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Research paper

Use of silicon nanoparticle surface coating in infection control: Experience in a tropical healthcare setting

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Abstract *Background:* A nano-scale surface coating containing silicon nanoparticles (Bacterlon®) creates a hydrophobic surface which prevents the growth of bacteria. Study objective was to evaluate the performance of this silicon nano-coating in Sri Lankan healthcare setting.
Methods: This prospective study was conducted from September 2015 to December 2015 in an Intensive Care Unit and a medical ward in Base Hospital Homagama and a bacteriology laboratory in Medical Research Institute, Colombo, Sri Lanka. Silicon nanoparticle coating was applied to 19 high touch surfaces from those three sites. During the follow-up period, these test sites and non-coated control sites were used for routine work and were cleaned routinely as per institute protocol. Swabbing was done for coated and non-coated sites once a week for 12 weeks at unannounced times. Surfaces were categorized in to low ($\leq$10 CFU/cm^2) and high (>10–99 CFU/cm^2) contamination by Aerobic Bacterial Count (ABC) in non-coated sites at any given time.
Results: In low and high contaminated surfaces, an improvement in the mean percentage bioburden reduction from 36.18% to 50.16% was observed from 4th week to 12th week with silicon nanoparticles and a significant reduction ($p < 0.05$) was seen in ABC in each of the coated surface compared with their non-coated counterpart by the 12th week. The frequency of isolation of *Acinetobacter* spp. on coated surfaces had a significant reduction ($p < 0.01$).
Conclusion: Silicon nanoparticle coating demonstrates a significant reduction of the bacterial bioburden in low and high contaminated surfaces for 12 weeks in a tropical healthcare setting.

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Highlights

- SN coating reduced the bioburden on both low and high contamination surfaces.
- Effect of SN coating on environmental surfaces becomes more prominent with time.
- Isolation of *Acinetobacter* species from SN coated surfaces was significantly reduced.

Introduction

Healthcare associated infections (HAI) in hospitals are an overwhelming problem all over the world. Prevalence of HAI in Intensive Care Unit (ICU) settings varied from 8.3% to as high as 48.4% in different international studies [1,2]. Multidrug resistant (MDR) organisms were the common etiological agents of healthcare associated infections [1,3,4]. Similarly in the Sri Lankan health care system, antibiotic resistance is a major problem when considering HAI [5]. Recent studies showed high rates of MDR gram negative isolates in ICU settings [6,7].

The source of these infections with antibiotic resistant organisms could be the hospital environment around the patients [8—10]. Experts suggest that indirect transmission of resistant organisms via the surrounding environment can be as likely as direct person-to-person transmission and that the introduction of additional cleaning services could be more efficient in preventing transmission than attempting to perfect the hand-hygiene compliance of all the relevant healthcare workers (HCW) [11]. A reduction in the patient acquisition of resistant organisms from the hospital environment has been achieved by using adjunctive or enhanced infection control methods [12,13].

Therefore an important component of prevention and control of HAI is the attempt to reduce the burden of pathogens in the hospital environment, by disinfection. However, the routine chemical disinfection methods have practical difficulties and can cause adverse effects on HCW [14—16] and the environment.

Antimicrobial effects of nanoparticles have been explored by researchers especially with the use of silver, copper, titanium, zinc, gold and silicon nanoparticles [17]. These Nanomaterials have shown broad spectrum antimicrobial activity against gram positive and gram negative bacteria, mycobacteria and fungi [18]. Several recent studies have explored the use of nanoparticles in different biomedical applications [19—22] and silver nanoparticle surface coatings have been studied for the purpose of infection prevention [23,24]. Silicon nanoparticles (SN) are considered to be nontoxic and have good biocompatibility. Their use has been studied in biomedical applications such as a therapeutic ultrasound technological method for the suppression of *Escherichia coli* vitality [25].

Use of SN for the purpose of infection control has not been evaluated in a tropical setting before and only few reports of small studies conducted by individual institutes in Europe are currently available. One such study evaluating the effect of SN coated textiles in hospital interiors in Denmark found promising effects [26].

The current study evaluated the effectiveness of a SN surface coating (Bacterlon®, Nanopool GmbH) in a tropical healthcare setting. This was the first time that such a product was tested in a Sri Lankan health care setting. The aim of this study was to evaluate SN coating with regards to the effectiveness in reducing the bioburden on surfaces over a prolonged period of time in Sri Lankan healthcare setting.

Methods

Study setting

This prospective study took place during a twelve week period starting from September 2015 to December 2015 at general ICU and a medical ward from Base Hospital (BH) Homagama and a Microbiology laboratory Medical Research Institute (MRI) in the Colombo district of Sri Lanka. Ethical approval for conducting the study was obtained from Ethics Review Committee, Medical Research Institute, Colombo, Sri Lanka.

Selection of surface sites

A total of nineteen high touch surfaces (eight from ICU, six from ward and five from laboratory) were selected for the study. Each of these test surfaces were given a serial number. An identical control surface for each test surface was also selected, and given separate numbers. The numbers with their test/control status were recorded in a registry. The registry was accessible only to the investigators and the HCW and cleaning staff were kept unaware of which surfaces were treated with SN and which were not.

Intervention

Following a thorough identical cleaning procedure of both test and control surfaces, SN coating was applied to the test surfaces according to the specifications laid down by the manufacturer by a trained technician.

A swab was taken from all the surfaces immediately before the application of SN coating. During the 12-week follow-up period after application, the test surfaces were used for routine work. SN coated test sites and uncoated

sites were cleaned as per the cleaning protocol of the institution. General purpose detergents were used for cleaning of the selected surfaces at the ICU, ward and laboratory except for the stethoscope and the trolleys which were cleaned with 70% alcohol.

Collection of samples

The coated and uncoated surfaces of stethoscope and door knobs were swabbed over an area of 1 cm^2, telephones and bed railings were swabbed over an area of 5 cm^2, and the table at nurses stations, bedside cupboards, trolleys, sinks, the laboratory wall, bench top were swabbed over an area of 10 cm^2. A wider swabbing area was selected on larger surfaces in an attempt to represent the entire surface.

Swabbing was performed using sterile swabs moistened with sterile saline at an unannounced time once a week for 12 weeks by a trained Medical Laboratory Technologist (MLT). All the swabs were placed inside sterile containers without any transport medium and were transported immediately to the clinical bacteriology laboratory at room temperature.

Laboratory procedure

The swabs were mixed with 1 mL of sterile saline using a vortex mixer. This fluid was applied in to Petrifilm™ aerobic count plates (3M™) for the purpose of counting the aerobic bacterial count. The plates were incubated at 37 °C for 48 h. The number of colony forming units were counted for Aerobic Bacterial Count (ABC) according to manufacturer's recommendations.

The fluid was also inoculated on a 5% sheep blood agar plate and was incubated at 37 °C for 24 h. The organisms grown on the blood agar plate were identified up to species level using standard biochemical tests.

Results

Definitions

1 Aerobic Bacterial Count

Aerobic Bacterial Count (ABC), is the estimated concentration of all viable bacteria in a given sample. The count represents the number of colony forming units (CFU) per cm^2 of the area swabbed.

2 Percentage-reduction of Bioburden (PRB)

Percentage-reduction of bioburden (PRB) shows the reduction of ABC on the coated surfaces as compared to the uncoated (control group) surfaces at the end of a certain period of time. It was calculated using the following formula.

$$PRB = \frac{\text{Sum of colony count on uncoated surface} - \text{Sum of colony count on coated surface} * 100}{\text{Sum of colony count on uncoated surface}}$$

Initial bioburden

At the start of the study the initial bioburden following the thorough cleaning procedure was negligible with very low ABC ($\leq$1 CFU/cm^2) in all coated and uncoated surfaces. This ensured that initial bioburden on the surfaces was minimum at the start of the study and created an identical environment on both test and control surfaces to investigate the accumulation bacterial bioburden over time.

Categorization of surfaces according to level of contamination

Surfaces were categorized into low and high contamination by aerobic bacterial count on uncoated surfaces (control). A similar study previously had used $>$15 CFU/cm^2 as the cutoff level for heavy contamination [26]. In the current study a surface was defined as low or high contamination, if the ABC was $\leq$10 CFU/cm^2 and $>$10–99 CFU/cm^2 respectively, on uncoated surfaces at any given time in the 12 week sampling period. The surfaces with $\geq$100 CFU/cm^2 were excluded from part of the data analysis that used ABC because of the technical difficulty in accurately quantifying the ABC. The level of contamination in different surfaces in the ICU, medical ward and laboratory are given in Table 1.

Percentage reduction of bioburden (PRB)

PRB in low and high contamination surfaces in different units are given in Table 2. The highest mean PRB at the end of the 12th week period was seen in the ICU. There is a gradual increase of the mean PRB with time in all three units.

Comparison of silicon nanoparticle-coated and uncoated surfaces using mean ABC

The means of the ABC of treated and untreated surfaces were compared using the paired samples T test. The results are given in Table 3. As time progressed from 4th week to 12th week, a higher number of coated surfaces showed significant reductions in bioburden compared to their respective control (uncoated) surfaces. By the 12th week all low and high contamination coated surfaces had reached a significant reduction in bioburden. The degree of reduction of bioburden in coated surfaces had progressively increased with time.

Types of organisms isolated in the blood agar

Thirteen types of organisms were isolated from the growth in blood agar. The nineteen surfaces were swabbed weekly for 12 weeks, so the number of times a particular organism was identified (frequency of isolation) was expressed as a number out of 228. The results are shown in Fig. 1.

Table 1 Level of contamination in different surfaces.

Site	Low contamination ($\leq$10 CFU/cm^2)	High contamination (>10–99 CFU/cm^2)	CFU number too numerous to count ($\geq$100 CFU/cm^2)
ICU	Stethoscope	Telephone	Side cupboard
	Table at nurses' station	Bed railing	Trolley
		Door knob	Sink
Medical ward	–	Bed railing	Side cupboard
			Telephone
			Table at nurses station
			Trolley
			Sink
Laboratory	Laboratory wall	Telephone	Work bench
			Sink
			Door knob

CFU: Colony Forming Units. ICU: Intensive Care Unit.

Table 2 Percentage reduction of bioburden (PRB) in different units.

Unit	Surface	Percentage reduction of Bioburden (%)			
		4th week	6th week	8th week	12th week
ICU	Telephone	10.25	11.30	24.27	32.37
	Bed railing	34.09	55.69	71.63	62.18
	Door knob	73.33	59.45	63.01	65.27
	Nurses table	26.88	30.26	33.33	38.57
	Stethoscope	50.00	85.71	89.47	83.78
	Mean	**38.91**	**48.48**	**56.34**	**56.43**
Laboratory	Telephone	25.65	32.33	30.58	33.81
	Wall	40.74	40.54	47.56	49.18
	Mean	**33.19**	**36.43**	**39.07**	**41.49**
Medical Ward	Bed railing	28.57	35.91	38.46	36.15
All three units	**Mean**	**36.18**	**43.89**	**49.78**	**50.16**

ICU: Intensive Care Unit.

Table 3 Mean Aerobic Bacterial Count (ABC) of low and high contamination surfaces over time.

Unit	Surface	Uncoated/Coated Status	Mean Aerobic Bacterial Count (CFU/cm^2)							
			4th week	*p* value	6th week	*p* value	8th week	*p* value	12th week	*p* value
ICU	Stethoscope	Uncoated	1.00	0.182	2.33	0.270	2.37	0.116	3.08	0.012*
		Coated	0.50		0.33		0.25		0.50	
	Telephone	Uncoated	3.90	0.843	5.60	0.633	6.90	0.187	8.70	0.012*
		Coated	3.50		4.96		5.22		5.88	
	Bed railing	Uncoated	2.20	0.183	3.16	0.174	4.02	0.031*	5.00	0.001**
		Coated	1.45		1.40		1.14		1.89	
	Table	Uncoated	4.65	0.008**	4.56	0.002**	4.58	0.000**	4.97	0.001**
		Coated	3.40		3.18		3.85		3.05	
	Door knob	Uncoated	3.75	0.351	7.40	0.158	10.42	0.027*	13.09	0.001**
		Coated	1.00		3.00		3.85		4.54	
Laboratory	Wall	Uncoated	0.675	0.076	0.616	0.018*	1.02	0.037*	3.050	0.009**
		Coated	0.40		0.366		0.53		1.550	
	Telephone	Uncoated	10.13	0.105	10.64	0.019*	10.74	0.002**	12.69	0.000**
		Coated	7.53		7.20		7.45		8.40	
Ward	Bed railing	Uncoated	1.75	0.063	4.63	0.509	5.85	0.243	8.85	0.025*
		Coated	1.25		2.96		3.60		5.65	

(*$p < 0.05$, **$p < 0.01$).
CFU: Colony Forming Units. ICU: Intensive Care Unit.

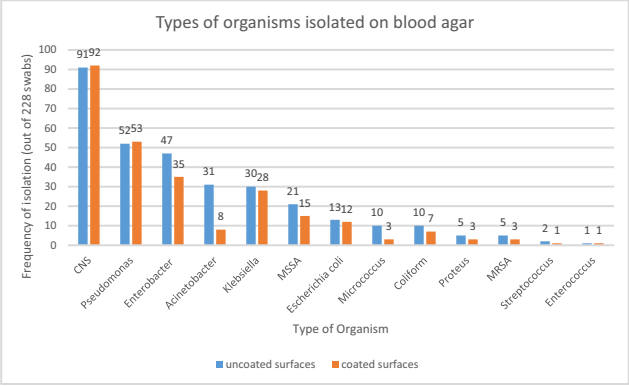

Figure 1 Frequency of isolation of organisms on blood agar. CNS: Coagulase negative Staphylococci, MSSA: Methicillin Sensitive *Staphylococcus aureus*, MRSA: Methicillin Resistant *Staphylococcus aureus*, Coliform: Coliforms other than *Escherichia coli*, *Klebsiella spp.*, *Enterobacter* spp., and *Proteus* spp.

Organisms that had highest frequency of isolation in both coated and uncoated surfaces were Coagulase negative *Staphylococcus* (CNS) and *Pseudomonas* spp. There was a statistically significant reduction in the frequency of isolation of *Acinetobacter* spp. on coated surfaces compared to uncoated surfaces (8 *vs* 31, $p < 0.01$). This was noted in both the ICU (5 *vs* 18, $p < 0.01$) and the ward (3 vs 10, $p < 0.05$). Interestingly *Enterobacter* spp. (35 *vs* 47), Methicillin Sensitive *Staphylococcus aureus* (15 *vs* 21), *Micrococcus* spp. (3 *vs* 10), and other coliforms (7 *vs* 10) also showed a trend of reduced frequency of isolation in the coated surfaces compared to the uncoated although the difference was not statistically significant. Most of the other organisms showed somewhat similar isolation rates during the 12-week period in both coated and uncoated surfaces.

Discussion

The inanimate environmental surfaces in healthcare settings can become durably contaminated after exposure to patients colonized with MDR organisms. New patients who are not yet colonized with MDR pathogens are then at risk of acquiring them from their surroundings [27]. There is also evidence to suggest that healthcare workers' hands can be equally contaminated with MDR organisms from contact with high touch environmental surfaces as from direct contact with colonized patients [28–30]. Therefore this can lead to indirect transmission of organisms and since most nosocomial pathogens are able to survive on inanimate surfaces for days, weeks or even months [31,32] preventing HAIs can become a major challenge. This has led to an increased interest in assessing new emerging technologies for the purpose of disinfection in hospitals [33].

This study explored the use of a novel infection control strategy using a nano-thin layer of silicon dioxide, which creates a stable surface coating with the thickness of 80 nm–100 nm. It's a passive coating which is hydrophobic, easy to clean and considered environmental and user friendly because it is based on fluorocarbon free technology [26].

Previous evaluation conducted in the United Kingdom by the National Health Service (NHS) show that this SN coating can reduce the level of bioburden on a range of hospital surfaces and that it has the potential to improve the effectiveness of the cleaning regime in hospitals. They have also shown that this coating could be applied in a busy hospital setting with minimal disruption [34].

In the current study, the mean PRB in SN coated surfaces compared to uncoated surfaces in all three settings (ICU, ward, and laboratory) showed an increase with time starting from 36.18% at 4th week, rising to 50.16% by 12th week. SN coating had achieved significant bioburden reduction by 12th week on all of the low and high contamination surfaces in our setting. The five coated surfaces which revealed significant reduction of bioburden earlier in time, showed a greater degree of reduction of bioburden as compared to the other three surfaces which reached statistically significant bioburden reduction only at 12 weeks, by the end of the study period ($p < 0.01$ vs $p < 0.05$). These findings lead us to postulate that the reduced accumulation of dirt and bacterial colonization over time on the coated surfaces compared to the uncoated surfaces, resulted in this increased efficacy of SN later in time.

The performance of SN in the current study appear to be better than the previous findings from the evaluation done in the United Kingdom which detected a 25% reduction of microbial contamination on surfaces coated with nanoscale silicon coating using Adenosine Triphosphate (ATP) scores during 12 weeks. There had been no significant difference when considering Total Viable Count (TVC) scores [34]. However they have also concluded that the majority of TVC scores had been low indicating that the study was undertaken only in clinical areas with very low microbial contamination [34]. In contrast, the current study included both low and high contamination areas. This difference may also have been due to a variation in the bioburden of the environment in tropical climate.

This report from United Kingdom also showed that SN coating performed better on some surfaces compared to others [34]. In the current study this observation is noted again where some surfaces had a significant reduction in bioburden from as early as 4th week, 6th week onwards when other surfaces had not. The reason for these discrepancies is uncertain, probably being multifactorial with possible effects from type of surface material, differences in cleaning protocols and the frequency and type of use.

The organisms with higher frequency of isolation in ICU and ward setting were CNS, *Pseudomonas* spp., *Acinetobacter* spp., *Escherichia coli*, *Klebsiella* spp., *Staphylococcus aureus* and *Enterobacter* spp. These organisms are among the pathogens identified as the most frequent causes of hospital acquired infections in local [6,7] and international [1–3] literature.

There was a significant reduction in the frequency of isolation of *Acinetobacter* spp. on coated surfaces ($p < 0.01$). This shows a potential benefit of using SN for ICU settings where *Acinetobacter* spp. is an important pathogen causing HAI [7]. There was no statistically significant difference in the frequency of isolation of the other organisms.

It is possible for a novel infection control strategy to be more efficacious at reducing one type of organism compared to the rest [13]. However there were observable reductions in the isolation rates in the coated surfaces with many other organisms without reaching statistical significance in the current study. This may have been due to the small sample size of this study which was considered as one limitation.

Furthermore, the overall isolation frequency of Methicillin Resistant *Staphylococcus aureus* (MRSA) which is another important nosocomial pathogen, was also reduced on coated surfaces compared to uncoated surfaces (3 vs 5), but the sample size may have been too low to detect a significant difference during the study duration of 12 weeks. These findings warrant further large scale studies with quantification of different types of bacteria.

Another limitation was that the surfaces with $\geq$100 CFU/cm^2 were removed from the part of the analysis that used ABC. Further studies are needed to evaluate the effect of silicon nano-coating on surfaces with very high contamination levels ($\geq$100 CFU/cm^2).

Conclusion

In a tropical healthcare setting silicon nanoparticle coating showed promising effect in reduction of bioburden in low and high contamination surfaces and its efficacy was further improved with time.

Ethics

Ethical approval for conducting the study was obtained from Ethics Review Committee, Medical Research Institute, Colombo, Sri Lanka.

Authorship statement

LK and PK conceived the study; LK, KG, PK, SP and DP designed the study protocol; LK, KG, DP, RJ and SP carried out the field work, laboratory examinations and interpretations, LK, YW and PK performed the data analysis, LK, YW and PK drafted the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

Ecocorp Asia Pvt Ltd company provided silicon nanoparticle product, and laboratory test materials. The principle investigator and other co-investigators were not given any payment in cash or kind by the company for the conduct of the study and have no conflicts of interest.

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Provenance and peer review

Not commissioned; externally peer reviewed.

Data statement

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

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