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Engineering waterborne *Pseudomonas aeruginosa* out of a critical care unit

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ABSTRACT

Objective: To describe engineering and holistic interventions on water outlets contaminated with *Pseudomonas aeruginosa* and the observed impact on clinical *P. aeruginosa* patient isolates in a large Intensive Care Unit (ICU).
Design: Descriptive study.
Setting: Queen Elizabeth Hospital Birmingham (QEHB), part of University Hospitals Birmingham (UHB) NHS Foundation Trust is a tertiary referral teaching hospital in Birmingham, UK and provides clinical services to nearly 1 million patients every year.
Methods: Breakpoint models were used to detect any significant changes in the cumulative yearly rates of clinical *P. aeruginosa* patient isolates from August 2013–December 2016 across QEHB.
Results: Water sampling undertaken on the ICU indicated 30% of the outlets were positive for *P. aeruginosa* at any one time. Molecular typing of patient and water isolates via Pulsed Field Gel Electrophoresis suggested there was a 30% transmission rate of *P. aeruginosa* from the water to patients on the ICU. From, February 2014, QEHB implemented engineering interventions, consisting of new tap outlets and PALL point-of-use filters; as well as holistic measures, from February 2016 including a revised tap cleaning method and appropriate disposal of patient waste water. Breakpoint models indicated the engineering and holistic interventions resulted in a significant ($p < 0.001$) 50% reduction in the number of *P. aeruginosa* clinical patient isolates over a year.
Conclusion: Here we demonstrate that the role of waterborne transmission of *P. aeruginosa* in an ICU cannot be overlooked. We suggest both holistic and environmental factors are important in reducing transmission.

1. Introduction

Pseudomonas aeruginosa is a ubiquitous and important opportunistic pathogen in immunocompromised or critically ill patients (Quick et al., 2014; Garvey et al., 2016a; Crivaro et al., 2009; Davis et al., 2015). *P. aeruginosa* is commonly found in a wide range of moist, nutrient-limited environments and can colonise hospital and domestic water, taps, sinks, drains, toilets and showers (Walker et al., 2014). *P. aeruginosa* forms biofilms that allow persistence of micro-organisms in water systems for long periods, and this helps account for the observed high colonisation rates of hospital water systems (Walker et al., 2014; Costa et al., 2015; Reuter et al., 2002a). Nosocomial *P. aeruginosa* outbreaks have been associated with hospital water sources (Garvey et al., 2016a; Wise, 2012; Ambrogi et al., 2016; Reuter et al., 2002b). Other potential routes of transmission include cross-infection, for example, carriage on the hands of healthcare workers, or via contaminated medical equipment (Reuter et al., 2002b; Moolenaar et al., 2000; Wildmer et al., 1993; DiazGranados et al., 2009).

Water outlet components have been implicated as the probable source of *P. aeruginosa* infection following some high-profile incidents in the UK, notably in neonatal units in Northern Ireland (Crivaro et al., 2009; Walker et al., 2014; Wise, 2012). In 2013, the Department of Health (DoH, England) published the Health Technical Memorandum (HTM) 04-01 guidance which covers the control

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of *P. aeruginosa* in healthcare premises, and has introduced the role of the water safety group (Health Technical Memorandum 04-01, 2013, 2016). The water safety group (WSG) is a multidisciplinary group formed to undertake the commissioning, development and ongoing management of water safety in a hospital (Health Technical Memorandum 04-01, 2016). The WSG advises on remedial action required when water systems or outlets are found to be contaminated and posing an increased risk to susceptible patients (Walker et al., 2014; Health Technical Memorandum 04-01, 2013, 2016; Walker and Moore, 2016). The DoH recently updated this guidance emphasizing the role of water in nosocomial infections other than *P. aeruginosa* (Health Technical Memorandum 04-01, 2016). The updated document also highlights that a risk-management approach to the safety of water is pivotal in the control of infection and a WSG should develop a water safety plan that identifies all potential hazards associated with local water distribution and supply (Health Technical Memorandum 04-01, 2016). Despite the guidance, there has been very little evidence in the published literature of how important water is as a source of *P. aeruginosa* transmission and potential infection risk in an adult Intensive Care Unit (ICU). Furthermore, there are no studies evaluating the effect of remedial actions on transmission.

This article suggests that contamination of water outlets with *P. aeruginosa* may result in transmission of infection to patients in an ICU. We describe the influence of engineering and holistic interventions on contamination of water outlets with *P. aeruginosa* and the impact on clinical *P. aeruginosa* patient isolates in a critical care unit.

2. Materials and methods

2.1. Setting

Queen Elizabeth Hospital Birmingham (QEHB), part of University Hospitals Birmingham (UHB) NHS Foundation Trust is a tertiary referral National Health Service teaching hospital in Birmingham, UK that provides clinical services to nearly one million patients every year. QEHB has one of the largest co-located ICUs in the world with 100 beds; is a major specialist centre for burns, plastic surgery and neurosciences; and has a specialist cancer centre. The ICU at QEHB has 231 water outlets with 130 of these being clinical outlets i.e. wash hand basins in the patient bed spaces or patient showers. The ICU at QEHB consists of 4 separate 25 bedded units. ICU area A specializes in liver, renal surgery and transplant services; ICU area B specialises in trauma, vascular and burns surgery; ICU area C specializes in neurosurgery; ICU area D specializes in cardiac and thoracic surgery and transplant services.

2.2. Clinical surveillance

At QEHB we undertake clinical surveillance of *P. aeruginosa* infection or colonization by recording all first isolates from patients who have been in the critical care unit for more than 48 h (Garvey et al., 2016a). No proactive surveillance in the form of admission screening was undertaken. Isolates from patients deemed to have had possible transmission events with *P. aeruginosa* were typed and compared to positive water samples from geographically linked outlets taken at the six-monthly water sampling [as per Health Technical Memorandum (HTM) 04-01 addendum, 2013, 2016]. Transmission events were characterised as a patient culturing *P. aeruginosa* from a clinical specimen and a geographically linked water outlet being positive for *P. aeruginosa*, confirmed by molecular typing.

2.3. Water sampling

Water samples from all 231 outlets (tap and shower) in the critical care unit at QEHB were collected by an independent company (Future Water Limited, UK) as per the national HTM 04-01 (Health Technical Memorandum 04-01, 2013, 2016). Water samples (500 ml) were obtained from water outlets in critical care every 6 months and no additional sampling was undertaken (Garvey et al., 2016a). Water samples were taken at the end of the night shift before any tap flushing had been undertaken on ICU where activity and use of water in ICU was at its lowest. It was decided taking water at this time would pick up the majority of pre-flush water samples. One cannot rule out that the tap had been used in the 2 h before collection. All samples were tested for the enumeration of microorganisms by membrane filtration (Garvey et al., 2016a). Tryptone soya agar (Biomerieux) and Cetrimide agar (Biomerieux) plates were incubated for 48 h at 37 °C. Results were expressed as Total Viable Count (TVC)/100 ml (Garvey et al., 2016a).

2.4. Isolation and characterisation of P. aeruginosa

Any suspected *P. aeruginosa* growing on the membrane filtration agar plates were identified using biochemical identification tests as per standard microbiological investigations (Eurofins, Food and Environmental Laboratory, Wolverhampton, UK) (Garvey et al., 2016a).

2.5. Epidemiological typing

P. aeruginosa isolates considered to be possibly linked to a transmission event were sent to the Public Health England Antimicrobial Resistance and Healthcare Associated Infections (AMRHAI) reference laboratory for typing via Pulsed Field Gel Electrophoresis (PFGE) (Kaufmann, 1998).

2.6. 'Breakpoint' time series

A 'breakpoint' time series analysis model was used to detect any significant changes in the cumulative rate of *P. aeruginosa* infections from August 2013–December 2016 (Hughes et al., 2013; Bradley et al., 2017). The Changepoint package in R^{20} was used to calculate the breakpoints and fitted means for the *P. aeruginosa* rates. The package utilized a segment neighbourhood algorithm with cumulative sum statistics, using a likelihood-based framework for detecting breakpoints.

2.7. Statistics

A Kruskal-Wallis test for differences between the cumulative rate of *P. aeruginosa* infections in the different breakpoint sections was performed. A post-hoc test for inter-section differences identified from the break point analysis was carried out, to clarify the sources of heterogeneity. The test chosen was a Conover-Iman test, with a Holm correction for multiple comparisons. The cumulative rates of *P. aeruginosa* infection for the different breakpoint sections on ICU area A were analyzed with a Mann-Whitney *U* test. All statistical analyzes were performed using the R statistical programming language (Bradley et al., 2017; R version 3.3.1, 2016).

2.8. Holistic interventions

In February 16, a revised tap cleaning method was implemented as described by Garvey et al. (2016c). In addition, patient waste water was disposed of in the sluice where possible or where use of a macerator required, absorbent gel sheets were used to solidify waste water prior to disposal (Garvey et al., 2016a).