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ORIGINAL PAPER

Sustained Reduction in Sexual Behavior that May Pose a Risk of HIV Transmission Following Diagnosis During Early HIV Infection Among Gay Men in Vancouver, British Columbia

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Abstract Increased viral load during early HIV infection (EHI) disproportionately contributes to HIV transmission among gay men. We examined changes in sexual behavior that may pose a risk of HIV transmission (condomless anal sex (AS) with a serodiscordant or unknown status partner, CAS-SDU) in a cohort of 25 gay men newly diagnosed during EHI who provided information on 241 sexual partners at six time points following diagnosis. Twenty-two (88%) participants reported ≥1 AS partner (median time to first AS 80 days) and 12 (55%) reported ≥1 partnership involving CAS-SDU (median 116 days). In hierarchical generalized linear mixed effects models, AS was significantly less likely in all time periods following diagnosis and more likely with serodiscordant partners. The likelihood of CAS-SDU decreased three months after diagnosis and was higher in recently versus acutely infected participants. Most men in our study abstained from sex immediately after diagnosis with sustained longer-term reduction in CAS-SDU, confirming the importance of timely diagnosis during EHI.

Keywords HIV · Sexual behavior · Gay men · Diagnosis · Cohort study

Introduction

Antiretroviral treatment and viral load suppression dramatically reduces the risk of HIV transmission among gay, bisexual and other men who have sex with men (MSM), a strategy known as treatment as prevention (TasP) [1]. However, HIV infection rates have not declined in many settings despite increasingly high levels of uptake and adherence to antiretroviral therapy among MSM, as is the case in British Columbia [2–4]. This reinforces the need for a more nuanced and integrated understanding of the multiple drivers of HIV transmission among MSM that span biological, behavioral, social and structural factors in order to mount a comprehensive HIV prevention response [3]. One such driver is the increased risk of transmission during early HIV infection (EHI), the first 6 months after HIV infection [5].

While estimates vary, up to half of new HIV infections in phylogenetic studies among MSM are acquired from an individual during EHI, an observation likely explained by both intrinsic biological and sexual network characteristics [10]. EHI includes acute HIV infection, the period of up to 4–6 weeks immediately following infection when there is

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an initial peak in viral load in blood and semen which is correlated with a higher risk of transmission; acute infection is typically identified by laboratory tests demonstrating presence of the HIV virus in the absence of a strong antibody response [11]. As there is a narrow time window in which to identify acute HIV infection on the basis of laboratory markers, EHI can also be established on the basis of HIV test history (i.e., a negative HIV test in the past 6–12 months before diagnosis, referred to in this paper as "recent infection"). Other possible biological factors contributing to greater transmission risk during EHI include host factors (such as coinfection with sexually transmitted infections, or immature host immune response), properties of the transmitted founder virus, and viral homogeneity during this period [10, 12]. Sexual network factors that may enable higher risk of transmission during EHI among MSM compared to other populations include intrinsically higher transmissibility of HIV via anal versus vaginal sex, density of sexual networks, higher levels of partner concurrency, and rates of partner change [13]. Furthermore, during EHI most MSM will be unaware of their infection and therefore may misapply risk reduction sero-adaptive strategies based on their own assumed sero-negative status. Given the brevity of this stage, enhancing capacity for HIV diagnosis during EHI is key to reducing the contribution of EHI to HIV transmission among MSM [5]. While some have recently suggested that the contribution of EHI to HIV transmission has been overestimated, these conclusions are based on re-analysis of cohort data in generalized heterosexual epidemics [6, 7]. A disproportionate contribution of EHI to HIV transmission among MSM—particularly in the context of increasing treatment coverage and viral load suppression—remains a plausible explanation [8, 9].

Research on the sexual behavior of MSM immediately before and after an HIV diagnosis during EHI is needed as one part of better untangling these factors (e.g., informing modeling studies) as well as determining the need for additional interventions to reduce transmission risk during this infectious period [6]. However, the narrow time window in which to diagnose HIV during EHI, recruitment at the time of a new HIV diagnosis, and ability to observe pre- and post- diagnosis periods renders these studies challenging. Accordingly, few observational studies of risk behavior before and after the time of diagnosis during EHI have been conducted among MSM [14–17]. These studies have also often relied on aggregate self-reported measures of sexual risk behavior (e.g., condomless anal sex in the past 3 months) leading to an inability to examine the nuances of behavior at a sexual event level, or how partnership characteristics may influence behavior. Some of these studies also took place before advances in scientific knowledge that have had an influence on the sexual lives of MSM, such as TasP and the increasing recognition of the importance of initiating treatment during EHI to maximize long-term clinical outcomes, now recommended as standard clinical practice [18, 19]. This knowledge has also led to shifts in community-based prevention strategies employed by MSM as seroadaptive risk reduction strategies have expanded to incorporate viral load sorting, where viral load status informs sexual acts in order to reduce the risk of HIV acquisition or transmission by HIV negative and positive men [20].

To address these gaps, we established a cohort of gay men diagnosed during EHI in Vancouver, British Columbia in order to describe the impact of this diagnosis on their social and sexual lives. This study took place in the context of a sustained increase in the number of acute HIV diagnoses in the region following the introduction of pooled nucleic acid amplification testing (NAAT) at six clinics serving gay men in Vancouver in 2009, promotion of its availability through social marketing campaigns, and rapid delivery of acute HIV test results and counseling to reduce transmission risk during this potentially infectious period [21]. Our mixed-methods study took place between 2009 and 2013, a time when the above-mentioned shifts in clinical practice and community-based risk reduction strategies were becoming more pronounced. We have previously demonstrated the profound importance of these shifts in qualitative research from this same cohort, where in interviews men discussed the importance of HIV diagnosis, starting treatment and changing viral loads (becoming "undetectable") as key milestones in relation to their sexual lives [22, 23]. This approach to sequentially analyzing qualitative and quantitative data permitted us to consider the findings from these previously analyzed qualitative interviews when conducting the quantitative analysis. While this paper presents a quantitative analysis of men's sexual behaviours, we have referenced findings from previously published qualitative analysis that informed our interpretation and serves to further contextualize the quantitative analyses.

In this paper, our objective was to use self-reported data on specific sexual partnerships within this cohort to quantify changes in sexual behavior following diagnosis during EHI. As reduction or cessation of sexual activity after diagnosis in itself reduces transmission risk, we were interested in quantifying changes in both overall sexual behavior as well as specific behaviors that may pose a risk of HIV transmission. Given the prioritized follow-up and counseling of men diagnosed with acute HIV infection during this time period, we were particularly interested to see if we would observe differences between men diagnosed with acute HIV infection and other participants with

EHI. In consideration of findings from interviews with cohort participants we hypothesized: (i) that sexual behavior (overall, and specific risk behaviors) would decrease following diagnosis, followed by a longer-term increase to baseline levels [23, 24]; (ii) that sexual behavior post-diagnosis would be influenced by being on HIV treatment and having a suppressed viral load; [22] (iii) that risk behaviors post-diagnosis would be associated with pre-diagnosis levels of sexual risk; and (iv) that sexual behavior after diagnosis would be associated with partner characteristics including HIV status and significance of the relationship.

Methods

Interventions at Diagnosis

In British Columbia, all individuals with a new HIV diagnosis are routinely reported to public health, with counseling, support, and partner notification services provided by the diagnosing clinician or public health nurses. In tandem with implementation of pooled NAAT at six clinics accessed by gay men in Vancouver, providers at these clinics received training regarding the public health importance of EHI. Follow-up of individuals with a laboratory result suggestive of acute HIV infection was prioritized in order to ensure timely delivery of the diagnosis and counseling regarding increased transmission risk. A study-funded psychologist was available for referrals in order to provide support to newly diagnosed men at these clinics during the diagnosis period as needed. This counseling did not have an explicit focus on behavior change, and access to the study psychologist was not dependent on study participation.

Cohort Eligibility

Males receiving a new HIV diagnosis in BC were eligible to participate if they: self-disclosed having sex with men (i.e., gay, bisexual and other men who have sex with men); were aged 19 years or older; spoke English; and had a diagnosis of acute HIV infection (defined as detection of HIV RNA by NAAT in the absence of confirmed detection of HIV antibody via Western Blot). Due to slow recruitment and as increased risk of transmission during EHI extends beyond the laboratory-defined window of acute infection, on January 1, 2010 we expanded our eligibility criteria for EHI to include men diagnosed with recent HIV infection (defined as not meeting the criteria for acute HIV infection and having a negative HIV test in the past 12 months).

Recruitment

We recruited participants from April 14, 2009 to June 30, 2012, in tandem with the implementation of pooled NAAT testing. Men with early HIV infection (i.e., acute or recent) were recruited through referral to the study coordinator by diagnosing providers at one of the six clinics where pooled NAAT was implemented, either directly or indirectly via referral to the study psychologist funded through our study (who then referred to the study coordinator). Informed consent was obtained from all individual participants included in the study, including permission to access HIV or STI-related medical records.

To reach men with acute HIV infection outside of these study clinics, in collaboration with the BC Public Health Laboratory (PHL, which conducts >90% of all screening and all confirmatory HIV testing in BC), we added a message indicating the availability of our study psychologist to all reports of HIV tests with laboratory test results suggestive of acute infection in BC for males aged >18 years.

Data Collection

Each participant provided demographic information via an online questionnaire at the baseline visit. Sexual network data were collected through in-person or phone interviews by study personnel, who asked participants standardized, detailed questions related to their five most recent sexual partners at each time point, including: date of first and last sex, partner age, frequency of sex, and whether the relationship was ongoing or not. Data on partners prior to HIV diagnosis was captured through these questions at the time of the baseline visit. With respect to last sexual encounter with each partner, participants were asked about types of sexual behaviors and position, condom use, discussion of HIV status, and substance use. Questionnaires were administered six times over the course of the study with intended administration at 7, 30, 90, 180, 270, and 360 days following their HIV positive diagnosis. However, participants were not required to attend at these specific time points and delays were accrued. Participants received an honorarium of $25 for each study component completed.

We also used data from the provincial HIV surveillance database to document basic characteristics of all newly diagnosed men in the province, comparing those who did and did not participate in the cohort. We combined survey data collected from participants with four centralized provincial data sources: (1) the provincial HIV surveillance database, (2) the provincial STI surveillance database, (3) the PHL database, and (4) the provincial Drug Treatment Program registry housed at the BC Center for Excellence in

Table 1 Characteristics of participants and non-participants from six study clinics

Characteristic	Participants $n = 23^{a}$ (%)	Non-participants $n = 87$ (%)	p value[b]
Age in years (average)	40.0	36.5	0.13
Caucasian ethnicity (vs. other)	14/22 (64)	52/82 (63)	0.99
Residence in GVRD (vs. other)	20/23 (87)	70/87 (81)	0.99
Acute HIV infection (vs. recent)	11/23 (48)	39/87 (45)	0.80
Test using pseudonym or initials (vs. nominal)	2/19 (11)	16/82 (20)	0.51
Tested due to sero-conversion symptoms (vs. other reason)	6/23 (26)	16/87 (18)	0.40
First known HIV test at diagnosis (vs. not)	4/23 (17)	11/87 (13)	0.51
Partner known to be HIV positive (vs. not)	8/23 (35)	16/87 (18)	0.09
History of injection drug use (vs. not)	0/23 (0)	4/87 (5)	0.58
Study site			
Clinic A	10/23 (44)	22/87 (25)	0.16
Clinic B	9/23 (39)	36/87 (41)	
Other clinic	4/23 (17)	29/87 (33)	

GVRD Greater Vancouver Regional District

[a] Excludes two participants not recruited at a study clinic but via a recruitment message on a laboratory report

[b] Pearson's Chi square or Fisher's exact test, level of significance set at $p < 0.05$

HIV/AIDS which contains all viral load and treatment data in BC. Participant data within surveillance/clinical databases were extracted and linked to study data based on full name, date of birth, date of HIV positive test, and personal health number (if available). Data on STI (chlamydia, syphilis or gonorrhoea) were extracted from the BC STI surveillance and laboratory databases, to determine if participants had a STI between two years before and up to 30 days after diagnosis of HIV, which was used as a proxy for pre-diagnosis level of sexual risk. Viral load test results were extracted and recorded at the dyad level on the basis of the most recent viral load result (undetectable, detectable, not found) prior to date of last sexual encounter; undetectable viral loads were defined as <50 copies per mL). Treatment information was handled similarly, defined as being on treatment or not at the date of last sexual encounter.

Analysis

The level of significance for all analyses was set at $p < 0.05$. Demographic, sexual and substance use data available from the surveillance records from men who did and did not participate in the study were compared using Pearson Chi square or Fisher's exact test as appropriate.

Our main analyses take a dyad as the unit of analysis, where a dyad refers to the sexual partnership between a participant and one of their reported partners. The time between the date that the participant received their HIV diagnosis and the date of last sexual encounter (with a given partner) was calculated for each dyad and categorized into five new time-periods according to natural break-points in the distribution over time: −90 to 0; 1–92; 93–193; 194–333; and ≥334 days. We excluded dyads where the date of last sex was unavailable or occurred >90 days prior to HIV diagnosis.

Our primary measure of overall sexual behavior was anal sex, and our measure of sexual behavior that may pose a risk of HIV transmission was condomless anal sex with a sero-discordant or unknown HIV status partner (CAS-SDU). Kaplan–Meier survival curves were used to determine the time to first anal sex and/or CAS-SDU after diagnosis of HIV, with log-rank tests used to examine whether the time to these two events differed for acute and recent infection. Single-predictor analyses were conducted between anal sex or CAS-SDU and dyad level variables of interest using Student's t-tests, Mann–Whitney-U tests and Chi square tests as appropriate.

To examine the relationship between anal sex (dependent variable) and time-period after HIV diagnosis (hypothesis 1) we used a generalized linear mixed-effects model (GLMER) with time-period as the primary independent variable. Other hypothesized influences on sexual behavior post-diagnosis (indicated with a *) were included among dyad-level (or time-varying) predictor variables we considered: on treatment at date of last sex*; sero-concordant partner*; participant viral load status*; persistent partner* (based on relationship with partner reported as ongoing, and reporting having had sex more than once); use of crystal methamphetamine, poppers, or party drugs (defined as one of: crystal methamphetamine, ecstasy, GHB, cocaine, ketamine) prior to or during sex;

concurrency (dyad overlaps with at least one other dyad on the basis of first and last dates of sex reported); and whether a sexual partnership involved group sex (more than one sex partner during last sexual encounter). At the participant-level, we considered: age; ethnicity; highest level of education reported; income; prior STI diagnosis*; and infection status (acute vs. recent). The GLMER was fit using a forward stepwise approach; i.e., in each step, we evaluated each of the remaining predictors and added the one with the strongest individual effect on the fit. Predictors were retained if they were statistically significant in the model ($p < 0.05$) or if they had a strong effect on the overall fit measured by the Deviance Information Criterion (DIC) [25].

A second GLMER was constructed for dyads that reported anal sex during the sexual encounter using methods similar to the above model, with CAS-SDU as the dependent variable and 'sexual position' added to the list of independent variables. All analyses were conducted using SPSS version 14 and R version 2.24.2 [26, 27].

Results

In total, 25 (19%) of the 134 men eligible during the study period consented to participate and completed the baseline questionnaire: 23/110 (21%) via referral from the six study clinics and 2/24 (8%) via recruitment message on laboratory reports. The 23 participants recruited from the six study clinics were similar to the non-participants (Table 1; comparison for the two participants recruited via laboratory reports was not conducted due to small numbers). Participants were followed for a median of 433 days (interquartile range [IQR] 278–491) with the final surveys completed by September 2013. Of the 25 participants, 13 (52%) were diagnosed with acute HIV infection; other key characteristics of the participants are presented in Table 2. Baseline demographic and sexual network questionnaires were typically completed from one to three months (median: 34 days; IQR: 25–85) after diagnosis. A total of 241 dyads were included in our analysis with a median of 10 dyads (IQR: 6–14) per person. The distribution of participants and dyads in each of the five time periods is shown in Table 3.

All participants reported resuming sex after diagnosis and 22 (88%) reported at least one dyad involving anal sex following receipt of their HIV positive result. Ten (40%) participants reported not having a partner within the first 3 months of receiving their diagnosis. Overall,

Table 2 Description of the cohort at baseline (N = 25)

Characteristic	Number (%)
Age in years (average)	40
Sexual identity	
Gay	24/25 (96)
Bisexual	1/25 (4)
Relationship status	
Partnered or married (to a man)	5/25 (20)
Single or dating	20/25 (80)
Ethnicity	
Aboriginal	1/25 (4)
Caucasian	18/25 (72)
Hispanic	2/25 (8)
Other	4/25 (16)
Employment	
Full-time employment	13/25 (52)
All Other forms of employment	12/25 (48)
Income	
<$10,000	4/24 (17)
$10,000–$30,000	5/24 (21)
$30,001–$50,000	4/24 (17)
$50,001–$70,000	7/24 (29)
>$70,000	4/24 (17)
Highest education completed	
Elementary School	2/25 (8)
High School	8/25 (32)
College or University	15/25 (60)
HIV infection type	
Acute	13/25 (52)
Recent	12/25 (48)
Reason for testing (multiple responses possible)	
Recommended by physician	4/25 (16)
New relationship or partner requested testing	3/25 (12)
Long time since last test	4/25 (16)
Routine HIV test	8/25 (32)
Sexual event that risked transmission	12/25 (48)
Symptoms (seroconversion or other)	10/25 (40)
Known STI prior to diagnosis	
Yes (at least one)	7/25 (28)
No	18/25 (72)
HIV treatment	
Started during study	18/25 (72)
Started treatment after the study period	7/25 (28)
Days from diagnosis to first treatment	
Median	81
25th percentile	42
75th percentile	342

Table 3 Number of participants contributing to number of dyads during each time period (days following receipt of HIV diagnosis)

Measure	−90 to 0 days	1–92 days	93–193 days	194–333 days	≥334 days
Participants (n = 25)					
Number of participants	18	16	17	17	18
Number (percent) of participants reporting anal sex	17 (94.4)	13 (81.3)	15 (93.8)	16 (94.1)	12 (66.7)
Number (percent) of participants reporting CAS-SDU	11 (57.9)	7 (46.7)	6 (35.3)	4 (23.5)	6 (35.3)
Dyads (n = 241)					
Number of dyads	37	51	57	47	49
Number (percent) of dyads involving anal sex	32 (86.5)	37 (72.5)	38 (66.7)	38 (80.9)	37 (75.5)
Number (percent) of dyads involving CAS-SDU	14 (37.8)	21 (42.9)	10 (17.5)	8 (17.4)	8 (16.7)

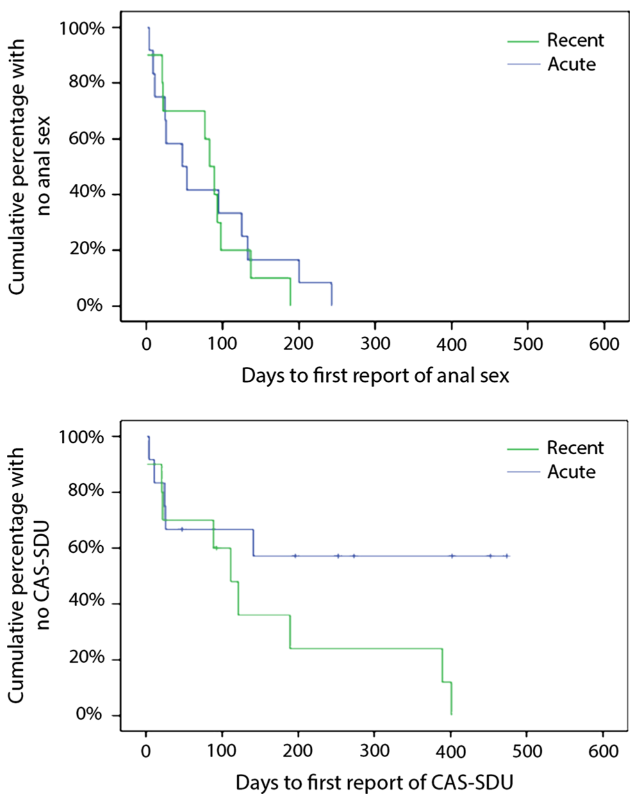

Fig. 1 Time to first anal sex (upper, 22 participants) and CAS-SDU (lower, 12 participants), stratified by recent or acute infection status. *Notes:* CAS-SDU = condomless anal sex with a serodiscordant or unknown status partner. Differences between groups were not significant in either analysis (log rank test: $p = 0.75$ for anal sex analysis, $p = 0.07$ for CAS-SDU analysis; level of significance set at $p < 0.05$)

the median reported time to first anal sex was 80 days (IQR: 21–127), which was not statistically different ($p = 0.75$) between the 12 acutely infected participants (median: 50 days, IQR: 15–131) and 10 recently infected participants (median: 86 days, IQR: 22–107) (Fig. 1a). Among participants reporting anal sex, 55% (12/22) reported at least one dyad involving CAS-SDU. Overall, the median (IQR) time to first CAS-SDU among those reporting anal sex was 116 days (24–302); 168 days (25–369) for 12 acute participants (7 censored at their last study visit) and 102 days (22–239) for 10 recent participants (1 participant censored at last study visit; $p = 0.07$ for the log-rank test comparing the acute and recent participants) (Fig. 1b).

In single predictor models, anal sex was significantly more likely in dyads involving a sero-concordant partner, each of the three individual substance use measures, or group sex, and less likely if the participant had an undetectable viral load (all $p < 0.05$, Table 4). CAS-SDU was more likely in dyads in which any of the three substance use measures were reported and if the participant was on treatment at the date of last sex, and differed significantly across categories of viral load (undetectable, detectable, and no result found) and knowledge of partner's serostatus (both aware, one aware, both unaware; all $p < 0.05$, Table 4).

After adjusting for on treatment during last sex, concurrency, knowledge of status, group sex, sero-concordant partner, diagnosis status (acute or recent infection), income and education, our final model showed a persistent reduction in the odds of having anal sex post-diagnosis for all time periods compared to the 90 days prior to diagnosis (all $p < 0.05$, Table 5), with a greater odds of anal sex with sero-discordant partners. Restricted to dyads involving anal sex, after adjusting for on treatment during last sex, concurrency, knowledge of status, persistent partner, diagnosis status (acute vs. recent), employment and income, the odds of having CAS-SDU was significantly lower for each period beyond 3 months post-diagnosis (all $p < 0.05$). In addition, participants who were diagnosed with a recent HIV infection were seven times more likely to have CAS-SDU than those with an acute infection (OR: 6.96 [95% CI: 1.63, 29.68]) (Table 6).

Table 4 Bivariate analysis of dyad-level characteristics with anal sex, and CAS-SDU

Dyad-level characteristic	Anal sex n (%) n = 182	No anal sex n (%) n = 58	*p* value[a]	CAS-SDU[b] n (%) n = 61	No CAS-SDU[b] n (%) n = 119	*p* value[a]
Persistent partner						
Yes	73 (43)	23 (42)	0.79	23 (41)	49 (46)	0.67
No	95 (57)	32 (58)		33 (59)	61 (55)	
Relationship described as ongoing						
Yes	73 (43)	23 (53)	0.44	24 (43)	49 (46)	0.81
No	95 (42)	33 (57)		37 (66)	70 (64)	
Undetectable viral load						
Undetectable	58 (32)	33 (57)	0.13	13 (21)	44 (37)	**0.01**
Detectable	85 (47)	9 (16)		28 (45)	56 (47)	
Not found	39 (21)	16 (28)		20 (34)	19 (16)	
Knowledge of other's HIV status						
Both aware	97 (78)	24 (65)	0.15	24 (73)	72 (80)	**0.04**
Partner or participant unaware	10 (8)	2 (5)		5 (15)	5 (3)	
Both unaware	18 (14)	11 (30)		4 (12)	13 (14)	
Sero-concordant partner						
Yes	84 (47)	16 (28)	**0.01**	0 (0)	84 (70)	**<0.001**
No	96 (53)	41 (72)		61 (100)	35 (30)	
Sexual position						
Receptive	95 (52)	N/A		34 (56)	60 (50)	0.69
Both	45 (25)			15 (24)	29 (25)	
Insertive	42 (23)			12 (20)	30 (25)	
Concurrency						
Yes	147 (83)	45 (78)	0.35	51 (85)	95 (83)	0.69
No	30 (17)	13 (22)		9 (15)	20 (17)	
Substance use—crystal meth						
Yes	37 (20)	3 (5)	**0.007**	18 (30)	19 (16)	**0.03**
No	145 (80)	55 (95)		43 (70)	100 (84)	
Substance use—poppers						
Yes	53 (29)	7 (12)	**0.004**	26 (43)	27 (23)	**0.005**
No	129 (71)	51 (88)		35 (57)	92 (77)	
Substance use—party DRUGS						
Yes	54 (3)	6 (10)	**0.003**	27 (44)	26 (22)	**0.002**
No	128 (70)	52 (90)		34 (56)	93 (78)	
Group sex						
Yes	30 (16)	3 (5)	**0.04**	10 (16)	20 (17)	0.94
No	152 (84)	53 (95)		51 (84)	99 (83)	
On treatment at date of last sex						
Yes	93 (52)	23 (46)	0.53	21 (34)	44 (38)	**<0.001**
No	85 (48)	27 (54)		40 (66)	71 (62)	

[a] Student's t-tests, Mann–Whitney U-tests, and Pearson's Chi square tests as appropriate, with significant results indicated in bold font ($p < 0.05$)

[b] Analysis restricted to dyads involving anal sex

Table 5 Individual and dyad-level characteristics associated with anal sex—based on 237 dyads, among 25 participants

Characteristic	Unadjusted odds ratio (95% confidence interval)	Adjusted odds ratio [95% confidence interval]	*p* value
Time period (vs. −90 to 0 days)			
1–92	0.45 (0.14, 1.38)	**0.06 (0.01, 0.47)**	0.008
93–193	**0.31 (0.11, 0.93)**	**0.09 (0.01, 0.93)**	0.04
194–333	0.66 (0.20, 2.17)	**0.06 (0.01, 0.57)**	0.01
≥334	0.48 (0.15, 1.52)	**0.02 (0.00, 0.28)**	0.002
On treatment during last sex (yes vs. no)	1.42 (0.64, 3.17)	2.97 (0.82, 10.84)	0.09
Concurrency (yes vs. no)	**2.24 (1.17, 4.29)**	1.13 (0.35, 3.65)	0.84
Knowledge of status (vs. both aware)			
Partner or participant aware	1.23 (0.25, 6.04)	1.39 (0.23, 8.44)	0.72
Both unaware	**0.41 (0.17, 0.96)**	1.21 (0.24, 6.03)	0.81
Group sex (yes vs. no)	2.71 (1.20, 6.09)	8.00 (0.73, 87.46)	0.09
Sero-discordant partner (yes vs. no)	**0.98 (0.95, 1.00)**	**4.26 (1.37, 13.29)**	0.01
Status (recent vs. acute)	1.19 (0.43, 3.28)	1.05 (0.31, 3.54)	0.93
Income (vs. <$10,000)			
$10,000–$30,000	3.54 (1.12, 11.20)	1.75 (0.28, 11.05)	0.55
$30,001–$50,000	1.09 (0.32, 3.64)	1.31 (0.18, 9.30)	0.79
$50,001–$70,000	0.49 (0.21, 1.16)	0.66 (0.10, 4.27)	0.66
>$70,000	0.50 (0.18, 1.36)	0.19 (0.03, 1.30)	0.09
Highest education completed (vs. Elementary School)			
High School	1.51 (0.08, 28.50)	12.43 (0.32, 485.5)	0.17
College or University	1.45 (0.08, 25.82)	11.47 (0.31, 422.59)	0.19

Deviance information criteria (DIC) = 131. Adjusted odds ratio is from the multi-predictor generalized linear mixed-effect model retaining all predictors shown; odds ratios with 95% confidence intervals not crossing 1 are shown in bold font. Predictors were retained if they were statistically significant in the final model at $p < 0.05$, or if retention had a strong effect on the overall fit of the model as measured by DIC. Not retained in final model: ethnicity, employment status, known to have STI prior to diagnosis and days from diagnosis to non-detectable viral load, use of crystal methamphetamine, use of poppers, use of party drugs, viral load during last sex, and sexual position

Discussion

In this study we have quantified sexual behavior for 25 gay men newly diagnosed during EHI for up to a year or longer following their diagnosis, with just over half of the participants recruited during the acute stage of HIV infection. The findings from this study afford a unique opportunity to describe sexual behaviors during this period of heightened risk of transmission. As found in interviews with participants [22, 23], our analysis of sexual partner data confirmed that the majority of men in our study ceased sexual activity during the time immediately following diagnosis, with 40% of participants reporting no sexual partners during the first three months post-diagnosis. For illustration, as we have reported elsewhere, one participant diagnosed in the acute HIV infection period described: "I mean for the first few weeks there was absolutely no sex drive at all, and then after that, like I said, I just sort of abstained, if you will, until I sort of knew that the riskiest transmission window had closed" [22]. All participants did resume sex after diagnosis with resumption of anal sex by 22 participants after a median of 80 days (IQR 21–127 days) and the odds of anal sex remaining lower with dyads during all post-diagnosis time periods evaluated.

Fewer study participants reported CAS-SDU, which typically occurred after resumption of anal sex (median 116 days, IQR 24–302 days). While the odds of CAS-SDU did not significantly differ immediately following diagnosis, the odds were lower during all remaining post-diagnosis periods. We observed few behavioral differences between participants with acute and recent HIV infection although, notably, acutely infected individuals had significantly lower odds of CAS-SDU. Based on our interviews with participants it is likely that receiving information about the nature of acute infection and heightened transmission risk at the time of diagnosis contributed to these reductions in sexual activity after diagnosis [22, 23]. These findings confirm that the most important public health response to a diagnosis during EHI is timely delivery of the result itself with appropriate counseling. However, we do

Table 6 Individual and dyad-level characteristics associated with CAS-SDU—based on 180 dyads that involve anal sex, among 22 participants

Characteristic	Unadjusted odds ratio (95% confidence interval)	Adjusted odds ratio (95% confidence interval)	p value
Time period (vs. −90 to 0 days)			
1–92	1.80 (0.69, 4.71)	0.43 (0.04, 4.19)	0.47
93–193	0.46 (0.17, 1.25)	**0.02 (0.00, 0.19)**	0.001
194–333	0.36 (0.12, 1.01)	**0.03 (0.00, 0.28)**	0.002
≥334	0.36 (1.01, 1.01)	**0.08 (0.01, 0.80)**	0.03
On treatment during last sex (yes vs. no)	**0.24 (0.11, 0.55)**	0.81 (0.16, 4.12)	0.80
Concurrency (yes vs. no)	0.84 (0.36, 1.98)	0.35 (0.07, 1.80)	0.21
Knowledge of status (vs. both aware)			
Partner or participant aware	2.77 (0.70, 10.94)	2.12 (0.34, 13.36)	0.42
Both unaware	0.98 (0.28, 3.44)	0.23 (0.03, 1.91)	0.17
Persistent partner (yes vs. no)	0.92 (0.44, 1.94)	0.56 (0.15, 2.04)	0.38
Status (recent vs. acute)	**3.94 (1.60, 9.69)**	**6.96 (1.63, 29.68)**	0.009
Employment (Full time vs. Not full time)	1.22 (0.43, 3.45)	1.43 (0.39, 5.33)	0.60
Income (vs. <$10,000)			
$10,000–$30,000	3.54 (1.12, 11.20)	2.48 (0.51, 12.15)	0.26
$30,001–$50,000	1.09 (0.32, 3.64)	0.72 (0.07, 7.55)	0.79
$50,001–$70,000	0.49 (0.21, 1.16)	0.29 (0.04, 2.43)	0.25
>$70,000	0.50 (0.18, 1.36)	0.53 (0.04, 6.87)	0.62

Deviance Information Criteria (DIC) = 87. Adjusted Odds Ratio is from the multi-predictor generalized linear mixed-effect model retaining all predictors shown; odds ratios with 95% confidence intervals not crossing 1 are shown in bold font. Predictors were retained if they were statistically significant in the final model at $p < 0.05$, or if retention had a strong effect on the overall fit of the model as measured by DIC. Not retained in final model: participant level: education, prior STI diagnosis, days from diagnosis to undetectable viral load; dyad level: sero-concordant partner, sexual position, use party drugs, viral load at last sex, and group sex

note that a minority of men diagnosed with acute infection reported CAS-SDU in the immediate post diagnosis time period which may indicate an ongoing need for support at the time of diagnosis for some men. Further research to better characterize this subset of men would be helpful.

Recruitment at the time of an HIV diagnosis is challenging, and there are only a few other studies of behaviors before and after diagnosis during EHI among MSM [14–17]. While all have reported an immediate decrease in overall behavior after diagnosis, other studies have reported rebounds in CAS-SDU by one year and have called for enhanced behavioral risk reduction interventions during this time [14, 15, 17]. Our differing results may be due to the counseling about transmission risk at diagnosis in our study for the participants with acute infection, differences in data collection or analytic methods, or the time period in which our study took place (with afore-mentioned shifts in clinical practice and seroadaptive prevention strategies). Finally, though standard at the time, the use of CAS-SDU as a measure of sex with risk for HIV transmission has limitations due to its lack of consideration of the simultaneous use of other seroadaptive strategies such as viral load-based strategies or seroadaptive positioning [14]. For example, in 62% of the 61 dyads involving CAS-SDU in our study the participant was undetectable or took the receptive position at the time of last sex, although neither viral load nor position were retained in our final adjusted model. We also did not see an association between being on treatment, having an ongoing relationship, or prior STI with either anal sex or CAS-SDU in our final models as we had hypothesized.

A major strength of our overall cohort study, is the use of both qualitative and quantitative data which allowed findings from our previous longitudinal qualitative analyses to refine and complement this quantitative analysis, creating a more comprehensive picture of men's sexual behaviours and experiences overtime. However, important findings from the qualitative arm (e.g., importance of being on treatment, having an undetectable viral load) arose during the course of the cohort study and questionnaires were not specifically designed to test these and other hypotheses. Accordingly, we relied on proxy measures which may be insufficient (e.g., documentation of an undetectable viral load in clinical records prior to the date of last sex does not necessarily mean participants were aware of their undetectable status or what it meant for transmission risk). While our study is based on a small number of participants, our use of time-varying, dyad-level data increases statistical power and allows analysis of contextual factors associated with a specific sexual event [28]. We were not always able to recruit participants soon after their diagnosis, which meant that only 18 participants contributed partner data to the pre-diagnosis time period (−90 to 0 days). Similarly, we cannot rule out the possibility of differential behavior among those lost to follow-up. Finally, we acknowledge that some participants in the acute phase of infection may have been misclassified as recent for this analysis given the narrow time window in which a diagnosis of acute infection can be made based on laboratory markers.

Ultimately, the most important intervention to reduce transmission from EHI is testing for and diagnosing HIV during this stage. On learning of their diagnosis during EHI participants initially abstained from sex when risk of transmission may be highest and reported sustained reductions in behaviors that may pose a risk of HIV transmission. Combinations of strategies are needed to reduce the contribution of EHI on ongoing transmission among MSM, starting with increasing laboratory capacity for detection of EHI and social marketing campaigns to promote its availability and increase HIV testing frequency [21]. Post-test counseling regarding risk of transmission during EHI, and recent changes to standards of clinical practice which emphasize rapid connection to clinical care and immediate treatment upon diagnosis regardless of stage of infection are also likely to have an impact.

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Compliance with Ethical Standards

Conflict of interest The authors declare they have no conflict of interest.

Ethical Approval All procedures performed involving human participants were in accordance with the ethical standards of the University of British Columbia research ethics board which approved this study, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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