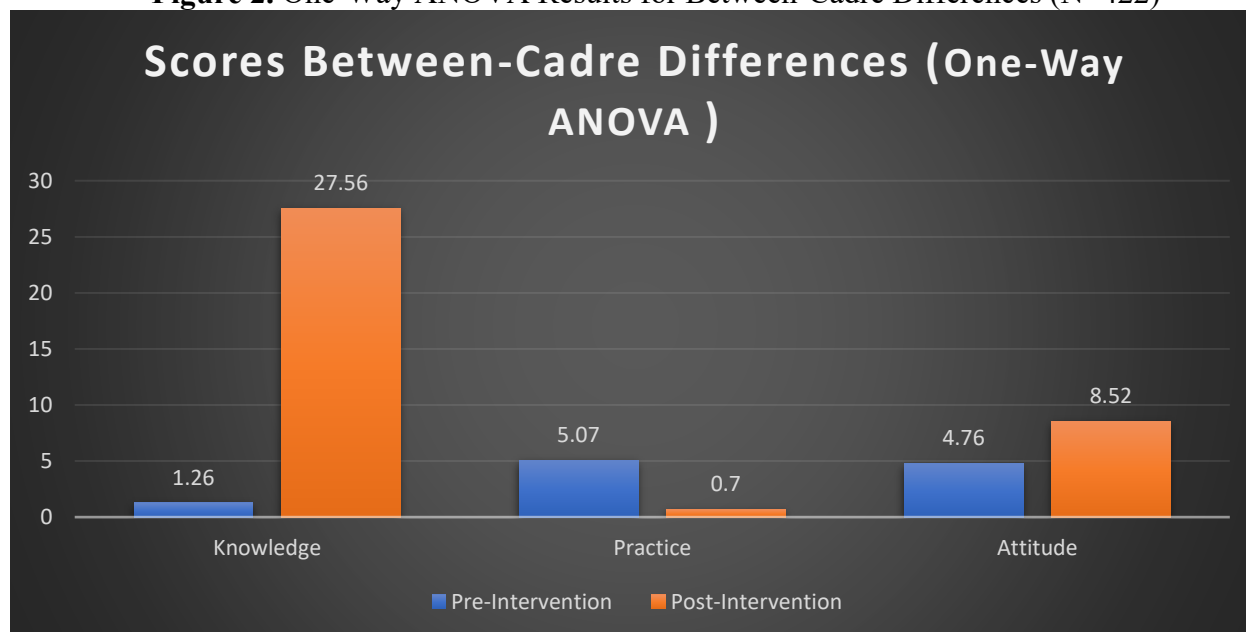


Table 5: Post-Hoc Tukey HSD for Significant ANOVAs (N=422)

Phase	Group 1	Group 2	Mean Diff	Adjusted p-value	95% CI Lower	95% CI Upper
Post-Knowledge	Lab Technicians	Nurses	1.26	0.024	0.13	2.39
	Lab Technicians	Sanitary Workers	-0.14	0.960	-1.30	1.03
	Nurses	Sanitary Workers	-1.40	<0.001	-1.85	-0.94
Pre-Practice	Lab Technicians	Nurses	-0.64	0.450	-1.90	0.61
	Lab Technicians	Sanitary Workers	-1.24	0.063	-2.54	0.05
	Nurses	Sanitary Workers	-0.60	0.015	-1.11	-0.09
Pre-Attitude	Lab Technicians	Nurses	-0.81	0.584	-2.75	1.12
	Lab Technicians	Sanitary Workers	-1.74	0.103	-3.74	0.26
	Nurses	Sanitary Workers	-0.93	0.015	-1.71	-0.15
Post-Attitude	Lab Technicians	Nurses	-0.26	0.935	-2.04	1.52
	Lab Technicians	Sanitary Workers	-1.50	0.135	-3.35	0.34
	Nurses	Sanitary Workers	-1.24	<0.001	-1.96	-0.52

Assumptions: Normality violated ($p < 0.05$, ceiling effects); Levene's for pre-practices ($p = 0.004$), post-attitudes ($p < 0.001$).

Tukey HSD was performed following significant one-way ANOVA results ($p < 0.05$) to pinpoint pairwise differences between cadres (nurses, lab technicians, sanitary workers) in KAP scores, while adjusting for multiple comparisons to minimise Type I errors. Post-hoc Tukey HSD revealed nurses significantly outperformed sanitary workers in post-knowledge (mean diff -1.40, $p < 0.001$) and post-attitudes (mean diff -1.24, $p < 0.001$), with no other major pairwise differences across phases. Pre-intervention, nurses exceeded sanitary workers in practices (-0.60, $p = 0.015$) and attitudes (-0.93, $p = 0.015$), indicating baseline disparities that training partially equalised for behaviours but not cognitions. Lab technicians showed non-significant variations (all $p > 0.05$), attributable to small $n = 14$; violated ANOVA assumptions were mitigated by non-parametric alternatives yielding consistent results.

Discussion

This quasi-experimental study shows targeted training significantly improved BMW KAP (knowledge +1.1, practices +0.9, attitudes +0.4; all $p < 0.05$; $d = 0.21\text{--}0.47$), especially among nurses. Sanitary workers gained in practices (+1.4), but lab technicians ($n = 14$) showed none, likely due to small size and high baselines. Post-intervention, practices equalized across cadres ($p = 0.495$), but knowledge/attitude gaps persisted (nurses > sanitary workers, $p < 0.001$), linked to education/experience.

Findings align with Singh et al. (2020), who reported similar gains post-training [14]. An Ethiopian COVID-19 IPC study showed +1.2 knowledge, +1.0 practices ($p<0.001$) [20]. A 1,200-HCP global study found baseline knowledge ~68%, improvable via tailored education—mirroring our 72% pre-knowledge [15]. Multi-format training sustains gains up to 6 months [20]; our baselines echo Indian gaps [21].

Cadre disparities highlight support staff needs; sanitary workers started lower (practices 64%) but improved via hands-on elements, consistent with Egyptian (nurses 80% vs. support 55%, $p=0.002$) [22] and Nigerian studies (20% non-clinical lag) [23]. Equalised practices support multidisciplinary simulations [24,25].

Implications: Enhanced KAP could reduce HAIs by 20–30% [17] and support WHO IPC [16]. For LMICs, integrate role-tailored curricula to curb resistance [26].

Baseline KAP Levels

Pre-training KAP (~68%) matches Saudi (68% knowledge, 55% practices) [15] and Lebanese (52–60%) [15] studies, tied to infrastructure (18–64% deficient) [3,13,21]. Higher in high-income settings (75–85%) [3].

Intervention Effects and Effect Sizes

Moderate effects ($d=0.46$ – 0.47) parallel Jordanian ($d=0.50$) [24] and Nepalese ($+0.8$ practices) [18] studies. Ethiopian $d=0.48$ for practices [20]; our one-off design limits longevity vs. reinforced programs [19].

KAP Disparities

Nurses outperformed sanitary workers (15–20% gaps, $p<0.001$) [15,22]; training narrowed practices by 15–20% [20]. Ugandan study: No attitude change in auxiliaries without visuals [23].

Limitations

No control risks overestimation; short follow-up (1 week) limits durability [27]. Single-site convenience sampling and small lab $n=14$ reduce generalizability/power (post-hoc power~0.20). Future: RCTs with long-term audits, oversampling subgroups.

Conclusion:

This quasi-experimental study demonstrates that a targeted, multi-format training intervention significantly enhances knowledge, attitudes, and practices (KAP) related to biomedical waste (BMW) management among healthcare workers in a tertiary care setting in India. With overall improvements of +1.1 in knowledge ($p<0.001$, $d=0.47$), +0.9 in practices ($p<0.001$, $d=0.46$), and +0.4 in attitudes ($p=0.004$, $d=0.21$), the program proved particularly effective for nurses and sanitary workers, equalising practice behaviours across cadres while highlighting persistent knowledge and attitudinal gaps in support roles. These cadre-specific gains underscore the value of tailored educational strategies in addressing baseline disparities driven by education and experience levels, ultimately fostering safer waste handling and reducing occupational and environmental risks. Future research should prioritise multi-site randomised controlled trials (RCTs) with extended follow-up (e.g., 6–12 months) to evaluate KAP durability and cost-effectiveness, incorporating objective measures like waste audits. Exploring digital innovations, such as e-learning platforms and augmented reality simulations, could enhance scalability in resource-limited settings.

In essence, empowering healthcare workers through precision-oriented BMW training not only curtails immediate hazards but also builds resilient systems against emerging threats like pandemics and climate-driven waste surges. By averting up to 30% of discard-related environmental and health burdens, these efforts advance equitable, sustainable healthcare infrastructures, safeguarding communities for generations to come.

Recommendations

- **E-Learning Platforms and Self-Paced Courses:** Asynchronous modules with videos, quizzes, and certifications. Ideal for busy HCWs, focusing on regulations, segregation, and disposal.
- **On-Demand Compliance Portals:** Integrated platforms combining training with waste scheduling and compliance tracking.
- **Live Webinars and Interactive Sessions:** Synchronous tools for real-time Q&A and demonstrations.
- **Simulation and Modelling Tools:** Software for scenario-based training on waste processes.
- **AR/VR Immersive Training:** Virtual environments for hands-on practice without risks.
- **Free/Downloadable Modules:** WHO-style resources for basic awareness.

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