Universal decontamination of hospital surfaces in an occupied inpatient room with a continuous 405 nm light source.

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Structured summary

Background

Previous work has shown that a ceiling-mounted, 405 nm high-intensity narrow-spectrum light environmental decontamination system (HINS-light EDS) reduces bacterial contamination of environmental surfaces in a burns unit by between 27% and 75%. Examination of the efficacy of the light over extended exposure times and its probable mode of action was performed.

Aims

Studies were designed to ascertain the correlation between bacterial kill achieved on sampled surface sites around the Burns Unit and both irradiance levels of the 405 nm light, and exposure time.

Method

Seventy samples were taken using contact agar plates from surfaces within an occupied side room in the burns unit before, during and after a seven day use of the HINS-light EDS. This was repeated in three separate studies. Statistical analysis determined if there was significant decrease in environmental contamination during prolonged periods of HINS-light treatment, and if there was a relationship between irradiance and bacterial kill.

Findings

A decrease of between 22% and 86% in the mean number of surface bacteria was shown during the use of the HINS-light EDS. When the light ceased to be used, increases of between 78% and 309% occurred. There was no correlation between bacterial kill and irradiance levels at each sampling site but strong correlation between bacterial kill and exposure time.

Conclusions

Prolonged exposure to the HINS-light EDS causes a cumulative decontamination of the surfaces within a burns unit. The importance of exposure time and possible airborne effect over irradiance levels is emphasised.

Keywords: Infection control, environment, decontamination, bacterial contamination, burns unit, 405 nm light

Introduction

Burns patients are exceptional in their propensity to dissipate large numbers of bacteria into the environment and their susceptibility to infection. This renders the burns unit an area liable to facilitate cross-contamination of hospital acquired infections (HAI). The spread of multi-drug resistant organisms has serious consequences for patients, units and hospitals. The burns unit is a uniquely challenging environment in which to address infection control. Transmission may be direct or indirect, with staff, the air and surfaces all acting as potential vectors of transmission.

As antimicrobials become ineffective against resistant strains of bacteria, a growing focus has become environmental decontamination, as desiccated bacteria can survive for weeks on hospital surfaces.[1-4] Frequent cleaning of surfaces and hands, and the use of personal protective equipment (PPE) remain essential. However, surfaces are cleaned sporadically or ineffectively, with contamination fluctuating throughout the day.[5]

The high-intensity narrow-spectrum light environmental decontamination system (HINS-light EDS) uses a narrow bandwidth of 405 nm light, which has extensive bactericidal effect, yet is safe for continuous use in a clinical environment.[6] Its effectiveness has been demonstrated in the hospital setting during treatment periods of up to five days, with decontamination of between 27% and 75%, over and above that achieved by standard infection control methods.[7,8, 9]

The dose received at any one site is a function of the exposure time and irradiance at that site, and this study aimed to determine which was more important. Furthermore, a universal effect around the room may indicate a contribution of the decontamination of airborne bacteria. Particles released from burns patients have been shown to be relatively small, making them airborne for substantial periods of time.[8] It was hypothesised that if the decontamination effect of the HINS-light EDS took place only on surface-associated bacteria, the irradiance received on any one site would be directly related to the amount of kill achieved at that surface. However, if the decontamination effect mainly occurred on airborne bacteria, which were then precipitated at random, little correlation between the amount of kill and levels of irradiance received at that site would be shown.

Methods

Setting

The studies took place in the burns inpatient unit at Glasgow Royal Infirmary, a 13 bed adult burns ward. Ethical approval was granted by NHS Scotland (West of Scotland Research Ethics Service). Throughout the studies, standard isolation and cleaning protocols continued. These included the wearing of PPE, hand hygiene, and daily room cleaning, with additional periodic wiping down of

visibly contaminated surfaces with disinfectant wipes. The rooms were maintained at a negative pressure and incoming air was passed through High Efficiency Particulate Air (HEPA) filters.

The HINS-light EDS is a ceiling-mounted light-based continuous decontamination system. It emits a blue-violet (405 nm) light, with white LEDs incorporated to produce a soft pale violet light in conjunction with normal room lighting. Safety analysis had previously demonstrated the light emitted to be well within safe levels set by the American Conference of Governmental Industrial Hygienists (ACGIH).[9] It is powered by mains electricity and was timed to be on between 0800h and 2200h.

Bacterial sampling

Bacterial monitoring was based on a previously described protocol.[7,8,9] Samples were taken using Baird Parker with egg yolk telurite agar (BPA) 25cm^2 contact agar plates, inoculated by pressing the agar surface onto the environmental surface, and incubated for 48 hours at 37°C. BPA is a selective growth medium for staphylococcal-type organisms and therefore a good indicator of human contamination.

Studies were carried out with one HINS-light EDS on for 7-days. A different patient occupied the isolation room during each of the three studies. The same protocol was repeated: (1) *Before use* samples were collected from selected sites around the room; (2) the HINS-light EDS was switched on for seven consecutive days, during which time between one and three sets of *during use* samples were collected; and (3) *after use* samples were taken two or three days after the HINS-light EDS exposure had been discontinued.

Seventy selected sites around the patient's room were sampled for each of the three studies (Table I). Environmental sampling was always performed at 0800h, as previous work had shown this to be the most consistent time to carry out environmental surface sampling in the burns isolation room setting.[6]

Patients

Patient A was a 48 year-old with a 12 % total body surface area (TBSA) scald. He had had a protracted stay of two months due to respiratory infections. Patient B was a 38 year-old with a 50 %TBSA flame burn. At the time of study, 40 %TBSA had been excised and covered with skin graft or synthetic substitute. Patient C was a 65 year-old with a 19 %TBSA flame burn. At the time of study approximately 11 %TBSA remained unhealed. The study protocol for each patient is summarised in Figure 1.

Irradiance measures

A radiant power meter and photodiode detector (Oriel Instruments, Stratford CT, USA) was used to measure the irradiance, in mW/cm^2, received at each of the sampling sites around the isolation room. Measurements were taken with the blue-violet 405 nm light of a single HINS-light EDS switched on, and other light eliminated.

Statistical analysis

Following enumeration of bacterial colony-forming units (cfu), the mean cfu per plate for each study was calculated. Percentage reduction in bacterial count *during use*, and % increase *after use* were also calculated. Further analysis was performed on log-transformed counts using Minitab V16. ANOVA and Dunnett's post-hoc comparisons were done to examine for significant differences between *before use* and each of the *during use* periods for each study, and between *after use* and the final *during use* period for each study. P values of <0.05 was considered significant.

The 70 contact plate sample sites were grouped into 18 sample areas (e.g. bedside table, six samples – see Table II). For each area, the mean % reduction achieved following seven days' use of the HINS-light EDS was calculated. A scatter graph was produced to determine the relationship between irradiance and mean % reduction after seven days' exposure to each area. Pearson's correlation coefficients demonstrated the significance of any interaction between irradiance and % bacterial kill.

Results

Decontamination effect over different time periods

A decrease was seen in the mean bacterial count when a single HINS-light EDS was used for any time between two and seven days. Subsequent increases in bacterial contamination were demonstrated in all three studies when the EDS was switched off again.

The studies, displayed as graphs, show the mean bacterial cfu/plate during each sampling session (Figures 2). Decontamination increases with increased exposure time: this is particularly apparent in the study in Patient C's room. Statistically significant decreases in mean bacterial counts were produced during the studies of Patients B and C, but not Patient A. Significant increases were demonstrated when EDS use was discontinued in all three studies (Table II).

Relationship between decontamination effect and irradiance levels

The results for the mean % bacterial reduction in each area, and correlation with the irradiance received at that area are summarised in Table I. Figure 3 is a scatter graph demonstrating poor correlation between irradiance and the mean % bacterial reduction at each sampling site. Statistical analysis confirmed no significant correlation with Pearson correlation of 0.171 and P value of 0.497

(not significant). There is a consistent reduction of between a 50 % and 100 % regardless of irradiance at that site with use of the HINS-light EDS.

Discussion

Burns units are a key area of focus for infection control as outbreaks of HAI are common and devastating and burns patients are particularly susceptible to cross-contamination.[12] Technologies such as ultraviolet light, portable HEPA filters and fogging with hydrogen peroxide vapour have attempted to tackle environmental decontamination.[13-17] Although effectively bactericidal, these methods are restricted to sporadic use in unoccupied, sealed rooms. This is time consuming and costly, requiring an operator and period when the room is out of commission. Furthermore, bacterial load quickly returns to pre-treatment levels following cessation of use.[18,19] The HINS-light EDS uses visible light at a safe irradiance, and can thus be used continuously throughout the day. Another continuous technology under development is the release of essential oil vapour, although no clinical studies have been carried out to date.[20] Other technologies include products with antimicrobial coatings such as silver, but these do not achieve the universal decontamination effect seen with HINS-light EDS.[21,22]

All three studies demonstrated a decrease in bacterial bio-burden following HINS-light EDS use of between two and seven days, with a cumulative effect clearly demonstrated in the study in Patient C's room: A 53 % decrease after 2 days; 69 % decrease after four days; and 86 % after seven days. Of note, the bacterial kill achieved was comparable in these studies where one HINS-light EDS was used, to that seen in previous studies where two were used in the same room.[8,9] This suggests that one HINS-light EDS may be as effective as two, provided it is used for a sufficient time period. The mass effect of the HINS-light EDS over the whole room has previously been demonstrated in a study where an EDS was mounted in one half of a room, and the relative decrease in bio-burden compared between the two sides of the room.[7] A similar effect was seen in both halves of the room, although it was greater in the half where the HINS-light EDS was sited.

The measurement of irradiance levels (a function of dose) in the current study supports this theory, and also suggests a possible bactericidal effect on airborne bacteria. Simultaneous evaluation of % bacterial reduction and the irradiance at each sampling site demonstrated that no correlation was found between the two. The irradiance received on surfaces is small (between 0.0000023 W/cm^2 and 0.000231 W/cm^2), whereas the exposure time (in seconds) is relatively greater during several days of exposure. As dose is a function of both measures, the irradiance received at any one site is less important than the time of exposure. In a system designed to be used continuously, high doses can therefore be achieved at low irradiance levels. In addition, bacteria are suspended in the air almost indefinitely depending on size of the particles before being precipitated onto surfaces.[23] This puts them in closer proximity to the EDS than those bacteria on surfaces, and therefore exposed to higher doses of 405 nm light.

No attempt was made to isolate the bacteria in the environment, other than the use of BPA contact agar plates, which is an indicator of human-originating pathogens. Preliminary studies using broader spectrum agars yielded too dense a population of bacterial CFUs to count in many circumstances, as well as higher proportion of bacteria of unknown significance. Laboratory studies carried out on bacteria pertinent to burns patients have demonstrated that Gram positive bacteria (including Multi-drug resistant *Staphylococcus aureus* and *Streptococcus pyogenes*) are inactivated by HINS-light at a faster rate than Gram negative bacteria (including *Acinetobacter baumanii* and *Pseudomonas aeruginosa*), although all bacteria tested demonstrated significant reductions after two hours' exposure and complete kill within less than six hours' exposure using the same ceiling mounted HINS-light that was used in the current studies .[6, 24]

Comparisons between studies on different patients are difficult due to huge variability in bacterial dispersal between burns patients. However, the studies on Patients B and C achieved similar reductions to those previously reported, although the study on Patient A did not show a statistically significant reduction.[7,8,9] However, examination of the *after use* bacterial counts from the study reveal them to be considerably higher than both the *during use* and *before use* counts. In fact, a 120 % increase is shown following cessation of the EDS use. Considering the effect of the EDS that has been demonstrated repeatedly during previous inpatient studies, this suggests that the *before use* bacterial counts were unusually low in this study. An explanation for this is not available from the contemporaneous information gathered. The most likely scenarios are that either an extra clean was performed prior to the *before use* sample collection, or the patient mobility and activity around the room increased significantly following *before use* sample collection. Previous work showed that there is more variation of bacterial levels when samples were taken at times of increased activity within rooms,[8] a factor that is almost impossible to control in a clinical environment, but which was mitigated against by examination of ANOVA plots for significant outliers.

In addition, at the time of sampling, much of Patient A's burns had healed, with only 11% TBSA still unhealed, possibly contributing to lower than expected *before use* samples. Furthermore, both Patients B and C were receiving treatment for chest sepsis, and as such environmental contamination may have also been from a respiratory source. None had an active burn wound infection at the time of the study although with burns of this size and age the wounds will likely be colonised with a range of Gram positive and negative bacteria, which are not routinely quantified or isolated unless clinically relevant. These differences between patients highlight why in the design of all our studies we have used patients as their own controls with a *before, during* and *after* model to avoid intra-patient comparisons. Although the studies were only carried out on rooms containing three patients, the significant decreases in environmental contamination during use of the HINS-light EDS were comparable with multiple previous studies where use of the HINS-light EDS in the burns unit resulted in an average reduction in environmental bacterial load of between 27% and 86%.[7, 8 ,9] The current study provides further evidence from several thousand contact plate samples that the use of

the HINS-light EDS reduces environmental bacterial load over and above standard hospital cleaning protocols within the burns unit environment.

With the introduction of any novel technology such as the HINS-light EDS it is important to consider possible impact on patient wellbeing and comfort. There has been an increasing awareness of the importance of lighting conditions on factors such as mood and awareness. Normal operation of the EDS, as applied during this study involved synchronising on-off timing with normal ward lighting so as not to disturb patient sleep. It is however also the case that lighting conditions experienced prior to sleeping are important and this is particularly the case with exposure to blue light which can interfere with circadian rhythm thereby increasing alertness and interfering with sleep onset. It is now known that the eye possesses photosensitive retinal ganglion cells (pRGCs) whose function is to modulate diverse physiological responses to light, including circadian physiology and pupil constriction.[25] The pRGCs have an absorption max (i.e. peak sensitivity) at around 480 nm. As HINS-light utilises 405 nm violet light to achieve the bactericidal effect, this is far below the 480 nm blue light value so that HINS-light should have little effect on the pRGCs and their associated physiological effects.

Conclusions

A ceiling-mounted 405 nm wavelength light source is an effective method of environmental decontamination, as demonstrated in the challenging environment of the burns unit inpatient room. It is safe for continuous use in the presence of patients and staff, and the bactericidal effect increases with treatment time. A universal decrease in bio-burden is seen on surfaces throughout the room, despite ongoing activities within the room and the variation in irradiance levels on the surfaces. This suggests either the variation in irradiance is outweighed by exposure time, or the possible airborne effect on suspended bacteria.

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Conflict of interest

The intellectual property rights of the HINS-light EDS belong to the University of Strathclyde. As co-inventors MM, SJM, JGA have a share of intellectual property rights. All HINS-light EDS are made by the University are for research purposes only. However, since this work was carried out, there has subsequently been commercial uptake of this technology in the US from which the University and the co-inventors will benefit.

Tables

Table I: List of sampling sites and mean irradiance and % reduction following 7-day use of a single HINS-light EDS, at each sampling area.

Area	*Number of samples taken (n)*	*Mean irradiance (mW/cm^2)*	*Mean % reduction after 7 days*
Door area	2	0.0030	89.4
EDS power supply box 1	2	0.0023	93.5
Chair	2	0.0070	-70.9
Upper ledge near light	4	0.0023	81.4
Upper ledge far from light	4	0.0160	88.8
Lower ledge near light	6	0.0027	90.8
Lower ledge far from light	6	0.0337	77.6
TV	4	0.0035	-200.0
Left bed rail	2	0.0096	93.2
Right bed rail	4	0.0562	94.7
Top bed rail	10	0.0160	77.1
Locker top	6	0.2310	79.4
Bedside table	1	0.0072	87.8
Drip	2	0.0025	97.9
Toilet door	4	0.0885	84.2
EDS power supply box 2	4	0.0805	94.8
Bins	4	0.0850	77.7
Sink	3	0.0560	56.1
Mean % reduction			60.7
Pearson correlation of mean irradiance and mean % reduction			0.171
P value (significant)			0.497 (no)

Table II: Summary of the statistical analysis, for the seven-day use of a single HINS-light EDS in three different patient rooms. P values, based on log-transformed data are in brackets. * denotes a statistically significant change (95% confidence)

	Patient A	***Patient B***	***Patient C***
% decrease in mean bacterial count (P values)			
during use 1	22 (0.999)	34 (0.014)*	53 (<0.001)*
during use 2	n/a	74 (<0.001)*	69 (<0.001)*
during use 3	n/a	n/a	86 (<0.001)*
Significant reduction	No	Yes	Yes
% increase in mean bacterial count *after use* (P values)	120 (<0.001)*	78 (0.036)*	309 (<0.001)*
Significant increase	Yes	Yes	Yes

Figure legends

Figure 1: Diagram illustrating protocols for three studies investigating the effect of a single HINS-light EDS in an occupied inpatient room.

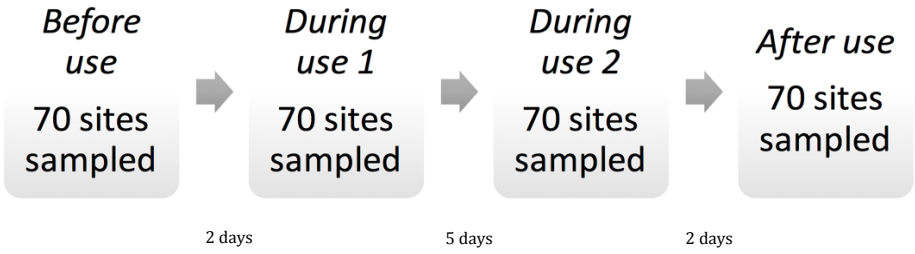
Figure 2: Graph illustrating the mean bacterial counts on surfaces within the rooms of Patients A, B and C *before use*, *during use* and *after use* of the HINS-light EDS (n=70). Error bars denote standard errors.

Figure 3: Scatter graph illustrating the mean % reduction in surface bacteria following seven days' exposure to the HINS-light EDS at each sampling site, correlated with the mean irradiance at each sampling site.

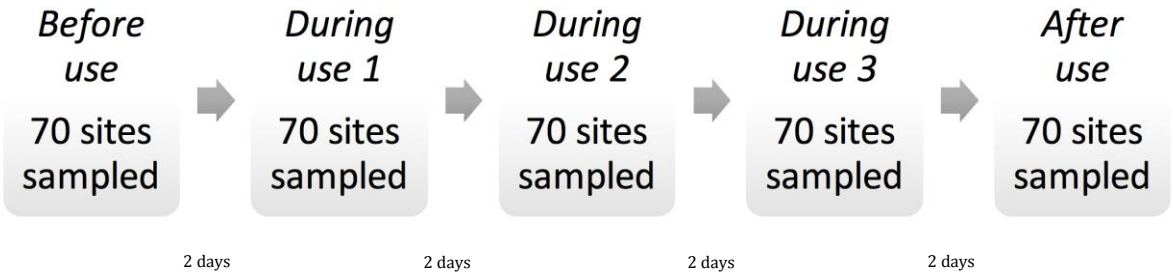
1

1a. Patient A Study protocol

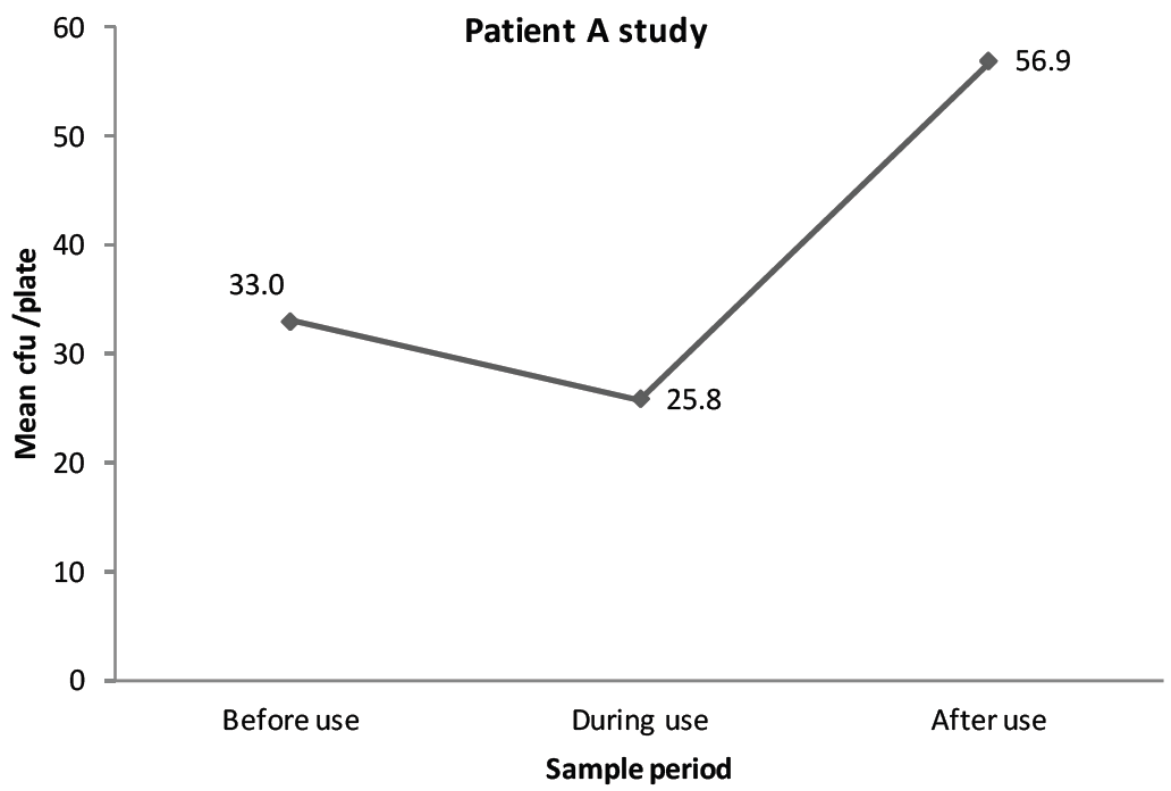
1b. Patient B Study protocol



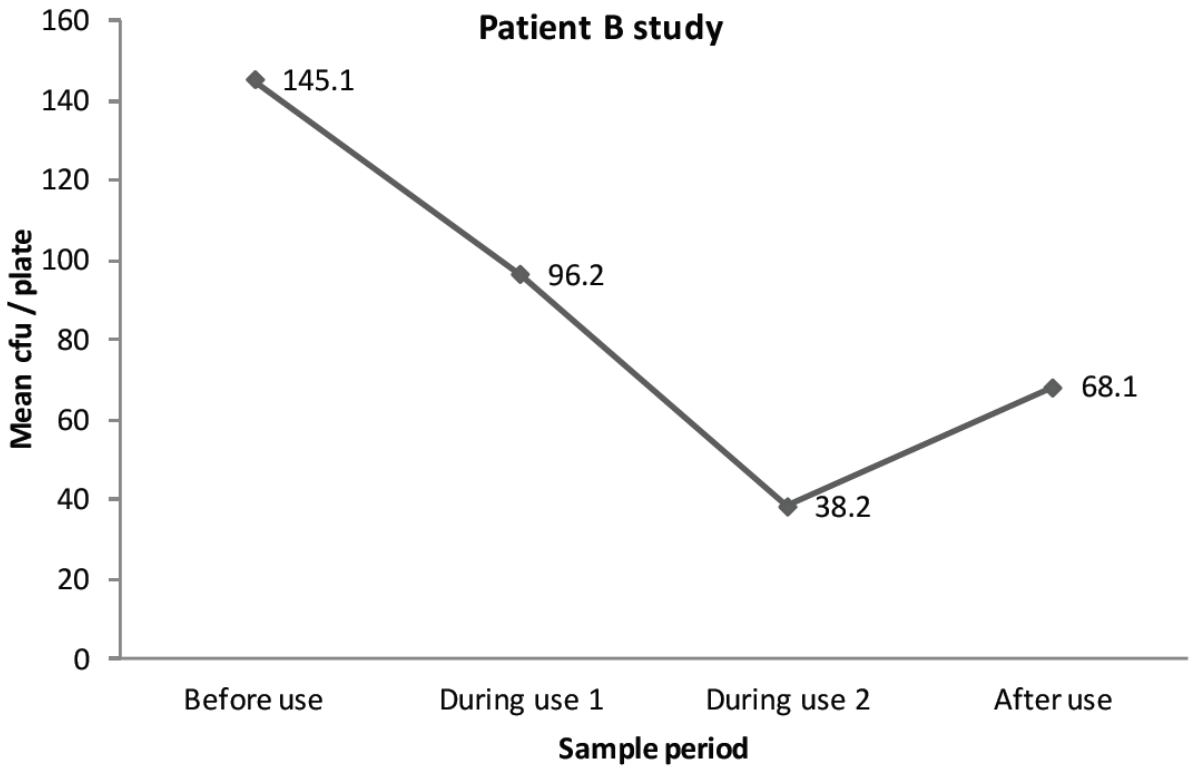
1c. Patient C Study protocol



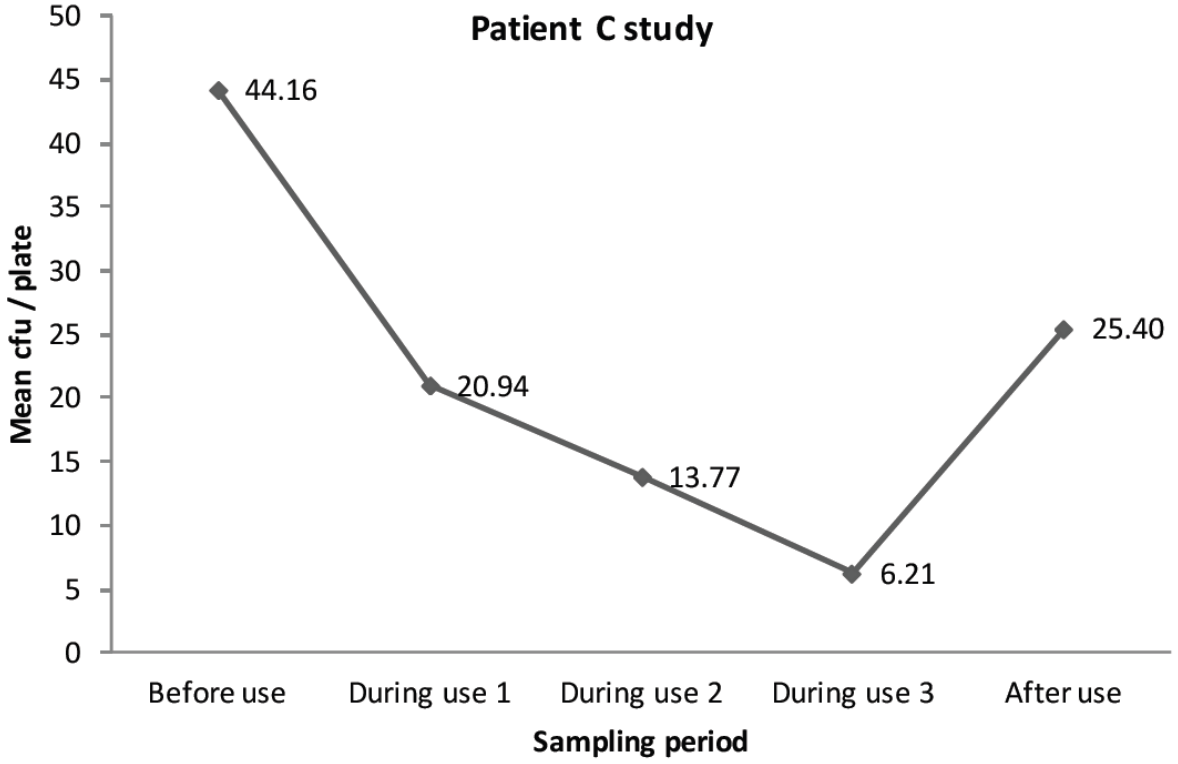
2A


Patient A study
60
50
40
30
20
10
0
Mean cfu /plate
33.0
25.8
56.9
Before use
During use
After use
Sample period

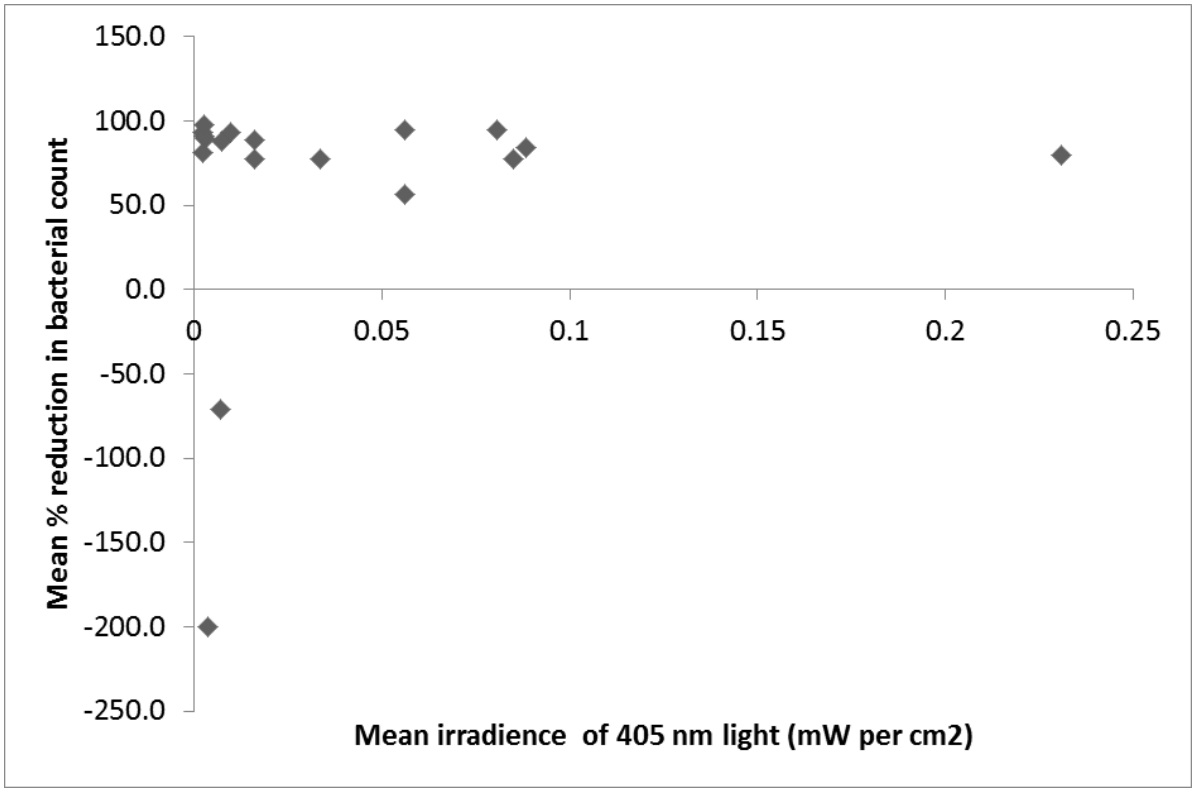
2B


Patient B study
160
140
120
100
80
60
40
20
0
Mean cfu / plate
145.1
96.2
38.2
68.1
Before use
During use 1
During use 2
After use
Sample period

2C


Patient C study
Mean cfu / plate
50
45
40
35
30
25
20
15
10
5
0
44.16
20.94
13.77
6.21
25.40
Before use
During use 1
During use 2
During use 3
After use
Sampling period

3


Mean % reduction in bacterial count
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
-250.0
0
0.05
0.1
0.15
0.2
0.25
Mean irradience of 405 nm light (mW per cm2)