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Multidrug-resistant *Pseudomonas aeruginosa* outbreaks in two hospitals: association with contaminated hospital waste-water systems

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SUMMARY

Background: Multidrug-resistant *Pseudomonas aeruginosa* (MDR-P) expressing VIM-metallo-beta-lactamase is an emerging infection control problem. The source of many such infections is unclear, though there are reports of hospital outbreaks of *P. aeruginosa* related to environmental contamination, including tap water.

Aim: We describe two outbreaks of MDR-P, sensitive only to colistin, in order to highlight the potential for hospital waste-water systems to harbour this organism.

Methods: The outbreaks were investigated by a combination of descriptive epidemiology, inspection and microbiological sampling of the environment, and molecular strain typing.

Findings: The outbreaks occurred in two English hospitals; each involved a distinct genotype of MDR-P. One outbreak was hospital-wide, involving 85 patients, and the other was limited to four cases in one specialized medical unit. Extensive environmental sampling in each outbreak yielded MDR-P only from the waste-water systems. Inspection of the environment and estates records revealed many factors that may have contributed to contamination of clinical areas, including faulty sink, shower and toilet design, clean items stored near sluices, and frequent blockages and leaks from waste pipes. Blockages were due to paper towels, patient wipes, or improper use of bedpan macerators. Control measures included replacing sinks and toilets with easier-to-clean models less prone to splashback, educating staff to reduce blockages and inappropriate storage, reviewing cleaning protocols, and reducing shower flow rates to reduce flooding. These measures were followed by significant reductions in cases.

Conclusion: The outbreaks highlight the potential of hospital waste systems to act as a reservoir of MDR-P and other nosocomial pathogens.

Introduction

Multidrug-resistant *Pseudomonas aeruginosa* (MDR-P), sometimes expressing VIM metallo-beta-lactamase (*bla*VIM) and sensitive only to colistin, is increasingly being recognized

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as a serious problem in hospitals in the UK and elsewhere.[1] A recent HPA report noted that 73 British hospitals had reported cases of *bla*VIM MDR-P.[2] Though the report did not indicate how many of these hospitals had experienced outbreaks, nor the sources of these infections, there have been reports of pseudomonas (including MDR-P) in association with hospital tap water, including some high-profile outbreaks.[3,4] However, any wet or moist environment may harbour pseudomonas, and it is important that other possible sources are not overlooked.[5]

We report two hospital outbreaks of MDR-P, where the hospital waste pipe system was the likely reservoir and source of infection. The outbreaks occurred in large university teaching hospitals in the south of England — one in London ('outbreak 1'), and one on the south coast ('outbreak 2'). Outbreak 1 was hospital-wide, outbreak 2 affected just one specialist medical unit.

Methods

Both outbreaks were investigated by a combination of descriptive epidemiological methods, environmental inspection and microbiological sampling in order to ascertain possible sources and reservoirs of the organism. Cases were defined as patients from whom *P. aeruginosa* resistant to all antibiotics tested except colistin was isolated in any microbiological sample. Antibiotics tested included carbapenems (imipenem and/or meropenem), ceftazidime, gentamicin, amikacin, piperacillin–tazobactam, ciprofloxacin, aztreonam and colistin.

Isolates obtained from routine diagnostic samples were phenotypically identified using biochemical testing. Non-lactose-fermenting oxidase-positive Gram-negative rods were confirmed as *P. aeruginosa* using routine methods (API, bioMérieux, France). Sensitivity testing was performed using BSAC disc diffusion methodology. Molecular typing by serotyping, pulsed-field gel electrophoresis (PFGE) and variable nucleotide tandem repeat (VNTR) analysis was carried out in the Health Protection Agency Laboratory for Healthcare Associated Infection (LHCAI), Colindale, London.

In outbreak 1, cases were mapped according to ward and dates of admission and discharge, in order to identify clustering and overlap between cases. When a new case was identified on a ward, screening swabs were taken to identify further carriers. Swabs were taken from the groin, axilla, oropharynx and perineum, and inoculated on a CLED agar plate (Oxoid, Basingstoke, UK). Any colony growing around a 10 μg gentamicin disc (Oxoid) was fully identified and had further antibiotic susceptibility testing. A second case on the same ward within a month was categorized as overlapping. A questionnaire was applied to cases in order to identify possible sources or risks that could be explored further with a case–control study. Environmental inspections and microbiological sampling were carried out on wards whenever cases or clusters of cases occurred. Sampling was focused around the affected patients; when clusters of cases occurred on a ward, sampling was extended to the whole ward. Particular attention was given to swabbing wet surfaces such as taps and tap handles, sink drain traps ('U-bends'), shower heads and drains, ward sluices and toilets, as well as common patient areas, such as bed spaces or tables. Samples were inoculated on CLED agar (Oxoid) with a 10 μg gentamicin disc, as above. In addition, during and after clusters of cases on the intensive care unit and haematology unit, all water outlets on affected wards ($N = 51$ on the haematology unit, and $N = 9$ on the intensive care unit) had 300 mL samples taken and sent for formal analysis by a commercial testing company (Alcontrol Laboratories, Hawarden, UK). Samples were collected between 09:00 and 11:00, and transported in a container containing sodium thiosulphate. Samples were filtered and cultured on pseudomonas agar containing potassium sulphate and magnesium chloride to enhance pigment production, and cetryl trimethylammonium bromide and nalidixic acid as selective agents. Water samples that yielded *P. aeruginosa* were sent to the clinical laboratory for full identification and sensitivity testing.

In outbreak 2, as there were fewer cases on a single ward over a shorter time, investigations focused on questioning the patients and staff, followed by environmental screening of likely sources as identified during this questioning.

Results

Epidemiology

Outbreak 1 comprised 85 identified cases from 2005 to 2011. The epidemic curve is shown in Figures 1 and 2. The cases peaked in 2008, and most were in the main hospital wing: 31 cases were on the general intensive care unit, seven were on the haematology unit, and 27 were found on a wide number of other wards in that wing. The remaining 20 cases were either in other hospital wings (12) or in outpatients who had previously been on a hospital ward (Figure 1). Most cases (78/85) were first identified more than 48 h after admission. Of those that were detected at the time of admission, all had previously been inpatients in recent months; there were no cases where the acquisition of the bacterium was unequivocally in the community. In all, cases were identified in or associated with 21 different inpatient wards. The pattern of infection was one of sporadic cases or small clusters (no more than four cases in a calendar month), with long infection-free intervals (Figure 2). The mean interval between consecutive cases was 25.4 days, ranging from 0 to 130 days. Only 25/85 cases (29%) overlapped, suggesting that person-to-person spread did not play a major role in the outbreak.

A hypothesis-generating questionnaire (applied to 24 cases and 24 control patients on the intensive care unit) did not identify any common links or exposures that could be explored further with a case–control study.

Outbreak 2 comprised four cases of MDR-P infection occurring in neutropenic inpatients on a haematology ward between April 2009 and June 2010. The ward consisted of six single rooms with en-suite wet rooms.

Clinical features and outcome

The cases in outbreak 1 varied by site of infection, severity and outcome. The overall case fatality rate was 34/85 (40%). However, the case fatality rate was 14/18 (78%) in patients who had bacteraemia. Haematology patients were more likely to be bacteraemic (6/7 cases), and all the bacteraemic haematology patients died.

The cases in outbreak 2 were all bacteraemic, with two admitted to intensive care. One patient developed orchitis resulting in orchidectomy. There were no deaths directly attributable to MDR-P infection in outbreak 2.

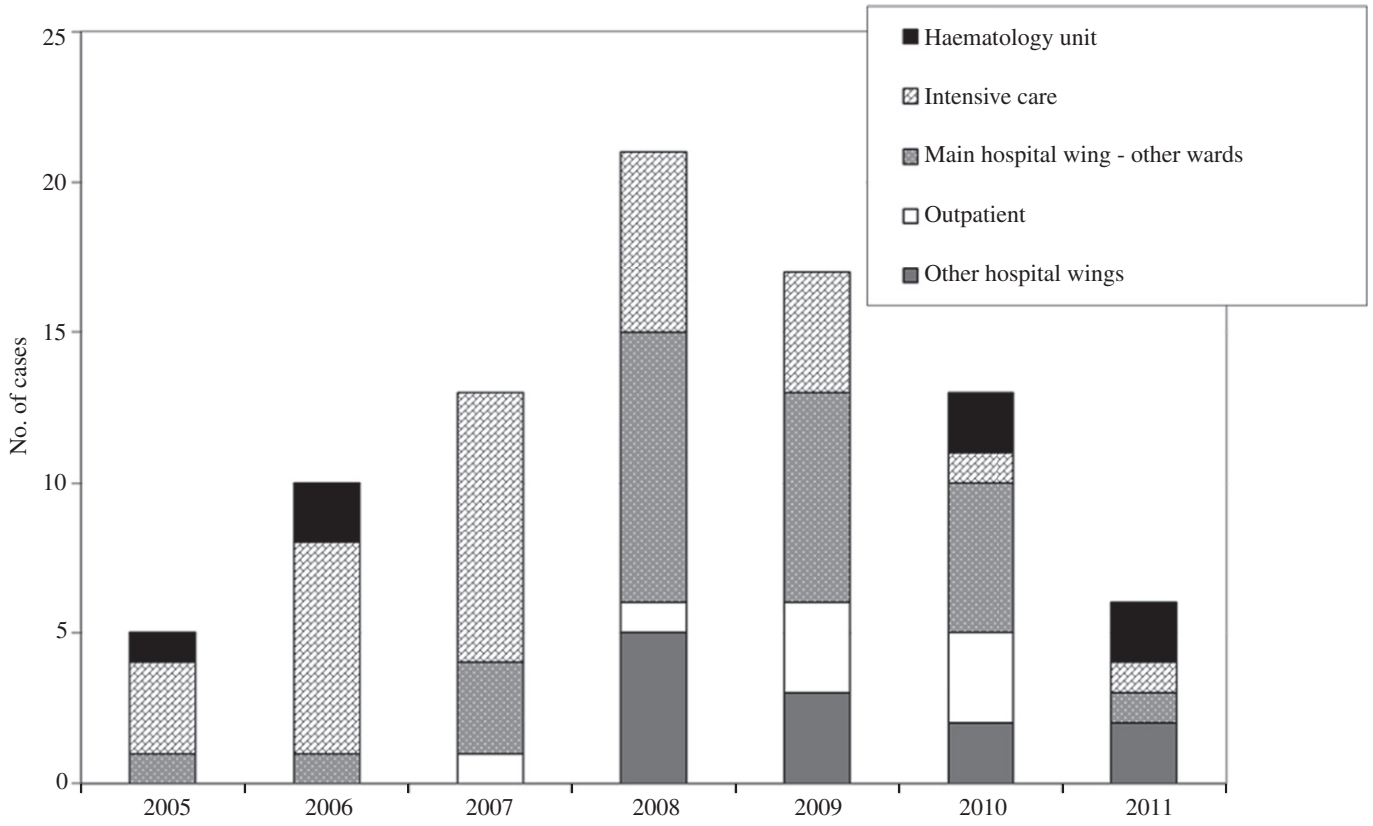

Figure 1. Outbreak 1: cases of multidrug-resistant *Pseudomonas aeruginosa* for each year 2005—2011, broken down by location within the hospital.

Microbiology

Most isolates from outbreak 1 (74/85), and all the isolates from outbreak 2, were sent to the Health Protection Agency Laboratory for Healthcare Associated Infections for molecular typing. The results indicated that each outbreak was caused by a different genetic type of *P. aeruginosa*. Both strains expressed VIM-2 carbapenemase. Each strain was unique to its hospital.

Environmental investigations

The cases in outbreak 1 — in particular the clusters in the intensive care and haematology units — were subject to extensive environmental inspection and investigation. Inspections revealed occasional suboptimal hygiene practices, in addition to examples of poor handbasin design (where the water was directed directly into the outlet, allowing splashback from the sink drain trap), and poor design and usage of sluice facilities (with excessive splashing, and inappropriate storage of clean items). Inspection of the plant room directly above the haematology unit also revealed evidence of a previous waste pipe leak which could possibly have led to contamination of clinical areas.

Multiple samples of hot and cold tap water from outlets were negative for MDR-P. Waste outlets (sink and shower plugholes, sluices, toilet pans and cisterns, macerators) were also sampled extensively — most samples were negative, but a small number of waste outlets on the intensive care and haematology units yielded the outbreak strain of MDR-P. As these results raised the possibility that the waste pipe system was a reservoir of the organism, a sewage leak in the X-ray department was sampled early in 2011 (at a time when there were no known cases on the wards); this also yielded the outbreak strain of MDR-P. This hypothesis was further explored when the main hospital sewer was tested for MDR-P by means of a Moore swab.[6] The swab was left in the sewer for 48 h, and then inoculated in a selective broth containing vancomycin and meropenem. The swab yielded MDR-P, although at the time of testing, there had been no known clinical case of MDR-P for several months. Records showed that from 2005 to 2010 there had been a mean of 391 notifications of blocked sinks, toilets or sluices in the hospital each year. Anecdotal reports suggested that most of these blockages were due to paper towels or patient wipes.

Of the four cases in outbreak 2, three had been housed in the same single room. Questioning staff and patients revealed longstanding concerns about slow drainage of water from the showers, frequent foul smells emanating from the shower drains and recurring problems with blocked sewage pipes leading to backflow of dirty water into toilets and showers. These problems were attributed to blockage caused by inappropriate disposal of paper towels down toilets. Environmental inspection revealed a failure to clean the shower drains, with large quantities of hair and slime found beneath the lid covering the trap. The design of the toilets was found to impede cleaning with the flush water flowing in a closed

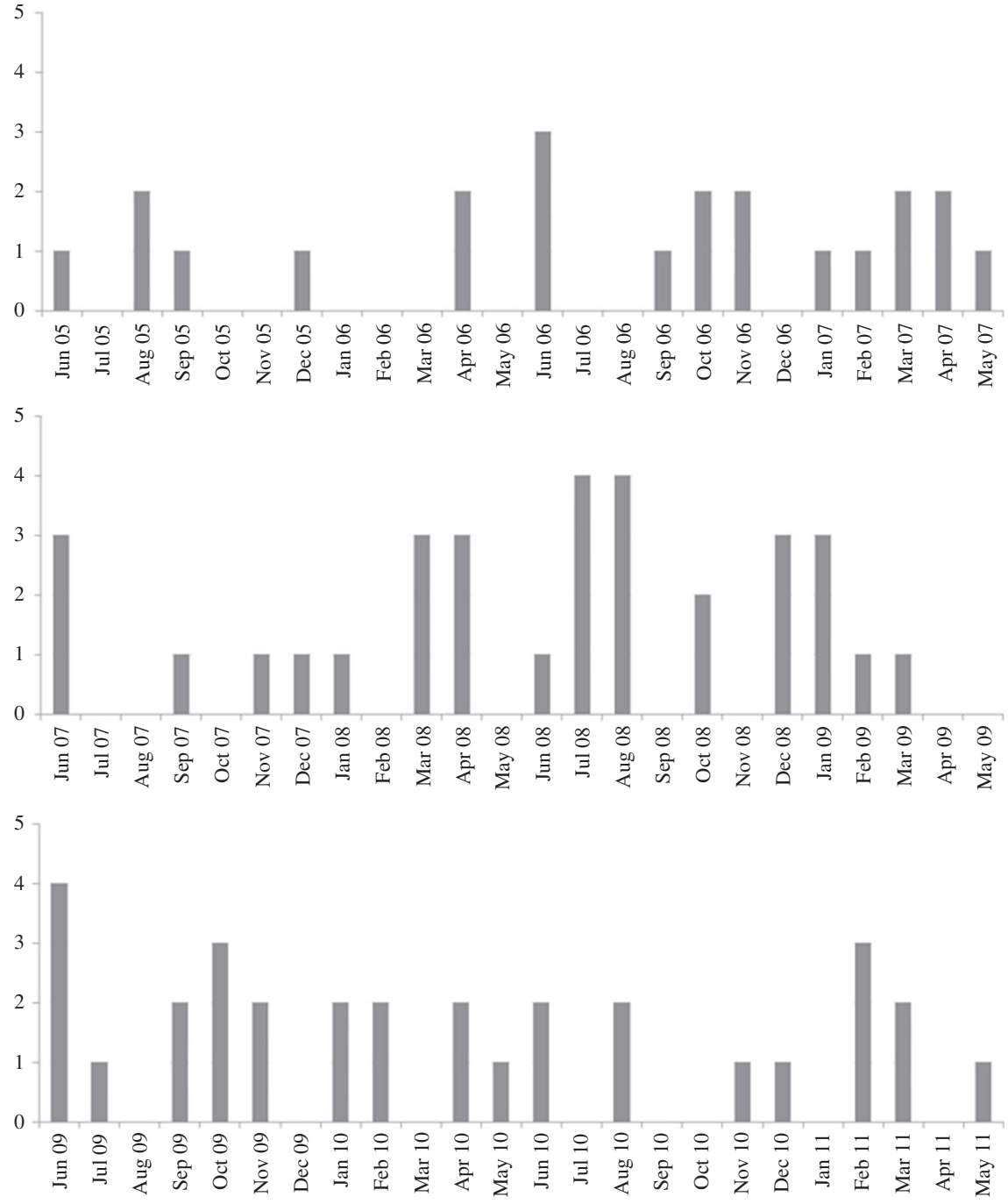

Figure 2. Outbreak 1: epidemic curve, showing cases of multidrug-resistant *Pseudomonas aeruginosa* each calendar month from 2005 to 2011.

channel within the rim. No other environmental concerns were identified. Cleaning procedures were observed and found to be satisfactory. The hands of staff were inspected and no cases of onychomycosis or other finger nail issues were found.

Environmental samples yielded growth of the outbreak strain from shower drains, toilet bowls and toilet brushes. Incoming waters for drinking, hand washing and showering were negative. Pseudomonas was not isolated from cleaning equipment, soaps and skin antiseptic preparations.

Detailed investigation of the causes of sewage blockages took place. Blockages were found to be partly due to paper towels and clinical wipes down toilets, confirming reports of inappropriate disposal of these items. In addition, macerator use was found to be defective with macerators being overloaded, switched off mid-cycle and challenged with indestructible items such as mop heads and clothing. The blockages were compounded by the presence of a 'T-junction' on the main waste pipe, although the plans for the building had mandated a gradual curve.

Control measures

Outbreak 1

Because of the scale and duration of the outbreak, and initial uncertainty concerning the source, many interventions were implemented over time in an effort to reduce cases. These included enhanced cleaning and decontamination measures, and refurbishment/replacement of taps, sinks, toilets and sluice areas where these were identified as suboptimal. After the recognition in 2011 that the waste pipe system was the likely reservoir of infection, measures were targeted at reducing back-contamination of clinical areas. These included avoidance of inappropriate storage of clean items in sluice areas; education of staff to reduce the number of waste pipe blockages, switching paper towels to a more degradable type, upgrading handwash basins to models with integral back outlets, and introduction of rimless toilet pans.[7] It was decided not to institute a programme of regular environmental screening for the organism, as it was felt that the waste water system was likely to remain colonized indefinitely with this organism, and the control measures were intended to reduce contamination of clinical areas, rather than eliminate this colonization. Since May 2011 there has only been one case of the outbreak strain of MDR-P identified.

Outbreak 2

Although it remained possible that colonized patients were contaminating their environment rather than vice versa, the association of infected patients with reports of sewage floods led the outbreak control team to re-plumb the main wastepipe, replace toilet bowls with an easily cleaned design, reduce incoming shower water pressure, re-educate staff, patients and visitors on the safe disposal of sanitary items, add shower drain cleaning to the cleaner's routine duties and order the weekly disposal of toilet brushes. Since these measures were introduced there has been a marked decrease in foul odours and blockages and to date there have been no further cases of MDR-P infection on the unit.

Discussion

These outbreaks, though very different in scale, illustrate both the emerging threat posed by *P. aeruginosa* producing metallo-beta-lactamase[8] — particularly concerning as the isolates are frequently susceptible only to colistin — and also the danger of pseudomonas infection from hospital waste systems. Initially, in outbreak 1, the likely reservoir was unidentified, and it was thought that the isolates from waste outlets might indicate transfer from patients, rather than vice-versa. However, on reflection, the weight of evidence favours the waste system being the actual source of infection: MDR-P was not isolated from any other environmental samples; some environmental MDR-P isolates were recovered when there were no clinical cases present; blockage data suggest the frequent potential for waste-water organisms to contaminate clinical areas; the pattern of infection (with 21 wards affected, yet with long intervals without any cases, and with only 29% of cases overlapping) suggests a widespread environmental reservoir. Finally, the biology of pseudomonas means that it is liable to colonize any moist environment, and waste outlets in sinks and showers have been implicated in previous hospital outbreaks, though recent concern in the UK at least is focused more on the risk from hospital tap water.[4,9–13]

Both outbreaks serve as a reminder of the importance of hospital design and engineering in controlling and preventing infection, a factor that is probably under-appreciated by many clinical staff.[14] Hospital waste systems will be heavily colonized by bacteria, and given the antibiotic selection pressure in hospitals, it is unsurprising that many of these bacteria have been shown to express various mechanisms of antibiotic resistance.[15–17] The factors which reduce the chance of these organisms spreading back to clinical areas include regular flushing of sinks/toilets/sluices, cleaning of the accessible parts of outlets to reduce scale and biofilm, and a free-flowing system that can rapidly carry away waste water. Sink traps help prevent pests and vermin gaining access to clinical areas, but they will also act as a reservoir of bacteria. As observed in these outbreaks, several factors can lead to back-contamination. Poorly designed sinks, with water flowing directly into the plughole, will lead to splashback from the U-bend, and have been previously implicated in MDR-P outbreaks.[18] Contamination of the environment with pathogenic bacteria also occurs when toilets and sluices are flushed.[19] This should be self-evident, but given the lack of storage space on many hospital wards, it is possible that this risk will be overlooked from time to time, and clean items stored in sluice areas. Toilet bowls with rims and dual flushing outlets are harder to clean, and thus pose a greater infection risk. Shower trays with inadequate drainage (which is more likely if the outlets are not cleaned regularly, or if the showers deliver too much water) will lead to pooling in the shower tray: this is likely to be a mixture of tap and stagnant shower-trap water. Any waste pipe leak will inevitably lead to contamination of nearby areas. Similarly, blockages of waste-pipe systems will lead to backflow upstream, and flooding of outlets. The frequency of blockage reports was a surprise to the investigators in outbreak 1. Reports from both hospitals suggested that the most common cause of blockages was incorrect disposal (into toilets) of paper towels and patient wipes. Patient wipes were particularly problematic as they were less degradable. Blocked bedpan macerators were also identified as a common cause of blockages in outbreak 2. Design factors of the waste system itself may play a part — for example sharp angles and long horizontal runs in the piping will be prone to blockage, as noted in outbreak 2.[14]

Finally, it is worth noting that these outbreaks were recognized because of the highly unusual antibiotic resistance pattern of the organisms. Hospital waste systems could also be the source of many cases of infection with different bacteria, as a result of the factors described above. However, unless the organisms are distinctive in some way, such as being multiply resistant, or several cases with the same species linked in time or place, it is likely that the source of many such infections will remain unrecognized.

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Conflict of interest statement
None declared.

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