EPIDEMIOLOGIC STUDY

Mycoplasma genitalium infection among gay, bisexual and other men who have sex with men in Montréal, Canada

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Abstract

Background: The bacteria *Mycoplasma genitalium* has been identified as a causative agent of urethritis in men, especially in gay, bisexual and other men who have sex with men (gbMSM). Canadian clinic-based data have identified a high prevalence of *M. genitalium* and resistance to antibiotic treatments. This article estimates the prevalence of *M. genitalium* infections among Montréal gbMSM, explores correlates for *M. genitalium* infection and estimates the prevalence of mutations associated with antimicrobial resistance (AMR).

Methods: Engage Cohort Study is a multi-site longitudinal study on sexually active gbMSM, aged 16 years and older, recruited via respondent-driven sampling in Montréal, Toronto and Vancouver. Participants completed a questionnaire on behaviour and were tested for sexually transmitted and blood-borne infections at each visit. For this sub-study, Montréal participants with a follow-up visit that occurred between November 2018 and November 2019 were included.

Results: A total of 2,064 samples were provided by 716 participants. Prevalence of *M. genitalium* infection was 5.7% at rectal and/or urethral sites, 4.0% at rectal site and 2.2% at urethral site. Correlates for *M. genitalium* infection were younger age and reporting six or more sexual partners in the past six months. Prevalence of macrolide resistance associated mutations (MRAM), quinolone resistance associated mutations (QRAM) and either MRAM or QRAM, was 82%, 29% and 85%, respectively.

Conclusion: This first population-based study among gbMSM in Canada documents a high prevalence of urethral and rectal *M. genitalium* infection and high levels of AMR. Our results highlight the importance of access to testing and AMR detection when indicated.

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Introduction

Mycoplasma genitalium has been identified as a growing health concern for sexually active gay, bisexual and other men who have sex with men (gbMSM) by causing acute, persistent or recurrent urethritis (1–6). The data concerning *M. genitalium* as a causative agent of clinical proctitis are conflicting (4–8). *Mycoplasma genitalium* co-infection with other bacterial sexually transmitted infections (STIs) has been frequently reported in gbMSM (7,9).

Mycoplasma genitalium infection is not a notifiable condition in Canada (10,11) yet there are no published Canadian community-based studies concerning *M. genitalium* infection. Studies conducted in 2013 (Ontario), 2016 (Alberta) and 2019 (Saskatchewan), among men and women who had STI symptoms or sought medical attention for STI screening, have shown high rates of *M. genitalium* infection and macrolide resistance associated mutations (MRAM) and a significant presence of quinolone resistance associated mutations (QRAM) (12–14).

More detailed Canadian data are required to guide testing and treatment of *M. genitalium* infections in gbMSM. The objectives of this study are to 1) estimate the prevalence of *M. genitalium* infection and other selected bacterial STIs by anatomical site among Montréal gbMSM, 2) explore correlates of *M. genitalium* infection and 3) estimate the prevalence of MRAM and QRAM.

Methods

Engage Cohort Study

Engage Cohort Study is a collaboration between researchers and community-based organizations to study the sexual health, including human immunodeficiency virus (HIV) and sexually transmitted and blood-borne infections (STBBIs), of gbMSM in Montréal, Toronto and Vancouver. Details for this cohort study were described elsewhere (15–17). In brief, participants were recruited using respondent-driven sampling (RDS), a survey method for sampling hard-to-reach populations deriving from chain referral sampling (18). Thus, enrolled participants recruited other eligible participants through their social networks. Eligibility criteria were as follows: French or English-speaking cisgender or transgender men; 16 years of age or older; and reporting at least one sexual encounter with a man in the prior six months. After recruitment, participants were invited every 6–12 months for subsequent visits at the community study site. At each visit, participants completed a self-administered computer-assisted questionnaire and provided biological samples, including first-pass urine, a pharyngeal and a rectal swab and a blood sample.

Sub-study in Montréal

Montréal recruitment into the Engage Cohort Study started in February 2017. For this one-time point sub-study, participants with a follow-up visit that occurred between November 2018 and November 2019 were included.

Biological specimen collection and laboratory testing

To detect *Neisseria gonorrhoeae* and *Chlamydia trachomatis*, nucleic acid amplification tests were used (cobas® 4800; Roche Diagnostics, Branchburg, New Jersey). For *M. genitalium* detection, samples were kept at room temperature in the cobas® PCR Media (Roche Diagnostics) for a maximum of one year or as frozen eluates. Specimens were analyzed using the Allplex™ CT/NG/MG/TV assay (Seegene Inc.). *Mycoplasma genitalium*-positive samples were subsequently analyzed by real-time PCR to detect MRAM and QRAM by using the Allplex™ MG & AziR and Allplex™ MG & MoxiR assays, respectively.

Outcomes and correlates

Using current knowledge based on existing literature, variables were selected from the Engage Cohort Study questionnaire (19,20). Variables were grouped into the following categories: sociodemographic; sexual partners in the past six months (P6M); methods of finding sexual partners in the P6M; substance use in the P6M; and STBBIs in the P6M. The variable "chemsex" was defined as crystal methamphetamine, gamma-hydroxybutyrate (GBH), ecstasy/3,4-methylenedioxymethamphetamine (MDMA), ketamine, or poppers (i.e. alkyl nitrites) consumption in the two hours before or during sex with at least one of the last five sexual partners in the P6M. The variable "self-reported STI diagnosis" refers to a diagnosis by a healthcare professional in the P6M of *C. trachomatis*, *N. gonorrhoeae*, lymphogranuloma venereum (LGV) or syphilis. An individual was considered to have an *M. genitalium* infection if either their urine or their rectal sample was positive. Key mutations associated with azithromycin resistance (positions 2058 or 2059 in region V of the 23S ribosomal ribonucleic acid gene) and moxifloxacin resistance (S83I, S83R, S83N, D87N, or D87Y in *parC*) were used to define MRAM and QRAM, respectively.

Statistical analyses

Prevalence and odds ratios (OR) were estimated and adjusted for the recruitment method as well as censoring, using a combination of RDS-II weights (21) and inverse-probability-of-censoring weights (22). The RDS-II weights are inversely proportional to the participants' network size, meaning that data for individuals with large networks were weighted less. The 95% confidence intervals (CI) were calculated using robust (sandwich) variance estimation to account for the within-subject correlation induced by weighing (23). Prevalence data was not adjusted MRAM and QRAM since one individual with a larger weight could easily dominate the subsample within small subsamples (each MRAM and QRAM subsample had n fewer than 100 positive specimens). Logistic regression was used to predict *M. genitalium* infection among gbMSM. Since the aim was prediction, there was no need to consider confounding or effect modification. Predictive performance was assessed using Akaike information criterion (AIC).

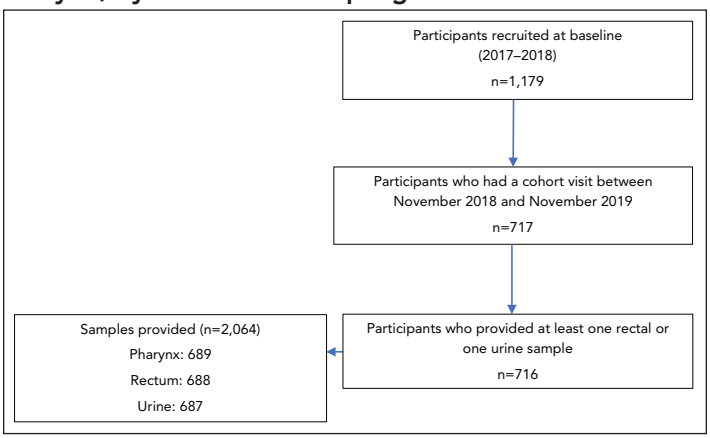
Ethics

Ethics approval was received from the Research Institute of the McGill University Health Centre.

Results

Between February 2017 and June 2018, 1,179 participants were recruited in Montréal. A follow-up study visit, during which samples were collected for *M. genitalium* testing, occurred for 717 participants. One participant was excluded from *M. genitalium* prevalence analyses because only a pharyngeal sample was provided. Overall, 716 participants provided a total of 2,064 samples (**Figure 1**).

Figure 1: Flow diagram of Engage Cohort Study in Montréal study participants and samples included in the analysis, by anatomical sampling sites



Most participants identified their ethnocultural identity as French or English Canadian (53.5%) and their sexual orientation as gay (82.2%). The majority reported having an education level higher than high school level (79.1%), a gross annual income of $30,000 or less (60.1%), being HIV-negative (84.9%) and having five or fewer male sexual partners in the P6M (67.6%) (**Table 1**).

Prevalence of *Mycoplasma genitalium* infection and other sexually transmitted infections

Mycoplasma genitalium prevalence was 5.7% (95% CI: 4.0–8.1) (rectal or urethral site) with anatomical site-specific prevalence being 4.0% (95% CI: 2.6–6.0) at the rectal site and 2.2% (95% CI: 1.2–4.0) at the urethral site (**Table 2**). The overall prevalence of *M. genitalium* was detected at the pharyngeal site in only two individuals (0.2%, 95% CI: 0.1–0.9). Prevalences of *C. trachomatis* and *N. gonorrhoeae* are detailed in Table 2. Among the individuals with urethral *C. trachomatis* infection, one of five were co-infected with *M. genitalium* (20%); among those with rectal *C. trachomatis* infection, two of 22 were co-infected with *M. genitalium* (9.1%) (**Table 3**). Among those with rectal *N. gonorrhoeae* infection, two of 12 were co-infected with *M. genitalium* (16.7%); no urethral *N. gonorrhoeae* infection was observed.

Table 1: Sociodemographic characteristics of the Engage Cohort Study in Montréal participants[a] who provided specimen(s) for *Mycoplasma genitalium* analysis, November 2018–November 2019, n=716

Characteristics	Adjusted proportion (%)[b]	95% CI
Age (years)		
29 or younger	30.2	24.5–36.7
30–45	38.5	31.6–45.8
46 or older	31.3	24.6–38.9
Education level		
High school degree or less	20.9	15.7–27.3
More than high school degree	79.1	72.7–84.3
Annual income (CAD)		
0–29,999	60.1	53.1–66.7
30,000–59,999	31.7	25.6–38.6
60,000 or more	8.2	6.1–11.0
Ethnocultural group		
French Canadian	45.0	37.9–52.4
English Canadian	8.5	5.6–12.5
European	12.7	9.1–17.4
Latin American	13.7	9.1–20.1
South or East Asian	4.9	2.1–11.2
Arab or North African	5.8	3.2–10.2
East or West African or Caribbean	3.5	1.7–7.1
Other[c]	5.9	3.4–10.1
Immigration		
Born in Canada	59.2	51.7–66.2
Moved to Canada in the past 2 years	5.1	2.7–9.3
Moved to Canada in the past 3 years or more	35.7	28.4–42.9
Gender identity		
Cisgender man	92.9	88.7–95.7
Transgender man	1.8	0.6–5.4
Other[d]	5.2	3.1–8.8
Sexual orientation		
Gay	82.2	76.6–86.7
Bisexual	9.2	6.0–13.8
Queer	4.6	2.6–8.2
Other[e]	4.0	2.1–7.3
Sexual behaviours P6M		
Any condomless anal sex	56.0	48.4–63.4
Any chemsex[f]	10.8	7.7–14.9
Number of male sexual partners		
5 or fewer	67.6	61.0–73.6
6–10	16.0	11.4–21.9
11 or more	16.4	12.5–21.2

Table 1: Sociodemographic characteristics of the Engage Cohort Study in Montréal participants[a] who provided specimen(s) for *Mycoplasma genitalium* analysis, November 2018–November 2019, n=716 (*continued*)

Characteristics	Adjusted proportion (%)[b]	95% CI
HIV status		
Living with HIV	15.1	11.0–20.3

Abbreviations: CI, confidence interval; HIV, human immunodeficiency virus; P6M, past six months
[a] Montréal's Engage Cohort Study participants who had a follow-up visit in the window period between November 2018 and November 2019 and provided at least one rectal or urethral sample
[b] Adjusted for respondent-driven sampling recruitment and censoring
[c] Other ethnocultural group included Aboriginal or Indigenous
[d] Other sexual orientations included bisexual and queer
[e] Other gender identities included participants identifying as genderqueer, non-binary, or two-spirit
[f] Chemsex includes crystal methamphetamine, GHB (gamma-hydroxybutyrate), ecstasy/MDMA (3,4-methylenedioxymethamphetamine), or ketamine consumption in the two hours before or during sex with at least one of the last five partners participants reported having sex within the P6M (17). Poppers (i.e. alkyl nitrites) are included in the chemsex definition

Table 2: Prevalence of *Mycoplasma genitalium*[a] and of *Neisseria gonorrhoeae* and *Chlamydia trachomatis* infections[b] by anatomical site, n=716

Type of sample (n)	Positive samples	Adjusted prevalence[c]	
	n	%	95% CI
Pharyngeal swab (n=688)			
M. genitalium	2	0.2	0.1–0.9
N. gonorrhoeae	15	1.5	0.8–2.6
C. trachomatis	7	0.8	0.2–3.0
Urethral swab (n=687)			
M. genitalium	23	2.2	1.2–4.0
N. gonorrhoeae	0	0.0	N/A
C. trachomatis	5	1.9	0.4–8.6
Rectal swab (n=688)			
M. genitalium	41	4.0	2.6–6.0
N. gonorrhoeae	12	1.4	0.6–3.3
C. trachomatis	22	2.6	1.2–5.5
Rectal or urethral swab (n=716)			
M. genitalium	61	5.7	4.0–8.1

Abbreviations: CI, confidence interval; *C. trachomatis*, *Chlamydia trachomatis*; *M. genitalium*, *Mycoplasma genitalium*; *N. gonorrhoeae*, *Neisseria gonorrhoeae*; N/A, not available
[a] Using Allplex™ CT/NG/MG/TV Assay
[b] Using the cobas® 4800 system
[c] Adjusted for respondent-driven sampling recruitment and censoring

Table 3: Co-infections of *Mycoplasma genitalium*, *Neisseria gonorrhoeae* and *Chlamydia trachomatis* by anatomical site, n=716

Type of sample (n)		*C. trachomatis*		*N. gonorrhoeae*	
		Negative	Positive	Negative	Positive
Urethral swab (n=672)					
M. genitalium	Negative	645	4	649	0
	Positive	22	1	23	0
Rectal swab (n=683)					
M. genitalium	Negative	622	20	632	10
	Positive	39	2	39	2

Abbreviations: *C. trachomatis*, *Chlamydia trachomatis*; *M. genitalium*, *Mycoplasma genitalium*; *N. gonorrhoeae*, *Neisseria gonorrhoeae*

Mycoplasma genitalium infection correlates

Younger age (29 years or younger) and the following factors (all reported in the past six months) were significantly associated in univariate analysis having more male sexual partners (6–10 partners and 11 or more partners compared to five or fewer); having at least one new sexual partner; reporting at least one condomless anal sex act (insertive or receptive) with another man; engaging in chemsex; and having received a diagnosis of an STI (**Table 4**). Living with HIV was not associated with *M. genitalium* infection. The best predictive regression model of *M. genitalium* infection included the following factors: younger age (29 years or younger) (OR: 2.5, 95% CI: 1.2–5.5); and declaring more male sexual partners P6M (6–10 partners and 11 or more partners) (respective OR: 3.3, 95% CI: 1.3–8.5, and OR: 5.7, 95% CI: 2.3–14.1) (**Table 5**).

Table 4: Correlates of *Mycoplasma genitalium* infection (urethral or rectal site) in univariate analyses (n=716)

Characteristics	aOR[a]	95% CI
Sociodemographics		
Age (years)		
46 or older		Reference
30–45	1.0	0.4–2.6
29 or younger	2.9	1.3–6.5
Born in Canada		
No		Reference
Yes	1.0	0.5–1.9
Ethnocultural group		
French Canadian		Reference
English Canadian	1.5	0.5–4.5
European	2.8	0.9–7.8
Latin American	0.5	0.1–2.0
South or East Asian	0.9	0.2–5.0
Other[b]	1.2	0.4–3.1
Education level		
Higher than high school degree		Reference
High school degree or less	0.5	0.2–1.4
Annual income (CAD)		
0–29,999		Reference
30,000–59,999	1.8	0.9–3.6
60,000 or more	2.9	1.0–7.5
Sexual orientation		
Gay		Reference
Other[c]	0.6	0.2–1.7
Gender identity		
Cisgender man		Reference
Transgender man	2.4	0.4–13.2
Other[d]	1.8	0.6–3.1
Living with HIV		
No		Reference
Yes	1.4	0.6–3.1

Table 4: Correlates of *Mycoplasma genitalium* infection (urethral or rectal site) in univariate analyses (n=716) (*continued*)

Characteristics	aOR[a]	95% CI
Sexual partners (P6M)		
Number of male sexual partners		
5 or fewer		Reference
6–10	3.9	1.5–10.3
11 or more	7.4	3.1–17.7
New sex partner		
No		Reference
Yes	3.9	1.5–10
Condomless anal sex acts with a man		
None		Reference
1 or more	3.3	1.3–8.6
Methods of finding sexual partners (P6M)		
Attending a bath house or sex club		
No		Reference
Yes	1.4	0.7–2.8
Attending a group sex event		
No		Reference
Yes	2.4	0.9–6.4
Substance use (P6M)		
Any chemsex[e]		
No		Reference
Yes	2.3	1.2–4.4
Crystal methamphetamine use		
No		Reference
Yes	2.0	0.8–4.9
Drug injection		
No		Reference
Yes	N/A[f]	N/A
STBBI (P6M)		
Self-reported sexually transmitted infection diagnosis[g]		
No		Reference
Yes	3.3	1.4–7.9
Co-infection with *C. trachomatis* or *N. gonorrhoeae*		
No		Reference
Yes	1.4	0.4–3.6

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; *C. trachomatis*, *Chlamydia trachomatis*; *N. gonorrhoeae*, *Neisseria gonorrhoeae*; N/A, not applicable; P6M, past six months; STBBI, sexually transmitted and blood-borne infections
[a] Adjusted for respondent-driven sampling recruitment and censoring
[b] Other ethnocultural groups included Arab or North African, East or West African or Caribbean and Aboriginal or Indigenous
[c] Other sexual orientations included bisexual and queer
[d] Other gender identities included participants identifying as genderqueer, non-binary, or two-spirit
[e] Chemsex includes crystal methamphetamine, GHB (gamma-hydroxybutyrate), ecstasy/MDMA (3,4-methylenedioxymethamphetamine) or ketamine consumption in the two hours before or during sex with at least one of the last five partners participants reported having sex within the P6M (17). Poppers (i.e. alkyl nitrites) are included here in chemsex definition
[f] Too few *M. genitalium* infections among participants who injected drugs to permit valid inference
[g] Self-reported STI (sexually transmitted infection) diagnosis by a healthcare professional in the P6M like *C. trachomatis*, *N. gonorrhoeae*, lymphogranuloma venereum (LGV) or syphilis

Table 5: Multivariable predictive model of *Mycoplasma genitalium* infection

Characteristics	aOR[a]	95% CI
Number of male sexual partners P6M		
5 or fewer		Reference
6–10	3.3	1.3–8.5
11 or more	5.7	2.3–14.1
Age (years)		
30 or older		Reference
29 or younger	2.5	1.2–5.5
Condomless anal sex at least once P6M		
No		Reference
Yes	2.1	0.8–5.4

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; *M. genitalium*, *Mycoplasma genitalium*; P6M, past six months
[a] Adjusted for respondent-driven sampling recruitment and censoring

Antimicrobial resistance of *Mycoplasma genitalium*

For the three participants who were infected at both the urethral and rectal sites, the results obtained from the urethral site were used to calculate the prevalence of antimicrobial resistance (AMR). Prevalence of MRAM was 82% (n=46/56) and prevalence of QRAM was 29% (n=16/55) (**Table 6**). Prevalence of either MRAM or QRAM was 85% (n=46/54), while prevalence of both MRAM and QRAM was 28% (n=15/54).

Table 6: Macrolide resistance and quinolone resistance-associated mutations detected by real-time polymerase chain reaction in *Mycoplasma genitalium*-positive specimens, n=61[a]

Resistance-associated mutations (genes)	Mutations	Real-time polymerase chain reaction results	
		n	%
MRAM (23S rRNA), n=56[b]	Wild type	10	18%
	A2058G	7	12%
	A2059G	39	70%
QRAM (*parC*[c]), n=55[b]	Wild type	39	71%
	S83I (G248T)	13	23%
	S83R (A247C)	2	4%
	D87Y (G259T)	1	2%

Abbreviations: *M. genitalium*, *Mycoplasma genitalium*; MRAM, macrolide resistance-associated mutations; QRAM, quinolone resistance-associated mutations; rRNA, ribosomal ribonucleic acid
[a] The 64 positive samples obtained from the urethral or rectal site were from 61 distinct individuals (three were infected at both sites). For the three participants who were infected at both the urethral and rectal site, the results obtained from the urethral site were used to calculate the prevalence of resistance
[b] An invalid result (amplification failure) was obtained in five cases for the macrolide assay and six cases for the quinolone assay
[c] No mutation in the *gyrA* gene, nor the S83N or the D87N mutations in *parC* was found

Discussion

This first Canadian community-based study estimates the prevalence of *M. genitalium* infection at 5.7% (urethral or rectal infection) among gbMSM. It is challenging to contextualize our data since population-based prevalence studies are lacking. Compared to Canadian STI clinic-based studies, the urethral *M. genitalium* prevalence in our study (2.2%) was lower than previous estimates among men in Ontario (4.5%, 2013), Alberta (5.3%, 2016) and Saskatchewan (6.2%, 2019) (12–14). In Australia, urethral *M. genitalium* prevalence among men who have sex with men (MSM) recruited in STI clinics ranged from 2.7–4.7% and prevalence of rectal infections (7.0%–8.9%) was higher than in our study (4.0%) (24,25). Consistent with our results (n=3/689; 0.4%), a very low number of pharyngeal *M. genitalium* infections among MSM were reported in Australia (n=0/508 to n=8/464; 2.0%) (9,25). We hypothesize that oral transmission is negligible, and we excluded *M. genitalium*-positive pharyngeal samples from our prevalence estimation. Rectal *M. genitalium* infection (4.0%) was more common than rectal *C. trachomatis* (2.6%) and *N. gonorrhoeae* (1.4%) infections. Urethral *M. genitalium* prevalence estimates were more similar to those of *C. trachomatis* infection (*M. genitalium*, 2.2%; *C. trachomatis*, 1,9%; *N. gonorrhoeae*, 0%). A United States cohort study conducted in 2018–2019 among young gbMSM and transgender women found that *M. genitalium* was more prevalent than other STIs in both rectal (*M. genitalium*, 21.7%; *C. trachomatis*, 8.8%; *N. gonorrhoeae*, 6.8%) and urine samples (*M. genitalium*, 8.9%; *C. trachomatis*, 1.6%; *N. gonorrhoeae*, 0.8%) (26). A 2017–2018 Australian study found that among asymptomatic MSM, *C. trachomatis* prevalence was comparable to *M. genitalium* in rectal samples (*M. genitalium*, 7.0%; *C. trachomatis,* 8.5%; *N. gonorrhoeae*, 6.2%) and urine samples (*M. genitalium*, 2.7%; *C. trachomatis*, 1.7%; *N. gonorrhoeae*, 0.7%). It also found that 9.2% of MSM that tested positive for rectal *C. trachomatis* were co-infected with *M. genitalium* while 6.1% of positive rectal *N. gonorrhoeae* samples demonstrated co-infection with *M. genitalium* (24). In our study, 9.1% of gbMSM that tested positive for *C. trachomatis* at the rectum were co-infected with *M. genitalium*, 16.7% of rectal *N. gonorrhoeae* infections showcased *M. genitalium* co-infection.

In univariate analyses, multiple risk factors for STI transmission, such as chemsex P6M, new sexual partners P6M and a STI diagnosis P6M, were identified. Younger age and having multiple male sexual partners were retained in our predictive model. These findings are consistent with studies that identified younger age (24,27,28) and multiple sexual partners (19,20,29,30) as correlates of *M. genitalium* infection. While a United Kingdom study documented a higher prevalence of *M. genitalium* among gbMSM living with HIV (31), HIV infection was not associated with *M. genitalium* infection in our study. More studies are needed to clarify the role of *M. genitalium* in HIV acquisition or transmission among gbMSM as it has been identified as a risk factor of HIV infection, especially in MSM (32,33).

The very high prevalence of MRAM (82%; n=46/56) and QRAM (29%; n=16/55) found among the Engage Cohort Study Montréal's gbMSM is a worrisome finding. This prevalence is higher than previous Canadian MRAM estimates (men in Alberta in 2016, 64%; women and men in Saskatchewan in 2019, 63% and men in Ontario in 2013, 63%) (12–14). Treatment failure with azithromycin has been well described with single nucleotide polymorphisms at positions 2058 and 2059 in region V of the 23S ribosomal ribonucleic acid (34). For QRAM, S83 in the *parC* gene is significantly associated with moxifloxacin resistance (34). While several single nucleotide polymorphisms contribute to quinolone resistance, none are as strong predictors of treatment failure than macrolide resistance with 23S ribosomal ribonucleic acid single nucleotide polymorphisms (34,35). Previous Canadian studies found a QRAM prevalence of 11%–20% among men and women (12–14). A meta-analysis compiling studies from 2010–2019 estimated MRAM and QRAM prevalence at 52% and 10%, respectively, in the Americas region (2). A 2017–2018 United States clinic-based study among men with urethritis found MRAM and *parC* QRAM prevalence levels of 64% and 12%, respectively (28). Being infected with a macrolide-resistant *M. genitalium* is more likely in gbMSM than in women and men with female partners only (1,36,37). This could be explained by transmission in closely-knit sexual networks and increased exposure to antibiotics (37). The increasing azithromycin resistance could be explained by its widespread use for the treatment of certain STIs (2,7,38–40). In our study, 28% of *M. genitalium*-positive samples had both MRAM and QRAM. Dual resistance has already been reported in gbMSM on HIV PrEP and those living with HIV (36,41).

Implications for research and practice

In our study, we identified a high prevalence of *M. genitalium* infections among gbMSM, especially among younger individuals and those reporting multiple male sexual partners. Although most current guidelines state that routine screening for *M. genitalium* infection is not recommended (as it would contribute to selection pressure of resistant strains), they vary in terms of testing indications and timing in symptomatic individuals (42–44): at the time of initial presentation of urethritis (concomitantly with *N. gonorrhoeae* and *C. trachomatis* testing) (42–44), only for recurrent non-gonococcal urethritis (4) or only for non-chlamydial non-gonococcal persistent or recurrent urethritis, following empiric treatment for *N. gonorrhoeae* and *C. trachomatis* and when pretreatment nucleic acid amplification tests or follow-up test of cure are negative for *C. trachomatis* and *N. gonorrhoeae* (45). Regarding rectal screening, some clearly state it is not recommended (4) or do not mention extra genital testing (46). The high prevalence of *M. genitalium* infection among gbMSM with *C. trachomatis* or *N. gonorrhoeae* infection demonstrates the need for clinicians to remain highly vigilant of a possible co-infection in the case of persistent symptoms after adequate treatment. Our findings of 4.0% prevalence of rectal *M. genitalium* among gbMSM in Montréal, being almost two-fold the prevalence of urethral *M. genitalium* infection (2.2%),

and much higher than *N. gonorrhoeae* rectal infection (1.4%) or *C. trachomatis* infection (2.6%), may add to epidemiologic evidence in the process of updating the Canadian guidelines (45). Finally, the most recent guidelines touching upon the management of *M. genitalium* infection recommend AMR-guided therapy (4,42,44). This approach has demonstrated potential in reducing treatment failures (47,48). Based on the identified susceptibility profile, doxycycline is used as initial empiric treatment and is followed by either azithromycin or moxifloxacin (49). Because of limited availability of tests in Canada and according to the current Canadian guidelines, treatment initiation for *M. genitalium* should occur in the context of syndromic management of persistent or recurrent urethritis (10). Recommended treatment consists of azithromycin and moxifloxacin as first and second lines of treatment (45). The high AMR observed in our study supports the need for *M. genitalium* detection and AMR testing in a short turnaround time (42,44,47). It also highlights the need, when both QRAM and MRAM are detected, for an easier and quicker access to alternative treatments such as pristinamycin, which can currently be requested through the Health Canada's special access program (42,46,50).

Limitations

The small sample size limited our ability to identify correlates of infection or AMR. Data regarding STI-related symptoms was not collected in the study questionnaire which was designed prior to the initiation of this sub-study and was focused on societal and community contexts, social relationships and sexual behaviour. Hence, we could not evaluate the prevalence of *M. genitalium* in association with clinical presentation. Despite using the RDS method for recruitment, some subgroups of the gbMSM population may be over- or under-represented. Potential biases related to RDS were attenuated by adhering to recommended recruitment procedures, having a large sample size with long recruitment chains and adjusting with RDS-II weights. The AMR data were not RDS-adjusted because they were obtained from too small a subsample. Our prevalence findings might not be generalizable to non-urban Canadian gbMSM populations. We did not find comparison studies analyzing the performance of the Allplex CT/NG/MG/TV Assay, which limited our appreciation of potential information biases. Le Roy *et al.* calculated an overall agreement of 94.6% between in-house real-time PCR and the Allplex MG & AziR Assay (51). The assay, however, showed low sensitivity for macrolide resistance compared to sequencing (sensitivity of 74.5%, specificity of 97.6%).

Conclusion

This first population-based study among Canadian gbMSM documented a high prevalence of urethral and rectal *M. genitalium* infection. The observed levels of AMR, which exceed the 5% threshold at which a change in empirical treatment is recommended by the World Health Organization, supports the need for AMR-guided therapy (52). Efforts should be made to facilitate targeted *M. genitalium* detection and AMR testing when indicated.

Authors' statement

ASL — Methodology, data interpretation, visualization, writing–drafting
ACL — Conceptualization, methodology, data interpretation, visualization, writing–review and editing, supervision
AF — Methodology, data curation, formal analysis, data interpretation, writing–review and editing
MD — Methodology, formal analysis, writing–review and editing
JC — Manuscript review and editing, project administration, funding acquisition
CF — Conceptualization, investigation, writing–review and editing
IM — Writing–review and editing
DG — Writing–review and editing
TAH — Writing–review and editing
DMM — Writing–review and editing
GL — Conceptualization, methodology, investigation, formal analysis, data interpretation, writing–review and editing, project administration, funding acquisition, supervision

All authors revised the manuscript critically for important intellectual content, approved the final version to be published and agreed to be accountable for all aspects of the work.

Competing interests

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References

1. McIver R, Jalocon D, McNulty A, Jeoffreys NJ, Chen SC, Power M, Couldwell DL. Men Who Have Sex With Men With Mycoplasma genitalium-Positive Nongonococcal Urethritis Are More Likely to Have Macrolide-Resistant Strains Than Men With Only Female Partners: A Prospective Study. Sex Transm Dis 2019;46(8):513–7. DOI PubMed

2. Machalek DA, Tao Y, Shilling H, Jensen JS, Unemo M, Murray G, Chow EP, Low N, Garland SM, Vodstrcil LA, Fairley CK, Hocking JS, Zhang L, Bradshaw CS. Prevalence of mutations associated with resistance to macrolides and fluoroquinolones in Mycoplasma genitalium: a systematic review and meta-analysis. Lancet Infect Dis 2020;20(11):1302–14. DOI PubMed

3. Baumann L, Cina M, Egli-Gany D, Goutaki M, Halbeisen FS, Lohrer GR, Ali H, Scott P, Low N. Prevalence of Mycoplasma genitalium in different population groups: systematic review andmeta-analysis. Sex Transm Infect 2018;94(4):255–62. DOI PubMed

4. Centers for Disease Control and Prevention. Sexually Transmitted Infections Treatment Guidelines, 2021. Mycoplasma genitalium. Atlanta, GA: CDC; 2021 [Accessed 2023 Jan 16]. https://www.cdc.gov/std/treatment-guidelines/mycoplasmagenitalium.htm

5. Taylor-Robinson D, Jensen JS. Mycoplasma genitalium: from Chrysalis to multicolored butterfly. Clin Microbiol Rev 2011;24(3):498–514. DOI PubMed

6. Gnanadurai R, Fifer H. Mycoplasma genitalium: A Review. Microbiology (Reading) 2020;166(1):21–9. DOI PubMed

7. Peel J, Aung E, Bond S, Bradshaw C. Recent advances in understanding and combatting Mycoplasma genitalium. Fac Rev 2020;9:3. DOI PubMed

8. Wood GE, Bradshaw CS, Manhart LE. Update in Epidemiology and Management of Mycoplasma genitalium Infections. Infect Dis Clin North Am 2023;37(2):311–33. DOI PubMed

9. Latimer RL, Vodstrcil L, De Petra V, Fairley CK, Read TR, Williamson D, Doyle M, Chow EP, Bradshaw C. Extragenital Mycoplasma genitalium infections among men who have sex with men. Sex Transm Infect 2020;96(1):10–8. DOI PubMed

10. Public Health Agency of Canada. Case definitions: Nationally notifiable diseases. Ottawa, ON: PHAC; 2023. [Accessed 2023 Jan 09]. https://diseases.canada.ca/notifiable/diseases-list

11. Public Health Agency of Canada. Mycoplasma genitalium Infections. Ottawa, ON: PHAC; 2018. [Accessed 2022 Jan 09]. https://publications.gc.ca/collections/collection_2022/aspc-phac/HP40-1-2018-3-eng.pdf

12. Gesink D, Racey CS, Seah C, Zittermann S, Mitterni L, Juzkiw J, Jamieson H, Greer J, Singh S, Jensen JS, Allen V. Mycoplasma genitalium in Toronto, Ont: estimates of prevalence and macrolide resistance. Can Fam Physician 2016;62(2):e96–101. PubMed

13. Gratrix J, Plitt S, Turnbull L, Smyczek P, Brandley J, Scarrott R, Naidu P, Parker P, Blore B, Bull A, Shokoples S, Bertholet L, Martin I, Chernesky M, Read R, Singh A. Prevalence and antibiotic resistance of Mycoplasma genitalium among STI clinic attendees in Western Canada: a cross-sectional analysis. BMJ Open 2017;7(7):e016300. DOI PubMed

14. Parmar NR, Mushanski L, Wanlin T, Lepe A, Lang A, Minion J, Dillon JR. High Prevalence of Macrolide and Fluoroquinolone Resistance-Mediating Mutations in Mycoplasma genitalium-Positive Urine Specimens From Saskatchewan. Sex Transm Dis 2021;48(9):680–4. DOI PubMed

15. Hart TA, Moore DM, Noor SW, Lachowsky N, Grace D, Cox J, Skakoon-Sparling S, Jollimore J, Parlette A, Lal A, Apelian H, Sang JM, Tan DH, Lambert G; Engage Study Team. Prevalence of HIV and sexually transmitted and blood-borne infections, and related preventive and risk behaviours, among gay, bisexual and other men who have sex with men in Montreal, Toronto and Vancouver: results from the Engage Study. Can J Public Health 2021;112(6):1020–9. DOI PubMed

16. Harvey-Lavoie S, Apelian H, Labbé AC, Cox J, Messier-Peet M, Moodie EE, Fourmigue A, Moore D, Lachowsky NJ, Grace D, Hart TA, Jollimore J, Fortin C, Lambert G. Community-Based Prevalence Estimates of Chlamydia trachomatis and Neisseria gonorrhoeae Infections Among Gay, Bisexual, and Other Men Who Have Sex With Men in Montréal, Canada. Sex Transm Dis 2021;48(12):939–44. DOI PubMed

17. Lambert G, Cox J, Fourmigue A, Dvorakova M, Apelian H, Moodie EE, Grace D, Skakoon-Sparling S, Moore DM, Lachowsky N, Jollimore J, Lal A, Parlette A, Hart TA; Engage Study Team. HIV incidence and related risks among gay, bisexual, and other men who have sex with men in Montreal, Toronto, and Vancouver: informing blood donor selection criteria in Canada. Transfusion 2022;62(12):2555–67. DOI PubMed

18. World Health Organization. Regional Office for the Eastern Mediterranean. Introduction to HIV/AIDS and sexually transmitted infection surveillance. Module 4. Introduction to respondent-driven sampling. Cairo (EG): WHO-EM; 2013. https://applications.emro.who.int/dsaf/EMRPUB_2013_EN_1539.pdf

19. Sonnenberg P, Ison CA, Clifton S, Field N, Tanton C, Soldan K, Beddows S, Alexander S, Khanom R, Saunders P, Copas AJ, Wellings K, Mercer CH, Johnson AM. Epidemiology of Mycoplasma genitalium in British men and women aged 16–44 years: evidence from the third National Survey of Sexual Attitudes and Lifestyles (Natsal-3). Int J Epidemiol 2015;44(6):1982–94. DOI PubMed

20. Manhart LE, Holmes KK, Hughes JP, Houston LS, Totten PA. Mycoplasma genitalium among young adults in the United States: an emerging sexually transmitted infection. Am J Public Health 2007;97(6):1118–25. DOI PubMed

21. Volz E, Heckathorn DD. Probability Based Estimation Theory for Respondent Driven Sampling. J Off Stat 2008;24(1):79–97. https://www.scb.se/contentassets/ca21efb41fee47d293bbee5bf7be7fb3/probability-based-estimation-theory-for-respondent-driven-sampling.pdf

22. Robins JM, Rotnitzky A, Zhao LP. Analysis of Semiparametric Regression Models for Repeated Outcomes in the Presence of Missing Data. J Am Stat Assoc 1995;90(429):106–21. DOI

23. Austin PC. Variance estimation when using inverse probability of treatment weighting (IPTW) with survival analysis. Stat Med 2016;35(30):5642–55. DOI PubMed

24. Read TR, Murray GL, Danielewski JA, Fairley CK, Doyle M, Worthington K, Su J, Mokany E, Tan LT, Lee D, Vodstrcil LA, Chow EP, Garland SM, Chen MY, Bradshaw CS. Symptoms, Sites, and Significance of Mycoplasma genitalium in Men Who Have Sex with Men. Emerg Infect Dis 2019;25(4):719–27. DOI PubMed

25. Couldwell DL, Jalocon D, Power M, Jeoffreys NJ, Chen SC, Lewis DA. Mycoplasma genitalium: high prevalence of resistance to macrolides and frequent anorectal infection in men who have sex with men in western Sydney. Sex Transm Infect 2018;94(6):406–10. DOI PubMed

26. Munson E, Morgan E, Sienkiewicz L, Thomas Y, Buehler K, Ryan D, Clifford A, Mustanski B. Molecular screening in a longitudinal cohort of young men who have sex with men and young transgender women: associations with focus on the emerging sexually transmitted pathogen Mycoplasma genitalium. Sex Transm Infect 2021;97(6):434–40. DOI PubMed

27. Getman D, Jiang A, O'Donnell M, Cohen S. Mycoplasma genitalium Prevalence, Coinfection, and Macrolide Antibiotic Resistance Frequency in a Multicenter Clinical Study Cohort in the United States. J Clin Microbiol 2016;54(9):2278–83. DOI PubMed

28. Bachmann LH, Kirkcaldy RD, Geisler WM, Wiesenfeld HC, Manhart LE, Taylor SN, Seña AC, McNeil CJ, Newman L, Myler N, Fuchs R, Bowden KE; MAGNUM Laboratory Working Group. Prevalence of Mycoplasma genitalium Infection, Antimicrobial Resistance Mutations, and Symptom Resolution Following Treatment of Urethritis. Clin Infect Dis 2020;71(10):e624–32. DOI PubMed

29. Andersen B, Sokolowski I, Østergaard L, Kjølseth Møller J, Olesen F, Jensen JS. Mycoplasma genitalium: prevalence and behavioural risk factors in the general population. Sex Transm Infect 2007;83(3):237–41. DOI PubMed

30. Torrone EA, Kruszon-Moran D, Philips C, Morris MR, Bowden KE, Papp J, Bachmann LH, Weinstock H, Kersh EN. Prevalence of Urogenital Mycoplasma genitalium Infection, United States, 2017 to 2018. Sex Transm Dis 2021;48(11):e160–2. DOI PubMed

31. Soni S, Alexander S, Verlander N, Saunders P, Richardson D, Fisher M, Ison C. The prevalence of urethral and rectal Mycoplasma genitalium and its associations in men who have sex with men attending a genitourinary medicine clinic. Sex Transm Infect 2010;86(1):21–4. DOI PubMed

32. Napierala Mavedzenge S, Weiss HA. Association of Mycoplasma genitalium and HIV infection: a systematic review and meta-analysis. AIDS 2009;23(5):611–20. DOI PubMed

33. Zhao N, Li KT, Gao YY, Xu JJ, Huang DS. Mycoplasma Genitalium and Mycoplasma Hominis are prevalent and correlated with HIV risk in MSM: a cross-sectional study in Shenyang, China. BMC Infect Dis 2019;19(1):494. DOI PubMed

34. Murray GL, Bodiyabadu K, Danielewski J, Garland SM, Machalek DA, Fairley CK, Jensen JS, Williamson DA, Tan LY, Mokany E, Durukan D, Bradshaw CS. Moxifloxacin and sitafloxacin treatment failure in Mycoplasma genitalium infection: association with parC mutation G248T (S83I) and concurrent gyrA mutations. J Infect Dis 2020;221(6):1017–24. DOI PubMed

35. Bissessor M, Tabrizi SN, Twin J, Abdo H, Fairley CK, Chen MY, Vodstrcil LA, Jensen JS, Hocking JS, Garland SM, Bradshaw CS. Macrolide resistance and azithromycin failure in a Mycoplasma genitalium-infected cohort and response of azithromycin failures to alternative antibiotic regimens. Clin Infect Dis 2015;60(8):1228–36. DOI PubMed

36. Guiraud J, Helary M, Le Roy C, Elguero E, Pereyre S, Bébéar C. Molecular Typing Reveals Distinct Mycoplasma genitalium Transmission Networks among a Cohort of Men Who Have Sex with Men and a Cohort of Women in France. Microorganisms 2022;10(8):1587. DOI PubMed

37. Guiraud J, Lounnas M, Boissière A, Le Roy C, Elguero E, Banuls AL, Bébéar C, Godreuil S, Pereyre S. Lower mgpB diversity in macrolide-resistant Mycoplasma genitalium infecting men visiting two sexually transmitted infection clinics in Montpellier, France. J Antimicrob Chemother 2021;76(1):43–7. DOI PubMed

38. Horner P, Ingle SM, Garrett F, Blee K, Kong F, Muir P, Moi H. Which azithromycin regimen should be used for treating Mycoplasma genitalium? A meta-analysis. Sex Transm Infect 2018;94(1):14–20. DOI PubMed

39. Lau A, Bradshaw CS, Lewis D, Fairley CK, Chen MY, Kong FY, Hocking JS. The Efficacy of Azithromycin for the Treatment of Genital Mycoplasma genitalium: A Systematic Review and Meta-analysis. Clin Infect Dis 2015;61(9):1389–99. DOI PubMed

40. Read TR, Fairley CK, Tabrizi SN, Bissessor M, Vodstrcil L, Chow EP, Grant M, Danielewski J, Garland SM, Hocking JS, Chen MY, Bradshaw CS. Azithromycin 1.5g Over 5 Days Compared to 1g Single Dose in Urethral Mycoplasma genitalium: Impact on Treatment Outcome and Resistance. Clin Infect Dis 2017;64(3):250–6. DOI PubMed

41. Dionne-Odom J, Geisler WM, Aaron KJ, Waites KB, Westfall AO, Van Der Pol B, Xiao L. High Prevalence of Multidrug-Resistant Mycoplasma genitalium in Human Immunodeficiency Virus-Infected Men Who Have Sex With Men in Alabama. Clin Infect Dis 2018;66(5):796–8. DOI PubMed

42. Jensen JS, Cusini M, Gomberg M, Moi H, Wilson J, Unemo M. 2021 European guideline on the management of Mycoplasma genitalium infections. J Eur Acad Dermatol Venereol 2022;36(5):641–50. DOI PubMed

43. Soni S, Horner P, Rayment M, Pinto-Sander N, Naous N, Parkhouse A, Bancroft D, Patterson C, Fifer H. British Association for Sexual Health and HIV national guideline for the management of infection with Mycoplasma genitalium (2018). Int J STD AIDS 2019;30(10):938–50. DOI PubMed

44. Australasian Society for HIV, Viral Hepatitis and Sexual Health Medicine. Australian STI Management Guidelines For Use in Primary Care. Mycoplasma genitalium. Sydney (AU): ASHM; 2021. [Accessed 2023 Apr 28]. https://sti.guidelines.org.au/sexually-transmissible-infections/mycoplasma-genitalium/

45. Public Health Agency of Canada. Mycoplasma Genitalium guide: Key information and resources. Ottawa, ON: PHAC; 2021. [Accessed 2022 May 22]. https://www.canada.ca/en/public-health/services/infectious-diseases/sexual-health-sexually-transmitted-infections/canadian-guidelines/mycoplasma-genitalium.html

46. Read TR, Jensen JS, Fairley CK, Grant M, Danielewski JA, Su J, Murray GL, Chow EP, Worthington K, Garland SM, Tabrizi SN, Bradshaw CS. Use of Pristinamycin for Macrolide-Resistant Mycoplasma genitalium Infection. Emerg Infect Dis 2018;24(2):328–35. DOI PubMed

47. Read TR, Fairley CK, Murray GL, Jensen JS, Danielewski J, Worthington K, Doyle M, Mokany E, Tan L, Chow EP, Garland SM, Bradshaw CS. Outcomes of Resistance-guided Sequential Treatment of Mycoplasma genitalium Infections: A Prospective Evaluation. Clin Infect Dis 2019;68(4):554–60. DOI PubMed

48. Durukan D, Doyle M, Murray G, Bodiyabadu K, Vodstrcil L, Chow EP, Jensen JS, Fairley CK, Aguirre I, Bradshaw CS. Doxycycline and Sitafloxacin Combination Therapy for Treating Highly Resistant Mycoplasma genitalium. Emerg Infect Dis 2020;26(8):1870–4. DOI PubMed

49. Manhart LE, Geisler WM, Bradshaw CS, Jensen JS, Martin DH. Weighing Potential Benefits and Harms of Mycoplasma genitalium Testing and Treatment Approaches. Emerg Infect Dis 2022;28(8):e220094. DOI PubMed

50. Health Canada. Health Canada's special access programs: Request a drug. Ottawa, ON: HC; 2022. https://www.canada.ca/en/health-canada/services/drugs-health-products/special-access/drugs.html

51. Le Roy C, Bébéar C, Pereyre S. Performance of Three Commercial Molecular Diagnostic Assays for the Simultaneous Detection of Mycoplasma genitalium and Macrolide Resistance. J Clin Microbiol 2021;59(6):e00020–1. DOI PubMed

52. Tapsall J, Surveillance WH, Team C. Antimicrobial resistance in Neisseria gonorrhoeae. World Health Organization 2001. A background document for the WHO global strategy for containment of antimicrobial resistance. https://iris.who.int/handle/10665/66963