



# Use of ATP bioluminescence for assessing the cleanliness of hospital surfaces: A review of the published literature (1990–2012)

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**Summary** Hospital cleanliness tends to be considered by patients and the public as an important indicator of the general quality of healthcare. Tests for detecting the presence of adenosine triphosphate (ATP) as a proxy of microbial contamination are increasing in popularity, and several studies have been conducted on this topic in the last few decades. The aim of the present study was to review the published literature on this topic and summarize and discuss the available results. The review focused on relevant English-language articles that were identified through searches of two databases [PubMed and Scopus (1990–2012)] by using the keywords "ATP", "bioluminescence", "hospital", and "surfaces". Twelve articles were included and analyzed. ATP measurements showed a wide variation, with values ranging from 0 to >500,000 relative light units (RLU)/s before cleaning and from 3 to 500,000 RLU/s after cleaning. ATP benchmarks used by authors ranged from 100 to 500 RLU/s. The percentage of surfaces exceeding the chosen cut-off limit showed a failure rate varying from 21.2% to 93.1% before cleaning and from 5.3% to 96.5% after cleaning. Although the use of ATP bioluminescence can be considered a quick and objective method for assessing hospital cleanliness, it appears to be still poorly standardized at both the national and international level.

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## Contents

Introduction .....	93
Materials and methods .....	94
Results .....	94
Discussion .....	94
Conclusion .....	97
Conflicts of interest .....	97
Funding .....	97
Acknowledgements .....	97
References .....	97

## Introduction

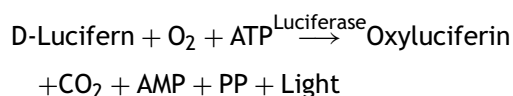
Hospital cleanliness tends to be thought of by patients and the public as an important indicator of the general quality of healthcare, primarily due to the fact that dirty surfaces can be highly contaminated by microorganisms that expose patients to the risk of acquiring infections [1]. This risk can be alarming in hospital settings, and several studies have well documented the environmentally mediated transmission of antibiotic-resistant pathogens [2,3]. Despite this finding, routine housekeeping practices are often suboptimal, and some authors have observed that disinfection can be improved to 82%, resulting in an average 68% decrease in bacteriological environmental contamination [4,5]. In addition, improved routine disinfection has been associated with an average 40% decrease in the transmission of vancomycin-resistant *Enterococcus* (VRE) and methicillin-resistant *Staphylococcus aureus* (MRSA) [6,7]. As a consequence, cleaning and disinfecting hospital environments have been claimed as one of the best strategies for preventing healthcare-associated colonization and infections [8].

Unfortunately, a major problem associated with the translation of these recommendations into actions is the lack of a definition of a "clean" and "acceptable" surface. The food industry was the first industry to recognize the need to be able to judge cleanliness by standardized methods. In this sense, the Hazard Analysis and Critical Control Points (HACCP) implementation reflects the awareness that relevant pathogens are widespread, occurring with large variations in time and space. To address these concerns, several internationally agreed upon microbiological standards have been proposed and adopted by food industries for the monitoring of air, water, and food preparation surfaces.

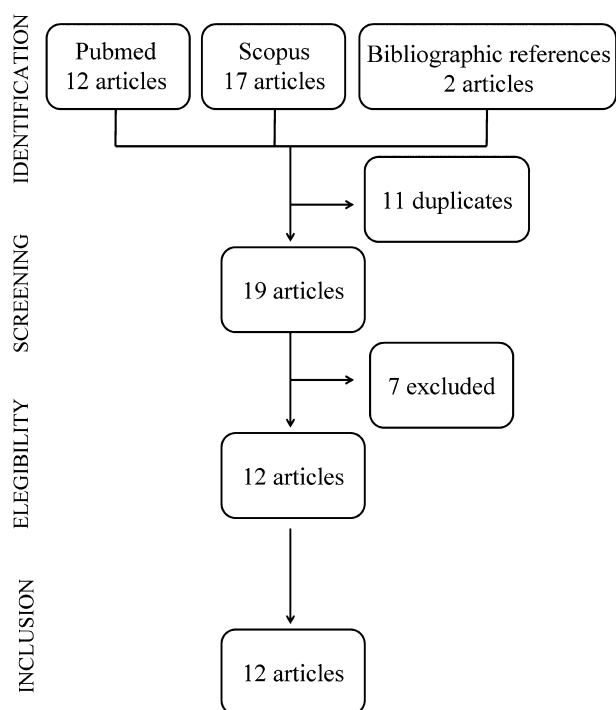
Although similar reasoning could be applied to hospital settings, to date, there is a general lack of standards that would enable managers and

infection control committees to assess the risk of infection to patients (and staff) and compare results between different clinical units and different hospitals [9]. Quite often, the only method used for evaluating hospital cleanliness is visual inspection, which does not necessarily correspond to microbiological risk.

In 2010, the Centers for Disease Control and Prevention identified the main tools and methods (direct practice observation, swab and/or agar slide cultures, fluorescent markers, and adenosine triphosphate bioluminescence) for evaluating environmental cleanliness on a more scientific basis [10]. In particular, among these different methods, tests for detecting the presence of adenosine triphosphate (ATP) have increased in popularity in recent decades. ATP is the basic source of energy for all plant, animal, and microbial cells, and, consequently, its presence on environmental surfaces provides an estimate of the presence of organic matter, including microbiological contamination [11]. Bioluminescence tests are based on a chemical reaction catalyzed by luciferase, as shown in the following equation:



The amount of light (bioluminescence) generated by this reaction, which is proportional to the amount of ATP present, is expressed as relative light units (RLU)/s. Therefore, the measurement of light intensity by bioluminometers enables quick monitoring of cleanliness by providing a standardized sensitive measure of the total organic material present. Several studies have been conducted to ascertain whether ATP bioluminescence monitoring could be utilized in healthcare settings as an evaluation method for environmental decontamination [11,12]. However, to date, results from these studies have not been systematically summarized. To address this gap in the literature, the aim of the



**Figure 1** Flow-chart of the bibliographic research according to the PRISMA statement.

present study was to review these studies and to summarize and discuss their results.

## Materials and methods

The review included relevant English-language articles that were identified through searches of two databases [PubMed and Scopus (1990–2012)]. The keywords used were “ATP” AND “bioluminescence” AND “hospital” AND “surfaces”. Additionally, this search was complemented with an iterative process in which reference lists of all relevant publications were consistently reviewed. The bibliographies of all these recovered manuscripts were retrieved, and the searching strategy was repeated until no new information was found. After the completion of these reviews, as shown in Fig. 1, a total of 31 articles were considered in the analysis: 12 studies were found in Pubmed; 17 were found in Scopus; and 2 were found in the reference lists of the studies found in Pubmed and Scopus. Eleven articles were present in both databases and were thus considered only once. Seven articles were excluded because they did not pertain to hospital surfaces, had an experimental design, or were published before 1990. Finally, 12 articles were included and analyzed in this review.

This literature review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement and was completed in January 2013 [13].

All data were analyzed and graphed using the R statistical software package [14].

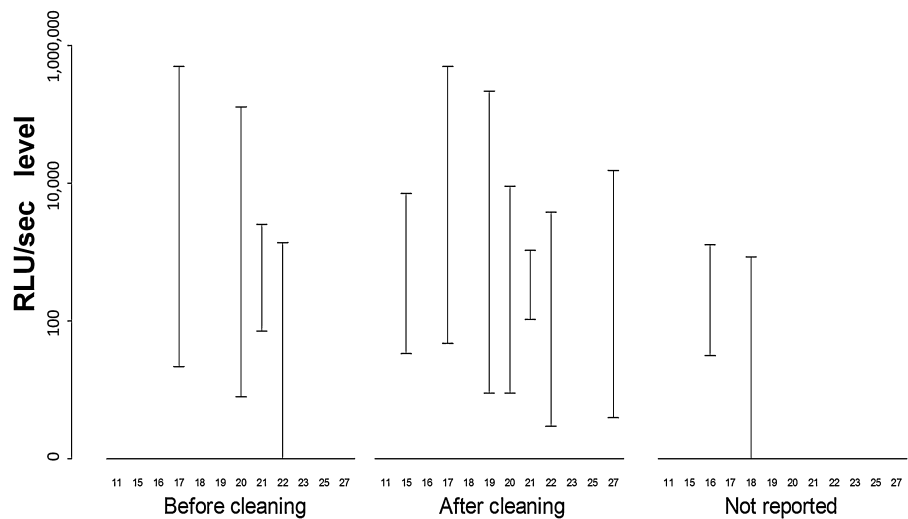
## Results

The general characteristics of the 12 studies included in this review are shown in Table 1. All the studies were carried out from 2000 to 2011, and a large majority of the studies ( $n=8$ , 66.7%) were conducted in UK hospitals. Among the other studies, one was conducted in Brazil [15] and three were conducted in the U.S. [16–18].

Four studies (33.3%) monitored surfaces after cleaning; 6 (50%) studies monitored surfaces both before and after cleaning; and 2 studies (16.7%) did not report this information. Five (41.7%), 4 (33.3%), and 3 (25%) of the investigations were conducted using bioluminescence tools provided by 3M, Bio-trace, and Hygiena, respectively. ATP thresholds were 100 RLU/s for 2 (16.7%) studies, 250 RLU/s for 5 (41.7%) studies, and 500 RLU/s for 4 (33.3%) studies; only 1 (8.3%) study considered both 250 and 500 RLU/s as ATP thresholds. As reported in Fig. 2, ATP measurements showed a wide variation, with values ranging from 0 to >500,000 RLU/s before cleaning and from 3 to 500,000 RLU/s after cleaning. Fig. 3 depicts the failure rates associated with different ATP benchmarks with respect to cleaning procedures. Two studies did not report whether ATP measurements had been made before or after cleaning, and they reported very different failure rates (38.9% [19] vs. 84% [20]) for the threshold of 100 RLU/s. In 6 studies, after-cleaning failure rates at 250 and 500 RLU/s were reduced of about 20%, whereas after-cleaning failure rates were increased of about 3% in 1 study [21]. Generally, irrespective of the established threshold, a wide variability was observed among different studies, with failure rates ranging from 21.2% [22] to 93.1% [21] before cleaning and from 5.3% [22] to 96.5% [21] after cleaning.

## Discussion

Although cleanliness of hospital surfaces is internationally advocated as necessary to control hospital infections, to date, there is still no consensus regarding the preferred methods for assessing environmental cleanliness. In recent decades, several



**Figure 2** ATP bioluminescence ranges (in RLU/s) reported in the studies (numbered as reported in the References section) included in this review.

authors have proposed the detection of ATP bioluminescence as a method of monitoring hospital cleanliness.

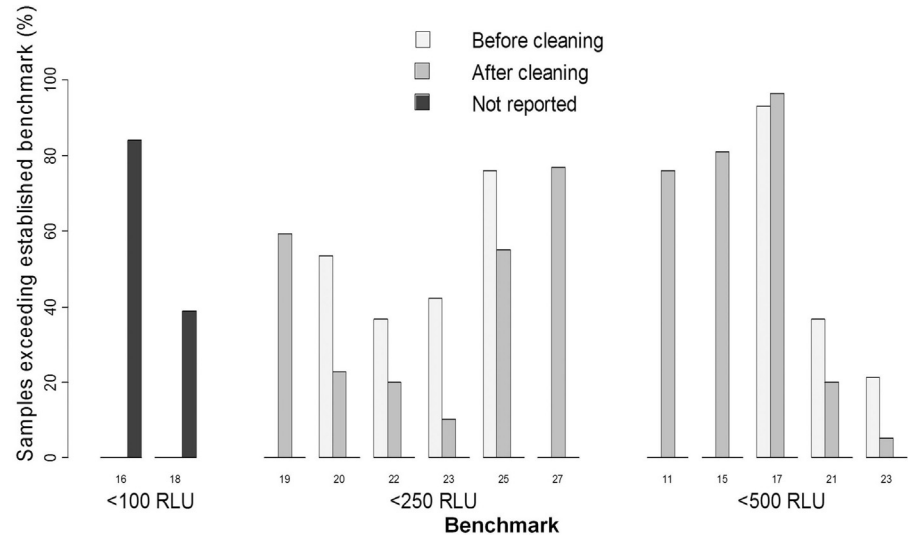
The present review shows that although the use of ATP bioluminescence can be considered a quick and objective method for assessing the cleanliness of hospital surfaces, it is still poorly standardized at an international level. This consideration is supported by three main observations.

First, a large majority of the included studies were carried out in UK hospitals that likely implemented similar cleaning and disinfection procedures. Thus, to date, with the exception of four studies carried out in Brazil and the U.S.

[15–18], the published literature allows a comparison between ATP measurements only on a national basis.

Second, the reported data were derived from measurements performed with different ATP bioluminescence tools that could have different sensitivities. This finding could be responsible for the very wide variability of ATP levels among the different studies. In particular, some kits [21,23] yielded measurements with very high maximum RLU/s values compared with other kits.

However, according to Mulvey et al., it should be noted that fluctuating ATP measurements could also be caused by the presence of chemicals and



**Figure 3** Failure rates (%) at different ATP benchmarks with respect to cleaning procedure time.

**Table 1** General characteristics of the studies included in this review.

Authors, year [reference]	Setting	Samples/sites, number	ATP bioluminescence tool	ATP benchmark
Griffith et al., 2000 [11]	General hospital (UK)	31 sites <sup>b</sup>	Biotrace Cleantrace system (Biotrace Ltd.)	500 RLU/s
Ferreira et al., 2011 [15]	Philanthropic hospital (Brazil)	100 sites <sup>b</sup>	Clean-Trace ATP System (3M)	500 RLU/s
Boyce et al, 2010 [16]	500-bed university affiliated hospital (U.S.)	294 samples <sup>b</sup>	Clean-Trace ATP System (3M)	250 RLU/s
Willis et al, 2007 [17]	Three hospital wards (UK)	54 sites <sup>c</sup>	Hygiena system (Hygiena Int. Ltd.)	100 RLU/s
Anderson et al, 2011 [18]	District general hospital (UK)	44 sites <sup>c</sup>	SystemSure Plus system (Hygiena Int. Ltd.)	100 RLU/s
Cooper et al, 2007 [19]	Four acute hospitals (UK)	552 samples <sup>a</sup> 547 samples <sup>b</sup>	Biotrace Cleantrace system (Biotrace Ltd.)	500 RLU/s
Moore et al, 2010 [20]	Two central London teaching hospitals (UK)	400 samples <sup>a</sup> 400 samples <sup>b</sup>	Clean-Trace ATP System (3M)	250 RLU/s 500 RLU/s
Lewis et al, 2008 [21]	1300-bed teaching hospital (UK)	180 samples <sup>b</sup>	Biotrace Cleantrace system (Biotrace Ltd.)	250 RLU/s
Mulvey et al, 2011 [22]	Teaching hospital Glasgow (UK)	90 samples <sup>a</sup> 90 samples <sup>b</sup>	Hygiena system (Hygiena Int. Ltd.)	250 RLU/s
Sherlock et al, 2009 [23]	700-bed adult tertiary referral hospital (UK)	120 samples <sup>a</sup> 120 samples <sup>b</sup>	Biotrace Cleantrace system (Biotrace Ltd.)	500 RLU/s
Boyce et al, 2011 [25]	500-bed university affiliated hospital (U.S.)	500 sites <sup>a</sup> 500 sites <sup>b</sup>	Clean-Trace ATP System (3M)	250 RLU/s
Boyce et al, 2009 [27]	University affiliated community teaching hospital (U.S.)	510 samples <sup>a</sup> 503 samples <sup>b</sup>	Clean-Trace ATP System (3M)	250 RLU/s

<sup>a</sup> Before daily cleaning.  
<sup>b</sup> After daily cleaning.  
<sup>c</sup> Not reported.

other materials, as well as disinfectants, microfiber products, and manufactured plastics used in the cleaning and laundering industries [24].

Third, surface cleanliness has been assessed on the basis of different thresholds ranging from a minimum value of 100 to a maximum value of 500 RLU/s. Interestingly, the ATP thresholds

established by several authors were different even if their studies had been carried out in the same geographic area (UK) and with the same ATP tools. This last consideration seems to support poor agreement regarding, as well as a lack of guidelines for, ATP biomonitoring at the national level. However, the possibility cannot be excluded that the

variability of used benchmarks reflects uncertainty due to the inconsistent correlations observed by several authors between ATP levels and microbial contamination or fluorescent markers [15,18,25,26].

Despite the previous concerns, ATP bioluminescence is usually considered a useful method for performing a rapid assessment of hospital cleanliness.

Quick and objective feedback on surface cleanliness is of paramount importance for continuously educating housekeepers and healthcare staff [17] and is necessary to achieve compliance with recommended daily cleaning practices [19,27]. According to these suggestions, in all hospital settings but one [19], ATP failure rates after cleaning significantly decreased compared with those measured before cleaning. As claimed by Sherlock et al., chemical tests for ATP may provide additional information on cleaning efficacy, and ATP trends allow identification of environmental surfaces that may require additional cleaning or cleaning schedule amendments [25]. In this sense, by considering ATP measurements before and after cleaning procedures, two authors [20,21] raised major concerns regarding the consistency of implementation and, thus, the management of their own cleaning process. Alternatively, as reported by Boyce et al., ATP readings played a very important role in providing quantitative evidence of improved cleanliness of high-touch surfaces after the implementation of an intervention program [18].

## Conclusion

As previously stated, the comparison of studies performed with different materials and methods, as well as the different sensitivities of different ATP bioluminescence tools, could represent a major limitation of the present review, most likely diminishing the comparability of the presented results and considerations.

Considering this concern and the relatively high costs attributable to ATP biomonitoring, further investigations may help to better understand the importance, cost-effectiveness, and possible new applications of bioluminescence in hospital settings. Despite these limitations, the present review is, to our knowledge, the first attempt to provide a systematic description of the published data on this important topic.

## Conflicts of interest

None declared.

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