Phenotypic and genotypic antimicrobial susceptibility patterns of the emerging human respiratory pathogen *Mycoplasma amphoriforme* isolated from the UK and Denmark

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**Objectives:** To determine the phenotypic and genotypic antibiotic susceptibility of *Mycoplasma amphoriforme* isolates recovered from patients in the UK and Denmark.

**Methods:** Seven isolates of *M. amphoriforme* were examined for antimicrobial susceptibility to seven antibiotics using the microbroth dilution assay in line with the CLSI guidelines for mycoplasmas. Each isolate was additionally subjected to WGS to identify resistance-associated mutations. Based on the consensus sequences from the genomic data, PCR primers were designed, and tested, for the amplification of the QRDR within the *parC* gene.

**Results:** Of the seven isolates investigated, four (57%) were resistant to moxifloxacin (0.5–1 mg/L) and levofloxacin (1–2 mg/L), compared with those that were susceptible (0.03–0.06 and 0.006 mg/L, respectively). Isolate H29 was resistant to five of the seven antibiotics tested: moxifloxacin, 0.5 mg/L; levofloxacin, 2 mg/L; azithromycin, 64 mg/L; erythromycin, 128 mg/L; and clindamycin, 64 mg/L. All isolates were susceptible to tetracycline (0.06 mg/L) and lefamulin (0.001–0.004 mg/L). Mutations from genomic data confirmed the presence of an S89F mutation within the ParC protein among all fluoroquinolone-resistant isolates and an A2059G mutation in the 23S rRNA gene in the macrolide- and lincosamide-resistant isolate H29.

**Conclusions:** To the best of our knowledge, this is the first time where phenotypic and genotypic resistance data have been paired for *M. amphoriforme* confirming a correlation between the two. These data suggest the need for focused testing and resistance determination of isolates from high-risk patients given the backdrop of a high prevalence of antimicrobial resistance.

**Introduction**

*Mycoplasma amphoriforme* was first isolated in 1999 from an immunocompromised patient with chronic bronchitis.\(^1\) Since this initial report, further studies have confirmed the presence of this emerging pathogen within clinical samples by both culture- and molecular-based approaches.\(^2–7\) These studies have shown *M. amphoriforme* predominantly detected within samples from immunocompromised patients or those with pre-existing respiratory complications (20%)\(^5\) and, to a lesser extent, among immunocompetent patients (2%–6%).\(^2,4\) With evidence of transmission among immunocompromised patients attending an outpatients clinic on the same day as well as detections from children from within the same family.\(^4,8\)

Like other mycoplasmas, the lack of a cell wall renders *M. amphoriforme* intrinsically resistant to many antibiotics primarily leaving macrolides, fluoroquinolones and tetracyclines as potential options. Acquired resistance further limits...
Materials and methods

Bacterial isolates and culture

Seven M. amphoriforme isolates were examined in this study, six of which were isolated in the UK from different sources and one from Denmark.

Table 1. MIC values and mechanisms of resistance for M. amphoriforme isolates

| M. amphoriforme | maxifloxacin (mg/L) | levofoxacin | tetracycline | azithromycin | erythromycin | clindamycin | lefamulin | Molecular mechanism of resistance |
|-----------------|---------------------|-------------|-------------|--------------|--------------|-------------|-----------|----------------------------------|
| A39 (NCTC 11740) | 0.5                 | 2           | 0.06        | 0.03         | 0.06         | 0.5         | 0.001     | phenylalanine (F) [ON924760]    |
| A55             | 0.03                | 0.06        | 0.001       | 0.125        | 0.25         | 0.001      | 0.001     | adenine (A) [ON907762]          |
| A70             | 0.03                | 0.06        | 0.001       | 0.125        | 0.25         | 0.001      | 0.001     | adenine (A) [ON907762]          |
| A84             | 1                   | 1           | 0.0005      | 0.125        | 0.25         | 0.001      | 0.001     | adenine (A) [ON907762]          |
| H04             | 0.06                | 0.06        | 0.001       | 0.125        | 0.25         | 0.001      | 0.001     | adenine (A) [ON907762]          |
| H29             | 0.5                 | 2           | 0.06        | 64           | 64           | 0.004      | 0.001     | adenine (A) [ON907762]          |
| M5572           | 0.03                | 0.06        | 0.001       | 0.125        | 0.25         | 0.001      | 0.001     | adenine (A) [ON907762]          |

M. pneumoniae

| M. pneumoniae | maxifloxacin (mg/L) | levofoxacin | tetracycline | azithromycin | erythromycin | clindamycin | lefamulin | Molecular mechanism of resistance |
|---------------|---------------------|-------------|-------------|--------------|--------------|-------------|-----------|----------------------------------|
| M129 (ATCC 29342) | 0.06               | 0.5         | 0.25        | 0.001        | 0.03         | 0.5         | 0.001     | alanine (A) [NC_000912]          |
| M5572         | 0.03                | 0.06        | 0.001       | 0.125        | 0.25         | 0.001      | 0.001     | adenine (A) [NC_000912]          |

Bold type denotes resistance.
set that amplifies the QRDR of the parC gene allowing for sequencing was designed, from genome consensus sequences, and tested. PCRs included GoTaq G2 Green Master Mix (Promega, UK) with a final MgCl₂ concentration of 1.5 mM and 0.2 μM for primers MAM_parC-F (5′-AAACCC GTCAACGGACGGAT-3′) and MAM_parC-R (5′-TCAGTGATCGATGCGACA-3′). Thermocycling conditions were as follows: 95°C for 3 min followed by 30 cycles of denaturation at 95°C for 30 s, annealing at 52°C for 30 s and extension at 72°C for 1 min, followed by a final extension at 72°C for 5 min. PCRs were then run on a 2% w/v agarose gel and visualized with ethidium bromide and a UV transilluminator. The expected product was 248 bp. To confirm specificity, the PCR products were purified and sequenced as previously described.²

**Results**

**MIC data for M. amphoriforme**

Only three out of seven isolates (42%) were susceptible to all antibiotics examined (A70, H04 and M5572), with four out of seven isolates (57%) having resistance to one or more antibiotics (Table 1). Three isolates (A39, A55 and A84) had elevated MIC values of the fluoroquinolone antibiotics moxifloxacin (range 0.5–1 mg/L) and levofloxacin (1–2 mg/L) and were deemed resistant, compared with the susceptibility of the other isolates (range 0.03–0.06 mg/L for moxifloxacin and 0.06 mg/L for levofloxacin). One isolate, H29, was resistant to moxifloxacin (0.5 mg/L), levofloxacin (2 mg/L), azithromycin (64 mg/L), erythromycin (128 mg/L) and clindamycin (64 mg/L). All isolates were susceptible to tetracycline (0.06 mg/L) and lefamulin (0.001–0.004 mg/L).

**Presence of genotypic antibiotic resistance markers among M. amphoriforme sequences**

Only the S89F substitution in the QRDR of ParC was consistent between all fluoroquinolone-resistant isolates (A39, A55, A84 and H29) (Table 1). Alignment of the 23S rRNA sequence revealed 18 differences between isolates (Table 2). The majority of these (12/18) were specific to the M5572 isolate. Two differences were specific for isolate H04, two were specific for A84 and H29, two were specific for A39 and A55 and two were specific for H29. The SNP at nucleotide A2059G within the H29 23S rRNA sequence corresponded with the macrolide resistance-determining site A2058 of *Escherichia coli*.

**Design and testing of parC QRDR PCR primers for fluoroquinolone resistance mutation detection**

PCR products for amplification of the QRDR of parC yielded a product of approximately 248 bp. The DNA sequence confirmed specificity for the target and amplification of the region of interest when aligned with the data obtained from WGS (data not shown).

**Discussion**

Several publications have identified the presence of *M. amphoriforme* within patient samples, in the absence of other known pathogens, suggesting a potential role in infectious disease.¹,²,⁵,⁶ Although detected on several occasions, there are currently limited data on the antimicrobial susceptibility of this organism. To help guide future treatment of suspected cases, a knowledge of susceptibility patterns and markers for resistance is required. Resistance to fluoroquinolone antibiotics moxifloxacin and levofloxacin was present in four of the seven isolates. Such fluoroquinolone resistance is reminiscent of the findings presented by Gillespie et al.,⁷ who identified fluoroquinolone resistance mutations among isolates from eight of the nine patients. Macrolide resistance was present in one of our isolates, H29, which was additionally resistant to fluoroquinolone antibiotics and clindamycin. These data were not surprising when considering the immunocompromised CVID patient had been receiving long-term prophylactic azithromycin.

To the best of our knowledge, our study is the first to look at the activity of lefamulin against a panel of *M. amphoriforme* isolates, which is a protein synthesis inhibitor belonging to the pleuromutilin class of antibiotics and approved for the treatment of community-acquired bacterial pneumonia in adults. Our data suggest lefamulin may represent a therapeutic option due to its activity against all antibiotic-resistant isolates in this study, which complements clinical efficacy data in patients with community-acquired bacterial pneumonia and *M. pneumoniae* at baseline.¹²,¹³ Due to the slow-growing nature of *M. amphoriforme*, phenotypic characterization may not be feasible in many laboratories. For this reason, we examined the presence of mutations associated with resistance to predict resistance. Of the four isolates
with elevated MIC values of fluoroquinolones, an amino acid substitution of serine to a phenylalanine was present at residue 89 (S89F) of the ParC protein. An amino acid substitution at this residue has previously been associated with fluoroquinolone resistance in M. amphoriforme, M. genitalium and Ureaplasma spp., with varying degrees of impact on MIC values. An A2059G (2058 in E. coli numbering) within domain V of the 23S rRNA was identified within isolate H29, which has been reported among other macrolide-resistant mycoplasmas. Our study builds on the work by Gillespie et al., who also used WGS to determine the presence of resistance-associated mutations in the absence of phenotypic data, whereas the study herein includes this important phenotypic data on resistance.

WGS may not be an option in all laboratories; therefore, we designed and confirmed the ability of a primer set to amplify the QRDR of the parC gene in which mutations are associated with fluoroquinolone resistance in this species. These primers will complement those published by Rehman et al. for the amplification of the region surrounding the 2059 residue of the 23S rRNA gene associated with macrolide resistance.

In conclusion, this study correlated MIC values with resistance genotypes and demonstrated that, concordant with other fastidious mycoplasmas, identification of resistance-associated mutations is a feasible and rapid alternative method for inferring antimicrobial resistance. As the role of this organism in human disease becomes more apparent, additional susceptibility data are essential.

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