JIP

Assessing the efficacy of photocatalytic oxidation on bacterial contamination in a clinical setting – a randomised controlled trial

Anwar Abbas Jafri[1,*], Sanjay Gupta[2], Zaki Ibrahim[2], Paul Baker[2], Tamsin Oswald[2], Mike R Reed[2]

1. Department of Orthopaedics, University Hospital of North Tees, Stockton, UK. Email: anwarabbasjafri@hotmail.com
2. Northumbria Healthcare NHS Foundation Trust & University Hospital of North Tees, Stockton, UK
**Corresponding author*

Accepted for publication: 6 June 2011
Key words: Bacterial contamination, cleaning, infection control, infection, prevention

Abstract

Airborne contamination has been shown to be a significant source of wound contamination in orthopaedic surgery. This is the first reported study looking at the efficacy of ActivTek 300, a portable UV/TiO2-based air purifier unit to reduce airborne contamination in a clinical setting. In this randomised study the investigator was blinded as to whether the unit had been on or off for the previous seven days.

Air contamination was measured weekly using a validated technique in ward treatment rooms using a Mini Air Sampler (MAS-100) and agar plates, over a period of 12 weeks. The agar plates were then incubated for 24 hours and the results were expressed as number of colony forming units per plate (cfu). The biomedical scientist who manually counted the number of cfus was blinded as to whether the unit was on or off. Measurements were duplicated to improve the accuracy of the study, and in addition to this an identical experiment was set up in a second treatment room on a separate randomisation schedule. Analysis of the data demonstrated median colony count was significantly lower with the unit on (Median = 43 interquartile range (IQR) 30 to 83) than when it was off (median = 95 IQR 44 to 143) ($p < 0.01$). This represents a 55% mean reduction in the colony count. This study suggests that the portable UV/TiO2-based air purifier unit is efficacious in reducing airborne contamination in the clinical environment and may have a promising role in reducing overall infection rates in surgical patients.

Introduction

Reducing surgical site infection remains one of the greatest challenges in orthopaedic surgery. Airborne contamination is a known source of wound contamination in orthopaedic theatres (Holton et al, 1990; Lidwell et al, 1983). Throughout the past few decades innovations such as antibiotics and laminar air flow have proved successful in decreasing the incidence of infection (Lidwell et al, 1982). More recently the importance of postoperative wound management and the environment for dressing changes has been suggested (Bosco et al, 2010). Many potential techniques for improving this environment and reducing airborne contamination have been described.

The germicidal properties of ultraviolet (UV) light are well known (Chang et al, 1985), but widespread clinical use has been limited by the carcinogenic and potentially lethal side effects (Miller et al, 1991; Sinha and Hader, 2002). Unipolar ion emission has been shown to reduce airborne particle concentration (Grinshpun et al, 2007), while photo-oxidation involving UV radiation and TiO_2 as a photocatalyst has been shown to detoxify organic contaminants (Alberici et al, 2000) and inactivate micro-organisms in water (Sunada et al, 1998).

We evaluated a new innovation, the ActivTek 300 (Radal Technology Limited BB11 5UB, UK). This device acts by the process of photocatalytic reaction, which is called radiant catalytic ionisation. Air is directed through a self-contained unit through use of a fan. Within the unit a broad spectrum UV lamp produces electromagnetic energy of 185, 254, 360 and 380 nm wavelengths respectively. This radiation is then directed to a metallic cell containing TiO_2, which produces superoxides, hydroperoxides and other reactive oxygen species that have been shown to cause microbial inactivation (Maness et al, 1999). As a self-contained air decontamination unit, the device does not have some of the drawbacks associated with the use of UV technology.

There are a number of commercial air cleaners that produce ozone as a biocide or as a bi-product. These devices have raised health concerns. The United States Environmental Protection Agency states that devices which produce ozone in enough quantity to remove contaminants should not be used when people are present, because of respiratory tract irritation and damage (Weshler, 2006). Devices utilising the radiant catalytic ionisation

Peer reviewed article

10.1177/1757177411415447

technology do not produce the potentially toxic ozone or other harmful by-products (Fujishima et al, 2000; Rhincon and Pulgarin, 2000). Laboratory data has suggested that this technology significantly decreases the number of viable airborne pathogens (Mayya et al, 2004). The aim of our study was to determine whether use of the unit decreases airborne microbiological contamination in the clinical environment.

Materials and methods

The efficacy of this system was determined over a period of 12 weeks by assessing contamination using a Mini Air Sampler (MAS-100, Merck, Darmstadt, Germany). Prior to commencing the study, a power analysis was performed which determined that 19 samples would be required in each group to give 80% power, at the 5% level of significance, to detect a 50% reduction in the colony count. To ensure we had adequate numbers, in case of an error in processing or contamination of the samples, we obtained 22 samples in each group. We therefore sampled for 11 weeks following an initial baseline period of one week with the unit switched off.

To minimise the chance of confounding factors the study was conducted as two parallel experiments. These were performed simultaneously under identical conditions during the same 12 week period in two separate orthopaedic treatment rooms on different wards, with different randomisation schedules.

The experiments were performed in orthopaedic treatment rooms in the senior author's (MRR) unit. The experiments were performed every Wednesday at 11am after the rooms had been used for inspection and re-dressing of surgical wounds and procedures such as insertion of central lines. All windows were kept closed during the study period. The treatment rooms did not have any additional air-handling mechanisms such as HEPA filtration. Staff were instructed to keep clinic-room traffic to a minimum, with the door shut after passage. The ActivTek 300 units were placed on a shelf at a height of 2 m, as recommended by the manufacturers. The unit has dimensions of 165 x 165 x 175 mm and was programmed to be on the maximum setting. The MAS-100 was used to sample air contamination (Gangeux et al, 2006; Vavricka et al, 2006). It was placed at a height of 1 m above ground level in a horizontal position. The positions of the unit, the furniture, and the air sampler were consistent throughout the duration of the study. To avoid bias the machine indicator lights were masked and air sampling staff were unaware of the previous week's randomisation.

The air sampler was used to aspirate 100 litres air/min on to a 90 mm diameter agar plate. Each sampling time was standardised to 10 minutes (1,000 litres of air) and was then repeated. The agar plates had previously been prepared under sterile conditions with Columbia horse blood agar (PP0120) enriched with 5% Defibrinated Horse Blood (supplied by E&O laboratories Ltd, Bonneybridge, Stirlingshire). The plates were then sent for 24 hours incubation at 37°C in a moist 5% carbon dioxide environment before the numbers of colonies were counted manually. The biomedical scientist processing the specimens was blinded to whether the unit had been on or off.

In total three agar plates from the same batch were used per experiment with one control plate to ensure that there was no pre-existing contamination of the agar and two sample plates. Statistical analysis was performed using SPSS version 11 (SPSS Inc, Chicago, Illinois).

Results

The baseline reading results at week one were not elevated, demonstrating there was no detectable contamination of the environment prior to commencement of the experiment. The mean colony count with the ActivTek unit on was 57, which was lower than the mean colony count of 102 observed with the unit off (Figure 1). However, further analysis of the two test groups revealed that as the data was skewed it was not suitable to undergo parametric analysis.

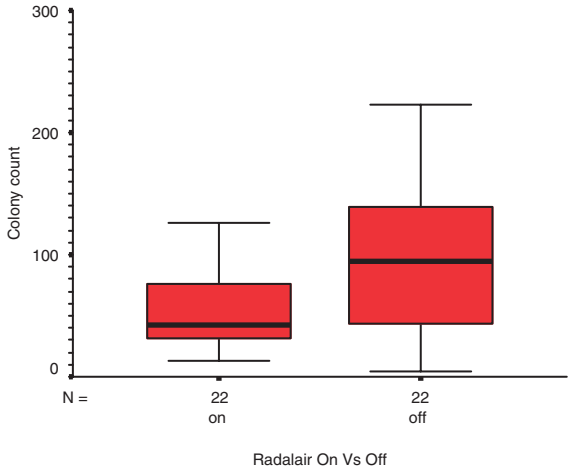

Figure 1. Boxplot demonstrating the colony count with the ActivTek 300 unit on vs off

Non-parametric analysis demonstrated that the median MAS colony count was significantly lower with the unit on for the previous seven days (median = 43, interquartile range (IQR) 30 to 83) when compared to the unit being off for the previous seven days (median = 95, IQR 44 to 143) (Mann Whitney U test, $p < 0.01$) (see Figure 1). This represents a 55% reduction in the colony count.

The isolates were principally coagulase-negative staphylococci and this did not change throughout the study. No fungi were grown on any of the agar plates.

Discussion

This study demonstrates that use of the ActivTek 300 purification unit, when left on continuously for a week or more significantly reduces the median airborne contamination by 55% within the setting of a ward treatment room. Interestingly, it was noted that the baseline air counts were lower than the following intervention arms. We believe this may be attributed to the initial deep clean of the treatment rooms prior to the commencement of the study.

Bacterial loads were noted to be at their highest in the room when there was greater patient and staff turnover. As photocatalytic microbial degradation typically takes minutes, further work is needed to prove if these results are transferrable to the clinical setting, and in turn if there is any reduction in the infection rates.

A potential limitation of the study is that the agar plates were incubated for a period of only 24 hours in a moist carbon dioxide environment. We felt this to be a suitable duration for growth, but it is possible that some organisms were stressed and not given sufficient time to recover.

Antimicrobial light technology and continuous air disinfection is a growing area. Maclean et al (2008) have developed the 'high-intensity narrow spectrum light environmental decontamination system' (HINS-light EDS). This visible light technology has an optimal inactivation wavelength of 405 nm and has proven to be effective against *Staphylococcus aureus* in a burns patient setting (Maclean et al, 2010). The use of continuous UV light in the healthcare setting remains common, but its role as a stand-alone disinfectant remains unclear (Memarzadeh et al, 2010). Pulsed UV light, however, is thought to enable higher intensity energy to be applied over a short time period, which facilitates rapid microbial inactivation. The increased peak power that can be applied yields better inactivation of pathogens in liquids or on contaminated surfaces in comparison to continuous UV (Anderson et al, 2000).

There are a number of other new strategies that have been proposed in the literature to reduce bacterial contamination. They range from employing additional cleaning staff, to the use of vaporised hydrogen peroxide (HPV). Dancer et al (2008) demonstrated that by simply

employing additional cleaning staff there was a 32.5% reduction in contamination, at a cost of £13,320 per annum. Similarly, Boyce et al (2008) and Boyce et al (2009) advocate the role of hydrogen peroxide in decreasing microbial contamination and nosocomial infection rates. We acknowledge that decontamination methods such as UV and HPV inactivate microbes in both the air and on surfaces, whereas the photocatalytic method of the ActivTek 300 only inactivates microbes in the air. However, both UV and HPV decontamination techniques are limited by their cost and practical considerations, i.e. staff and patients need to vacate rooms and the rooms need to be sealed.

When considering healthcare interventions one must consider efficacy, safety, cost and practicality. This study demonstrates that use of the ActivTek 300 purification unit significantly reduces the airborne contamination by 55% within the setting of a ward treatment room. This technology could potentially therefore play a vital role in reducing the literature reported aerial loads of meticillin-resistant *Staphylococcus aureus* (Gehanno et al, 2009) and *Clostridium difficile* (Best et al, 2010). Furthermore, it is safe with no production of ozone, and is not expensive at £320 per unit. In terms of practicality it can be left on whilst patients and staff are in the same confined space, is not noisy, and does not emit any odour. For these reasons, we feel that the ActivTek 300 offers advantages that warrant further evaluation on a larger clinical scale to determine if the novel technique is associated with a decrease in actual surgical site infection rates.

Acknowledgements

We would like to acknowledge biomedical scientists Karen Morris and Jane Heatherington for their expert advice and assistance with this research.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interests

The authors of this paper did not receive any financial or technical support from the manufacturers of the decontamination unit.

References

Alberici RM, Canela MC, Eberlin MN, Jardim WF. (2000) Catalyst deactivation in the gas phase destruction of nitrogen containing organic compounds using Ti02/UV-VIS. *Applied Catalysis B; Environmental* **793**: 1–9.

Anderson JG, Rowan NJ, MacGregor SJ, Fouracre RA, Farish 0. (2000) Inactivation of food-borne enteropathogenic bacteria and spoilage fungi using pulsed light. *IEEE Transactions on Plasma Science* **28**(**1**): 83–8.

Best EL, Fawley WN, Parnell P, Wilcox MH. (2010) The potential for airborne dispersal of *Clostridium difficile* from symptomatic patients. *Clinical Infectious Diseases* **50**(**11**): 1450–57.

Bosco III JA, Slover JD, Haas JP. (2010) Perioperative strategies for decreasing infection. *Journal of Bone and Joint Surgery America* **92**: 232–9.

Boyce JM. (2009) New approaches to decontamination of rooms after patients are discharged. *Infection Control and Hospital Epidemiology* **30**: 515–7.

Boyce JM, Havill JM, Otter JA, McDonald LC, Adams NMT, Cooper T, Thompson A, Wiggs L, Kilgore G, Tauman A, Noble-Wang J. (2008) Impact of hydrogen peroxide vapour room decontamination on Clostridium difficile contamination and transmission in a healthcare setting. *Infection Control and Hospital Epidemiology* **29**:723–9.

Chang JCH, Ossoff SF, Lobe DC, Dorfman MH, Dumais CM, Qualis RG, Johnson JD. (1985) UV inactivation of pathogenic and indicator microorganisms. *Applied and Environmental Microbiology* **49**(**6**): 1361–5.

Dancer SJ, White L, Robertson C. (2008) Monitoring environmental cleanliness on two surgical wards. *International Journal of Environmental Hygiene* **10**: 357–64.

Fujishima A, Rao TN, Tryk DA (2000) Titanium dioxide photocatalysis. *Journal of Photochemistry and Photobiology* **1**(**1**): 1–21.

Gangeux JP, Gangeux FR, Gicquel C, Tanquerel JJ, Chevrier S, Poisson M, Aupee M, Guiger C. (2006) Counts in hospital air: comparative yields for 4 sieve impactor air samplers with 2 culture media. *Infection Control and Hospital Epidemiology* **27**(**12**): 1405–8.

Gehanno JF, Louvel A, Nouvellon M, Caillard JF, Pestel-Caron M. (2009) Aerial dispersal of methicillin-resistant Staphyloccocus aureus in hospital rooms by infected or colonised patients. *Journal of Hospital Infection* **71(3)**: 256–62.

Grinshpun SA, Adhikari A, Honda T, Kim KY, Toviola M, Rao KJ, Reponen T. (2007) Control of aerosol contaminants in indoor air. *Environmental Science and Technology* **41**: 606–12.

Holton J, Ridgeway GL, Reynoldson AJ. (1990) A microbiologist's view of commissioning operating theatres. *Journal of Hospital Infection* **16**: 29–34.

Lidwell OM, Lowbury EJ, Whyte W, Blowers R, Stanley SJ, Lowe D. (1982) Effect of ultraclean air in operating rooms on deep sepsis in the joint after total hip or knee replacement: a randomised study. *British Medical Journal (Clin Res Ed)* **285**: 10–14.

Lidwell OM, Lowbury EJ, Whyte W, Blowers R, Stanley SJ, Lowe D. (1983) Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. *Journal of Hospital Infection* **4**: 111–31.

Maclean M, Murdoch LE, Lani MN, MacGregor SJ, Anderson SG, Woolsey GA. (2008) Photoinactivation and photoreactivation response by bacterial pathogens after exposure to pulsed UV-light. *IEEE International Power Modulators and High Voltage Conference* 326–9.

Maclean M, MacGregor SJ, Anderson JG. (2010) Environmental decontamination of a hospital isolation room using high-intensity narrow-spectrum light. *Journal of Hospital Infection* **76**: 247–51.

Maness PC, Smolinski S, Blake DM, Huang Z, Wolfrum E, Jacoby W. (1999) Bactericidal activities of photocatalytic TiO2 reactions: towards an understanding of its killing mechanisms. *Applied and Environmental Microbiology* **65**: 4094–8.

Mayya YS, Sapra BK, Khan A, Sunny F. (2004) Aerosol removal by unipolar ionisation in indoor environments. *Journal of Aerosol Science* **35**: 923–41.

Memarzadeh F, Olmsted RN, Bartley JM. (2010) Applications of ultraviolet germicidal irradiation disinfection in health care facilities: effective adjunct, but not stand-alone technology. *American Journal of Infection Control* **38**(**5 Suppl 1**): S13–24.

Miller RV, Jeffrey W, Mitchell D, Elasri M. (1991) Bacterial responses to ultraviolet light. *ASM News* **65**(**8**): 535–41.

Rhincon AG, Pulgarin C. (2000) Use of coaxial photocatalytic reactor (CAPHORE) in the TiO2 assisted treatment of mixed E. Coli and Bacillus sp. and bacterial community present in wastewater. *Catalysis Today* **101**(**3–4**): 331–44.

Sinha RP, Hader DP. (2002) UV induced DNA damage and repair: a review. *Photochemical and Photobiological Sciences* **1**: 225–36.

Sunada K, Kikuchi Y, Hashimoto K, Fujishima A. (1998) Bactericidal and detoxification effects of TiO2 thin film photocatalysts. *Environmental Science and Technology* **32**: 726–8.

Vavricka S, Tutuian R, Imhof, Wildi S, Gubler C, Fruehauf H, Ruaf C, Fried M. (2006) Air suctioning during colon biopsy acquisition reduces bacterial contamination. *Gastrointestinal Endoscopy* **63**(**5**): AB108.

Weshler CJ. (2006) Ozone's impact on public health: contributions from indoor exposures to ozone-initiated chemistry. *Environmental Health Perspectives* **114**(**10**): 1489–96.