Use of RODAC plates to measure containment of Mycobacterium tuberculosis in a Class IIB biosafety cabinet during routine operations

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ARTICLE INFO

Article history:
Received 14 January 2016
Accepted 31 January 2016
Available online 17 February 2016

Keywords:
Biosafety
Environmental sampling
Ethanol
Propidium monoazide
Replicate Organism Detection and Counting
Tuberculosis

ABSTRACT

Objective/background: Guidelines for the manipulation of Mycobacterium tuberculosis (MTB) cultures require a Biosafety Level 3 (BSL-3) infrastructure and accompanying code of conduct. In this study, we aimed to validate and apply detection methods for viable mycobacteria from surfaces in a BSL-3 MTB laboratory.

Methods: We evaluated phenotypic (Replicate Organism Detection and Counting [RODAC] plates) and molecular (propidium monoazide [PMA]-based polymerase chain reaction [PCR]) approaches for the detection of viable mycobacteria, as well as the effect of 70% ethanol applied for 5 min for disinfection against mycobacteria. For validation of the method, recovery of serial dilutions of Mycobacterium bovis bacillus Calmette–Guérin from glass slides was measured. Subsequently, we stamped surfaces in and around the biosafety cabinet (BSC) after different technicians had manipulated high bacterial load suspensions for routine drug-susceptibility testing in a Class II BSC.

Results: RODAC stamping could detect as few as three bacteria on slides stamped either 5 min or 60 min after inoculation. PMA-based PCR, tested in parallel, did not pass validation. Mycobacteria were still detected after 5-min disinfection with ethanol 70%. In the BSL-3, from 201 RODAC-stamped surfaces, MTB was detected in four: three inside a BSC—on a tube cap and on an operator’s gloves—and one outside, on an operator’s gown.

Conclusion: RODAC plates detect mycobacteria at low numbers of microorganisms. In addition, this method allowed us to show that 70% ethanol does not reliably kill mycobacteria when applied for 5 min to a dried surface, and that MTB bacilli may arrive outside a Class II BSC during routine practice, although the route could not be documented.

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Introduction

Manipulation of Mycobacterium tuberculosis (MTB) cultures requires Biosafety Level 3 (BSL-3) infrastructure, equipment, and practices [1]. Use of liquid culture media and inoculating-loop manipulation increase the risk of creating aerosols, while only a few mycobacteria are sufficient to infect a laboratory worker [2,3]. The emergence of multidrug-resistant and extremely resistant strains requires particular attention to containment, both by the importance an infection may imply and by the increased volume of drug-susceptibility testing (DST) performed [4,5]. Despite the general recognition that BSL-3 measures effectively contain airborne, high-risk pathogens, there is little information on the concrete value of individual measures commonly incorporated in BSL-3 practices [6,7].

Culture-based tools are commonly used for detection of microorganisms in the environment. The presence of viable airborne particulates can be estimated using settling plates [8], whereas monitoring for surface-bound particulates can be done using Replicate Organism Detection and Counting (RODAC) plates, without the need for a decontamination step that could decrease the sensitivity of detection [9–14]. To allow for detection of slow-growing mycobacteria, a modified medium selective for preventing overgrowth by nonmycobacterial contaminants and enriched for supporting the growth of these fastidious microorganisms should be used [15]. Although this method has not to date been validated for mycobacteria, RODAC recovery rates described for other bacteria are highly variable; for example, for Listeria monocytogenes, the recovery rate is only 4.15%, and for Clostridium difficile, it is dependent on the medium used, and ranges from 0.3% to 45.8% [16,17].

Molecular methods are powerful and fast tools to detect traces of genetic material [18]. In particular, propidium monoazide (PMA)–polymerase chain reaction (PCR) is useful in this regard as it selectively amplifies DNA from viable bacteria [19]. This method has already been successfully applied to diagnose patients with drug-resistant MTB infection [20,21].

Surface decontamination of materials leaving the biosafety cabinet (BSC) is recommended, despite lack of evidence that MTB can be reaerosolized from surfaces, and subsequently establish infection [1,22]. Where carried out, such decontamination should be done with a fast-acting disinfectant that does not affect bacilli inside culture tubes. Ethanol (70%) is used in some settings, however, data on its effectiveness are contradictory, with viable bacilli detected 1 min, 5 min, or 10 min after decontamination in two seminal studies [23,24].

Although BSL-3 standards call for a Class II cabinet (open, with laminar flow), this is based primarily on data from flow measurements rather than experimental evidence with bacterial detection, and these Class II cabinets are used in many laboratories handling MTB worldwide, in both high- and low-resource settings, where most laboratories do not meet all BSL-3 standards [25].

In this study, we evaluated both a culture-based and a molecular method for detection of mycobacteria from surfaces. We subsequently used the validated culture-based method to test the effect of ethanol decontamination of surfaces and to sample different surfaces in the environment after routine manipulation of MTB in a BSC Class II B1 [26].

Material and methods

Test strains

Validation experiments were performed using the non-pathogenic MTB complex (MTBC) Mycobacterium bovis Calmette–Guérin (M. bovis BCG; ITM-110295), which was cultured on home-made Stonebrink medium (Löwenstein–Jensen with pyruvate) for 3–4 weeks.

For quality control of media, we used the MTB reference strain (H37Rv; ITM-083715), M. bovis BCG (ITM-110295), and Mycobacterium terrae (ITM-110258) from the BCCM mycobacteria culture collection (Belgian Coordinated Collections of Microorganisms, Institute of Tropical Medicine, Antwerp, Belgium).

Because the sampling was part of a risk analysis in our TB laboratory, in accordance with our biosafety consultant, ethical approval was neither required for the BCCM samples nor for anonymous sampling in the BSL-3 laboratory, including those stamped on technicians’ laboratory coats.

RODAC method

RODAC plates were prepared using Middlebrook 7H11 agar, consisting in DIFCO Mycobacteria 7H11 agar (Becton Dickinson, Erembodegem, Belgium) supplemented with 2.1%, Middlebrook oleic acid–albumin–Catalase–dextrose enrichment 10% [1.5% alpha-D(+)]-glucose (Acros Organics, Geel, Belgium), 0.06% oleic acid (Sigma–Aldrich, Diegem, Belgium), 5% albumin bovine fraction V with pH modified at 6.3 (Acros Organics), glycerol 0.5% (Merck, Overijse, Belgium), ticarcillin 50 mg/L, trimethoprim 10 mg/L, amphotericin B 10 mg/L, and colistin 200 mg/L (all antibiotics from Sigma–Aldrich). Each plate was prepared with 16 mL of medium, shaped as a parabolic meniscus, and stored at 4–8 °C for a maximum of 6 weeks. Each lot was validated by direct inoculation of one plate with MTB H37Rv or M. bovis BCG, and another one with M. terrae. Both plates should yield growth after 7–14-day incubation at 34–38 °C with 7.5% CO2.

To validate the recovery of mycobacterial bacilli from surfaces, a suspension (1 mg/mL) of M. bovis BCG was prepared [about 10⁶–10⁷ colony-forming units (CFU)/mL according to positive control plates] with serial dilution until achieving 1 CFU on 3 different days (each starting from a different BCG subculture). Nonsterile microscopy slides were inoculated with 50 μL of those dilutions and placed in the BSC for subsequent stamping by the RODAC plates at different time points: within 10 s, about 5 min, or 60 min after pipetting. Each slide was stamped once, and the stamping covered about 1 cm². At this point, slides had not yet completely dried except for the 60-min time point. The contact time between slide and RODAC plate was 1 s in the two first adjustment experiments and subsequently 1 min. Where mentioned,
Sampling was performed in the BSL-3 laboratory at the ITM Mycobacteriology Unit in Antwerp, Belgium. After completion of manipulations for DST, multiple places on the operator and in and around the BSC Class IIB were stamped by RODAC plates, with a 1-min contact time. Those DST manipulations, considered at risk, were performed on routine or research samples growing MTB, using serial 10^2× and 10^3× dilutions from a 1-mg/mL bacterial suspension (approximately 10^4–10^7 CFU/mL) for first-line DST, and 10× and 10^3× dilutions for second-line DST. As for the RODAC validation step, colonies were counted after 28 days’ incubation, and considered negative at 10 weeks. Strains were identified as MTBC with the MPT 64 antigen test (SD Bioline, Yongin, Korea).

Results

Validation of the RODAC method

Growth of the positive control, the direct inoculum, was similar between the antibiotic-containing RODAC plate and Petri dish with plain 7H11 medium (Table 1). The CFUs obtained on control plates were in line with CFUs from routine positive control plates.

With a 1-s contact time between RODAC plates and the slides, the capture rate by stamping was not linear. Compared with direct inoculation, RODAC stamping with a 1-s contact time detected bacteria directly or after 5 min, but none were detected when stamping after 60 min, even after moistening (data not shown). When the contact time was increased to 1 min, the capture rate increased, especially at 60 min. Upon analyzing plates with countable numbers of colonies, the capture rate was found to be 60% (standard deviation [SD] 35%) after 5 min, and 32% (SD 38%) after 60 min (confidence interval 0–100% for both stamping times). Individual measurements are shown in Fig. 1A. In addition, a suspension with 2+ growth (on control) showed a similar growth when stamped after 5 min, and a 1+ growth when stamped after 60 min. No contamination was observed.

Inactivation by ethanol

On average, slides inoculated with diluted M. bovis BCG grew seven colonies; addition of ethanol 5 min after inoculation reduced the colony growth to six (87%, SD 25%). Individual measurements are shown in Fig. 1B. When ethanol was added 60 min after inoculation, the number of colonies decreased from 1+ to 0–3 colonies (range) or, for low dilutions (3 and 14 colonies on average), to zero.

Optimization of the PMA–PCR method

Linearity of the DNA extraction and quantitative PCR without PMA was established from 10 to 10^6 DNA copies (1 DNA copy/...
bacterium). Detection of <10 bacteria was possible, but not consistently: five of the ten experiments had a signal for the theoretic point of one bacterium. Although PMA has a theoretical ability to improve discrimination between viable and nonviable bacteria, we observed that PCR signals from dead bacteria were not completely inhibited after reaction with PMA, whereas PCR signals from live bacteria were inhibited in proportions similar to dead bacteria after reaction with PMA.

Sampling in BSL-3 TB laboratory with RODAC plates

On 30 different days, after one of eight different technicians had just completed manipulations for DST of MTB, we sampled from a number of different locations, including the technician's double-gloved little finger, both (gowned) forearms and thighs, two positions on the arm rest of the BSC, and the caps of inoculated MTB culture tubes (MGIT, LJ, or 7H11). In total, 201 RODAC plates were stamped. The exact locations are shown in Fig. 2. Fig. 2 also shows how the little finger is used during DST manipulations. The schedule of sampling is summarized in Table 2.

From those 201 stampings, five RODAC plates were positive on different days: two colonies and 1+ growth, respectively, on two plates stamped on little fingers, one colony from a tube cap (on the same day as the finger plate which grew 2 colonies), one colony from a forearm, and one colony from a thigh. All plates grew MTBC, except the positive RODAC plate from the forearm, with one colony that failed to grow on subculture and could not be further identified. No contamination by non-mycobacteria was observed.

Discussion

The assessment of TB biosafety by monitoring the TB laboratory environment for the presence of viable mycobacteria is hampered by the absence of an established methodology and scanty data [6,7]. We developed an approach to assess the presence of mycobacteria on surfaces in the TB laboratory, and present data on the efficacy of decontamination with 70% ethanol.

Stamping with RODAC plates using a 1-min contact time showed a high sensitivity on glass, down to 3 CFU, yet with a wide confidence interval for capture rate; some replicates could not be cultured, suggesting that stamping at least three plates is necessary to evaluate the absence of viable mycobacteria. Sensitivity is presumably increased by extending sampling to multiple surfaces.

Our capture rate with MTBC appears to be in line with results obtained with other bacteria, detecting bacteria at a variable rate up to 50% [16,17]. Unlike C. difficile, our results on positive controls suggest that antibiotics used for selectivity did not have a detectable inhibitory effect on mycobacterial growth [28]. This finding suggests that a specific liquid growth medium could be developed for inoculation from non-decontaminated swabs, potentially shortening growth time [29,30]. As a different application, this medium might be tested in settings where TB cultures present a high contam-

Fig. 1 – Validation experiments. (A) Stamping efficiency and (B) ethanol effect. Graph showing the number of colonies growing on each of the three RODAC plates on 2 days at the most discriminatory dilution (10^5 in 1 experiment and 10^3 and 10^4 on another day). Individual measures are represented by symbols: black circles (Series 1), light grey squares (Series 2), dark grey triangles (Series 3), whereas mean and standard deviation from triplicates are represented by horizontal lines: solid (Series 1), long-dashed (Series 2), or short-dashed (Series 3). (A) Control represents the direct inoculation on a RODAC plate; Sampling 5' and Sampling 60' are from RODAC plates stamped after 5 min and 60 min, respectively, with a 1-min contact time. (B) Control 5' represents RODAC plates stamped after 5 min, without adding ethanol. Ethanol 70% was added 5 min after bacterial inoculation on a microscopy slide, and stamped 5 min after ethanol addition. RODAC = Replicate Organism Detection and Counting.
ination rate, not sufficiently managed when following the World Health Organization recommendations [31].

Our RODAC approach was considered sufficiently sensitive and selective to detect mycobacteria on surfaces in the BSL-3 TB laboratory, and therefore could be used for biosafety assessment in TB laboratories worldwide. In our case, we applied the RODAC method to operators (technicians) and the environment following DST, in which high concentrations of bacteria (1 mg/mL, about $10^6$–$10^7$ CFU/mL) are manipulated in liquid medium. This experiment took place in a routine environment that respects all current recommendations for TB manipulation: technicians had been trained on biosafety and specific techniques according to the good laboratory practices in place in our ISO 15189-accredited (BSL-3) laboratory, and the BSC is checked and maintained every 6 months according to recommendations. It is not clear whether the MTB colony on the technician’s gown arrived directly by aerosol from the (open front) Class II BSC, or by contact with a contaminated finger, which might occur if unnoticed contaminated gloves are not removed inside the BSC prior to taking one’s hand out to retrieve additional material not stored in the BSC. Even when an (contaminated) outer glove is removed inside the BSC, inner gloves may also be contaminated by colonies on the tube caps when specimens are removed from the BSC. Laminar flow might also have been disturbed by movements around the BSC, like incubator or laboratory door opening [12]. In our case, stamping on the arm rest, at risk of contamination in case of an airborne leak, was always negative, making airborne contamination, which would constitute a higher biosafety risk, less likely. Contamination on the laboratory gown represents an additional risk of transporting mycobacteria away from the BSC, with potential reaerosolization when removing the gown.

The present results prompted us to retrain our staff on always removing the outer gloves upon taking hands out of the BSC, even if only briefly. In addition, a customized closed-front Class II BSC has been installed in our BSL-3 laboratory. A closed-front BSC would better contain mycobacteria at the source, dramatically reducing the potential risk of any direct escape of aerosols [32]. Moreover, using wrist cuffs and double gloves reinforces removal of the outer gloves before exiting the arm sleeves. Such an approach may provide an alternative to a negative pressure laboratory in settings with limited resources, with priorities focused on a well-functioning BSC, its maintenance and calibration, training, and its periodic reinforcement [25].

Detection of bacteria on laboratory coat, gloves, and tubes also showed that RODAC stamping with our adapted medium works on surfaces other than glass, even if capture rate may be different.

PMA had been shown to be a promising approach to identify DNA from live bacteria, including mycobacteria [19–21]. Previous results were however from experiments with large numbers of bacteria, and PMA was used to distinguish between dead and living bacteria, as an alternative to DST. Our results suggest that detecting scarce live mycobacteria...
among a dead mycobacterial population is much more difficult, and PMA–PCR does not appear to be suitable for environmental monitoring.

In line with the results of Best et al. [23], 70% ethanol does not appear to be effective at killing mycobacteria, although our sample size is too small to draw firm conclusions.

Conclusions

In conclusion, we validated an approach—mycobacterium-specific RODAC stamping—that can be readily applied in TB laboratories to monitor biosafety. Our results further call into question whether open Class II BSC and current recommendations are sufficient to contain mycobacteria at the source in a routine environment, particularly when handling high-risk specimens. While ethanol did not completely kill mycobacteria, further experiments are required to compare disinfectants suitable for decontaminating culture tubes without affecting their content’s viability.

Conflicts of interest

None declared.

Acknowledgments

This work was partially supported by European Research Infrastructure on Highly Pathogenic Agents of European Commission (Grant No 262042); a European Research Council Starting Grant to B.C.dJ. (Grant No 311725), and the Fonds Wetenschappelijk Onderzoek by Flemish Government from Belgium. We thank Professor Bruno Gryseels for helpful suggestions and discussions regarding approaches to evidence-based biosafety improvements, and Dr. Kevin Peterson for his useful feedback on the manuscript.

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