Identification of novel microbes associated with pelvic inflammatory disease and infertility

Catherine L Haggerty,1,2 Patricia A Totten,3 Gong Tang,1 Sabina G Astete,2 Michael J Ferris,4 Johana Norori,4 Debra C Bass,1 David H Martin,5 Brandie D Taylor,1 Roberta B Ness6

ABSTRACT

Objectives As pelvic inflammatory disease (PID) aetiology is not completely understood, we examined the relationship between select novel bacteria, PID and long-term sequelae.

Methods Fastidious bacterial vaginosis (BV)-associated bacteria (Sneathia (Lepotrichia) sangeinogens, Sneathia amnionii, Atopobium vaginae and BV-associated bacteria 1 (BVAB1)), as well as Ureaplasma urealyticum and Ureaplasma parvum were identified in cervical and endometrial specimens using organism-specific PCR assays among 545 women enrolled in the PID Evaluation and Clinical Health study. Risk ratios and 95% CIs were constructed to determine associations between bacteria, histologically confirmed endometritis, recurrent PID and infertility, adjusting for age, race, gonorrhea and chlamydia. Infertility models were additionally adjusted for baseline infertility.

Results Persistent detection of BV-associated bacteria was common (range 58% for A. vaginae to 82% for BVAB1) and elevated the risk for persistent endometritis (RRadj 8.5, 95% CI 1.6 to 44.6) 30 days post-cefoxitin/doxycycline treatment, independent of gonorrhea and chlamydia. In models adjusted for gonorrhea and chlamydia, endometrial BV-associated bacteria were associated with recurrent PID (RRadj 4.7, 95% CI 1.7 to 12.8), and women who tested positive in the cervix and/or endometrium were more likely to develop infertility (RRadj 3.4, 95% CI 1.1 to 10.4). Associations between ureaplasmas and PID sequelae were modest.

Conclusions To our knowledge, this is the first prospective study to demonstrate that S. sangeinogens, S. amnionii, BVAB1 and A. vaginae are associated with PID, failure of the Centers for Disease Control and Prevention-recommended treatment to eliminate short-term endometritis, recurrent PID and infertility. Optimal antibiotic regimens for PID may require coverage of novel BV-associated microbes.

INTRODUCTION

Pelvic inflammatory disease (PID), infection and inflammation of the uterine lining (endometritis) and fallopian tubes (salpingitis), is a frequent condition among young women that often results in tubal factor infertility, chronic pelvic pain and recurrent PID.1 Tubal factors account for approximately a quarter of infertility with a significant proportion linked to prior PID.2 A primary treatment option is in vitro fertilisation, which is costly and results in lower birth rates than among women with other forms of infertility, particularly if hydro-salpinx is present.3

Although PID is a recognised complication of Chlamydia trachomatis and Neisseria gonorrhoeae infections,4,5 the aetiology of up to 70% of cases is unknown. One clue about the trigger for nongonococcal/non-chlamydial cases is the association between PID and bacterial vaginosis (BV), a condition marked by vaginal overgrowth of anaerobic bacterial species.6 Anaerobic Gram-negative rods, frequently present in BV flora, have been cultured from the upper genital tract in women with PID.7 Recent application of culture-independent broad-range PCR and bacterial 16S rRNA gene sequencing has identified specific, novel bacterial species in BV8 Gram-negative anaerobes Sneathia (Lepotrichia) sangeinogens/amnionii have been linked in case reports to postpartum fever,9 endometritis,10 tuboovarian abscesses,11,12 amnionitis and preterm labour.11 The Gram-positive anaerobe Atopobium vaginae has been associated with tuboovarian abscesses, tubal factor infertility,12 endometritis13 and fetal death.14 Totten et al identified bacterial 16S sequences in the fallopian tubes of 24% of women with salpingitis but in none of controls,15 including phylotypes closely related to Sneathia and A. vaginae.

Emerging evidence implicates Mycoplasma genitalium as a significant aetiological agent of PID,16,17 yet less is known about the role of other mollicutes, including ureaplasmas, in PID. Undifferentiated Ureaplasma spp have been cross-sectionally associated with PID and infertility,18 although not consistently.6 Recently, the two biovars of Ureaplasma urealyticum have been classified as separate species:19 U. urealyticum, which has been associated with urethritis in men and Ureaplasma parvum that has not.20

As there have been no prospective studies examining the role of recently identified fastidious BV-associated bacteria or the newly differentiated ureaplasma species in PID or its sequelae, we examined the relationships among the BV-associated bacteria S. sangeinogens, S. amnionii, A. vaginae, BVAB1, as well as U. urealyticum and U. parvum, and the outcomes of histologically confirmed endometritis, post-treatment endometritis, recurrent PID, infertility and chronic pelvic pain in a cohort of women with PID followed for a mean of 7 years.
Materials and methods

Patient population
Women who participated in the PID Evaluation and Clinical Health (PEACH) study and had archived cervical and endometrial specimens were studied. The PEACH study methods have been described in detail elsewhere. Briefly, 831 women aged 14–37 years with clinically suspected PID (pelvic pain <30 days duration, pelvic organ tenderness and leucorrhoea, mucopurulent cervicitis or untreated cervicitis) were recruited between March 1996 and February 1999 from emergency departments, OB/GYN clinics, STD clinics and private practices at 13 US clinical sites and randomised to inpatient or outpatient cefoxitin and doxycycline treatment.

Endometrial biopsies and microbiological studies
At baseline and 30 days, an endometrial biopsy was obtained for histology, chlamydial PCR (Roche Diagnostics), M. genitalium PCR and gonococcal culture. A modification of the criteria proposed by Kiviat et al. was used to diagnose endometritis, defined by at least five neutrophils in the endometrial surface epithelium in the absence of menstrual endometrium and/or at least two plasma cells in the endometrial stroma. Cervical swabs were used for N. gonorrhoeae culture and C. trachomatis and M. genitalium PCR.

For this subset, previously frozen endometrial biopsy (N=609) and cervical swab (N=691) specimens stored in −80°C freezers were thawed, purified using the MasterPure DNA purification kit for patient specimens (Epicentre) and tested by species-specific PCR assays. The preservation of bacterial DNA suitable for PCR analysis of specimens stored long term under these conditions has been previously demonstrated. Specimens and endometrial histology were available from 545 women, with occasional missing assessments of specific bacterium. PCR assays for S. sanguinegens/amnionii, A. vaginae, and BVAB1 were performed as previously described,21 22 and the U. urealyticum and U. parvum assays were performed using a modification of the procedure of Xiao et al. Separate tests were performed for each species and contained 1× PCR buffer (Mg++ free, Promega), 5 mM MgCl2, 5U Taq DNA polymerase; 200 μM of each of the four dNTPs, and the primers described by Xiao et al. (0.2 and 0.3 μM for the forward primers of U. urealyticum and U. parvum, respectively, and 0.5 μM for both reverse primers) and 2 μL of purified patient specimen in a total volume of 100 μL. PCR was performed in the Viia7 real-time PCR system (Applied Biosystems) under amplification conditions of: initial denaturation (95°C for 10 min) and the following cycling programme (40 cycles): denaturation: 95°C for 15 s, annealing at 55°C for 50 s and extension at 72°C for 45 s, final elongation at 72°C for 10 min, and a final soak set at 4°C indefinitely. U. urealyticum and U. parvum PCR assay specificities were confirmed by detection of the appropriate sized PCR product (152 bp for U. urealyticum and U. parvum) on agarose gels and reactivity with the U. urealyticum biotin labelled U127#1 probe (5′-biotin-ACACCGATTGATGATGAAATCATACTACAA-3′)23 and U. parvum UP063#1 probe (5′-biotin-CCCCATTTCAGCCATGGTGGCATTCA-3′) on Southern blots hybridised at 58°C and 60°C, respectively, then visualised on Kodak BioMax XAR film after reaction in the chemiluminescence assay using the ECL kit (Amerham). Inhibition testing was performed using the M. genitalium internal control assay24 on every 10th specimen negative for all assays; no inhibition was detected.

Follow-up
Participants were monitored with in-person visits at 5 and 30 days and telephone interviews every 3–4 months until June 2004, at which point we had follow-up information for 541 women, representing a mean follow-up of 84 months. Infertility was defined when a sexually active woman with at least 12 months of follow-up did not report conception (positive urine or blood test or doctor’s diagnosis) despite rare or no use of a contraceptive method. Chronic pelvic pain was defined as pain reported during at least two consecutive interviews, suggesting a minimum of 6 months duration. Recurrent PID was self-reported and confirmed in 76% of medical records. Since few women experienced an ectopic pregnancy (N=6), we did not include as an outcome.

Statistical methods
In our primary analysis, cross-sectional associations between bacteria and endometritis were determined using logistic regression models, adjusted for age and race. Logistic regression was used to construct relative risks and 95% CIs between each bacterium and endometritis at 30 days, recurrent PID, infertility and chronic pelvic pain, and included age, and race as explanatory variables. Models predicting infertility and post-treatment endometritis were adjusted for age, race, gonorrhoea, chlamydia, self-reported infertility at baseline and self-reported partner treatment, respectively. In exploratory analyses, all the above models were additionally analysed in a subset of women negative for both chlamydia and gonorrhoea (see web appendix). Subsequent exploratory models included terms representing interactions between BV-associated bacteria and chlamydia/gonorrhoea. Analyses were conducted first using both cervical and endometrial PCR results combined and were then repeated using only endometrial PCR. SPSS V20.0 for Windows was used for statistical comparisons.

Results
S. sanguinegens (54%), S. amnionii (66%), A. vaginae (83%), BVAB1 (65%), U. urealyticum (30%) and U. parvum (58%) were commonly isolated from the cervix and/or endometrium. As expected, S. sanguinegens, S. amnionii, A. vaginae and BVAB1 were significantly associated with BV determined by Nugent’s27 and Amseel’s28 criteria (p<0.0001 for all comparisons). Cervical identification was strongly associated with endometrial identification, suggesting lower to upper genital tract ascension (S. sanguinegens: OR 9.6, 5.8–15.9; S. amnionii: OR 12.1, 7.8–19.0; A. vaginae: OR 4.3, 2.8–6.7; BVAB1: OR 2.8, 2.0–4.1; U. urealyticum: OR 20.3,9.5–43.0; U. parvum: OR 13.1, 6.7–25.8). Women testing positive for each of these bacteria in the cervix were significantly more likely to test positive for each of the other bacteria (p<0.05 for all comparisons) with the exception of U. parvum, which was not associated with any other bacterium. Similarly, endometrial identification of each bacteria was linked to endometrial detection of the other bacteria (p<0.05 for all comparisons). The exception was BVAB1, which was not associated with ureaplasmal bacteria. S. sanguinegens and S. amnionii, two closely related Gram-negative anaerobes, co-occurred in the endometrium in 97% of samples testing positive for S. sanguinegens and in 52% of samples testing positive for S. amnionii. As S. sanguinegens, S. amnionii, A. vaginae and BVAB1 thus constituted a microbial community (as previously reported among women with BV)29 we termed them ‘fastidious BV-associated bacteria’ and grouped them together in remaining analyses.

Women testing positive versus negative for any or all four fastidious BV-associated bacteria in the endometrium at baseline were at significantly elevated risk for endometritis (table 1). Cervical and/or endometrial fastidious BV-associated bacteria...
Ureaplasma urealyticum further elevated risk of persistent endometritis. Endometrial endometritis was strongly linked to endometrial re-detection of with persistent endometritis. In comparison, continuance of positive baseline tests remaining positive at the 30-day visit. In the Centers for Disease Control and Prevention persistence 30 days post-treatment befell 43% of women despite receipt of the CDC-recommended cefoxitin and doxycycline. Persistent bacterial detection after cefoxitin and doxycycline was common, with 46% of women with S. amnionii, 55% with S. amnionii, 82% with BVAB1, 58% with A. vaginae, 46% with U. urealyticum and 49% with U. parvum-positive baseline tests remaining positive at the 30-day visit. In comparison, continue of N. gonorrhoeae and C. trachomatis occurred among only 8% and 10% of the cohort. Endometritis persistence 30 days post-treatment befell 43% of women despite receipt of the Centers for Disease Control and Prevention (CDC)-recommended cefoxitin and doxycycline. Persistent endometritis was strongly linked to endometrial re-detection of the combined fastidious BV-associated bacteria (table 2, RRadj 5.7, 95% CI 1.4 to 23.3). This relationship remained significant after excluding women with gonorrhoea and chlamydia (see online supplementary table S2, RRadj 8.5, 95% CI 1.6 to 44.6). Women who tested positive for both fastidious BV-associated bacteria and chlamydia and/or gonorrhoea did not have a further elevated risk of persistent endometritis. Endometrial U. urealyticum and U. parvum were associated, albeit marginally, with persistent endometritis.

Table 1 Associations between selected fastidious bacterial vaginosis-associated bacteria (BVAB*), ureaplasmal bacteria and histologically confirmed endometritis

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Endometritis+ n=258</th>
<th>Endometritis− n=287</th>
<th>Adjusted OR† (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVAB* (1 or more +)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>233/258 (90.3)</td>
<td>250/287 (87.1)</td>
<td>1.1 (0.6 to 2.0)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>183/247 (74.1)</td>
<td>166/270 (61.5)</td>
<td>1.6 (1.1 to 2.4)</td>
</tr>
<tr>
<td>BVAB* (all +)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>93/118 (78.8)</td>
<td>81/118 (68.6)</td>
<td>1.3 (0.7 to 2.6)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>27/93 (29.0)</td>
<td>18/129 (14.0)</td>
<td>2.0 (1.0 to 4.0)</td>
</tr>
<tr>
<td>Ureaplasma urealyticum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>75/247 (30.4)</td>
<td>70/271 (25.8)</td>
<td>1.2 (0.8 to 1.8)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>24/254 (9.4)</td>
<td>22/281 (7.8)</td>
<td>1.2 (0.6 to 2.2)</td>
</tr>
<tr>
<td>Ureaplasma parvum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>128/252 (50.8)</td>
<td>164/276 (59.4)</td>
<td>0.7 (0.5 to 1.0)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>47/254 (18.5)</td>
<td>49/281 (17.4)</td>
<td>1.1 (0.7 to 1.7)</td>
</tr>
</tbody>
</table>

* Sneathia sanguinegens, Sneathia amnionii, Atoxoplasm vagina and BVAB1. Comparison group consists of women who tested negative for all four bacteria. In model of ‘all positive’, women testing positive for some but not all bacteria are excluded.
† Adjusted for body mass index and self-reported partner treatment.
‡ Adjusted for age and race.

Table 2 Associations between selected fastidious bacterial vaginosis-associated bacteria (BVAB*), ureaplasmal bacteria and histologically confirmed endometritis 30 days following treatment for pelvic inflammatory disease

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Endometritis+ n=175</th>
<th>Endometritis− n=238</th>
<th>Adjusted RR† (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVAB (1 or more +)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>149/175 (85.1)</td>
<td>199/238 (83.6)</td>
<td>1.1 (0.6 to 2.2)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>111/169 (65.7)</td>
<td>140/234 (59.8)</td>
<td>1.2 (0.7 to 2.0)</td>
</tr>
<tr>
<td>BVAB (all positive)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>37/63 (58.7)</td>
<td>32/71 (45.1)</td>
<td>2.3 (0.9 to 5.9)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>11/69 (15.9)</td>
<td>5/99 (5.1)</td>
<td>5.7 (1.4 to 23.3)</td>
</tr>
<tr>
<td>Ureaplasma urealyticum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>40/167 (24.0)</td>
<td>49/231 (21.2)</td>
<td>1.0 (0.5 to 1.7)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>15/170 (8.8)</td>
<td>11/235 (4.7)</td>
<td>1.7 (0.6 to 4.3)</td>
</tr>
<tr>
<td>Ureaplasma parvum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cervix and/or endometrium</td>
<td>69/169 (40.8)</td>
<td>70/234 (29.9)</td>
<td>1.9 (1.2 to 3.2)</td>
</tr>
<tr>
<td>Endometrium</td>
<td>27/170 (15.9)</td>
<td>31/235 (13.2)</td>
<td>2.0 (1.0 to 3.9)</td>
</tr>
</tbody>
</table>

* Sneathia sanguinegens, Sneathia amnionii, Atoxoplasm vagina and BVAB1. Comparison group consists of women who tested negative for all four bacteria. In model of ‘all positive’, women testing positive for some but not all bacteria are excluded.
† Adjusted for age, race and self-reported partner treatment.

and chlamydia and/or gonorrhoea were highly correlated (p<0.001), with 36% of women testing positive for both. In a subset of women testing negative for chlamydia and gonorrhoea, results were attenuated and no models were statistically significant (see online supplementary table S1). However, the OR for endometritis associated with at least two fastidious BV-associated bacteria was significantly higher in women testing positive for chlamydia and/or gonorrhoea than that in women testing negative (ORadj 3.6, 95% CI 1.4 to 9.2). The relationship between a positive test for all four BV-associated bacteria and endometritis was significant after adjustment for M. genitalium (ORadj 5.1, 95% CI 1.2 to 21.7). U. urealyticum and U. parvum were not significantly associated with endometritis.

Persistent bacterial detection after cefoxitin and doxycycline treatment was common, with 46% of women with S. sanguinegens, 55% with S. amnionii, 82% with BVAB1, 58% with A. vaginae, 46% with U. urealyticum and 49% with U. parvum-positive baseline tests remaining positive at the 30-day visit. In comparison, continue of N. gonorrhoeae and C. trachomatis occurred among only 8% and 10% of the cohort. Endometritis persistence 30 days post-treatment befell 43% of women despite receipt of the Centers for Disease Control and Prevention (CDC)-recommended cefoxitin and doxycycline. Persistent endometritis was strongly linked to endometrial re-detection of the combined fastidious BV-associated bacteria (table 2, RRadj 5.7, 95% CI 1.4 to 23.3). This relationship remained significant after excluding women with gonorrhoea and chlamydia (see online supplementary table S2, RRadj 8.5, 95% CI 1.6 to 44.6). Women who tested positive for both fastidious BV-associated bacteria and chlamydia and/or gonorrhoea did not have a further elevated risk of persistent endometritis. Endometrial U. urealyticum and U. parvum were associated, albeit marginally, with persistent endometritis.

Long-term sequelae rates in the cohort were high among women testing positive for fastidious BV-associated bacteria (table 3). Endometrial detection of all four fastidious BV-associated bacteria was associated with recurrent PID. Similarly, detection of all BV-associated bacteria was significantly predictive of recurrent PID in subsets of women who tested negative for chlamydia and gonorrhoea (see online supplementary table S3, RRadj 4.7, 95% CI 1.7 to 12.8). Detection of all four fastidious BV-associated bacteria in the cervix and/or endometrium was also associated with subsequent infertility, although risks were attenuated when these microbes were identified only in the endometrium. Similarly, women testing positive for all BV-associated bacteria were significantly more likely to develop infertility in subsets of women without gonorrhoea or chlamydia (see online supplementary table S3, RRadj 3.4, 95% CI 1.1 to 10.4). In contrast to these novel bacteria, women with chlamydial infection had a marginal elevation in infertility risk (RRadj 1.9, 95% CI 0.9 to 4.2) and those with gonococcal infection had no increased infertility risk (RRadj 1.1, 95% CI 0.6 to 2.2). Neither U. urealyticum nor U. parvum were consistently associated with long-term morbidity.

**DISCUSSION**

In our study of 545 women with clinically suspected PID, women who tested positive for S. sanguinegens, S. amnionii, A. vaginae or BVAB1 were more likely to have endometritis at PID diagnosis and experience recurrent PID and subsequent infertility. Women who tested positive for all four BV-associated bacteria in the endometrium had a twofold increased likelihood of having histologically confirmed endometritis, were nearly six times as likely to experience persistent endometritis after PID treatment and were four times as likely to have recurrent PID.
Further, women who tested positive for all four BVAB in the cervix and/or endometrium were nearly four times as likely to experience subsequent infertility.

To our knowledge, this is the first cohort study to show that molecularly identified BV-associated bacteria are associated with PID and its sequelae. Results are consistent with our prior culture study demonstrating that anaerobic black-pigmented pathogens to develop recurrent PID.

Atopobium vaginae has been reported to be susceptible to cefoxitin.12 Although it was often identified 30 days post-treatment in our study, it was not associated with persistent endometritis. The high rates of persistence were predictable, as ureaplasmas have been shown to express tetracycline resistance2 and contain tetM genes that encode such resistance.2

Women testing positive for fastidious BV-associated bacteria at PID diagnosis were nearly four times as likely to develop subsequent infertility, even after adjustment for confounders. Our results extend previous culture studies demonstrating that BV categorised by Gram stain is associated with tubal infertility among women undergoing in vitro fertilisation.

<table>
<thead>
<tr>
<th>Table 3 Long-term sequelae following pelvic inflammatory disease (PID) with selected fastidious bacterial vaginosis–associated bacteria (BVAB)* and ureaplasmal bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical and/or endometrial BVAB 1 or more+ N=629 <strong>n (%)</strong></td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Recurrent PID 126 (21.1)</td>
</tr>
<tr>
<td>Infertility 117 (18.9)</td>
</tr>
<tr>
<td>Chronic pelvic pain 254 (42.0)</td>
</tr>
</tbody>
</table>

**Adjusted RR** refers to the adjusted relative risk. All models are adjusted for age and race. Infertility model additionally adjusted for self-reported infertility at baseline. 

*Leptotrichia amnionii, Sneathia amnionii, Atopobium vaginae, and BVAB1. Comparison group consists of women who tested negative for all four bacteria. In model of all positive, women testing positive for some but not all bacteria are excluded.

†All models are adjusted for age and race. Infertility model additionally adjusted for self-reported infertility at baseline.
 Major strengths of our study are the prospective design and the characterisation of specific BV-associated microorganisms. As our study is limited to four selected BV-associated bacteria measured using targeted qualitative PCR, further research examining concentrations of a broader phylogenetic range of BV-associated microbes among PID and infertility patients using high-throughput sequencing and quantitative real-time PCR assays is warranted. Further, it is possible that transvaginal sampling of the endometrium may have resulted in contamination of endometrial biopsy specimens by vaginal or cervical microorganisms. However, as possible contamination would not be expected to differ by the study outcomes, it is unlikely to be a major source of bias. Further, associations between cervical PCR and outcomes should be unaffected. Lastly, our study is limited by the lack of a truly unaffected control group of women. All women enrolled in the PEACH study had clinically suspected PID. Thus, our comparison groups of women with negative PCR comprised women who presented with characteristics consistent with PID. This may have biased our findings towards the null.

Our results must be confirmed in other prospective studies as they highlight the concerning possibility that currently recommended antibiotics do not treat a range of BV-associated organisms associated with PID sequelae. Our findings highlight the need for commercially available and affordable multiplex PCR-based genital tract microorganism tests of BV-associated bacteria for incorporation in screening and treatment programmes to prevent PID. Such tests could also be included in standard work-up of PID to determine microbiological aetiology and allow clinicians to tailor patient treatment. For example, as our study found that A. vaginae persisted post-cefoxitin therapy, other CDC-recommended PID antibiotics active against A. vaginae such as clindamycin or ampicillin/sulbactam might be used. Recent evidence suggests that the broad spectrum antibiotic nifurtimox is effective against C. trachomatis and Mycoplasma spp. as well as G. vaginalis and A. vaginae, without affecting lactobacilli. However, no clinical trials of nifurtimox for PID treatment have been conducted to date. The CDC treatment guidelines suggest optional metronidazole inclusion for additional anaerobic coverage. However, as A. vaginae and Sneathia spp. have been shown to be metronidazole resistant in some studies, clinical trials including metronidazole with other antimicrobials for mitigating short-term and long-term PID sequelae are needed.

We previously reported that C. trachomatis and N. gonorrhoeae are associated with endometritis in this cohort. We now demonstrate that fastidious BV-associated bacteria and chlamydia/gonorrhoea in combination elevates endometritis likelihood three-and-a-half-fold. As BV-associated bacteria and chlamydia/gonorrhoea were frequently co-present, and as the relationship between BV-associated bacteria and endometritis was identified primarily among women with chlamydia and/or gonococcal infection, this suggests that chlamydia/gonorrhoea may pave the way for anaerobic bacteria ascension into the upper genital tract where they can persist post-PID treatment and cause recurrent PID and infertility, as demonstrated in our study. Alternatively or in addition, it is possible that persistent anaerobic infection may increase the risk of recurrent chlamydial or gonococcal infection.

That infertility was only marginally associated with chlamydial PID and not associated with gonococcal PID suggests that, in contrast to older studies that strongly implicated these bacteria in infertility, women in our study received timely and effective antibiotics for these pathogens. Indeed, approximately 90% of our patients were free of gonorrhoea/chlamydia at the 30-day follow-up. Moreover, the combination of gonorrhoea/chlamydia plus fastidious BV-associated bacteria produced no additional degree of persistent endometritis and long-term PID sequelae beyond the effect from BV-associated bacteria alone.

Currently, the approach for PID treatment is empiric, using broad spectrum antibiotics to target a range of pathogens but largely directed towards eliminating *N. gonorrhoeae* and/or *C. trachomatis*. However, approximately 60% of women on our cohort had non-gonococcal, non-chlamydial PID. Fastidious BV-associated bacteria, commonly found in the endometrium at baseline, often persisted after CDC-recommended PID treatment as did endometritis. A sizeable proportion of women receiving timely, standard PID treatment may thus have ongoing upper genital tract inflammation as a result of continued infection with previously unrecognised pathogens. Such treatment failure appears to eventuate current PID and infertility among some women. Replication of our results would dictate that optimal diagnosis and treatment regimens for PID be re-evaluated.

**Key messages**

- Current pelvic inflammatory disease (PID) treatment regimens use broad spectrum antibiotics to target a range of pathogens, but largely directed towards eliminating *Neisseria gonorrhoeae* and/or *Chlamydia trachomatis*.
- Among women treated with cefoxitin and doxycycline, *Sneathia sanguinegens/amnionii*, bacterial vaginosis-associated bacteria 1 and *Atopobium vaginae* were associated with persistent endometritis, recurrent PID and infertility.
- Optimal antibiotic regimens for PID may require coverage for novel bacterial vaginosis-associated microbes.

**Handling editor** Jackie A Cassell

**Contributors** CLH was involved in the conception and design of the study, analysis and interpretation of data and wrote the paper. PAT was involved in the conception and design of the study, DNA extraction, PCR, analysis and interpretation of data and provided significant revisions. GT was involved in the conception and design of the study, analysis and interpretation of data, and provided significant revisions. SGA and JN were involved in the analysis and interpretation of data and samples and provided significant revisions. MIF was involved in the conception and design of the study, PCR, analysis and interpretation of data, and provided significant revisions. DCB was involved in the acquisition of data, analysis of data and provided significant revisions. DHM was involved with the conception and design of the study, interpretation of data and provided significant revisions. BDT was involved in interpretation of data, drafting part of the background and provided significant revisions. RBN was involved in the conception and design of this study and the parent PEACH study, interpretation of data and provided significant revisions. All authors provided final approval.

**Funding** This work was supported by the Agency for Healthcare Research and Quality Development (HS060805-05 to RBN) and from the National Institute of Allergy and Infectious Diseases at the National Institutes of Health (SR01AI073940 to CLH).

**Competing interests** None declared.

**Patient consent** No.

**Provenance and peer review** Not commissioned; externally peer reviewed.

**Ethics approval** University of Pittsburgh Institutional Review Board (IRB number: 0608052).
Epidemiology

Data sharing statement All data are stored at the University of Pittsburgh, Pittsburgh, PA, under the direction of Dr Catherine Haggerty (haggerty@pitt.edu). An outside individual wishing to access the data must collaborate with Dr Haggerty to do so. A written protocol must be submitted, reviewed and approved prior to initiation of any new projects. In order to ensure integrity of the data, all analyses are conducted at the University of Pittsburgh under the direction of Dr Catherine Haggerty.

Open Access This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/

REFERENCES


