Methylobacterium and Its Role in Health Care-Associated Infection

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Methylobacterium species are a cause of health care-associated infection, including infections in immunocompromised hosts. The ability of Methylobacterium species to form biofilms and to develop resistance to high temperatures, drying, and disinfecting agents may explain the colonization of Methylobacterium in the hospital environment, e.g., endoscopes. Due to its slow growth, it can be easily missed during microbiological surveillance of endoscope reprocessing. The purpose of this minireview is to present an overview of documented infections and cross-contaminations with Methylobacterium related to endoscopic procedures and to illustrate the health care-associated relevance of this slow-growing bacterium.

Methylobacterium species are fastidious, Gram-negative bacilli which have been reported to be opportunistic pathogens in immunocompromised patients. These species form pink-pigmented colonies on agar plates and have been frequently isolated from tap water in hospitals. The ability to form biofilms and to develop tolerance to disinfecting agents, high temperatures, and drying may explain the frequent occurrence and colonization of Methylobacterium in the hospital environment. Here we review the microbiology and health care-associated relevance of this slow-growing bacterium with particular attention to biofilm formation in medical devices and transmission of Methylobacterium during endoscopic procedures.

MICROBIOLOGY, LABORATORY IDENTIFICATION, AND ANTIBIOTIC SUSCEPTIBILITY

The genus Methylobacterium, of the family Methylobacteriaceae (class Alphaproteobacteria), was described as a new genus of facultative methylotrophic bacteria by Patt et al. in 1976 (1). This genus, including the first Methylobacterium organophagum and 3 species from the Pseudomonas genus (e.g., Pseudomonas mesophilica, Pseudomonas radiola, and Pseudomonas rhodos), currently consists of 49 different species (http://www.bacterio.net/methylobacterium.html; last accessed 20 December 2013). Methylobacterium spp. are commonly isolated from various natural environments (i.e., leaf surfaces, soil, dust, and fresh water) (2, 3).

Methylobacterium spp. are strictly aerobic, facultatively methylotrophic, fastidious, slow-growing bacteria. They form small (1 to 2 mm in diameter), pink-pigmented colonies on ordinary solid media such as triptcase soy agar, sheep blood agar, nutrient agar, and Mueller-Hinton agar and on plate count agar and R2A agar, two media used for plate count analysis in drinking water (4). Optimum growth occurs between 25 and 30°C after 5 to 7 days of incubation, with moderate growth at 35°C and no growth at 42°C (4–6). The best growth was observed on Sabouraud dextrose agar incubation, with moderate growth at 35°C and no growth at 42°C (4–6). The best growth was observed on Sabouraud dextrose agar incubation, with moderate growth at 35°C and no growth at 42°C (4–6).

Methylobacterium spp. form small colonies on blood agar (i.e., Serratia, Azospirillum, R. seomonas, and Asaia). Methylobacterium spp. were reported to be catalase and oxidase positive (1) but were oxidase negative in tests with the dimethyl-paraphenylenediamine reagent (2).

Identification of Methylobacterium is performed using commercially available manual-identification test strips (8, 9). However, determination to the species level by these systems can be difficult. 16S rRNA gene sequence analysis can differentiate Methylobacterium isolates to the species level with pairwise similarity of 16S rRNA gene sequences of between 97% and 99.6% (10, 11). Recent developments in mass spectrometry (MS) have shed light on rapid and precise identification of Methylobacterium spp. Tani et al. (10) applied the whole-cell matrix-assisted laser desorption ionization–time of flight (MALDI) mass spectrometry (WC-MS) technique to identify Methylobacterium spp. collected from plant samples. A total of 213 Methylobacterium isolates were analyzed with WC-MS using MALDI Biotyper software (Bruker Daltonics), and this identification was confirmed by 16S rRNA gene sequencing. The WC-MS technique demonstrated high effectiveness in the identification of known and novel species of Methylobacterium.

Methylobacterium spp. are susceptible to amikacin, gentamicin, ciprofloxacin, and trimethoprim-sulfamethoxazole and have various levels of susceptibility to the β-lactam antibiotics (due to β-lactamase production), with high sensitivity to ceftriaxone, cefixime, and imipenem (6, 8, 12). Discordant carbapenem susceptibilities, with high sensitivity to imipenem (MIC = 0.25 to 1 mg/liter) and resistance to meropenem (MIC > 32 mg/liter), seem to be a distinctive feature of Methylobacterium spp. (13).

HEALTH CARE-ASSOCIATED TRANSMISSION OF METHYLOBACTERIUM

Members of the genus Methylobacterium are major inhabitants of aqueous environments, including potable water supplies and hospital tap water (4). Transmission of Methylobacterium spp. in the hospital environment has been related to contaminated tap water.
These species have also been isolated from water in dental and blood bank purification units (14, 15) and from endoscopes and automated endoscope reprocessors (AERs), which are probably contaminated by the use of nonsterile water for rinsing (16–18). High resistance to dehydration, chlorination, and elevated temperatures and slow growth and the ability to form biofilms can explain the frequent occurrence and colonization of Methylobacterium in the hospital environment (12, 18, 19). Since methylobacteria have been isolated from tap water in hospital units, Horne et al. (5) suggested monitoring water for the occurrence of methylobacteria in hospital units in which immunocompromised patients are admitted.

Despite low virulence, Methylobacterium is able to cause colonization and infections in immunocompromised patients (3, 8). Methylobacterium mesophilicum, Methylobacterium zatmanii, and Methylobacterium extorquens are the three most commonly reported species isolated from normally sterile body sites, i.e., blood, liquor cerebrospinalis, bone marrow, synovia, and ascitic and peritoneal fluids (3, 5). An underlying state of immunosuppression, including that corresponding to solid or hematologic malignancy, organ transplant, renal failure, HIV infection, tuberculosis, or alcoholism, may predispose subjects to a systemic infection caused by methylobacteria (3, 8). In general, Methylobacterium spp. cause mild clinical symptoms, such as fever, but severe infections, including bloodstream infections, peritonitis, and pneumonia, have also been reported (3, 8). Central catheter infections are the most common portal of infection in these situations.

Most reported Methylobacterium infections have been nosocomial. Two cases of bloodstream infections due to M. mesophilica were attributed to tap water used for oral irrigation for patients with mucositis as a complication after bone marrow transplantation (20). Contaminated preservative fluid used for bone marrow harvesting was a possible source of Methylobacterium bacteremia in a patient receiving hematopoietic stem cell transplantation (21). A patient receiving continuous ambulatory peritoneal dialysis developed recurrent peritonitis due to M. mesophilicum, which was also isolated from contaminated stagnant water in the bathroom (22). Several Methylobacterium infections in immunocompromised patients have been associated with environmental exposure (ingestion of raw vegetables, gardening, swimming in a river, and exposure to soil, leaves, and flowers) (3) just before development of infection.

ENDOSCOPE REPROCESSING AND METHYLOBACTERIUM TRANSMISSION RELATED TO ENDOSCOPIC PROCEDURES

Contaminated endoscopes are medical devices frequently associated with outbreaks of health care–associated infections (19, 23). These instruments are difficult to disinfect and easy to damage because of their complex design with multiple internal channels and narrow lumina. Most flexible endoscopes belong to semicritical devices which come into contact with mucous membranes during use and may be either sterilized or disinfected. Flexible endoscopes for therapeutic procedures (i.e., bronchoscopy and gastrointestinal endoscopic procedures) used in sterile body cavities are classified as critical devices and require sterilization after each procedure. Due to their material composition, most flexible endoscopes cannot be steam sterilized but tolerate ethylene oxide and hydrogen peroxide plasma sterilization.

Accurate reprocessing of flexible endoscopes involves cleaning and high-level disinfection followed by rinsing with bacterium-free water and drying before storage (19). Glutaraldehyde and peracetic acid are disinfecting agents frequently used for decontamination of flexible endoscopes. They are active against viruses, fungi, mycobacteria, and all vegetative bacteria, including Methylobacterium. However, resistance of M. mesophilicum to 2% glutaraldehyde has been reported (24). A recent study demonstrated high efficacy of 1% peracetic acid against M. extorquens in the planktonic state, but the disinfectant was less efficient in biofilms (18).

According to Furuhata and Koike (25), 70% (70/100) of examined samples from chlorinated drinking water were positive for Methylobacterium spp. and 25% to 93% of methylobacterial strains isolated from tap water were highly resistant to chlorine and survived contact at 0.1 mg/liter concentration of free residual chlorine for 5 min (11, 25).

Accurate endoscope drying is crucial, whereas a humid environment facilitates microbial growth during storage (19). The final drying steps greatly reduce the risk posed by remaining pathogens, as well as the possibility of recontamination of the endoscope by waterborne microorganisms such as Pseudomonas spp., Acinetobacter spp., and Methylobacterium spp. (19, 23). Members of the genus Methylobacterium have been reported to be highly resistant to dehydration and high temperatures (18). Hence, they can survive in endoscope channels during inadequate or insufficient drying, resulting in recontamination of endoscopes.

Methylobacterium outbreaks after endoscopic procedures have been related to contaminated tap water (6, 24). AERs containing biofilm (16), and contaminated endoscope channels (17, 18). Cross-contaminations with Methylobacterium in 7 patients during bronchoscopy have, despite the usual disinfection procedure, been related to contamination by tap water of endoscope channels (6). Growth of pink-pigmented bacteria, later identified as M. mesophilicum, was observed in mycological surveillance cultures of samples obtained from a bronchoscope which was used for a diagnostic procedure in a patient with an atypical pneumonia. Growth of Methylobacterium was discovered as a consequence of the extended incubation time for fungal culture. In the next 3 months, M. mesophilicum was isolated from 6 other patients after bronchoscopy. Cultures obtained from bronchoscopes, biopsy forceps, AERs, tubing, glutaraldehyde disinfectant, and environmental samples from the bronchoscopy unit were negative for this bacterium. M. mesophilicum was isolated from tap water collected from the sink faucet in the bronchoscopy room. It was considered a colonizer because none of the patients developed a postbronchoscopy infection from this organism.

Cross-contaminations with bronchoscopy-associated Methylobacterium in 18 patients have been documented by Kressel and Kidd (16). M. mesophilicum and Mycobacterium chelonae were isolated from deep respiratory specimens obtained from ventilated patients during bronchoscopy. None of the patients manifested postendoscopic infection with this bacterium. M. mesophilicum grew in the cultures obtained from AERs and from 2% glutaraldehyde used during the automated disinfection procedure and did not grow from bronchoscopes, tap water, or unopened glutaraldehyde containers or from the containers used for collecting the clinical samples. The presence of M. mesophilicum biofilm on the tubing from one of the AERs was confirmed. Contaminated endoscope disinfectors were replaced by new AERs that use peracetic acid instead of glutaraldehyde for disinfection procedures.
Nosocomial *M. mesophilicum* transmission was related to contaminated 2% glutaraldehyde solution used to manually disinfect the bronchoscopes (24). Environmental cultures from the AER, bronchoscopes, gastroscopes, and brushes were positive for this pink-pigment-forming bacterium. The procedure of reprocessing endoscopes was investigated and showed no shortcomings in technique. Endoscopes were sent for ethylene oxide sterilization, but *M. mesophilicum* from endoscope channels was identified again 2 months later. The water supply was assumed to be the source of contamination, and a submicron filter was installed to get filtered tap water for rinsing of endoscopes after cleaning and disinfection procedures. After disinfection and sterilization of the reprocessing equipment, subsequent cultures were negative for 4 months. *M. mesophilicum* caused no infections in patients after endoscopic procedures with contaminated bronchoscopes.

Repeated contaminations of flexible bronchoscopes with *Methylobacterium* spp. have been detected at the University Medical Center Groningen (UMCG), Groningen, The Netherlands (18). Growth of the bacterium, later identified as *M. extorquens*, was accidentally observed on Sabouraud dextrose agar used for culturing of surveillance samples from endoscopes. Because of the slow growth and unclear significance of this bacterium, it was necessary to prolong the incubation time for 7 days to recover these bacteria from the surveillance samples. Cultures were positive for *Methylobacterium* from 2009 to 2011 from endoscope channels, particularly from bronchoscopes. *Methylobacterium* was also isolated from bronchoalveolar lavage fluid samples from the patients after bronchoscopy. We considered *Methylobacterium* to be a contaminating nonpathogen causing the colonization, because no patient manifested true infection with this bacterium. The procedures of endoscope reprocessing revealed no recurrence. Environmental cultures from the endoscopy unit, including AERs and rinsing water, were negative for *Methylobacterium*. Biofilm formation inside bronchoscope channels was suspected. Strains of *M. extorquens* isolated from the contaminated flexible bronchoscope were investigated for the ability to form biofilms, and the effects of peracetic acid disinfection and drying on *M. extorquens* biofilm formation were studied (see the section discussing the impact of biofilm formation by *Methylobacterium* below).

To date, only one case of *Methylobacterium* bacteremia in a patient following endoscopy has been published (17). A 77-year-old patient with biliary lithiasis underwent a biliary sphincterotomy and implantation of a prosthesis in the biliary tract via endoscopic retrograde cholangiopancreatography. The prosthesis was removed by means of an endoscopic procedure 10 days later. The next day, the patient developed fever, and after 5 days, bacterial growth was detected in one aerobic blood culture bottle. *M. mesophilicum* was isolated from a positive blood culture, and the decontamination of a disinfectant into the underlying cells, chemical interaction between the biofilm itself and the disinfectant, and the low growth rate and nutrient limitation of microorganisms in biofilms (27).

The presence of biofilm on the tubing from one of the AERs with growth of *M. mesophilicum* was the source of an outbreak described in patients following bronchoscopy (16). Also, biofilm formation inside endoscope channels was suspected to be the cause of repeated cross-contaminations of flexible bronchoscopes with *M. extorquens* at the UMCG (18). Mimicking biofilm formation in an in vitro study, *M. extorquens* isolated from a contaminated bronchoscope was tested in 96-well microtiter plates (18). In this model, the effects of the 1% peracetic acid disinfectant (10 min incubation at 25°C) and with and without an additional drying (2 h at 50°C) were followed by 7 days drying at room temperature) on *M. extorquens* biofilm formation were studied to imitate the procedures used for reprocessing of flexible endoscopes.

* M. extorquens* had a strong biofilm-producing ability, with the highest biofilm amount and the maximum metabolic activity after 7 days incubation in R2A broth (18). The use of 1% peracetic acid disinfectant caused a marked inhibition of *M. extorquens* growth in 2-, 5-, and 7-day biofilms directly after treatment. Regrowth of *M. extorquens* biofilms occurred following 7 days of incubation with R2A broth directly after the disinfection procedure. Regrowth of *M. extorquens* biofilms was observed in wells after disinfection when the drying procedure was skipped. No biofilm regrowth was observed after a drying procedure. This study demonstrated insufficient efficacy of the peracetic acid against *M. extorquens* biofilms and high efficacy of the drying procedure after the disinfection step against *Methylobacterium* in biofilms.

According to the literature, *Methylobacterium* has a strong biofilm-producing ability (28–30). Simões et al. (29) tested the effects of sodium hypochlorite (liquid bleach) on the activity and culturability of *Methylobacterium* biofilms. *Methylobacterium* biofilms recovered their mass, activity, and culturability after 1 h of treatment with 0.01% sodium hypochlorite; a concentration of only 0.1% completely inactivated this bacterium in biofilms after 1 h of incubation. *Methylobacterium* in biofilms survived after contact with other cleaning agents, including 1% benzalkonium chloride for 24 h (28). They demonstrated a high tolerance to drying. Ten days after drying, the reduction in the survival of *Methylobacterium* was less than 1 log. Some strains of *Methylobacterium* in biofilms survived and exhibited a potential to grow after 4 weeks of desiccation without any nutrients.

**CONCLUSION**

*Methylobacterium* spp. are fastidious microorganisms that have been described as a cause of cross-contaminations related to en-
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Julia Kovaleva is a clinical microbiologist finishing her training at the Department of Medical Microbiology and Infection Control at the University Medical Center Groningen (UMCG), Groningen, The Netherlands. She obtained her M.Sc. degree in Medical Science at the Volgograd State Medical University, Russia, in 2000, followed by a Ph.D. degree in Clinical Pharmacology in 2004. In 2008, she received her second master’s degree in Medical Science from the Ghent University, Belgium, and started her specialization in Clinical Microbiology at the UMCG. Following 4 years of residency, she received a second Ph.D. in Medical Science at the University of Groningen in 2013. Her Ph.D. thesis was called Microbiological safety in endoscope reprocessing. Her research is focused on microbiological surveillance of endoscope reprocessing, development of postendoscopic infection and the impact of biofilm on endoscopes. Her research has been presented at the 19th, 20th, and 22th European Congress of Clinical Microbiology and Infectious Diseases and the 3M European Infection Prevention Expert Conference, where she was an invited speaker. She had authored a book chapter and a number of publications in peer-reviewed journals.