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Research article

Applying a multi-faceted infection control strategy to improve hospital environmental cleaning quality

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ABSTRACT

Background: Along with existing infection control policies, repeated education and training of environmental service workers (ESWs) improves their compliance and ultimately reduces hospital-associated infection (HAI) rates. However, only limited studies have explored the health behavioral determinants of ESWs regarding their cleaning performance after implementing an educational intervention with multi-faceted infection control strategy.

Objective: To determine whether an educational intervention with multi-faceted infection control strategy improves the health behavioral determinants associated with ESWs' cleaning performance.

Methods: Twenty-eight ESWs who received an educational intervention with multi-faceted hospital infection control strategy were included. ESWs' knowledge, perceived benefits and barriers, self-efficacy, health literacy, and cleaning performance were evaluated at pre-intervention, post-intervention, and 3-month follow-up.

Results: HAI-related adenosine triphosphate (ATP) levels decreased significantly at post-intervention and 3-month follow-up compared with pre-intervention levels (all $p < 0.05$). All post-intervention ATP levels met the standard criterion after the 2nd environmental cleaning, with a median score of 267 (range, 71–386). High baseline ATP levels (odds ratio [OR] = 4.195, 95%CI 2.500–7.042, $p < 0.05$) were positively associated with qualified post-intervention ATP levels, while high education (OR = 0.480, 95%CI 0.276–0.833, $p < 0.05$) and high baseline knowledge scores (OR = 0.481, 95%CI 0.257–0.903, $p = 0.023$) were negatively associated with qualified post-intervention ATP levels.

Conclusion: Educational intervention using a multi-faceted infection control strategy improves health behavioral determinants (baseline education, knowledge scores and ATP levels) associated with ESWs' hospital cleaning performance. Receiving an educational intervention may increase HAI knowledge of environmental cleaning among ESWs with high education or low baseline HAI knowledge.

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1. Introduction

Healthcare-associated infections (HAIs) are a major patient safety issue in hospitals and are shown to increase patient morbidity and mortality, as well as health services costs [1]. A 2017 investigation into the global prevalence of HAIs found that around 7 of every 100 hospitalized patients acquire HAIs in developed countries, compared with 10 of every 100 hospitalized patients in developing countries [2]. In higher-income developed countries, 5%–15 % of hospitalized patients acquire HAIs and between 9 % and 37 % of those admitted to intensive care units (ICUs) are also affected [3]. ICU patients are often critically ill, with increased susceptibility to HAIs. Taiwan Nosocomial Infections Surveillance System data collected in 2015 revealed HAI rates of 5.03 infections per 1000 patient-days, which is relatively high among Asian countries, compared with 2.74 in Japan and 2.76 in Korea [4].

The quality of environmental cleaning in hospitals has gained much attention in response to reports on the ability of infectious microorganisms to persist for long periods of time on hospital environmental surfaces, with documented survival of several organisms for weeks to months in the hospital environment [5]. Previous evidence revealed that environmental contamination makes a substantial contribution to hospital infection [6]. Improved environmental cleaning can reduce HAIs [6,7]. However, the quality of environmental cleaning in hospitals is widely acknowledged as unsatisfactory when cleaning is insufficient and high levels of residual microorganisms exist on surfaces [7,8]. Assessment and feedback on cleaning performance is a critical part of preventing environmentally disseminated infection.

Health behavioral theories and models are used to describe, predict and explain underlying determinants of certain behaviors within the healthcare context [9]. Variables used in the models include healthcare knowledge, motivation, intention, perceived benefits and barriers, and self-efficacy [9]. Health behaviors may influence work performance [10]. Recently, Imamura et al. [11] demonstrated that high health literacy (an individual's capacity to locate, comprehend, and apply health-related information in the process of making decisions about their health) in women may contribute to increased work performance and better health behaviors, implying that health behaviors such as health literacy may also influence the performance of environmental cleaning services.

Previous studies have suggested that repeated education and training improves the compliance of environmental service workers (ESWs) in the presence of existing hospital infection control policies or procedures and ultimately reduces HAI rates [12–15]. However, in practice, environmental cleaning is poorly executed [8]. A recent evaluation of outcomes from a targeted multi-modal bundle in terms of changes to HAI rates and cleaning performance suggested that this bundled intervention may improve hospital environmental cleaning [16]. To date, there are no studies addressing the health behavioral determinants (perceived benefits and barriers, self-efficacy and health literacy) of ESWs regarding their work and how these determinants may impact the effectiveness of cleaning after educational intervention with a multi-faceted infection control strategy. The aim of this study was to develop an educational intervention, including an environmental cleaning services bundle educational session that included ESWs' own hygiene behaviors, education on the optimal use and techniques on cleaning products, cleaning methods, designed to train ESWs in proper environmental cleaning practices and to investigate association of these health behavioral determinants and hospital environmental cleaning after implementing the intervention.

2. Materials and methods

2.1. Study design and participants

The study enrolled 28 ESWs working in a tertiary 381-bed public teaching hospital in Taipei, Taiwan, between October 2021 and April 2022. Eligible participants were: (1) aged >20 years; (2) able to read, write, speak and listen in Chinese; and (3) able to provide signed informed consent. A prospective quasi-experimental design was used, with repeated measures prior to and after the intervention, and at 3 months of follow-up. The three-month follow-up period was based on the turnover rate of contracted ESWs.

2.2. Ethics statement

The study protocol was reviewed and approved by the Institutional Review Board of the Tri-Service Veterans Hospital (IRB number: A202005138), and complied with the Helsinki Declaration (2008). All participants provided signed informed consent.

2.3. Educational intervention with a multi-faceted infection control strategy

Our multi-faceted infection control strategy included a multidisciplinary implementation team (one infectiologist, two staff members from the Infection Control Department, one from the Environmental Services Department and one member of the study research team), training of ESWs with an environmental cleaning bundle educational session [16,17], adenosine triphosphate (ATP) auditing results [14,16], and feedback on environmental cleaning practices [14]. The environmental cleaning bundle educational session (2-h session) was designed by the multidisciplinary implementation team according to educational courses of environmental cleaning provided by Taiwan's Centers for Disease Control (CDC) and included the ESWs' own hygiene behaviors, education on the optimal use and techniques of cleaning products, and cleaning methods. Training and supportive educational materials (e.g., session slides, video instructions on the use of cleaning tools and cleaning procedures) for ESWs were provided during the educational session. All ESWs and members of the multidisciplinary implementation team were present at the educational session (October 15, 2021), which was delivered (In-Person Format) by the infectiologist and two Infection Control Department members. At the end of the educational session, ESWs were tested by ATP auditing and they practiced with hands-on simulations of cleaning conditions. Each ESW received individual feedback on the ATP audit results and observations on environmental cleaning practices.

2.4. Outcomes

The primary outcome was changes in ATP testing results between the three time periods (preintervention, post-intervention and at 3-month follow-up), which represented the overall improvement or decline in cleaning performance [18]. Secondary outcomes included changes in ESWs' levels of perceived benefits and barriers, self-efficacy and health literacy between the three time periods, evaluated by a survey questionnaire.

2.5. Collection and measurement of environmental samples

Environmental samples were collected from the ICU and other (Internal Medicine, Surgery, and Obstetrics and Gynecology) departments that were cleaned by each ESW. Environmental samples from different touch points (20 samples per touch point) were collected and quantified for ATP using 3 M Clean-Trace surface ATP swabs (3 M™ Clean-Trace™ ATP Surface Test Kit, 3 M Science, St. Paul, MN, USA) immediately following cleaning and sanitation, according to the manufacturer's instructions; if ATP was present in the sample, these substances reacted with ATP and released a light signal, which was measured using a luminometer (3 M Science, St. Paul, MN, USA). The touch points concluded bed rails, bed buttons, rotary knobs of suction regulators and flowmeters, bedside tables and oxygen meter rotary knobs, because our routine checks on environmental cleaning have determined that these touch points are often ignored. Environmental samples were collected using standardized definitions as per hospital surveillance protocols and extracted for the study. Previous studies [19–21] have determined that a reading of 0–500 relative light units (RLU) is considered to be "clean" for general nursing units, while 0–250 RLU is "clean" for ICU purposes.

2.6. Survey procedures and measurements

Each ESW completed questionnaire prior (October 15, 2021) to and after (October 15, 2021) the intervention, and then again at 3 months' follow-up. This questionnaire consisted of five parts: 1) participants' demographic and descriptive characteristics and environmental cleaning knowledge (Table S1); 2) a perceived benefits scale (Table S2); 3) a perceived barriers scale (Table S3); 4) a self-efficacy scale (Table S4); and 5) a health literacy scale (Table S5). Environmental cleaning knowledge (measured by 10 items, constructed according to the environmental cleaning bundle lesson designed by the multidisciplinary implementation team and based on Taiwan's CDC educational course) was represented by an overall correct rate of environmental cleaning knowledge scale score. Scores on the scales of perceived benefits (7 items, constructed according to our previous study [22]) were 1, 2, 3, 4, or 5, representing "no influence," "some influence," "normal influence," "strong influence," and "absolute influence," respectively. Scores on the scales of perceived barriers (5 items, constructed according to our previous study [22]) were 1, 2, 3, 4, or 5, representing "absolute influence," "strong influence," "normal influence," "some influence," and "no influence," respectively. Participants' levels of self-efficacy (6 items) was based on the General Self-Efficacy Scale [23], measuring an individual's beliefs and ability to deal with different situations, with scores of 1, 2, 3, 4, or 5 representing "10%–20 % certainty," "30%–40 % certainty," "50%–60 % certainty," "70%–80 % certainty," and "90 % or more certainty," respectively. Health literacy (12 items) was assessed by the Test of Functional Health Literacy in Adults (TOFHLA) with slight modifications [24]; the scores of 5, 4, 3, 2, and 1 represented "very easy," "easy,""normal," "difficult," and "very difficult," respectively.

2.7. Statistical analysis

Continuous variables are presented asmedians with range and were used to perform comparisons between subgroups using the Mann-Whitney *U* test. Categorical variables are expressed as numbers (percentages) and assessed by Fisher's Exact test followed by Bonferroni correction for comparisons between subgroups. Two-way mixed ANOVA following Bonferroni post-hoc analysis determined ATP levels, participants' characteristics and health behavioral determinants over different time periods. The generalized estimating equation (GEE) was used to explore systematic differences in participants' characteristics, health behavioral determinants, and ATP levels between the preintervention and post-intervention periods, as previously described [25]. All statistical analyses were performed using SPSS, version 25.0 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Baseline characteristics, health behavioral determinants and ATP levels

Twenty-eight participants were included in this study. Participants' baseline characteristics, health behavioral determinants, and ATP levels are listed in Table 1. The median age was 63 (36–78) years (mean ± SD: 61 ± 11 years); 15 (53.6 %) participants were males. Three (10.7 %), 9 (32.1 %), 14 (50.0 %), and 2 (7.1 %) participants had elementary school, junior high school, senior high school, and college education, respectively. The median number of working years in hospital cleaning was 2.75 (0.17–12.00) years (mean ± SD: 4.31 ± 3.99 years). The median baseline scores for environmental cleaning knowledge, perceived benefits, perceived barriers, self-efficacy, and health literacy were 100.00 (70.00–100.00) (mean ± SD: 83.21 ± 19.82), 5.00 (2.29–5.00) (mean ± SD:

4.58 ± 0.78), 4.30 (2.00–5.00) (mean ± SD: 4.07 ± 0.89), 4.00 (2.00–5.00) (mean ± SD: 4.19 ± 0.58), and 4.13 (2.00–5.00) (mean ± SD: 3.91 ± 0.89), respectively. The median baseline ATP level in environmental samples was 642 (286–3750) RLU (mean ± SD: 797 ± 600 RLU).

3.2. Comparison of ATP levels between the preintervention and post-intervention periods

The ATP levels in environmental samples were significantly decreased at post-intervention (post-intervention vs preintervention: 291 vs 642, $p < 0.001$) and the 3-month follow-up (3-month follow-up vs: 366 vs 642, $p < 0.001$) when compared with preintervention levels (Fig. 1A); ATP levels in environmental samples did not differ significantly between the post-intervention and 3-month follow-up ($p = 0.098$, Fig. 1A). When ATP levels were compared for different touch points (bed rail, bed button, suction knob, bedside table and oxygen meter knob) in the ICU and general wards, ATP levels for each ICU touch point were significantly decreased at post-intervention and the 3-month follow-up compared with preintervention levels (all $p < 0.05$, Fig. S1); similar, significant decreases were also observed for each touch point in the general wards (all $p < 0.05$, Fig. S2). In some of the post-intervention environmental samples, the ATP levels did not meet the standard criterion (ICU <250 RLU; general nursing units <500 RLU), so the ESWs were required to perform a second environmental cleaning and undergo further evaluation of ATP levels. As shown in Fig. 1B, ATP levels were significantly decreased after the second environmental cleaning session compared with those after the first post-intervention cleaning ($p < 0.05$). ATP levels met the standard criterion after the second environmental cleaning session, with a median ATP level of 267 RLU (71–386).

3.3. Factors associated with ATP levels after the educational intervention

Educational levels, the number of working years in hospital cleaning, baseline scores of environmental cleaning knowledge, perceived benefits and barriers, self-efficacy, and health literacy, and baseline ATP levels, were grouped by median levels. Table 2 presents the study participants' demographic and descriptive characteristics, as well as associations between these characteristics and ATP levels prior to and after the intervention, and at 3-month follow-up. Two-way mixed ANOVA analysis showed that participants with high baseline self-efficacy scores (>4) had significantly lower ATP levels at post-intervention compared with those of participants with low baseline self-efficacy scores (≤4) ($p < 0.05$). Similarly, participants with high baseline health literacy scores (≥4.1) and those whose cleaning areas had high baseline ATP levels (>607 RLU) had significantly lower ATP levels at post-intervention compared with participants with low baseline health literacy scores and those whose cleaning areas revealed low baseline ATP levels (all $p < 0.05$). However, the variables, including age, sex, educational level, working years in hospital cleaning, and baseline environmental cleaning knowledge, perceived benefits and barriers scores, were not significantly associated with changes in ATP levels after the educational intervention (all $p > 0.05$).

Subsequently, in multivariate GEE analysis using ATP level as a continuous variable, participants with high baseline ATP levels had significantly greater decreases in ATP levels after the educational intervention compared with the decreases observed among participants with low baseline ATP levels (β = 229.450, 95 % CI 2.026–460.927, $p = 0.048$, Table S6). No significant associations were noted regarding age, sex, education, number of working years in hospital cleaning, and baseline environmental cleaning knowledge, perceived benefits and barriers, self-efficacy and health literacy scores with ATP levels at post-intervention (all $p > 0.05$, Table S6). Furthermore, in multivariate GEE analysis using ATP level as a categorical variable (with or without qualified ATP levels), a high baseline ATP level (OR = 4.195, 95 % CI 2.500–7.042, $p < 0.001$) positively predicted a qualified ATP levels at post-intervention and 3 months' follow-up, while high education (OR = 0.480, 95 % CI 0.276–0.833, $p = 0.009$) and high baseline environmental cleaning knowledge scores (OR = 0.481, 95 % CI 0.257–0.903, $p = 0.023$) negatively predicted a qualified ATP levels at post-intervention and

Table 1
Participants' baseline demographic and descriptive characteristics and ATP scores.

Parameters	Total (N = 28)
Age (years), median (range), mean ± SD	63 (36–78), 61 ± 11
Sex, n (%)	
Male	15 (53.6 %)
Female	13 (46.4 %)
Education, n (%)	
Elementary school	3 (10.7 %)
Junior high school	9 (32.1 %)
Senior high school	14 (50.0 %)
College	2 (7.1 %)
Working years in hospital cleaning, median (range), mean ± SD	2.75 (0.17–12.00), 4.31 ± 3.99
Environmental cleaning knowledge at baseline (%), median (range), mean ± SD	100 (70–100), 83.21 ± 19.82
Perceived benefits at baseline, median (range), mean ± SD	5.00 (2.29–5.00), 4.58 ± 0.78
Perceived barriers at baseline, median (range), mean ± SD	4.30 (2.00–5.00), 4.07 ± 0.89
Self-efficacy at baseline, median (range), mean ± SD	4.00 (2.00–5.00), 4.19 ± 0.58
Health literacy at baseline, median (range), mean ± SD	4.13 (2.00–5.00), 3.91 ± 0.89
ATP levels at baseline, median (range), mean ± SD	642 (286–3750), 797 ± 600

ATP, adenosine triphosphate; SD, standard deviation.

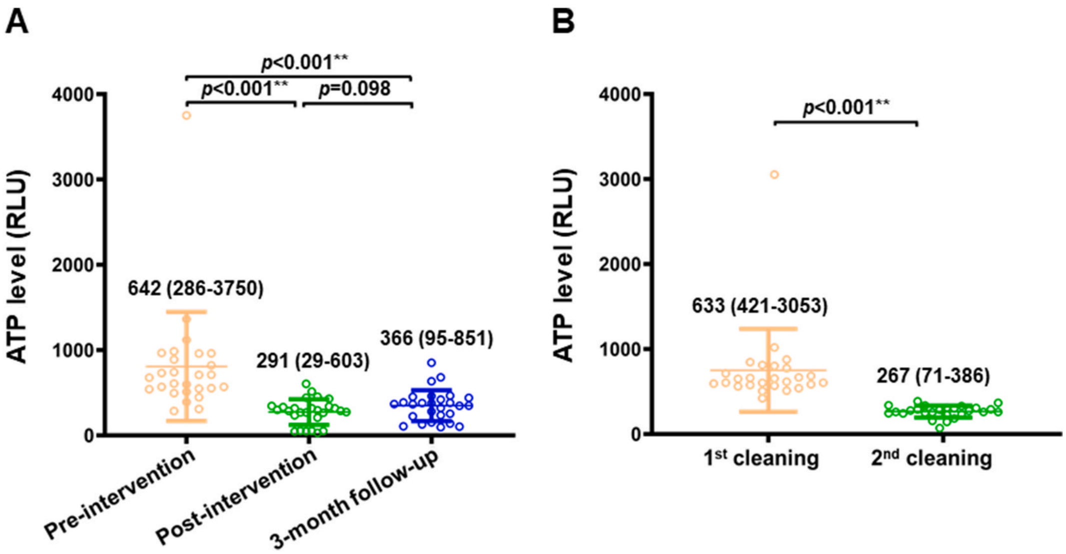

Fig. 1. (A) ATP scores (represented by medians and ranges) at the preintervention, post-intervention, and 3-month follow-up time periods. (B) ATP scores at the first and second post-intervention environmental cleaning assessments. $^{**}p < 0.001$ indicates statistical significance; ns indicates non-significant. ATP, adenosine triphosphate; RLU, relative light units.

Table 2
Participants' demographic and descriptive characteristics and ATP levels at the preintervention and post-intervention assessments.

Parameters	Preintervention	Post-intervention	3-month follow-up	*p*-value
Age (years), median (range)				0.520
<65	637 (286–3750)	281 (44–603)	356 (106–851)	
≥65	659 (390–965)	306 (29–514)	380 (95–634)	
Sex, median (range)				0.143
Male	569 (286–965)	299 (47–455)	379 (106–680)	
Female	740 (309–3750)	286 (29–603)	347 (95–851)	
Educational level, median (range)				0.331
≤ Junior high school	658 (286–3750)	284 (44–603)	300 (106–851)	
> Junior high school	622 (309–1362)	291 (29–455)	372 (95–465)	
Working years in hospital cleaning, median (range)				0.550
<3	708 (390–1362)	308 (29–455)	372 (95–680)	
≥3	588 (286–3750)	277 (44–603)	357 (106–851)	
Environmental cleaning knowledge at baseline (%), median (range)				0.135
≤90	710 (446–3750)	288 (44–603)	349 (95–851)	
>90	553 (286–1362)	394 (29–455)	367 (103–460)	
Perceived benefits at baseline, median (range)				0.147
<5	561 (390–965)	324 (266–514)	429 (236–634)	
≥5	720 (286–3750)	269 (29–603)	300 (95–851)	
Perceived barriers at baseline, median (range)				0.101
<4.4	569 (309–1362)	308 (266–514)	383 (347–634)	
≥4.4	720 (286–3750)	221 (29–603)	230 (95–851)	
Self-efficacy at baseline, median (range)				0.026*
≤4	569 (309–1362)	318 (266–514)	381 (223–680)	
>4	740 (286–3750)	51 (29–603)	151 (95–851)	
Health literacy at baseline, median (range)				0.013*
<4.1	569 (446–965)	318 (266–514)	340 (321–680)	
≥4.1	735 (286–3750)	221 (29–603)	230 (95–851)	
ATP levels at baseline, median (range)				0.003*
≤607	531 (286–607)	318 (47–455)	379 (151–680)	
>607	924 (676–3750)	267 (29–603)	301 (95–851)	

ATP, adenosine triphosphate. Educational level, working years in hospital cleaning, baseline environmental cleaning knowledge score, perceived benefits score, perceived barriers score, self-efficacy score, health literacy score and ATP levels are all grouped by medians. $^{*}p < 0.05$ represents statistical significance.

the 3-month follow-up (Table 3). A high baseline perceived benefit score was also as a negative factor for predicting qualified ATP levels at the post-intervention and 3-month follow-up, but was not statistically significant (OR = 0.556, 95 % CI 0.294–1.051, p = 0.071, Table 3).

4. Discussion

In this study, the analysis of health behavioral determinants among ESWs and ATP levels at the three time periods yielded the following insightful findings: first, ATP levels at post-intervention and 3-month follow-up were decreased in the included ESWs after educational intervention with a multi-faceted infection control strategy; second, all ATP levels at post-intervention were considered “clean” after the second environmental cleaning; third, high baseline ATP level positively predicted qualifying post-intervention ATP levels, while both high education and high environmental cleaning knowledge negatively predicted qualifying post-intervention ATP levels.

ESWs play a vital role in preventing HAIs [12–15]. In fact, ESW positions in local hospitals are often filled by individuals with relatively low education levels [26]. ESWs’ compliance with policies and infection and prevention control (IPC) standards is usually unsatisfactory [14]. ESWs’ attitudes towards cleaning, HAI awareness, and understanding of IPC standards may influence their intentions to clean and are critical in reducing HAIs [27]. In this study, HAI-related ATP levels improved significantly after the ESWs received an educational intervention with multi-faceted infection control strategy; these improvements persisted at 3-month follow-up. Most previous studies in this topic area have not examined the sustainability of the effects of educational interventions. One US-based study published in 2014 reported that ESWs were unable to sustain improvements in cleaning performance after completing an environmental-cleaning quality improvement program [28]. The study researchers therefore proposed implementing monthly feedback of performance data in face-to-face meetings with front-line personnel (ESWs and infection control personnel) and suggested that such feedback is essential for maintaining effective ‘environmental cleaning in adult ICUs [28]. Thus, combining cleaning performance evaluation/feedback with education/training sessions may significantly improve environmental cleaning performance.

Improving cleanliness in healthcare environments requires that the benefits and barriers to optimal cleaning and disinfection are well understood. In 2015, a knowledge, attitudes, and practice (KAP) survey involving frontline environmental service workers in 5 acute-care hospitals in New York, the USA, revealed that nearly three-quarters of the participants expressed interest in more education and the study researchers identified gaps in the KAP results, including knowledge of appropriate cleaning products, hand hygiene procedures and knowledge of the transmission mechanisms of hospital pathogens [29]. Another study found that further education of environmental services personnel is essential for addressing the different types of pathogens transmitted by contaminated environmental surfaces, and for identifying which specific pathogens are killed by bleach [13]. In one study that explored the effects of educational interventions designed specifically for ESWs, addressing gaps in KAPs and common barriers to implementing best practices, 93 % of the participants rated the interventions as “excellent” or “very good”, and agreed that the interventions increased their environmental cleaning knowledge and improved their daily cleaning of occupied patient rooms [30]. However, environmental cleaning knowledge scores in that study were not significantly different between the preintervention and post-intervention periods [30]. In contrast, our results revealed significantly lower post-intervention ATP scores compared with preintervention scores. Interestingly, a GEE analysis showed that a high baseline ATP level positively predicted ESW compliance with post-intervention cleaning performance, while a high education level and high baseline environmental cleaning knowledge scores negatively predicted such compliance. However, no significant associations were noted between age, sex, education, and working years in hospital cleaning and ATP levels at post-intervention. Ni et al. [26] showed that knowledge scores of environmental cleaning were not statistically significant based on age among ESWs in Chinese hospitals. This appears to indicate that educational intervention only improves the cleaning performance of ESW with high education, low baseline environmental cleaning knowledge, or high baseline ATP levels. We suggest that providing an educational intervention for environmental service workers increases their knowledge of environmental cleaning and ultimately reduces HAI rates.

HAI is a critical patient safety issue globally and is known to increase morbidity and mortality and increase health service costs [1]. Infectious organisms survive on surfaces for long periods of time [5], and contaminated surfaces are a significant source of HAI

Table 3
Logistic regression with generalized estimating equations analysis of participants’ characteristics and qualifying ATP scores.

Variables	Univariate		Multivariate	
	OR (95%CI)	*p*-value	OR (95%CI)	*p*-value
Age, years (<65 vs ≧ 65)	0.944 (0.474, 1.883)	0.871	0.880 (0.544, 1.422)	0.568
Sex (female vs male)	1.464 (0.749, 2.857)	0.265	1.456 (0.822, 2.579)	0.198
Education (>Junior high school vs ≦ Junior high school)	0.471 (0.240, 0.724)	0.006*	0.480 (0.276, 0.833)	0.009*
Working years (<3 vs ≧ 3)	0.887 (0.449, 1.748)	0.728	0.881 (0.452, 1.721)	0.711
Environmental cleaning knowledge at baseline (high vs low)	0.474 (0.251, 0.896)	0.022*	0.481 (0.257, 0.903)	0.023*
Perceived benefits at baseline (high vs low)	0.732 (0.357, 1.501)	0.395	0.556 (0.294, 1.051)	0.071
Perceived barriers at baseline (high vs low)	1.192 (0.603, 2.356)	0.613	1.181 (0.605, 2.304)	0.625
Self-efficacy at baseline (high vs low)	1.030 (0.512, 2.070)	0.934	1.599 (0.836, 3.055)	0.156
Health literacy at baseline (high vs low)	0.839 (0.424, 1.658)	0.613	0.606 (0.316, 1.159)	0.130
ATP levels at baseline (high vs low)	2.801 (1.484, 5.291)	0.001*	4.195 (2.500, 7.042)	<0.001*

ATP, adenosine triphosphate. The cut-off values for age, education, working years in hospital cleaning, baseline environmental cleaning knowledge score, baseline perceived benefits score, baseline barriers score, baseline self-efficacy score, baseline health literacy score, and baseline ATP levels were 65 years, junior high school, 3, 90, 5, 4.4, 4, 4.1, and 607, respectively. SD, standard deviation; OR, odds ratio; CI, confidence interval; ATP, adenosine triphosphate. *$p < 0.05$ represents statistical significance.

transmission [31]. The risk of acquiring an HAI increases significantly when the prior occupant of a patient room has been infected [32]. This risk can be reduced by thorough cleaning and disinfection practices to reduce surface contamination and remove or destroy the responsible microorganisms [33,34]. However, hospital hygiene is usually not satisfactorily enforced [8]. This may be due in part to inconsistencies in the approved best practices and in practical translation. One feasible approach to address this issue is to create an environmental cleaning "bundle," a set of simultaneously introduced key practices, which is shown to successfully prevent infection [17]. In this study, an environmental cleaning bundle that included hygiene behavior, information on optimal product use, cleaning techniques, staff training, and auditing with feedback, was integrated into the educational intervention. At the post-intervention session, significant improvement was observed in the cleaning performance of ESWs, suggesting that this environmental cleaning bundle is an effective way to reduce the risk of HAI acquisition.

This study did not analyze associations among health behavioral determinants, cleaning performance (ATP levels) and HAI rates. Nevertheless, our data provide evidence in support of a multi-faceted infection control strategy for improving environmental cleaning performance. In other previous studies, repeated education and training improved the compliance of ESWs with policies or procedures and ultimately reduced HAI rates [12–15]. Study evidence revealed that cleaning personnel perceive that they play a role in HAI prevention, but that this role is undervalued by clinical staff [35]. Thus, we believe that our multi-faceted infection control strategy would lower HAI rates due to an improvement in environmental cleaning performance and greater appreciation of the importance of feedback between management, clinical staff and ESWs.

4.1. Limitations

This study has several limitations. First, the ATP bioluminescence assay as an indicator of general organic contamination is available to monitor hospital contamination [36]. Gibbs et al. [37] demonstrated a correlation between ATP bioluminescence measurements and quantitative microbiology. Second, the generalization of our study findings to other populations and locations is limited by the small sample size from a single regional hospital. Third, as the study sample comprised selected volunteers, it is impossible to rule out voluntary response bias. Future research using random sampling and a larger ESW sample size overcome these limitations.

5. Conclusions

These study results demonstrate an increased level of awareness of IPC guidelines among ESWs after participation in an educational intervention with multi-faceted infection control strategy. Notably, cleaning performance was significantly improved among ESWs with low education, low baseline environmental cleaning knowledge, or high baseline ATP level. We suggest that health policy-makers and administrators consider implementing both the multi-faceted infection control strategy and this study's interventional approach.

Ethics statement

This study protocol was reviewed and approved by the Institutional Review Board of the Tri-Service Veterans Hospital (IRB number: A202005138), and complied with the Helsinki Declaration (2008). The study was conducted according to established ethical guidelines and written informed consent obtained from all participant**s.**

Data availability statement

The data will be made available from the corresponding author upon request.

CRediT authorship contribution statement

Hsin-An Lin: Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hsin-Chung Lin:** Writing – review & editing, Methodology, Data curation. **Lih-Chyang Chen:** Writing – review & editing, Formal analysis. **Kuo-Yang Huang:** Writing – review & editing, Formal analysis. **Jong-Long Guo:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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