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ORIGINAL PAPER

Frequency and Combination of Sequential Sexual Acts That May Lead to Sexually Transmitted Infections at Different Anatomic Sites Within the Same Person

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Abstract
Modeling studies suggest that transmission of gonorrhea and chlamydia to multiple anatomic sites within the same person is necessary to reproduce observed high rates of extragenital gonorrhea/chlamydia. Limited empiric behavioral data support this idea. In this cross-sectional study, we enrolled individuals assigned male at birth who reported sex with men (MSM) and denied receptive anal sex (RAS) in the past 2 years. Participants enrolled in-person at the Sexual Health Clinic in Seattle, Washington (December 2019–September 2021) or online (July 2021–September 2021), and completed a sexual history questionnaire that asked about specific sexual acts and sequence of those acts during their last sexual encounter. We enrolled 210 MSM during the 16-month recruiting period. The median number of sex acts reported at last sexual encounter was 4 (interquartile range 3–5). The most commonly reported acts at last sex were: kissing (83%), receiving oral sex (82%), and insertive anal sex (65%). There was substantial variability in the sequence of acts reported; no unique sequence of sex acts was reported by more than 12% of the population. Ninety percent of participants reported sequences of behaviors that could lead to gonorrhea or chlamydia transmission within the same person (respondent or partner); the most common of these combinations was kissing followed by receiving oral sex (64% reporting). Engaging in multiple sex acts within a single sexual encounter is common and may lead to gonorrhea/chlamydia transmission within the same person. This complicates empiric measurements of transmission probabilities needed to estimate population-level transmission.

Keywords Oral sex · Anal sex · Men who have sex with men · Infectious diseases transmission · Sexually transmitted infections

Introduction

The pharynx and rectum are common anatomic sites of infection for *Chlamydia trachomatis* (CT) and *Neisseria gonorrhoeae* (GC) (Centers for Disease Control & Prevention, 2019; Workowski et al., 2021). Accordingly, there is increasing interest in understanding the potential role of these extragenital sites of infection in sustained population-level CT and GC transmission, particularly in an era with record-high CT and GC rates (Centers for Disease Control & Prevention, 2019). However, transmission of CT and GC is difficult to measure, as individuals may engage in multiple sex acts during a single sexual encounter, which could result in transmission to multiple anatomic sites within the same person and to the other partner(s). Thus, quantifying how often extragenital infections lead to transmission requires a better understanding of the frequency and sequence of behaviors that may lead to CT/GC acquisition and transmission.

To date, most studies and surveys of sexual behavior have examined sexual behaviors as single sexual acts during a specific time period (e.g., participant has engaged in receptive oral sex in the past 2 months). These data are helpful to understand the prevalence of behaviors that may lead to STI acquisition and transmission. However, insofar as most individuals do not engage in just one sexual act during a given sexual encounter, these data do not allow us to fully

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understand CT and GC transmission that may occur between individuals or within the same person.

Recently, two mathematical models of men who have sex with men (MSM) that included "sequential sexual practices" (i.e., one sex act following another) found that transmission between multiple anatomic sites within a single sexual encounter are necessary to explain the high rates of CT and GC at more than one anatomic site (Xu et al., 2020, 2021). These models are critically important tools to help us understand the behavioral drivers of transmission and to inform how STI interventions may impact disease transmission. However, current models are lacking in empiric data on the frequency of different combinations of sex acts and on the most common sequence of behaviors. The goals of the present study were to describe the combination and sequence of sex acts during sexual encounters in order to inform studies of GC and CT transmission.

Method

Participants

This is a cross-sectional analysis which is a subset of a larger parent study ("Bottoms Up") that was designed to examine which behaviors other than receptive anal sex are associated with acquisition of rectal CT/GC. We began recruitment for Bottom's Up in December 2019; for this analysis, we used data from individuals who were enrolled through September 2021. Participants were eligible to enroll if they were at least 16 years old, were male sex at birth, reported sex with a man in the past 12 months, and did not report receptive anal sex in the past 2 years. These eligibility criteria were developed to be able to answer the parent study's primary research question.

Participants were recruited for the study through two mechanisms, in-person and online. In-person recruitment occurred at the Public Health—Seattle & King County Sexual Health Clinic in Seattle, Washington. We started in-person recruitment in December 2019, stopped recruiting in mid-March 2020 due to COVID-19 restrictions, and began recruiting again in October 2020 through September 2021. Study staff in the clinic approached patients about participating if they appeared to be eligible based on their responses to the clinic's routine clinical intake form, which queries patients on demographics and sexual history, among other topics. Study staff confirmed eligibility with the patient prior to informed consent. We started online recruitment in July 2021 and continued through September 2021. We recruited individuals from a geospatial social networking app and the social media platforms Facebook and Instagram, as well as third-party apps and website with which Facebook partners. We placed image-based study advertisements and text-based pop-up advertisements on these apps and sites, and we geotargeted the advertisements to residents of King, Pierce, and Snohomish Counties (the general catchment area of the Sexual Health Clinic) who reported being at least 18 years old. Upon clicking on the survey advertisement, individuals were taken to a survey landing page which described the purpose of the study. Individuals who chose to proceed were asked to complete a brief eligibility screener to ascertain their age, birth sex, residence, gender of sex partners in the past year, and history of receptive anal sex in the past 2 years. Eligible individuals were taken to an electronic consent page.

Measures and Procedure

There were two components to the study: completion of a survey (described below) and self-collection of a rectal specimen for CT/GC testing. The CT/GC test results are not relevant to the present analysis and are not discussed further. Participants were paid $25 for participating in the study. Study procedures were reviewed and approved by the University of Washington Institutional Review Board (IRB #00007226).

Enrolled participants were asked to complete a 10–20-min electronic survey (programmed into REDCap [Harris et al., 2009, 2019]) that queried participants about their sexual behavior history. Prior to implementing the survey, we conducted cognitive interviews with six patients from the Sexual Health Clinic to refine the survey. The goal of the interviews was to ensure the questions would be understood by the study population and were being answered as intended. We refined the survey questions after each interview in an iterative process. The definitions used in the survey are summarized in Table 1.

The present analysis focuses on one of the questions in the survey, which queried participants about the acts they engaged in the last time they had sex. The specific question was: "The last time you had sex, which of the following activities did you do? Check all that apply." The definitions to the behaviors had been previously provided in the survey (summarized in Table 1), but were re-iterated as shortened definitions within the response options. The next question presented a matrix with the behaviors that participants indicated they had engaged in the last time they had sex, and asked participants to indicate the order in which they engaged in the activities. These questions are included as Supplementary material.

Statistical Analyses

All analyses are descriptive. We report characteristics of the study population (Table 2) and the number and distribution of all sexual acts reported at the last sexual encounter (Table 3). We report the most common combinations of acts,

Table 1 Descriptions of sexual behaviors provided to participants within the study survey

Behavior	Explanation/description in survey
Deep kissing	This is also called "French kissing" and is when you touch tongues with another person while kissing, and there is saliva exchanged
Insertive oral sex (i.e., received oral sex)	This is when someone puts their mouth/tongue on your penis (i.e., gives you a blow job)
Receptive oral sex (i.e., gave oral sex)	This is when you put your mouth/tongue on a man's penis (i.e., give a man a blow job)
Insertive anal sex	This is also called topping and is when you put your penis in your partner's anus (butt)
Rimming someone	Rimming is when you put your mouth and/or tongue on someone's anus
Being rimmed	Being rimmed is when someone puts their mouths and/or tongue on your anus
Non-penetrative anal play (perianal play)	This is when your partner touches your anus with his penis without full penetration or when your partner's penis enters your anus a little bit but does not completely penetrate
Fingering	Being fingered in the anus is when someone puts their fingers on or in your anus. This is different than fisting, where someone puts their entire hand in your anus
Fisting	Being fisted is when someone puts their hand in your anus
Watersports	This is when someone urinates (pees) in your butt
Felching	This is when you suck semen out of someone's anus or vagina after ejaculation

stratified by number of acts during the last sexual encounter (Table 4). For example, for individuals who reported engaging in three acts at the time of their last sexual encounter, we list all three acts reported. In Table 4, we also report the most commons *sequence* of behaviors reported (far right column of Table 4). For this analysis of sequences, we only included unique behaviors in each sequence; thus, if an individual reported three acts (kissing, insertive oral sex, and insertive anal sex) but reported them in the sequence of kissing followed by insertive oral sex, followed by kissing, followed by insertive anal sex, we did not include the second act of kissing in the sequence and instead considered this to be kissing followed by insertive oral sex followed by insertive anal sex. For Tables 3 and 4, we included all behaviors, regardless of whether or not they could lead to transmission within the same person. In Fig. 1, we report the most common two-act sequences that could lead to GC or CT transmission within the same person (respondent or their partner), regardless of the total number of sex acts reported, in order to directly inform mathematical models of transmission. This analysis addresses the fact that some individuals may report the same sex act multiple times during a single sexual encounter, and allows individuals to be "counted" in the analysis multiple times. For example, if an individual reported kissing, followed by insertive oral sex, followed by kissing, followed by rimming, we considered that individual to have engaged in kissing followed insertive oral sex, insertive oral sex followed by rimming, and kissing followed by rimming.

Results

During the 16-month recruiting period, we enrolled a total of 210 participants, including 177 participants in-person and 33 participants online. About 30% of participants were less than 30 years old, nearly 20% self-reported their race as Black or African-American, and 97% identified as male gender (Table 2). Participants reported a median 4 sex partners in the past year.

The vast majority of participants (> 90%) reported more than one sex act during their last sexual encounter; the median number of sex acts reported was 4 (Table 2). The distribution of sexual behaviors at last sexual encounter is displayed in Table 3. Most participants reported kissing (83%), insertive oral sex (82%), receptive oral sex (63%), or insertive anal sex (65%) during their last sexual encounter. Rimming (receipt and giving) were the next most frequently reported behaviors, and were more often reported by individuals who engaged in at least three sex acts. Watersports and felching were not frequently reported, and fisting was not reported by any respondents.

There was substantial variability in the combination of behaviors reported (Table 4), with no single combination being reported by more than 12% of the study population. The two most common combinations of behaviors reported were: (1) kissing, insertive oral sex, and receptive oral sex, which was reported by 24 (11.4%) of 210 participants, of whom 79% reported those behaviors in that sequence; and (2) kissing, insertive oral sex, receptive oral sex, performing rimming, and insertive anal sex, which was reported by 23 (10.9%) of 210 participants, of whom 74% reported those behaviors in that sequence.

As described in the Method, we only included unique behaviors in each sequence (i.e., if someone reported a behavior twice, we only included it in the sequence the first time it was reported). Of the 84 individuals who reported sequences of acts in the order specified in Table 4 (sum of the numerators in the far-right column of Table 4 for those reporting at least 3 acts), 17% ($n = 14$) of individuals reported a behavior that was repeated in the sequence after first identification;

Table 2 Characteristics of study participants, $N = 210$

Characteristic	*N* (%)
Age	
16–24	22 (10.5)
25–29	42 (20.0)
30–34	51 (24.3)
35–44	47 (22.4)
≥44	48 (22.9)
Race/ethnicity	
American Indian/Alaska native	9 (4.3)
Asian	26 (12.4)
Black or African-American	39 (18.6)
Native Hawaiian, other Pacific islander	3 (1.4)
White	120 (57.1)
Unknown	13 (6.2)
Latinx ethnicity	48 (23.1)
Gender	
Female	1 (0.5)
Male	202 (96.7)
Non-binary/genderqueer	6 (2.9)
Highest level of education	
High school	66 (31.6)
Associate's degree	22 (10.5)
Bachelor's degree	85 (40.7)
Graduate or professional school	36 (17.2)
Number of sex partners in past 12 months, median (interquartile range)	4 (2–9)
Number of sexual acts reported at last sexual encounter	
1	18 (8.5)
2	22 (10.5)
3	55 (26.2)
4	42 (20.0)
5	42 (20.0)
6	19 (9.5)
7	10 (4.8)
8–9	2 (1.0)

for 10 of these 14, the behavior was kissing. For four, it was kissing plus another behavior. The order of the placement of the repeated behavior for these 14 individuals was unique to each person.

Overall, 189 (90%) of participants reported a sequence of sex acts at their last sexual encounter that could lead to GC or CT transmission within the same person (respondent or partner) (Fig. 1). The most commonly reported sequence of these behaviors was kissing followed by insertive oral sex (Fig. 1, Panel A), which was reported by 135 (64%) of 210 respondents (theoretical CT/GC transmission route: respondent's pharynx to partner's pharynx to respondent's urethra). Kissing followed by receptive oral sex (Fig. 1, Panel B; theoretical transmission route: partner's pharynx to respondent's pharynx to partner's urethra) and insertive oral sex followed by insertive anal sex (Fig. 1, Panel E; theoretical transmission route: partner's pharynx to respondent's urethra to partner's anus) were also commonly reported sequences, reported by 57% and 49% of the total population, respectively.

Discussion

In this cross-sectional study, we found that over 50% of participants reported at least four sex acts during their last sexual encounter, with the most commonly reported acts being kissing, insertive oral sex, receptive oral sex, and insertive anal sex. There was considerable variability in the combination of behaviors being reported; no single combination was reported by more than 12% of the population. Sequences of behaviors that could lead to GC or CT transmission within the same person were reported by 90% of study participants. Our findings lend support to recent modeling studies that have suggested that sequential sexual practices are necessary to replicate observed multi-site infections among MSM.

There have been a number of large studies—including population-based studies—that have measured the prevalence of sexual behaviors among MSM in the USA (Centers for Disease Control and Prevention, 2021; Sanchez et al., 2016; Wiatrek et al., 2021). However, most studies have asked about engagement in behaviors during a period of time, and not about combinations of behaviors or sequences of acts within a single sexual encounter. To our knowledge, the largest US study that has examined sex acts within a sexual encounter was a 2011 internet-based study by Rosenberger et al. (2011) that enrolled nearly 25,000 respondents. In that study, the majority of respondents reported between 5 and 9 sex acts at the last sexual encounter, and most men reported kissing (75%), insertive oral sex (73%), and receptive oral sex (75%). Likewise, we noted that the majority of participants reported at least four behaviors, and that kissing, insertive oral sex, and receptive oral sex were also the most commonly reported behaviors at 83%, 80%, and 63%, respectively. Notably, our study population—by design—excluded individuals who reported receptive anal sex in the past 2 years, whereas the Rosenberger et al. study did not. Despite these studies enrolling populations with different sexual behavior histories, the prevalence of reported behaviors was remarkably consistent across the two studies. Our study builds upon the findings of Rosenberger et al. by additionally providing information on the sequence of reported behaviors, which is more informative for measuring transmission than the combination alone.

The results of our study highlight the complexities of empirically measuring per-act CT and GC transmission probabilities, which are essential parameters to be able to understand disease transmission (Spicknall et al., 2019). We observed substantial variability in the combination of sex acts

Table 3 Distribution of sexual behaviors at last sexual encounter, by number of sex acts reported at last encounter, $N=210$*

Behavior	Total $N=210$ *N* (%)	2 acts $N=22$ *N* (%)	3 acts $N=55$ *N* (%)	4 acts $N=42$ *N* (%)	5 acts $N=42$ *N* (%)	>5 acts $N=31$ *N* (%)
Kissing	175 (83)	12 (55)	50 (91)	40 (95)	41 (98)	30 (97)
Insertive oral sex	173 (82)	13 (59)	48 (87)	35 (83)	40 (95)	30 (95)
Receptive oral sex	133 (63)	5 (23)	30 (55)	26 (62)	38 (90)	30 (97)
Insertive anal sex	137 (65)	11 (50)	27 (49)	31 (74)	35 (83)	30 (97)
Perform rimming	82 (39)	2 (9)	3 (5)	17 (40)	32 (76)	28 (90)
Received rimming	38 (18)	0 (0)	3 (5)	2 (5)	8 (19)	25 (81)
Fingering	25 (12)	0 (0)	3 (5)	5 (12)	5 (12)	12 (39)
Fisting	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Perianal play	30 (14)	0 (0)	1 (2)	9 (21)	9 (21)	12 (39)
Watersports	1 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3)
Felching	3 (1.4)	0 (0)	1 (2)	1 (2)	0 (0)	1 (3)

*18 individuals reported only one sex act during the last sexual encounter. They are included in the total column but not reported in a separate column

Table 4 Frequency of the combination and sequence of sexual acts reported at last sexual encounter, $N=210$[a]

Combination and sequence of behaviors	Prevalence of combination among the total population ($N=210$) *N* (%)	Prevalence of combination, among those reporting that number of acts *n*/*N* (%)[b]	Prevalence of combination in the sequence specified, among those reporting that combination[d] *n*/*N* (%)[c]
Two acts (n=22)			
IOS–IAS	8 (3.8%)	8/22 (36.3%)	7/8 (88%)
K–ROS	5 (2.4%)	5/22 (22.7%)	3/5 (60%)
K–IOS	4 (1.9%)	4/22 (18.2%)	4/4 (100%)
Three acts (n=55)			
K–IOS–ROS	24 (11.4%)	24/55 (43.6%)	19/24 (79%)
K–IOS–IAS	18 (8.6%)	18/55 (32.7%)	14/18 (78%)
K–ROS–IAS	3 (1.4%)	3/55 (5.5%)	2/3 (67%)
Four acts (n=42)			
K–ROS–IOS–IAS	10 (4.8%)	10/42 (23.8%)	6/10 (60%)
K–IOS–R–IAS	10 (4.8%)	10/42 (23.8%)	7/10 (70%)
K–ROS–R–IAS	3 (1.4%)	3/42 (7.1%)	3/3 (100%)
K–IOS–ROS–PP	3 (1.4%)	3/42 (7.1%)	2/3 (67%)
Five acts (n=42)			
K–IOS–ROS–R–IAS	23 (10.9%)	23/42 (54.8%)	17/23 (74%)
K–IOS–ROS–BR—IAS	4 (1.9%)	4/42 (9.5%)	3/4 (75%)
Six acts (n=19)			
K–IOS–ROS–R–BR–IAS	13 (6.2%)	13/19 (68.4%)	8/13 (62%)
K–IOS–ROS–R–F–IAS	3 (1.4%)	3/19 (15.7%)	1/3 (33%)

K kissing, *IOS* insertive oral sex (received oral sex), *ROS* receptive oral sex (gave oral sex), *IAS* insertive anal sex, *R* rimming someone, *BR* being rimmed, *PP* perianal play

[a]The combinations listed represent those where at least 5% of individuals in each category report that combination (categories being "two acts", "three acts", etc.)

[b]n = number who reported that combination of sex acts; N = number who reported that number of acts

[c]n = number who reported that sequence in the order specified; N = number who reported that combination of sex acts

[d]Of the 84 individuals who report sequences in the order specified (the sum of the numerators for those reporting at least 3 acts), 14 (17%) reported a behavior that was repeated in the sequence after first identification. For 10 of the 14, this behavior was kissing; for 4, it was kissing plus another behavior

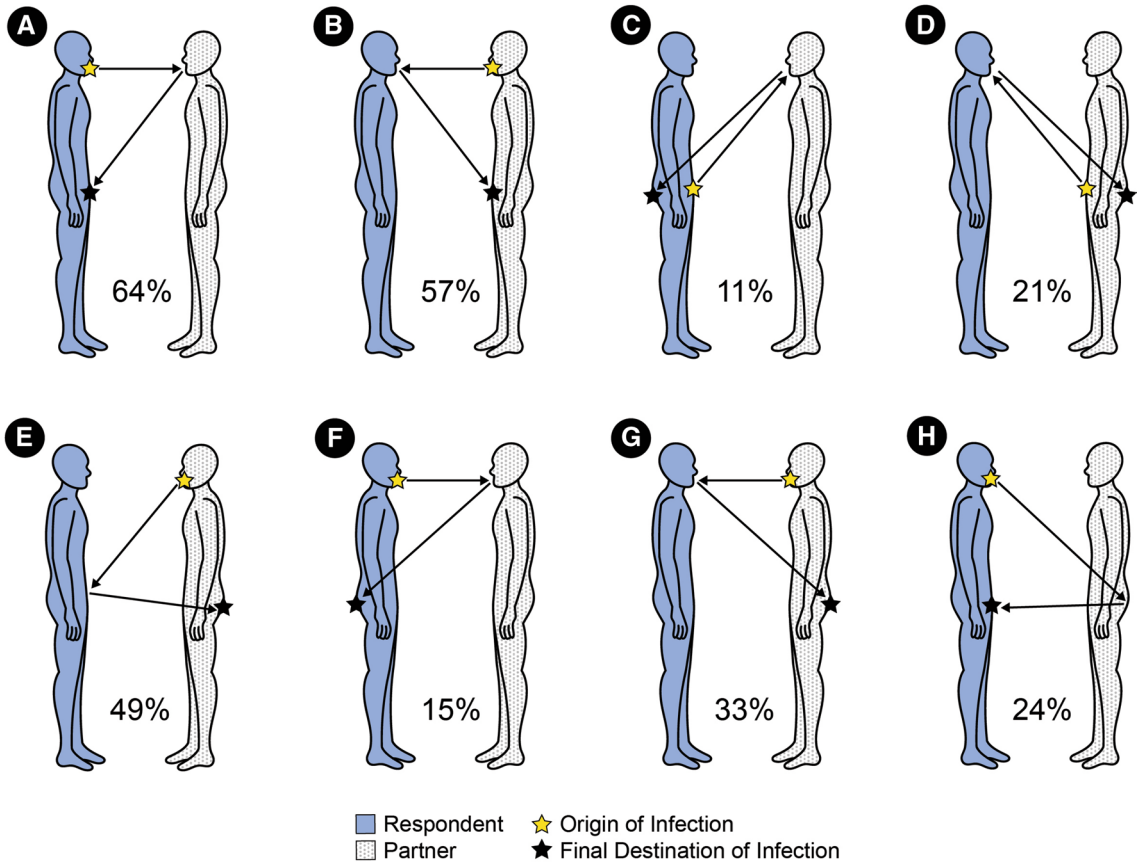

Fig. 1 Prevalence of sequences of sex acts that could lead to GC/CT transmission within the same person (respondent or partner). Percentages calculated as the number of respondents who reported that sequence of sex acts out of the total population of 210. Panel **A**: Kissing followed by insertive oral sex; Panel **B**: Kissing followed by receptive oral sex; Panel **C**: Insertive oral sex followed by being rimmed; Panel **D**: Receptive oral sex followed by performing rimming; Panel **E**: Insertive oral sex followed by insertive anal sex; Panel **F**: Kissing following by being rimmed; Panel **G**: Kissing followed by performing rimming; Panel **H**: Performing rimming followed by insertive anal sex

reported, as well as variability in the sequence in which acts were reported. This variability in combination and sequences creates a large number of potential transmission pathways at the anatomic sites of the pharynx, rectum, and urethra between partners and within a single person. Notably, our analysis of sequences of behaviors was a simplified one, in that we only considered reported acts one time per sequence. For example, if someone reported kissing, receptive oral sex, kissing, and insertive oral sex, we did not include the second kissing act in the sequence. We note that 17% of individuals ($n = 14$) who reported behaviors in the sequences outlined in Table 4 did report the same act multiple times in the sequence; each of these 14 individuals had unique sequences of behaviors. Our need to simplify this analysis highlights the complexities in measuring potential GC and CT transmission routes.

However, we did attempt to address this limitation of our analysis by also examining the most commonly reported two-act sequences that could lead to GC or CT transmission within the same person, allowing for multiple two-act sequences of behaviors to be counted for a single respondent. We found that 90% of individuals reported at least one sequence of behaviors that could lead to GC or CT transmission within the same person. The commonness of these sequences may help explain the relatively high prevalence of pharyngeal and rectal GC and CT observed in many sexual health clinic settings and highlights the need for and importance of extragenital GC and CT screening.

Our findings can be used to inform parameter estimation for mathematical models designed to estimate disease transmission. There have been a number of recent STI models that incorporate anatomic-specific STIs (Fairley et al., 2019; Jenness et al., 2017; Spicknall et al., 2019; Xiridou et al., 2013; Zhang et al., 2017), but until recently none had included sequential practices. In novel models of multi-site infection of GC and CT, Xu and colleagues found that the inclusion of

sequential sexual practices is necessary to replicate observed GC and CT site-specific prevalences (Xu et al., 2020, 2021). These new models demonstrated the importance of including sequential sexual practices to accurately model disease transmission; however, the prevalence of sequential behaviors used in the models were estimates. Our findings fill this gap by providing empiric data to inform these behavioral parameters. Given the complexities in directly measuring GC and CT transmission, coupled with recent calls for more data to understand the benefits and harms of screening among MSM (US Preventive Services Task Force et al., 2021)—including the role of screening in the development of antimicrobial resistance (Dijck et al., 2020; Kenyon, 2020; Kenyon et al., 2020a, 2020b)—developing robust mathematical models may be our best method to understand how interventions (e.g., screening, vaccines) may alter disease transmission, sequelae, and antimicrobial resistance(Craig et al., 2015; Gray et al., 2009; Spicknall et al., 2019).

Our analysis also highlights the dearth of empiric data on combinations of sexual acts and the sequence of these acts among heterosexual individuals. The same sequences of behaviors we describe in this analysis are also relevant for individuals who are female sex at birth, a population at risk of adverse reproductive health outcomes. For example, a female partner who has pharyngeal GC and performs oral sex on their male partner could transmit GC from their pharynx to their partner's urethra; and if the partners subsequently engage in vaginal sex, the male partner could then transmit GC from their urethra to their partner's vagina. To date, mathematical models of heterosexual GC and CT transmission have not included sequential sexual behaviors (Althaus et al., 2010, 2012; Lewis & White, 2018). Doing so may more accurately predict the role of extragenital screening on GC and CT transmission and health outcomes within heterosexual populations.

Our study is strengthened by recruitment from in-person and online venues, and by our use of a survey tool that was developed after extensive testing and interviewing with the study population. This study is also subject to important limitations. The participants we enrolled were individuals who attended our Sexual Health Clinic or clicked on an online advertisement and had not had receptive anal sex in the past 2 years. Thus, their reported behaviors may not be generalizable to populations who do report anal sex or to other MSM populations more broadly. However, the consistency of our findings with the largest study to date on this topic is reassuring that the behaviors of our study population may be at least somewhat representative. Second, we made analytic decisions to simplify the reporting of the prevalences of behaviors. For example, participants could indicate that they engaged in behavior more than one time during the course of the encounter, but for the purposes of this analysis we only reported the behavior in the sequence the first time it was reported. This affected 17% of reported sequences. We also split up sequences into two-act sequences (Fig. 1), acknowledging that this does not allow one to fully appreciate all anatomic sites that could be exposed during a single act. However, it does follow how modeling studies have parameterized sequential sex acts (Xu et al., 2020, 2021). Third, we included a set list of behaviors from which participants could choose, and this was not an exhaustive list of all behaviors. For example, we did not include mutual masturbation or ask about use of saliva as a lubricant (Cornelisse et al., 2018; Fairley et al., 2019). Instead, we focused on behaviors that have the potential to transmit GC or CT directly to the pharynx, urethra, or rectum. Fourth, we focused only on participants' last sexual encounter in an attempt to diminish recall bias. It is possible that the most recent sexual encounter is not representative of an individual's typical sexual behaviors, particularly for a population attending a sexual health clinic where their most recent encounter may have prompted the visit to the clinic. This may also overrepresent behaviors with participants' regular partners, but we did not specifically ask participants any details about their last sexual partner. Fifth, although we asked for data from the last sexual encounter, the results are still subject to recall bias, insofar as participants were unable to accurately recall their most recent sexual encounter. Finally, the two questions included in this analysis came at the end of a larger behavioral survey and it is possible that participants may have experienced survey fatigue which could have led to inaccuracies in reporting.

In summary, we found that the variability in the combination and sequence of sexual behaviors during sexual encounters complicates empiric measurement of per-act transmission probabilities of GC and CT. Gaining a better understanding of GC and CT transmission from all anatomic sites is essential in order to fully estimate population-level GC and CT transmission, and the prevalence estimates from our study can be used in mathematical models aimed to understanding disease transmission. We hope our study inspires more specific and detailed collection of sexual behavior data to fully capture sequential events. However, even well-designed prospective studies may not be able to directly estimate per-act transmission probabilities, as multiple behaviors could contribute to GC or CT acquisition at a single anatomic site. In the future, controlled human infection models (Hobbs & Duncan, 2019) could be a useful tool to be able to measure disease transmission in a controlled environment.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10508-022-02486-2.

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Author Contributions CK and LB led the study conception and design and data collection of the in-person study. DMC led the design and data collection of the online arm of the study. Data analyses were performed by CK. The first draft of the manuscript was written by CK, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability A complete de-identified dataset and code will be made available to interested parties by request, at the completion of the study (anticipated end date May 2023).

Declarations

Conflict of interest C.M.K. and L.A.B. report research support from Hologic, Inc. L.A.B. has received research support from SpeeDX outside of the submitted work and has received research support and consulting fees from Nabriva, unrelated to the submitted work. D.M.C. has no relevant financial or non-financial interests to disclose.

Consent to Participate Informed consent was obtained from all individuals included in the study.

Ethical Standard Approval for this study was obtained from the ethics committee (Institutional Review Board) at the University of Washington. The procedures used in the study adhere to the tenets of the Declaration of Helsinki.

References

Althaus, C. L., Heijne, J. C., & Low, N. (2012). Towards more robust estimates of the transmissibility of *Chlamydia trachomatis*. *Sexually Transmitted Diseases, 39*(5), 402–404.

Althaus, C. L., Heijne, J. C. M., Roellin, A., & Low, N. (2010). Transmission dynamics of *Chlamydia trachomatis* affect the impact of screening programmes. *Epidemics, 2*(3), 123–131.

Centers for Disease Control & Prevention. (2019). *Sexually Transmitted Disease Surveillance 2018*. US Department of Health and Human Services. https://www.cdc.gov/std/stats18/STDSurveillance2018-full-report.pdf

Centers for Disease Control & Prevention. (2021). *National HIV Behavioral Surveillance (NHBS)*. https://www.cdc.gov/hiv/statistics/systems/nhbs/index.html

Cornelisse, V. J., Fairley, C. K., Read, T. R. H., Lee, D., Walker, S., Hocking, J. S., Chen, M. Y., Bradshaw, C. S., & Chow, E. P. F. (2018). Associations between anorectal chlamydia and oroanal sex or saliva use as a lubricant for anal sex: A cross-sectional survey. *Sexually Transmitted Diseases, 45*(8), 506–510.

Craig, A. P., Gray, R. T., Edwards, J. L., Apicella, M. A., Jennings, M. P., Wilson, D. P., & Seib, K. L. (2015). The potential impact of vaccination on the prevalence of gonorrhea. *Vaccine, 33*(36), 4520–4525.

Fairley, C. K., Cornelisse, V. J., Hocking, J. S., & Chow, E. P. F. (2019). Models of gonorrhoea transmission from the mouth and saliva. *The Lancet Infectious Diseases, 19*(10), e360–e366.

Gray, R. T., Beagley, K. W., Timms, P., & Wilson, D. P. (2009). Modeling the impact of potential vaccines on epidemics of sexually transmitted *Chlamydia trachomatis* infection. *Journal of Infectious Diseases, 199*(11), 1680–1688.

Harris, P. A., Taylor, R., Minor, B. L., Elliott, V., Fernandez, M., O'Neal, L., McLeod, L., Delacqua, G., Delacqua, F., Kirby, J., Duda, S. N., & Consortium, R. E. (2019). The REDCap consortium: Building an international community of software platform partners. *Journal of Biomedical Informatics, 95*, 103208.

Harris, P. A., Taylor, R., Thielke, R., Payne, J., Gonzalez, N., & Conde, J. G. (2009). Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. *Journal of Biomedical Informatics, 42*(2), 377–381.

Hobbs, M. M., & Duncan, J. A. (2019). Experimental human infection with *Neisseria gonorrhoeae*. *Methods in Molecular Biology, 1997*, 431–452.

Jenness, S. M., Weiss, K. M., Goodreau, S. M., Gift, T., Chesson, H., Hoover, K. W., Smith, D. K., Liu, A. Y., Sullivan, P. S., & Rosenberg, E. S. (2017). Incidence of gonorrhea and chlamydia following human immunodeficiency virus preexposure prophylaxis among men who have sex with men: A modeling study. *Clinical Infectious Diseases, 65*(5), 712–718.

Kenyon, C. (2020). Does intense sexually transmitted infection screening cause or prevent antimicrobial resistance in sexually transmitted infections? it depends on one's underlying epistemology. *A Viewpoint. Sexually Transmitted Diseases, 47*(8), 506–510.

Kenyon, C., Baetselier, I., & Wouters, K. (2020a). Screening for STIs in PrEP cohorts results in high levels of antimicrobial consumption. *International Journal of STD and AIDS, 31*(12), 1215–1218.

Kenyon, C., Buyze, J., Spiteri, G., Cole, M. J., & Unemo, M. (2020b). Population-level antimicrobial consumption is associated with decreased antimicrobial susceptibility in *Neisseria gonorrhoeae* in 24 European countries: An ecological analysis. *Journal of Infectious Diseases, 221*(7), 1107–1116.

Lewis, J., & White, P. J. (2018). Changes in chlamydia prevalence and duration of infection estimated from testing and diagnosis rates in England: A model-based analysis using surveillance data, 2000–15. *Lancet Public Health, 3*(6), e271–e278.

Rosenberger, J. G., Reece, M., Schick, V., Herbenick, D., Novak, D. S., Van Der Pol, B., & Fortenberry, J. D. (2011). Sexual behaviors and situational characteristics of most recent male-partnered sexual event among gay and bisexually identified men in the United States. *Journal of Sexual Medicine, 8*(11), 3040–3050.

Sanchez, T., Zlotorzynska, M., Sineath, C., Kahle, E., & Sullivan, P. (2016). The annual American men's internet survey of behaviors of men who have sex with men in the United States: 2014 key indicators report. *JMIR Public Health and Surveillance, 2*(1), e23.

Spicknall, I. H., Mayer, K. H., Aral, S. O., & Romero-Severson, E. O. (2019). Assessing uncertainty in an anatomical site-specific gonorrhea transmission model of men who have sex with men. *Sexually Transmitted Diseases, 46*(5), 321–328.

US Preventive Services Task Force, Davidson, K. W., Barry, M. J., Mangione, C. M., Cabana, M., Caughey, A. B., Davis, E. M., Donahue, K. E., Doubeni, C. A., Krist, A. H., Kubik, M., Li, L., Ogedegbe, G., Pbert, L., Silverstein, M., Simon, M. A., Stevermer, J., Tseng, C. W., & Wong, J. B. (2021). Screening for chlamydia and gonorrhea: US Preventive Services Task Force Recommendation Statement. *Journal of the American Medical Association, 326*(10), 949–956.

Van Dijck, C., Laumen, J., Zlotorzynska, M., Manoharan-Basil, S. S., & Kenyon, C. (2020). Association between STI screening intensity in men who have sex with men and gonococcal susceptibility in 21 States in the USA: An ecological study. *Sexually Transmitted Infections., 96*(7), 537–540.

Wiatrek, S., Zlotorzynska, M., Rai, R., Sullivan, P., & Sanchez, T. (2021). The annual American Men's Internet Survey of Behaviors of Men Who Have Sex with Men in the United States: Key Indicators Report 2018. *JMIR Public Health and Surveillance, 7*(3), e21812.

Workowski, K. A., Bachmann, L. H., Chan, P. A., Johnston, C. M., Muzny, C. A., Park, I., Reno, H., Zenilman, J. M., & Bolan, G. A.

(2021). Sexually transmitted infections treatment guidelines, 2021. *MMWR–Recommendations and Reports, 70*(4), 1–187.

Xiridou, M., Vriend, H. J., Lugner, A. K., Wallinga, J., Fennema, J. S., Prins, J. M., Geerlings, S. E., Rijnders, B. J., Prins, M., de Vries, H. J., Postma, M. J., van Veen, M. G., Schim van der Loeff, M. F., & van der Sande, M. A. (2013). Modelling the impact of chlamydia screening on the transmission of HIV among men who have sex with men. *BMC Infectious Diseases, 13*, 436.

Xu, X., Chow, E. P. F., Ong, J. J., Hoebe, C. J. P. A., Zou, Z., Hocking, J. S., Fairley, C. K., & Zhang, L. (2020). *Chlamydia trachomatis* transmission between the oropharynx, urethra and anorectum in men who have sex with men: A mathematical model. *BMC Medicine, 18*(1), 326. https://doi.org/10.1136/sextrans-2020-054565

Xu, X., Chow, E. P. F., Ong, J. J., Hoebe, C. J. P. A., Williamson, D., Shen, M., Kong, F. Y. S., Hocking, J. S., Fairley, C. K., & Zhang, L. (2021). Modelling the contribution that different sexual practices involving the oropharynx and saliva have on *Neisseria gonorrhoeae* infections at multiple anatomical sites in men who have sex with men. *Sexually Transmitted Infections, 97*(3), 183–189.

Zhang, L., Regan, D. G., Chow, E. P. F., Gambhir, M., Cornelisse, V., Grulich, A., Ong, J., Lewis, D. A., Hocking, J. S., & Fairley, C. K. (2017). *Neisseria gonorrhoeae* transmission among men who have sex with men: An anatomical site-specific mathematical model evaluating the potential preventive impact of mouthwash. *Sexually Transmitted Diseases, 44*(10), 586–592.