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Research paper

# Evaluating bio-burden of frequently touched surfaces using Adenosine Triphosphate bioluminescence (ATP): Results from the Researching Effective Approaches to Cleaning in Hospitals (REACH) trial

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**Abstract** *Background:* Environmental cleaning is an important approach to reducing healthcare-associated infection. The aim of this short research paper is to describe changes in the efficacy of post-discharge cleaning by examining the amount of bio-burden on frequent touch points (FTPs) in patient areas, using a validated Adenosine Triphosphate (ATP) bioluminescence sampling method. In so doing, we present findings from a secondary outcome of a recent trial, the Researching Effective Approaches to Cleaning in Hospitals (REACH) study.
*Methods:* The REACH study used a prospective, stepped-wedge randomised cluster design. Cross sectional ATP sampling was conducted at three of the 11 participating hospitals. At each hospital, during the control and intervention phase of the study, six Frequent Touch Points (FTPs) were sampled: toilet flush, bathroom tap, inside bathroom door handle, patient call button, over bed tray table, and bed rails.
*Results:* Across the three hospitals, 519 surfaces in 49 rooms (control phase) and 2856 surfaces in 251 rooms (intervention phase) were sampled. Bedroom FTP cleaning improved across all three hospitals. The cleaning of bathroom FTPs was generally high from the outset and remained consistent throughout the whole study period. Average cleaning outcomes for bathroom FTPs were consistently high during the control period however outcomes varied

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between individual FTP. Changes in cleaning performance over time reflected variation in intervention effectiveness at the hospital level.
*Conclusion:* Findings confirm improvement in cleaning in the FTPs in bedrooms, demonstrating improvements in discharge cleaning aligned with the improvements seen when using fluorescent marking technology as a marker of performance.


**Highlights**

- We assessed cleaning using adenosine triphosphate bioluminescence and florescent marker technology.
- Assessment was embedded within a randomised control study.
- Cleaning of frequent touch points improved in participating hospitals.

## Introduction

One in 10 patients in an Australian hospital have a healthcare associated infection (HAI) [1], with an estimated 165,000 cases each year in Australia [2]. A vast amount of evidence has highlighted the role of contaminated surfaces in the transmission of healthcare associated pathogens [3]. More specifically, surfaces that are frequently touched by patients and healthcare workers (e.g. over-bed tray tables and door handles) are more susceptible to contamination and consequently can act as a reservoir for the transmission of pathogens [4–6]. Cleaning of surfaces is an important component of the overall strategy to reduce the risk of HAI transmission [7]. Studies have demonstrated that environmental cleaning interventions can improve the thoroughness of cleaning [8–10]. More recently, high quality studies have demonstrated the value of improving cleaning and its effect on reducing the incidence of HAI [11,12].

Despite the importance of cleaning in reducing the risk of infection, studies have demonstrated that cleaning practices and methods to evaluate cleaning vary [13,14]. Methods to assess and evaluate cleaning practices and hospital cleanliness include visual inspection, fluorescent marking (FM), microbiological sampling and Adenosine Triphosphate (ATP) bioluminescence sampling [14]. Visual inspection is subjective and may not be reliable, while microbiological sampling is time consuming, lacks immediacy of results and is constrained by cost [14–17].

Fluorescent marking with an ultraviolet light is one standardised approach used to evaluate whether a surface has been cleaned. Using this approach, gel dots are applied to surfaces in the patient environment [8]. The dots are invisible to the naked eye and are removed by routine cleaning. After cleaning, the sites can be checked using the ultraviolet light torch to determine whether the gel dot was removed. The FM method is a highly reliable way to measure that a cleaning process has been conducted on a surface but provides no indication as to the efficacy of the cleaning process.

Another monitoring approach is the use of ATP, which can be used to monitor the cleanliness of equipment, surfaces and medical devices. The presence of ATP is a proxy of organic matter on surfaces. Following adequate cleaning, ATP levels should be significantly reduced [18]. The level of ATP contamination (bioburden) is measured in Relative Light Units (RLUs). Rapid ATP testing devices measure all cellular ATP, including microbial ATP, thereby being a general measure for cleanliness [19]. The use of an intervention control step is required to reduce the risks of confounded results due to the underlying poor performance of a cleaning process [20].

While ATP sampling has been used in the hospitality industry for over three decades, its use in healthcare settings is debated. This is due to a lack of standardised sampling methodology and a wide variability of ATP devices (luminometers) that incorporate different threshold values, ranging anywhere between 45 and 1000 RLU [14,15,18,19,21,22]. As a result, there are a number of difficulties associated with comparability of results and measurements across studies and settings [21–23]. This method is also unable to distinguish between types of organic material, with differing evidence regarding the correlation between bacterial load and RLU [18]. Despite these factors, the advantages of this technique include its simplicity and ease of use, the ability to acquire real-time quantitative results (within 20 seconds of sampling) and to provide direct, objective instantaneous feedback [19,23,24]. Several studies have found evidence linking the use of ATP as a monitoring and feedback tool and improved environmental cleaning [23,25–29].

The aim of this paper is to describe changes in the efficacy of post-discharge cleaning by examining the amount of bio-burden on frequent touch points (FTPs) in patient areas, using a validated ATP sampling method [19]. In so doing, we present findings from a secondary outcome of a recent trial, the Researching Effective Approaches to Cleaning in Hospitals (REACH) study [30].

## Methods

### Design

The REACH study, conducted between May 2016 and July 2017, used a prospective, stepped-wedge randomised design [12]. The study intervention was a multi-modal cleaning bundle consisting of training for environmental services staff with a role in ward cleaning, attention to FTPs and cleaning technique, product use, FM audits and communication activities [12,30]. Further details on the study design, intervention and results from primary outcomes have been published [12,13,30–33].

## Setting

Cross sectional ATP sampling was conducted at three of the 11 hospitals participating in the REACH study. Each of these hospitals met the inclusion criteria of having a large training-accredited intensive care unit and being classified as a major hospital (public hospitals) or having more than 200 beds (private hospitals) [30].

## Data collection

The REACH study team aimed to sample up to eight bed and bathroom areas in each hospital every four weeks through the control and intervention periods in any of the wards being used for FM audit activities [30]. Rooms or bed bays were identified through liaising with the environmental services and nursing staff in each hospital. Bed and bathroom areas chosen were those that had been cleaned by environmental staff post-patient discharge within the previous 24 h, remained unoccupied and were accessible to the study team. Empty rooms, post-discharge clean, were chosen to minimise the possibility of recontamination from staff and patients between completion of the cleaning and the ATP sampling. The timing of the sampling required some flexibility due to room turnover, hospital preferences and holiday timings. The majority of samples were collected in the afternoon on Wednesday to Friday to coincide with the routine patient discharge timings at the hospitals.

## ATP sampling procedure and selection of FTPs

At each hospital, during each phase of the study, six FTP sites were sampled: toilet flush, bathroom tap, inside bathroom door handle, patient call button, tray table, and bed rails. These sampled sites were a subset of 15 FTPs audited as part of the REACH study, using FM technology [30]. The ATP sampling rooms were identified from the wards also used for the FM audit activities. However, for logistic reasons, the ATP sampling was separate in time and exact room location to that of the FM audit process. This was because the ATP required a room that had been cleaned post-discharge for every sampling episode. ATP sampling rooms were identified from a list generated by the hospital of rooms in eligible wards that had been discharge cleaned that day and remained empty.

The ATP sampling was performed with a pre-moistened swab (Hygiena UltraSnap™ Surface ATP Test) and Hygiena SystemSURE plus™ Luminometer, used according to the manufacturer's directions. On each surface, an area of 5 cm $\times$ 5 cm (25 cm$^2$) was sampled using the rapid ATP swab. The areas surrounding irregularly shaped surfaces (buttons and doorknobs) were also swabbed in order to achieve the estimated 25 cm$^2$ surface area.

Samples were collected by two study team researchers according to a published sampling algorithm, in order to reduce the impact of inherent variability in the measurement of ATP [19]. The sampling algorithm used is outlined in Fig. 1. A duplicate sampling approach was used, with two swabs taken as a first step on each FTP. Depending on the outcomes of the two swabs, a cleaning step was performed by the person undertaking the sampling, using a hospital

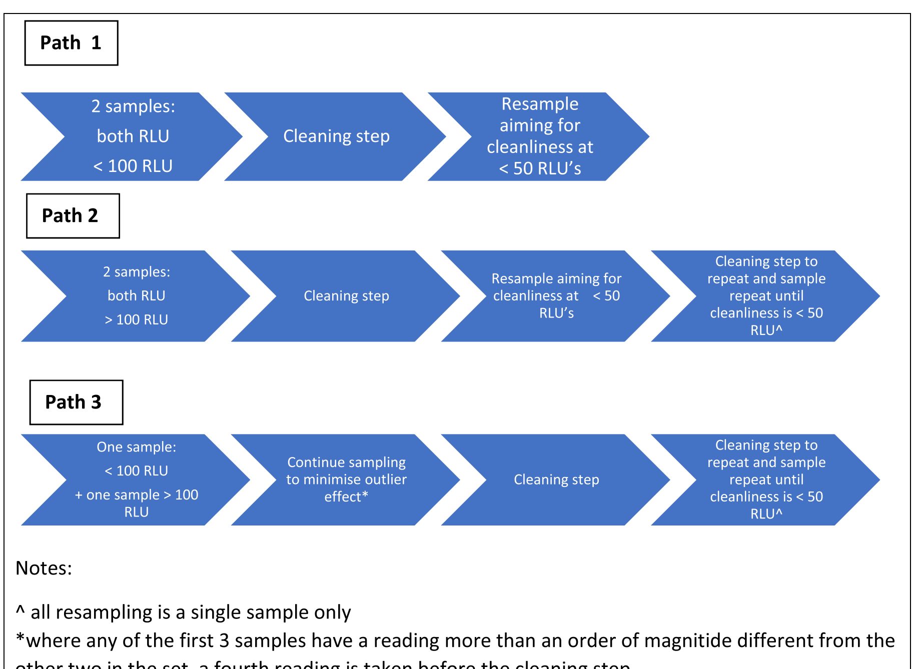


**Figure 1** ATP sampling algorithm.

grade neutral detergent wipe (Speedy Clean™ Wipes). A third swab was then taken, aiming for cleanliness at less than or equal to 50 RLUs. If the reading was above 50 RLUs, the cleaning step and swab was repeated until cleanliness reached less than or equal to 50 RLUs. The results follow a two-tier cleanliness threshold: If both swabs were below or equal to 25 RLU, the surface was considered 'Clean'. If one or both swabs were over or equal to 26 RLU, the surface was recorded as 'Not Clean'.

## Data analysis

Data collected from the start of the control period at each hospital up to a maximum of 50 weeks were included in all statistical analyses. For both exploratory data analysis and modelling, FTPs were classified on their location: Bathroom (door handle, tap, toilet flush) or Bedroom (bedrail, call button, tray table).

Descriptive statistics for ATP sampling outcomes based on the two-tier cleanliness threshold were stratified by hospital, FTP, FTP location and trial period. Binomial mixed effects modelling was used to test the effectiveness of the intervention on the number of clean ATP sites out of the number of sites sampled [33]. Three separate models were fitted to the data, to determine the presence and nature of the intervention effect. The first model assumed no change in FTP cleaning between control and intervention periods. The second model described the intervention effect by a binary independent variable, which switched from 0 to 1 when a hospital started the intervention period. The third model assumed a linear intervention effect, which was defined as the number of weeks since the start of the intervention period and equal to 0 in the control period.

All models included a random intercept for each hospital and FTP location (Bathroom, Bedroom) as an independent variable. For models that specified an intervention effect, interaction with FTP location was also tested. Model selection was performed using Akaike's Information Criterion (AIC), with lower AIC values indicating improved model fit. Residual diagnostics were carried out on the best fitting model to assess overall goodness-of-fit and identify potential outliers. Hypothesis testing for different model effects was based on a 5% level of statistical significance. Mixed modelling was completed using the 'lme4' and 'multcomp' packages in R version 3.3.2 [34,35].

## Results

Across the three hospitals, 519 surfaces in 49 rooms and 2856 surfaces in 251 rooms were sampled prior to a cleaning step or additional sampling (Path 3) during the control and intervention periods respectively. Changes in the percentage of clean ATP sites between the control and intervention phase are detailed in Table 1, Table 2 and in supplementary material (Table S1).

Bedroom FTP cleaning improved across all three hospitals, with Hospital 1 showing the greatest average improvement from 39% to 68% (Table 1). Average cleaning outcomes for bathroom FTPs was consistently high during the control period however outcomes varied between individual FTP. Changes in post-discharge cleaning performance over time reflected variation in discharge cleaning effectiveness at the hospital level (Fig. 2). Further investigation of cleaning outcomes at the individual FTP level indicated clustering by FTP location within each of the three hospitals (Figure S1).

Changes in FTP cleaning between control and intervention periods were best represented by a binary intervention effect (AIC = 498) compared with no intervention effect (AIC = 511) and gradual changes in cleaning performance

**Table 2** Mixed model outcomes for the change in the percentage of clean ATP sites, assuming a binary intervention effect.

| FTP Location | % clean ATP sites | | OR (Intervention vs. Control) | p-value |
|---|---|---|---|---|
| | Control | Intervention | Estimate [95% CI] | |
| Bathroom | 71.5 | 70.7 | 0.96 [0.62, 1.5] | 0.98 |
| Bedroom | 35.3 | 54.7 | 2.2 [1.5, 3.2] | <0.001 |

Note: OR: odds ratio; CI: confidence interval; p-value corresponds to $H_0$: OR = 0.

**Table 1** Hospital-level summary of ATP outcomes for bathroom and bedroom frequent touch points in control and intervention periods.

| Trial period | Control (8 weeks) % Clean (N) | | | Intervention (41–47 weeks) % Clean (N) | | |
|---|---|---|---|---|---|---|
| Frequent touch point | Hospital 1 | Hospital 2 | Hospital 3 | Hospital 1 | Hospital 2 | Hospital 3 |
| Bathroom | 77.4 (31) | 66.7 (48) | 65.7 (35) | 90 (180) | 72.2 (237) | 47.6 (269) |
| *Door handle* | 70 (10) | 18.8 (16) | 25 (12) | 81.7 (60) | 43 (79) | 30 (90) |
| *Tap* | 63.6 (11) | 87.5 (16) | 75 (12) | 90 (60) | 84.8 (79) | 48.9 (90) |
| *Toilet flush* | 100 (10) | 93.8 (16) | 100 (11) | 98.3 (60) | 88.6 (79) | 64 (89) |
| Bedroom | 39.2 (51) | 25.0 (48) | 44.7 (47) | 68.4 (225) | 36.8 (239) | 57.2 (278) |
| *Bedrail* | 41.2 (17) | 50 (16) | 31.3 (16) | 78.7 (75) | 49.4 (79) | 63.3 (90) |
| *Call button* | 29.4 (17) | 0 (16) | 50 (16) | 56 (75) | 28.8 (80) | 58.5 (94) |
| *Tray table* | 47 (17) | 25 (16) | 53.3 (15) | 70.7 (75) | 32.5 (80) | 50 (94) |

Note: A clean site is defined as per the two-tier sampling approach (both samples $\leq$ 25 RLUs). N = number of ATP sites assessed; RLU = Relative Light Units.

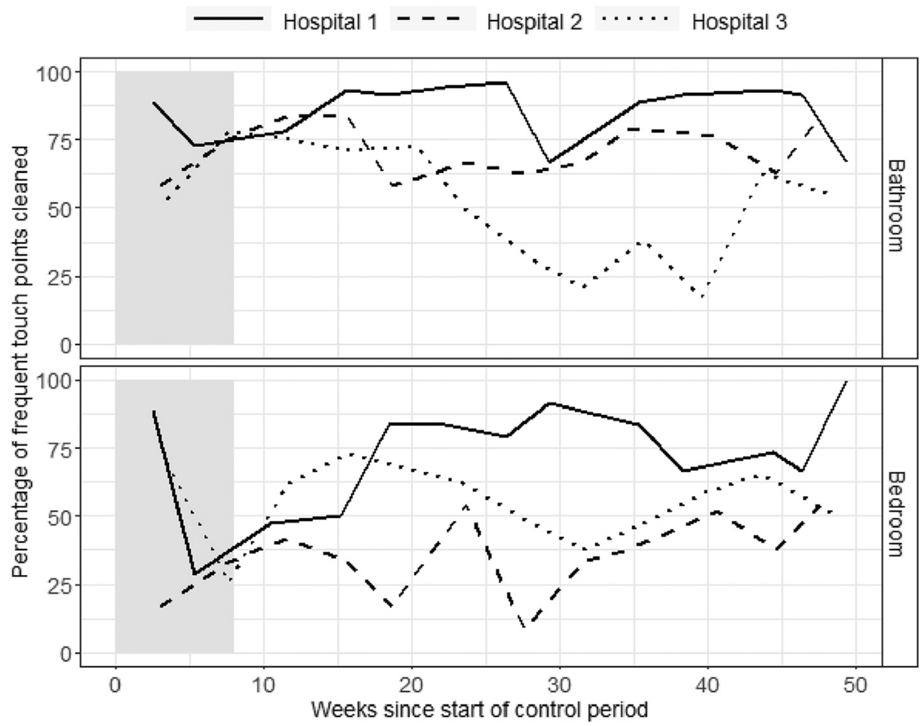


**Figure 2** Average percentage of clean FTPs located in patient bathrooms (top) and bedrooms (bottom) by hospital over time. Note: The grey shaded region represents the control period.

over time (AIC = 449). Expected cleaning outcomes were lower for bedroom FTPs during the control period (OR = 0.22; SE = 0.3; p-value<0.001) (Fig. 2). A statistically significant interaction between intervention effectiveness and FTP location (OR = 2.3; SE = 0.3; p-value = 0.005) indicated that changes in cleaning performance from the intervention varied between bathroom and bedroom FTPs. Follow-up testing of interaction effects identified a statistically significant improvement in bedroom FTP cleaning from 35% to 55% (OR: 2.2; 95% CI: 1.5 to 3.2) after accounting for between-hospital differences at baseline. Changes in bathroom FTP cleaning were negligible (OR: 0.96; 95% CI: 0.62 to 1.5) however outcomes were consistently high for both control (72%) and intervention (71%) periods. Residual analysis identified moderate variation in the estimated interaction effect (Figure S2), which reflected hospital-level heterogeneity in bathroom FTP cleaning performance during the intervention period.

## Discussion

The REACH study used a stepped-wedge design and made a significant advancement in knowledge by demonstrating a link between improved cleaning and reduction in infection [12]. The main study findings already published identified improvements in cleaning using FM technology [12]. In this paper, we present findings from a different outcome measure for cleanliness, namely ATP. In this study, the efficacy of post-discharge cleaning before and after an environmental cleaning bundle intervention was assessed by examining the amount of bioburden on FTPs in patient areas using a validated ATP sampling method.

Overall, the results indicated that bedroom FTP cleaning improved across all three hospitals. The cleaning of bathroom FTPs was generally high from the outset and on average remained consistent throughout the whole study period. Findings confirm improvement in cleaning, in particular of the FTPs in bedrooms, demonstrating that there were improvements in discharge cleaning that aligned with the improvements seen overall when using FM technology as a marker of performance. In an observational study undertaken in the United States, researchers compared FM, aerobic colony counts and ATP bioluminescence when assessing discharge cleaning practices [36]. They found that high-touch points deemed cleaned according to FM after terminal cleaning were very frequently also considered to be clean according to aerobic colony counts criteria, but less likely to be considered clean according to ATP criteria [36].

Our results could be explained by a number of factors. It is possible for example that discharge cleans have always received more attention from environmental services workers (ESWs) given the potential to reduce transmission between patients, and that much of this time has traditionally been spent cleaning bathrooms. By focusing on FTPs in both the bathroom and bedroom as part of the study intervention, including ESW training, improvement was seen in the cleaning of bedrooms particularly. However, this study was not powered or designed to carefully correlate FM and ATP results, and indeed caution should be taken when comparing this data, as they examine different aspects of the cleaning process.

The study has limitations. Firstly, length of time from actual room discharge cleaning and the ATP sampling time varied. Any touches to surfaces may have added extra biological material which has positively biased some results. Without standardisation of the cleaning or disinfecting products, residues may also have affected some results without operator detection [18,37,38]. Secondly, there is a potential Hawthorne effect, with ATP testing taking place at regular intervals, often at the same time of day. However, staff did not receive any feedback on their ATP results. The use of parallel environmental microbiological sampling would have also been a useful adjunct but was beyond the scope and costing for this study. Finally, for logistical reasons, the study team only sampled half of the wards in three out of the 11 hospitals that participated in the REACH study. Nonetheless, our study is an advancement to other studies, which have had a shorter time frame or have been cross-sectional in nature. A strength of the study is that the same personnel performed the majority of the samples, ensuring a standardised sampling procedure.

## Ethics

This project received human research ethics approval from the Uniting Care Health Human Research Ethics Committee and the Queensland University of Technology Human Research Ethics Committee. Local ethics and site-specific governance approvals were obtained for all participating hospitals.

## Authorship statement

Data collection was undertaken by AM and AF. The concept of this paper was developed by BM, AM, and AF. Initial drafting of the manuscript was undertaken by AM. Data analysis was led by NW and AM. All authors made contributions to the subsequent drafts of this paper through critical revision. All authors have given their final approval regarding this manuscript.

## Conflict of interest

GSW declares employment by Whiteley Corporation, although no product endorsement is implied in the use of the wipe used for the cleaning intervention step (Speedy Clean™ Wipes). GSW played no role in the design or analysis of the REACH study. The other authors have no conflicts to declare. One of the authors has an editorial affiliation with the journal. The author played no role in the peer review process or any editorial decision relating to this paper.

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## Provenance and peer review

Not commissioned; externally peer reviewed.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idh.2020.02.001.

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