

Using Respondent-Driven Sampling Methodology for HIV Biological and Behavioral Surveillance in International Settings: A Systematic Review

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Abstract To determine operational and analytical characteristics of respondent-driven sampling (RDS) in international settings and to explore factors that may affect recruitment of most-at-risk populations using RDS, we reviewed HIV biological and behavioral surveillance studies that used this method outside of the United States. We identified 123 eligible studies, 59 from Europe, 40 from Asia and the Pacific, 14 from Latin America, seven from Africa and three from Oceania. Studies collectively recruited 32,298 participants between 2003 and 2007; 53% of studies were conducted among injecting drug users, which generally had faster recruitment compared with studies among sex workers. All but 13 studies reached $\geq 90\%$ of their intended sample size, and six studies failed to reach equilibrium for key variables. This review has shown that RDS is an effective technique, when designed

and implemented appropriately, to sample most-at-risk populations for HIV biological and behavioral surveys.

Keywords HIV/AIDS · Most at risk populations · Respondent-driven sampling · Biological and behavioral surveillance

Introduction

With 33.2 million people worldwide currently infected, and with 2.1 million deaths in 2007 alone, the HIV pandemic is one of the most significant public health challenges of the 21st century (UNAIDS 2007). In most countries, the HIV epidemic is driven by sub-populations at highest risk (termed “most-at-risk populations”) for becoming infected with or transmitting HIV (UNAIDS/WHO Working Group on Global HIV/AIDS and STI Surveillance 2000). In two types of epidemic, low-level (prevalence of infection is $<5\%$ in most-at-risk populations) and concentrated (prevalence is $>5\%$ in most-at-risk populations but is not yet $>1\%$ in the general population) these most-at-risk populations include injecting drug users (IDUs), men who have sex with men (MSM), and sex workers (SWs) along with their sexual partners, as well as displaced populations, migrant workers, long-distance truck drivers, and youth (Mills et al. 2004). Even in generalized epidemics, in which prevalence is $>1\%$ in pregnant women attending antenatal clinics, there is recognition that risk is not uniformly distributed within populations and is driven, at least initially, by most-at-risk populations that bridge HIV to the lower-risk general population (Chopra et al. 2007; Doherty et al. 2006; Gregson et al. 2002; Halperin and Epstein 2004).

Accurate HIV data on incidence and prevalence and associated behavioral data from most-at-risk populations are

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essential for designing targeted prevention programs to reduce the further spread of the epidemic (Mills et al. 2004; Pisani et al. 2003; Zaba et al. 2006). In most countries, however, HIV surveillance systems, the primary source of epidemiologic data, do not generate representative samples of most-at-risk populations. Although probability-based sampling methods are the gold standard for collecting unbiased and generalizable biological and behavioral data on HIV, their application is limited when sampling most-at-risk populations such as IDUs, MSM and SWs, especially the hidden subsets of these groups. The methods are limited, first of all, because these populations generally do not have sampling frames from which to draw random samples using conventional probability-based sampling methods. In addition, the groups are too small to be captured in large enough numbers in surveys of the general population. Second, individuals within these populations often practice socially stigmatized or illegal behaviors, resulting in difficulties accessing them. As a result, they are often recruited through institutions (e.g., hospitals, jails, drug-treatment clinics) using convenience techniques, such as quota and snowball sampling, or they are recruited through visible venues (e.g., bars, clubs, street corners, shooting galleries) using targeted sampling (Magnani et al. 2005; Semaan et al. 2002; Watters and Biernacki 1989).

Respondent-driven sampling (RDS) is a relatively new sampling method that has been recognized and adopted by public health researchers as a promising alternative means to sample most-at-risk populations for biological and behavioral HIV surveys. RDS is a chain-referral sampling technique that uses statistical adjustments for network size to produce generalizable samples (Abdul-Quader et al. 2006a; Heckathorn 1997, 2002; Magnani et al. 2005; Salganik and Heckathorn 2004; Semaan et al. 2002). The RDS recruitment process begins with a set number of individuals, or “seeds,” selected purposefully from the target population. Seeds are trained to recruit a set number of individuals (“recruitment quota”) from their social network of peers. The recruits of the seeds who enroll in an RDS study are also trained to recruit a set number of individuals from their social network of peers. Both seeds and recruited participants typically receive incentives, both to be interviewed (referred to as “primary incentives”) and to refer additional recruits (“secondary incentives”). Ideally, this recruitment process continues to produce long recruitment “chains” made up of several “waves” of recruits. As the recruitment chains lengthen, the composition of the sample begins to reach a point of “equilibrium” whereby the composition of certain characteristics (e.g., age group, gender, ethnicity, HIV prevalence) within the sample eventually stabilizes, indicating that the final sample is not biased by the purposeful selection of seeds (Heckathorn 2002). It is generally understood that RDS can

be applied only in populations that are socially networked and in which members of the networks are willing to recruit from among their peers.

In addition to the recruitment process, RDS involves a complex analytical component that is crucial to generate representative estimates and confidence intervals. It is done through adjustments that factor in the sizes of participants’ social networks and the sample’s different recruitment patterns. In this paper, we refer to RDS as both the recruitment and analysis components.

Respondent-driven sampling was first used in 1994 to study HIV-related risk behaviors among IDUs in the eastern United States (Heckathorn 1997). Outside the United States, RDS was not used for HIV surveillance until 2003 (Wattana et al. 2007), but since then it has been employed widely by international researchers to gather biological and behavioral data on HIV. To date, there are ongoing discussions about the effectiveness of RDS in different socio-cultural settings and among certain most-at-risk populations (Abdul-Quader et al. 2006b). Additionally, misunderstandings exist about RDS methodology, the importance of statistical adjustment, and the method’s requirements (Heimer 2005; Johnston et al. 2008; Ramirez-Valles et al. 2005; Salganik 2006; Simic et al. 2006). To address these issues, we reviewed biological and/or behavioral HIV surveillance surveys that used RDS and that were conducted outside of the United States to sample HIV most-at-risk populations. In this paper, we summarize operational and analytical characteristics of RDS studies and discuss factors that may affect recruitment. Implementation and theoretical challenges to RDS studies are discussed in a companion paper (Johnston et al. 2008).

Methods

Literature Search

We searched published and unpublished manuscripts, abstracts, reports, protocols and notes from field supervisors related to HIV biological and/or behavioral surveillance (accessible from 2003 through October 1, 2007) that involved RDS in countries other than the United States. We excluded studies based in the United States because those conducted prior to 2006 have already been or are currently being reviewed (Abdul-Quader et al. 2006b; Robinson et al. 2006). We conducted initial searches using MEDLINE (1970–2007), PubMed and *Google Scholar* (up to the first 50 pages). This search included an iterative process to refine the search strategy by testing several search terms and incorporating new search terms as new relevant citations were identified. Multiple combinations of keywords and phrases were used to assess study eligibility,

including: (1) *methodology*: “chain-referral sampling” or “respondent-driven sampling”; (2) *population of interest*: “men who have sex with men”, “bisexual”, “sex workers” (male, female, transgender) and their partners, “drug users” (injectors or non-injectors), “homeless”, “run-away youth” or “migrant population”; (3) *medical domains*: “HIV”, “HCV”, “sexually transmitted infections”, “drug abuse”, “overdose” and “needle sharing”; (4) *language*: documents in English, Spanish, French, Portuguese, Farsi, or Arabic; (5) *location*: studies conducted in a country or countries other than the United States. We further conducted a “cited reference search” in Web of Science on the relevant papers and used the “related articles feature” in PubMed.

The majority of data was provided by co-authors and their collaborators directly involved in conducting RDS surveys and through contacts with organizations involved in specific RDS surveys, including Tulane University School of Public Health and Tropical Medicine; University of California, San Francisco Global Health Sciences; the Global AIDS Program, Centers for Disease Control and Prevention; Family Health International; the Federal University of Ceará, Brazil; and national ministries of health.

Eligibility Criteria

We assessed articles identified through our original search and differentiated studies that used the RDS recruitment process and analytical elements from those that did not. First we included studies in our review that (1) initiated recruitment chains with members of the target population, known as seeds; (2) used a recruitment quota; (3) collected data on the size of social network for all participants using a consistent set of parameters; and (4) systematically recorded who recruited whom. To ascertain whether a study was conducted among a population that was socially networked, we included only studies that either reported that one or more seeds could generate a minimum of three referral waves or, in case waves were unreported, that the study attained a minimum of 10% of its desired sample size. Second, we also excluded studies that (1) did not generate weighted estimates of variable frequency and confidence intervals using data on network size or, in the case of studies with only recently completed data collection, did not intend to use weighting in their analysis; (2) combined an RDS sample with other samples generated using other methods; or (3) combined samples from multiple RDS studies with different eligibility criteria or conducted in distinct geographical areas. We considered studies that fulfilled all inclusion criteria as complete RDS studies and included them in our review.

Categorizing Documents and Abstraction

We created a master table in Microsoft Excel, extracted key information from included surveys, and entered data into the table. Once we completed data entry, we divided studies into four sub-tables based on the population of interest: IDU, MSM, SW and high-risk heterosexual (HRH) men. We abstracted (1) the principal investigator or contact person or organization; (2) the year of the study; (3) where the survey was conducted; (4) eligibility criteria; (5) types of biological specimen(s) gathered and laboratory tests performed; (6) whether formative research was conducted prior to the survey; (7) interview method; (8) number of recruitment sites; (9) type of recruitment site; (10) whether mobile recruitment sites were used; (11) whether seeds were diversified, meaning they were selected differently from each other based on key demographic or risk behavior characteristics; (12) total number of seeds used for the study; (13) number of seeds that failed to recruit anyone; (14) whether additional seeds were added after the study began; (15) the maximum number of allowable referrals; (16) whether an expiration period was used, meaning the total number of days between when a participant completes the survey and his or her recruited peer enrolls in the survey; (17) the primary incentive amount, which is the amount given for completing the survey in US dollars calculated on October 15, 2007; (18) the secondary incentive amount, which is the amount given for each participant-referred recruit who enrolls in the survey; (19) other services offered during the survey; (20) design effect used to calculate a sample size; (21) desired sample size; (22) actual sample size; (23) maximum number of waves; (24) sampling duration in weeks; (25) whether equilibrium was reported as being reached; (26) whether survey data were adjusted using respondent-driven sampling analysis tool (RDSAT) (Volz et al. 2007) or a similar software program; and (27) description of any operational limitations.

We assessed the success of each study by the proportion of the pre-designated sample size that was actually recruited and whether the authors reported reaching equilibrium. We compared the number of successful recruits per seed per week using the Mann–Whitney *U* test with significance at $P = 0.05$ in STATA version 10 (StataCorp, College Station, Texas).

Results

We identified 155 biological and/or behavioral HIV surveys that were conducted among most-at-risk populations outside of the United States. Of these, 32 (21%) studies did not fulfill our RDS criteria and were excluded. Nineteen

(59%) of these studies combined RDS samples with samples collected using other sampling techniques; five (16%) failed to generate a minimum of three referral waves, four (13%) either did not report whether they had collected data on size of the social networks or reported them inconsistently; two (6%) did not analyze their data using proper RDS techniques; one (3%) did not provide sufficient information about RDS recruitment requirements; and one (3%) combined samples from two different RDS studies.

One hundred twenty-three studies met all of our eligibility criteria. Of these, one study was completed in 2003, nine studies in 2004, 34 in 2005, 65 in 2006, and 14 in 2007. Studies were conducted in 28 different countries and five continents: Europe (59, 48%), Asia (40, 33%), Latin America (14, 11%), Africa (7, 6%) and Oceania (3, 2%) (Table 1). Sixty-five studies (52%) were among IDUs (Table 2), 39 (32%) among MSM (Table 3), 18 (15%) among SW (Table 4), and one (1%) among HRH men (Table 5). Between 2003 and October 2007, a total of 32,298 participants were surveyed, of whom 17,434 (54.0%) were IDUs, 10,101 (31.0%) were MSM, 4,342 (13.5%) were SWs, and 421 (1.5%) were HRH men.

One hundred six studies (86%) reported collecting both HIV biological and behavioral data concurrently, and the remaining 17 (14%) were solely behavioral surveys. Sixty-four (53%) collected dried blood spots, 44 (36%) venous blood, 6 (5%) oral fluid and 25 (21%) urine or penile or vaginal swabs. Of the 112 studies with available information, 101 (90%) reported conducting some degree of a priori formative research. Although face-to-face methods were the most common means of interviewing (110 studies, 89%), audio computer-assisted structured interviews (ACASI) and self-administered instruments were used in eight (7%) and five (3%) studies, respectively. Participants were enrolled at a variety of sites including governmental hospitals, public health clinics, public health departments, non-governmental organizations providing services for target groups, voluntary counseling and testing clinics, hotel rooms, rented store

fronts, and mobile vans. Of the 114 studies that reported the number of recruitment sites, 92 (81%) used a single site, but as many as five sites were used. Only six (5%) studies reported using mobile vans as recruitment sites; and in one study, two vans were used but in stable locations.

One hundred twenty (99%) studies reported that seeds were diversified (i.e., selected differently from each other) based on key demographic or risk behavior characteristics; three studies did not report on diversification. Thirty-one (43%) of 72 studies with available data reported adding seeds beyond the original seeds. All but three studies set the allowable number of recruits per participant at three. Of 103 studies with available data, 59 (57%) did not limit the time during which participants were allowed to refer their recruits. Among 44 studies that did limit time for recruits to respond, the recruitment period ranged from 7 to 60 days.

Studies used a wide range of primary and secondary incentives for recruitment. Of the 107 studies that reported using primary incentives, a majority of 89 (83%) used cash incentives, 11 (10%) gave cash equivalents (e.g., food stamps) or small goods with minimal monetary value and 3 (3%) gave condoms and lubricants; 4 (4%) did not offer any primary incentive. Seventy-eight studies reported data on secondary incentives, and 72 (92%) offered them; these incentives were usually monetary (58 studies, 74%). Seventy-eight studies reported data on both primary and secondary incentives; the value of the primary incentive was higher than that of the secondary incentive in 52 (67%) studies, the same in 14 (18%), lower in seven (13%) and undetermined in four (5%) studies. One (1%) study did not offer any kind of incentive. Of these 78 studies, 55 (71%) gave money as both primary and secondary incentives, 8 (11%) provided money only for one of them, and 15 (19%) did not offer monetary incentives at all. In addition to incentives, studies offered a wide range of additional services, such as free HIV testing and counseling, referral for clinical follow-up, condoms, lubricants and information and educational materials.

We also summarize how successfully studies were able to recruit participants (Table 6). On average, RDS studies used 10 seeds (range, 2–32, median 8.0, intra-quartile range [IQR] 6.0–13.0) and had 1.6 (range 0–19, median 0, IQR 0–2.0) unsuccessful seeds per study. Of 86 studies with available data, 51 (59%) reported having no unsuccessful seeds. The median proportion of unsuccessful seeds per study was lower among studies of IDUs (0%, IQR, 0–5%) than among SWs (20%, IQR 14–30%, z score -3.872 , $P < 0.0005$). There was no significant difference in the median proportion of unsuccessful seeds per study between MSM and IDUs (z score -0.915) or MSM and SWs (z score -1.916). The greatest number of referral waves was among IDUs (34); the average number

Table 1 HIV biological and behavioral studies that used RDS by risk group and continent, 2003–2007^a

Continent	IDU	MSM	SW	HRH men	Total
Africa	2	3	1	1	7 (6%)
Asia	19	14	7	0	40 (33%)
Europe	42	16	1	0	59 (48%)
Latin America	2	5	7	0	14 (11%)
Oceania	0	1	2	0	3 (2%)
Total	65 (53%)	39 (31%)	18 (14%)	1 (1%)	123 (100%)

^a Studies conducted outside the United States only

Key: HRH = high-risk heterosexual; IDU = injecting drug user; MSM = men who have sex with men; SW = sex worker

Table 2 HIV biological and behavioral studies that used RDS, injecting drug users, 2003–2007^a

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds			Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added		Primary	Secondary	Desired	Actual			
2007																
Bosnia and Herzegovina (BiH), Banja Luka [1]	Injected drugs in past month; age ≥ 16; live in Banja Luka	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	11	2	Yes	3	\$14.62	\$7.31	250	250	12	11	Yes
BiH, Sarajevo [1]	Injected drugs in past month; age ≥ 16; live in Sarajevo	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	9	2	No	3	\$14.62	\$7.31	250	250	8	9	Yes
BiH, Zenica [1]	Injected drugs in past month; age ≥ 16; live in Zenica	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	8	3	No	3	\$14.62	\$7.31	250	250	9	10	Yes
Estonia, Kohtla-Järve [2]	Injected any drug in past 2 months	Venous blood for HIV, HBV, HBsAg, syphilis	No	Face to face	1	6	0	No	3	\$4.40 in food coupons	\$4.40 in food coupons	350	350	8	4	Yes
Estonia, Tallinn [2]	Injected any drug in past 2 months	Venous blood for HIV, HBV, HBsAg, syphilis	No	Face to face	1	5	0	No	3	\$4.40 in food coupons	\$4.40 in food coupons	350	350	16	4	Yes
Indonesia, Bandung [3]	Injected drugs in past month; age ≥ 15; live in survey area past 30 days	Finger prick blood for HIV and urine	Yes	Face to face	1	9	0	No	3	\$4 + (\$3 transportation)	\$5	250	250	8	6	NR
Indonesia, Surabaya [3]	Injected drugs in past month; age ≥ 15; live in survey area past 30 days	Finger prick blood for HIV and urine	Yes	Face to face	1	NR	0	No	3	\$4 + (\$3 transportation)	\$5	250	250	8	6	NR
Tanzania, Zanzibar [4]	Injected drugs in past month; age ≥ 15; live in Zanzibar	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	7	0	No	3	\$3.53	\$1.76	500	500	15	7	Yes
2006																
Egypt, Cairo [5]	Injected drugs recreationally in past month	Venous blood for HIV	Yes	Face to face	1	28	6	Yes	3	\$7.40	\$5.41	406	413	5	3	Yes
India, Bishenpur District, Manipur [6]	Male; injected drugs in past 6 months in Bishenpur district; age ≥ 18; willing to provide blood and urine specimens	DBS for HIV, HBV, HCV, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	2	8	0	Yes	3	\$1.76	\$0.75	400	420	NR	12	Yes
India, Churachandpur District, Manipur [6]	Male; injected drugs in past 6 months in Churachandpur district; age ≥ 18; willing to provide blood and urine specimens	DBS for HIV, HBV, HCV, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	1	6	0	No	3	\$1.76	\$0.75	400	419	7	9	Yes

Table 2 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds	Maximum referrals			Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
							Total	Failed	Added	Primary	Secondary	Desired	Actual			
India, Phek District, Nagaland [6]	Male; injected drugs in past 6 months in Phek district; age ≥18; willing to provide blood and urine specimens	DBS for HIV, HBV, HCV, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	2	9	0	Yes	3	\$1.76	\$0.75	400	440	12	5	Yes
India, Wokha District, Nagaland [6]	Male; injected drugs in past 6 months in Wokha district; age ≥18; willing to provide blood and urine specimens	DBS for HIV, HBV, HCV, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	2	9	0	Yes	3	\$1.76	\$0.75	400	420	22	6	Yes
India, Mumbai and Thane District, Nagaland [6]	Male; injected drugs in past 6 months in Mumbai and Thane district; age ≥18; willing to provide blood and urine specimens	DBS for HIV, HBV, HCV, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	5	NR	NR	NR	3	\$2.51	\$1.26	400	NR	NR	12	Yes
Iran, Tehran [7]	Injected drugs in past month; had track marks; age ≥18; not under influence of drugs at interview; received coupon in greater Tehran	Venous blood for HIV, HBV, HCV	Yes	Face to face	4	24	14	Yes	3	\$1.07, increased to \$2.14	\$0.54, increased to \$1.07	762	548	34	48	Yes
Ukraine, Cherkasu [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	6	0	NR	3	\$1.98	NR	NR	219	6	4	Yes
Ukraine, Dnepro-petrovsk [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	6	0	NR	3	\$1.98	NR	200	200	9	4	Yes
Ukraine, Dneprod-zhejvsk [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	4	0	NR	3	\$1.98	NR	150	150	9	4	Yes
Ukraine, Donetsk [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	7	0	NR	3	\$1.98	NR	200	200	9	4	Yes
Ukraine, Kahovka [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	100	106	7	4	Yes
Ukraine, Kharkov [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	150	151	9	3	Yes
Ukraine, Kherson [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	6	0	NR	3	\$1.98	NR	200	201	7	4	Yes

Table 2 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds			Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added		Primary	Secondary	Desired	Actual			
Ukraine, Kiev [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	9	0	NR	3	\$1.98	NR	350	356	8	8	Yes
Ukraine, Kirovograd [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	4	0	NR	3	\$1.98	NR	100	110	8	4	Yes
Ukraine, Krivoy Rog [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	4	0	NR	3	\$1.98	NR	150	150	5	5	Yes
Ukraine, Luganski [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	6	0	NR	3	\$1.98	NR	250	250	8	6	Yes
Ukraine, Luts'k [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	4	0	NR	3	\$1.98	NR	150	150	6	5	Yes
Ukraine, Makeyeva [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	100	100	5	3	Yes
Ukraine, Marupol [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	100	100	7	6	Yes
Ukraine, Nikolaev [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	200	200	5	3	Yes
Ukraine, Norovokunsk [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	100	100	3	3	Yes
Ukraine, Odessa [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	8	0	NR	3	\$1.98	NR	300	303	9	3	Yes
Ukraine, Poltava [8]	Injected drugs in past month	DBS for HIV	Yes	Face to Face	1	3	1	NR	3	\$1.98	NR	150	150	8	3	Yes
Ukraine, Sevastopol [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	2	0	NR	3	\$1.98	NR	100	100	8	4	Yes
Ukraine, Simferopol [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	5	1	NR	3	\$1.98	NR	200	205	6	3	Yes
Ukraine, Smela [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	100	99	5	5	Yes
Ukraine, Sumy [8]	Injected drugs in past month	DBS for HIV	Yes	Face to Face	1	3	0	NR	3	\$1.98	NR	150	152	6	3.5	Yes
Ukraine, Voznesensk [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	100	100	3	2	Yes
Ukraine, Yalta [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	8	0	NR	3	\$1.98	NR	100	100	9	3	Yes
Ukraine, Zhamenka [8]	Injected drugs in past month	DBS for HIV	Yes	Face to face	1	3	0	NR	3	\$1.98	NR	NR	122	6	3	Yes
UK, Bristol [9]	Injected drugs in past month; live in Bristol	DBS for HIV, HBV, HCV	Yes	Face to face with CAI	1	8	0	Yes	3	\$10.51	\$10.51	300	299	18	5	NR

Table 2 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds			Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added		Primary	Secondary	Desired	Actual			
2005																
Albania, Tirana (Stormer et al. 2006) [10]	Injected substances in past year; age ≥15	Venous blood for HIV, HBV, HCV syphilis	NR	Face to face	3	15	NR	No	2	\$14.29	\$7.14	200	225	NR	8	NR
Estonia, Kohtla-Järve (Platt et al. 2006) [2]	Injected drugs for non-medical purposes in past month; willing to give oral fluid sample for testing for HIV	Venous blood for HIV, HBV, HBsAg, syphilis	Yes	Face to face	1	2	0	No	3	\$4.40 in food coupons	\$4.40 in food coupons	100	100	4	2	NR
Estonia, Tallinn (Platt et al. 2006) [2]	Injected drugs for non-medical purposes in past month; willing to give oral fluid sample for testing for HIV	Venous blood for HIV, HBV, HBsAg, syphilis	Yes	Face to face	1	7	0	Yes	3	\$4.40 in food coupons	\$4.40 in food coupons	350	350	8	4	NR
Indonesia, Surabaya [3]	NR	None	Yes-Minimal	Face to face	1	19	1	No	3	NR	NR	500	496	13	29	Yes
Mexico, Ciudad Juárez (Frost et al. 2006) [11]	Injected drugs in past month; has track marks; age ≥18	Venous blood for HIV	NR	Face to face	1	9	8	No	3	\$10.00	\$5.00	200	197	8	2	Yes
Mexico, Tijuana (Frost et al. 2006) [11]	Injected drugs in past month; has track marks; age ≥18	None	NR	Face to face	3	15	9	No	3	\$20.00	\$5.00	200	207	8	8	Yes
Monte-negro, Podgorica (Simic et al. 2006) [12]	Injected drugs in past month; age ≥18; live and/or work in Podgorica	DBS for HIV, HBV, HCV, syphilis	Yes	ACASI	1	7	1	No	3	\$14.29	\$7.14	400	328	6	8	Yes
Nepal, Various sites [13]	Male; injected drugs for intoxication purposes for past 3 months; age ≥16	None	NR	Face to face	NR	17	NR	No	3	NR	NR	300	300	NR	NR	Yes
Russia, St. Petersburg (Platt et al. 2006; Simic et al. 2006); Stormer et al. 2006) [12, 14]	Injected recreational drugs in past 6 months; age ≥15	None	NR	Face-to Face	3	13	NR	Yes	3	Gifts worth \$10	Gifts worth \$5	200	200	NR	8	NR
Serbia, Belgrade (Simic et al. 2006) [12]	Injected drugs in past month; age ≥18; live and/or work in Belgrade	DBS for HIV, HBV, HCV, syphilis	Yes	ACASI	1	8	0	No	3	\$14.29	\$7.14	400	432	6	8	Yes

Table 2 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals	Incentives	Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed							
Secondary	Desired	Actual							Primary					
Ukraine, Kiev [8]	Injected drugs in past 3 months; age ≤ 23 ; not in treatment	None	Yes	Face to face	1	20	NR	NR	NR	200	205	7	5	No
Ukraine, Odessa [8]	Injected drugs in past 3 months; age ≤ 23 ; not in treatment	None	Yes	Face to face	1	20	NR	NR	NR	200	201	10	5	No
Ukraine, Pavlohrad [8]	Injected drugs in past 3 months; age ≤ 23 ; not in treatment	None	Yes	Face to face	1	20	NR	NR	NR	200	199	8	5	No
Ukraine, Poltava [8]	Injected drugs in past 3 months; age ≤ 23 ; not in treatment	None	Yes	Face to face	1	20	NR	NR	NR	200	203	6	5	No
Vietnam, Can Tho [15]	Male; injected drugs in past month; age ≥ 18	DBS for HIV	Yes	Face to face	NR	NR	NR	NR	\$1.87–\$3.12	299	298	NR	10	Yes
Vietnam, Danang [15]	Male; injected drugs in past month; age ≥ 18	DBS for HIV	Yes	Face to face	NR	NR	NR	NR	\$1.87–\$3.12	274	274	NR	10	Yes
Vietnam, Hanoi [15]	Male; injected drugs in past month; age ≥ 18	DBS for HIV	Yes	Face to face	NR	NR	NR	NR	\$1.87–\$3.12	296	296	NR	10	Yes
Vietnam, Ho Chi Minh City [15]	Male; injected drugs in past month; age ≥ 18	DBS for HIV	Yes	Face to face	NR	NR	NR	NR	\$1.87–\$3.12	296	296	NR	10	Yes
2004														
Indonesia, Bandung [3]	NR	None	Yes-Minimal	Face to face	1	17	1	No	NR	500	393	10	26	Yes
Russia, Togliatti (Platt et al. 2006) [12]	Injected drugs for non-medical purpose in past month; provide oral fluid sample for HIV test	Oral fluid for HIV	Yes	Face to face	3	15	0	Yes	None	450	450	12	3	NR
Vietnam, Hai Phong [15]	Injected drugs in past month; age ≥ 18 ; live and/or work in Hai Phong	Oral fluid for HIV	No	Face to face	4	20	1	No	\$4.00	400	417	7	12	Yes
Vietnam, Hanoi [15]	Injected drugs in past month; age ≥ 18 ; live and/or work in Hanoi	Oral fluid for HIV	No	Face to face	2	15	1	No	\$4.00	500	512	6	12	Yes

Table 2 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals		Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added	Primary	Secondary	Desired	Actual				
Vietnam, Ho Chi Minh City [15]	Injected drugs in past month; age ≥ 18; live and/or work in Ho Chi Minh City	Oral fluid for HIV	No	Face to face	4	20	1	No	3	\$4.00	\$1.50	400	420	7	12	Yes
2003																
Thailand, Bangkok (Wattana et al. 2007) [16]	Injected drugs in past 6 months; live in metropolitan Bangkok	None	NR	Face to face	4	16	NR	No	3	\$4.76	\$1.59	NR	963	16	16	Yes

^a Reported through October 1, 2007

Published references are in parentheses; numbers in square brackets refer to Appendix

Key: ACASI = audio computer-assisted self interview; CAI = computer-assisted interview, Chlamydia trachomatis; DBS = dried blood spot; HBV = hepatitis B virus; HBsAg = hepatitis B surface antigen; HCV = hepatitis C virus; HIV = human immunodeficiency virus, Neisseria gonorrhoeae; NR = not reported

for all studies was 9.2 waves (median 8.0, IQR 6.0–11.0, range 3–34).

The length of time for recruitment of subjects ranged from 2 to 56 weeks, with an average of 9.2 weeks (median 8.0 weeks, IQR 4.0–10.0). On average, studies recruited 41.0 (median 35.0, IQR 25.0–50.0) subjects per week or 6.4 subjects per seed per week (median 5.2, IQR 2.0–9.1). The recruitment process was relatively more productive in studies of IDUs (median of 7.5 recruits per seed per week), and slower in studies of MSM and SWs (3.6, z score 2.837, $P < 0.005$) and (3.5, z score 2.727, $P < 0.01$), respectively (Table 6). There was no significant difference in median recruits per seed per week between MSM and SW studies (z score 0.199).

In 91 studies with available data, design effects varied from 1.0 to 2.5; only 34 (38%) used a design effect of ≥ 1.5 when calculating sample sizes. One hundred eighteen (83%) studies reported their calculated sample size; the average was 280 and ranged from 100 to 800. One hundred eighteen (83%) studies also reported their final sample size, which ranged from 59 to 963 and averaged 273 (median 247.0, IQR 197–377.0). One hundred thirteen studies reported both calculated (desired) and final (recruited) sample sizes. Studies on average reached 98% of their intended sample size; studies among IDUs reached a greater proportion of their intended sample size (100.0%) than studies of SWs (97.0%) and MSM (94.0%). Thirteen studies (12%) failed to attain at least 90% of their intended sample size; 6 (46%) of these were MSM studies, 4 (31%) SW studies and three (20%) IDU studies. Eleven (85%) of these studies, nonetheless, reached equilibrium on at least one key variable of interest despite shortfalls in recruitment.

Of the 105 studies that reported whether or not they had reached equilibrium, 99 (94%) reached equilibrium and six (6%) had not. These six studies included four studies of IDUs and two studies of SWs. All four IDU studies attained intended sample sizes despite these two SW studies. Of the 18 studies that did not report whether or not they had reached equilibrium, 16 (89%) attained at least 90% of their intended sample size. All but two studies that completed data collection and attained their sample size used RDSAT software to adjust data for different social network sizes and recruitment patterns, and the other two used other methods of adjustment.

Discussion

We were able to identify 123 HIV biological and/or behavioral surveys that used RDS and were conducted

Table 3 HIV biological and behavioral studies that used RDS, men who have sex with men, 2004–2007^a

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals		Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added	referrals	Primary	Secondary	Desired	Actual			
2007																
Estonia, Tallinn [17]	Had oral or anal sex with a man in past 6 months; age ≥18; live and/or work in Tallinn	Venous blood for HIV, HBV, syphilis	Yes	SA	1	11	4	Yes	3	\$9.13	\$9.13	400	59	9	12	Yes
Indonesia, Bandung [3]	Had anal sex with a man in past 3 months; age ≥15; stayed in survey area past 30 days	Finger prick blood for HIV; urine and anal swabs	No	Face to face	1	8	0	No	3	\$4 + (\$3 transportation)	\$5	250	250	7	6	NR
Indonesia, Batam [3]	Had anal sex with a man in past 3 months; age ≥15; stayed in survey area past 30 days	Finger prick blood for HIV	No	Face to face	1	8	0	No	3	\$4 + (\$3 transportation)	\$5	250	250	7	6	NR
Indonesia, Malang [3]	Had anal sex with a man in past 3 months; age ≥15; stayed in survey area past 30 days	None	No	Face to face	1	5	0	No	3	\$4 + (\$3 transportation)	\$5	250	250	8	4	NR
Tanzania, Zanzibar [4]	Had anal sex with a man in past 3 months; age ≥15; live in Zanzibar	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	10	0	Yes	3	\$7.06; lowered to \$3.53	\$3.53; lowered to \$1.77	490	511	13	8	Yes
2006																
Bangladesh, Dhaka (Johnston et al. 2007) [18]	Had oral/anal sex with a man in past 3 months; did not sell sex; age ≥18; live and/or work in Dhaka	Venous blood for HIV, syphilis	Yes	Face to face	1	8	0	Yes	3	\$2.19	\$1.46	530	531	9	11	Yes
China, Beijing (Ma et al. 2007) [19]	Ever had sex with a man; age ≥16; live and/or work in Beijing	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	8	NR	Yes	3	None	\$2.30	NR	540	15	14	Yes
China, Guangzhou [19]	Reported oral/anal sex with a man in past 12 months; age ≥18; live in Guangzhou	Venous blood for HIV, syphilis	Yes	Face to face	1	NR	NR	NR	3	\$6.66	None	400	500	NR	28	Yes

Table 3 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds			Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added		Primary	Secondary	Desired	Actual			
China, Jinan [19]	Reported oral/anal sex with a man in past 12 months; age ≥ 18 ; live in Jinan	Venous blood for HIV, syphilis	Yes	SA	1	NR	NR	NR	3	\$4.00	None	400	460	NR	32	Yes
Croatia, Zagreb (Bozicevic et al. 2008; Stulhofer et al. 2007) [20]	Had anal sex with a man in past 12 months; age ≥ 18 ; live and/or work in Zagreb	Venous blood for HIV, HAV, HBV, HCV, HSV-2, CT, syphilis; urine, rectal swab for CT, NG	Yes	SA	1	10	2	Yes	3	\$19.30	\$9.58	400	360	13	14	Yes
Egypt, Alexandria [5]	Had sexual activities with other men in past 6 months	Venous blood for HIV	Yes	Face to face	1	32	19	Yes	3	\$7.22	\$5.42	406	267	3	10	Yes
Honduras, La Ceiba [21]	Had anal/oral sex with another man in past 12 months; age ≥ 18 ; live in metropolitan zone of La Ceiba	DBS, venous blood, rectal swab, urine for HIV, syphilis, CT, TV, NG, HSV2, MG, LGV	Yes	ACASI	1	9	0	Yes	3	Condoms and lubricants	Goods worth \$1.50–\$2.50	200	197	6	8	Yes
Honduras, San Pedro Sula [21]	Had anal/oral sex with another man in past 12 months; age ≥ 18 ; live in metropolitan zone of La Ceiba	DBS, venous blood, rectal swab and urine for HIV, syphilis, CT, TV, NG, HSV2, MG, LGV	Yes	ACASI	1	7	0	Yes	3	Condoms and lubricants	Goods worth \$1.50–\$2.50	200	204	9	8	Yes
Paraguay, Ciudad del Este [22]	Had sex with a man in past 12 months; age ≥ 16 ; reside in Ciudad del Este or neighboring cities; able to understand/ speak Spanish; willing to be tested for syphilis	Venous blood for HIV, syphilis	Yes	Face to face with hand-held assisted	1	6	1	Yes	3	\$6.50	\$3.50	403	296	22	24	Yes
Kosovo, Pristina [23]	Male–male sex	DBS and venous blood for HIV, HBV, HCV, syphilis CT, NG; swab for NG	No	NR	1	11	4	NR	3	\$14.29	\$7.14	200	69	NR	21	Yes
Ukraine, Cherkasu [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	100	100	NR	5	Yes

Table 3 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals		Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added	Primary	Secondary	Desired	Actual				
Ukraine, Dneprodzerjinsk [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	100	100	NR	4	Yes
Ukraine, Donetsk [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	200	200	NR	5	Yes
Ukraine, Ivan-Frankovsk [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	100	100	NR	6	Yes
Ukraine, Kherson [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	200	201	NR	4	Yes
Ukraine, Kiev [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	200	213	NR	9	Yes
Ukraine, Krivoy Rog [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	100	100	NR	5	Yes
Ukraine, Lugansk [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	150	149	NR	2	Yes
Ukraine, Nikolaev [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	200	201	NR	5	Yes
Ukraine, Odessa [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	200	200	NR	8	Yes
Ukraine, Simferopol [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	100	100	NR	5	Yes
Ukraine, Yalta [8]	Had oral/anal sex or touched another man's genitals in last 6 months	DBS for HIV	Yes	Face to face	1	NR	NR	NR	3	NR	NR	100	100	NR	2	Yes
2005 Albania, Tirana [10]	Had sexual activities with men in past year	Venous blood for HIV, HBV, syphilis	NR	Face to face	1	10–15	NR	NR	2	\$14.29	\$7.14	200	199	NR	8	NR

Table 3 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals		Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added	Primary	Secondary	Desired	Actual				
Brazil, Campinas [24]	Born male; had oral/ anal sex with a man or transvestite in past 6 months; age ≥15; reside in Metropolitan area of Campinas; willing to be tested for syphilis	Venous blood for HIV, syphilis	Yes	ACASI	1	30	8	Yes	3	Goods worth \$10	Goods worth \$5	800	658	23	56	Yes
Brazil, Fortaleza [25]	Had anal/oral sex with a man in past 12 months; age ≥14; live in Fortaleza metropolitan area	Venous blood for HIV	Yes	Face to face	2	10	0	No	4	\$6.00	\$5.00	380	406	11	6	Yes
Cambodia, Battambang [3]	Biological male; had insertive/ receptive anal intercourse in past 6 months; age ≥15; live in the survey city	Venous blood for HIV, syphilis, urine, rectal swabs	NR	Face to face	1	6	0	No	3	\$2	\$2	124	NR	5	10	NR
Cambodia, Phnom Penh [3]	Biological male; had insertive/ receptive anal intercourse in past 6 months; age ≥15; live in the survey city	Venous blood for HIV, syphilis, urine, rectal swabs	NR	Face to face	1	NR	0	No	3	\$3	\$3	300	300	6	10	Yes
Cambodia, Siem Reap [3]	Biological male; had insertive/ receptive anal intercourse in past 6 months; age ≥15; live in the survey city	Venous blood for HIV, syphilis, urine, rectal swabs	NR	Face to face	1	6	NR	No	3	\$2.00	\$2.00	124	NR	4	10	NR
China, Beijing [19]	Reporting ever had sex with a man; age ≥16; live and/or work in or near Beijing	Venous blood for HIV, syphilis	Yes	Face to face	1	10	NR	Yes	3	None	\$2.20	NR	427	15	14	Yes
Papua New Guinea, Port Moresby (Yeka et al. 2006) [26]	Had sex with a man in past 12 months; age ≥16; not drunk at time of interview	None	Yes	Face to face	1	10	5	No	3	\$6.00	\$3.00	200	225	NR	3	NR

Table 3 continued

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals		Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added	Primary	Secondary	Desired	Actual				
Vietnam, Hanoi [15]	Had sex with a man in past 12 months; age ≥ 15	DBS for HIV syphilis; urine, rectal swab for NG	Yes	Face to face	NR	NR	NR	NR	3	\$1.87–\$3.12	None	397	397	NR	10	Yes
Vietnam, Ho Chi Minh City [15]	Had sex with a man in past 12 months; age ≥ 15	DBS for HIV syphilis; urine, rectal swab for NG	Yes	Face to face	NR	NR	NR	NR	3	\$1.87–\$3.12	None	393	393	NR	10	Yes
2004																
Nepal, Katmandu [13]	Reported anal/oral sex with a man in past 12 months; age ≥ 16	None	No	Face to face	1	19	NR	No	3	NR	NR	350	358	4	NR	Yes
Uganda, Kampala (Kajubi et al. 2007) [27]	Self-identified gay/bisexual; age ≥ 18; live in Kampala	None	Yes	Face to face	NR	8	0	No	3	None	None	500	230	13	8	Yes

^a Reported through October 1, 2007

Published references are in parentheses; numbers in square brackets refer to Appendix

Key: ACASI = audio computer-assisted self-interview; CT = Chlamydia trachomatis; DBS = dried blood spot; HAV = hepatitis A virus; HBV = hepatitis B virus; HCV = hepatitis C virus; HIV = human immunodeficiency virus; HSV-2 = herpes simplex virus, type 2; I&E = information and educational materials; LGV = lymphogranuloma venereum; MG = Mycoplasma genitalium; NG = Neisseria gonorrhoeae; NR = not reported, SA = self-administered questionnaire; TV = Trichomonas vaginalis

Table 4 HIV biological and behavioral studies that used RDS, sex workers, 2004–2007^a

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed		Primary	Secondary	Desired	Actual			
2007															
Tanzania, Zanzibar [4]	Female; exchanged sex for money in past month with ≥ 1 man; age ≥ 15 ; live in Zanzibar	Venous blood for HIV, HBV, HCV, syphilis	Yes	Face to face	1	7	0	No	\$3.55	\$1.78	375	377	11	9	Yes
2006															
Honduras, Comayagua [21]	Female; exchanged vaginal/anal sex for money in past 12 months; age ≥ 18 ; live in metropolitan Comayagua city	DBS for HIV; venous blood for syphilis, HSV-2; vaginal swab for CT, TV, NG, BV, MG	Yes	ACASI	1	7	1	Yes	Carry purse worth \$2.00	T-shirt, phone card or pharmacy vouchers worth \$1.50–\$2.50	200	212	8	8	Yes
Honduras, La Ceiba [21]	Female; exchanged vaginal/anal sex for money in past 12 months; age ≥ 18 ; live in metropolitan La Ceiba city	DBS for HIV; venous blood for syphilis, HSV-2; vaginal swab for CT, TV, NG, BV, MG	Yes	ACASI	1	6	1	Yes	Carry purse worth \$2.00	T-shirt, phone card or pharmacy vouchers worth \$1.50–\$2.50	200	182	6	8	Yes
Honduras, San Pedro Sula [21]	Female; exchanged vaginal/anal sex for money in past 12 months; age ≥ 18 ; live in metropolitan San Pedro Sula city	DBS for HIV; venous blood for syphilis, HSV-2; vaginal swab for CT, TV, NG, BV, MG	Yes	ACASI	1	9	1	Yes	Carry purse worth \$2.00	T-shirt, phone card or pharmacy vouchers worth \$1.50–\$2.50	200	210	13	8	Yes
Honduras, Tegucigalpa [21]	Female; exchanged vaginal/anal sex for money in past 12 months; age ≥ 18 ; live in metropolitan Tegucigalpa city	DBS for HIV; venous blood for syphilis, HSV-2; vaginal swab for CT, TV, NG, BV, MG	Yes	ACASI	1	6	1	Yes	Carry purse worth \$2.00	T-shirt, phone card or pharmacy vouchers worth \$1.50–\$2.50	200	205	9	10	Yes
India, Dimapur District, Nagaland [6]	Female; sold sex for money in past month in Dimapur district; age ≥ 18 ; willing to give interview/provide blood/urine specimen	Venous blood for HIV, HSV2, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	2	10	3	Yes	\$2.02	\$0.76	400	426	14	8	Yes
India, Mumbai District, Maharashtra [6]	Female; sold sex for money in past month in Mumbai district; age ≥ 18 ; willing to give interview/provide blood/urine specimen	Venous blood for HIV, HSV2, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	5	9	NR	NR	\$2.53	\$1.27	400	393	14	12	Yes

Table 4 continued^a

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds			Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed	Added		Primary	Secondary	Desired	Actual			
India, Mumbai District, Maharashtra [6]	Female; sold sex for money in past month; age ≥ 18 ; works in bar in Mumbai; willing to give interview/ provide blood/urine specimen	Venous blood for HIV, HSV-2, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	3	NR	NR	NR	3	\$7.59	\$2.53	400	NR	NR	NR	Yes
India, Parbhani District, Maharashtra [6]	Female; sold sex for money in past month in Parbhani district; age ≥ 18 ; willing to give interview/ provide blood/urine specimen	Venous blood for HIV, HSV-2, syphilis; urine for NG, CT; swab external ulcer	Yes	Face to face	4	9	NR	NR	3	\$2.53	\$1.27	400	353	12	11	Yes
Paraguay, Ciudad del Este [22]	Female; exchanged sex for money/drugs/gifts in past 12 months; age ≥ 16 ; reside in Ciudad del Este or neighboring cities; speak Spanish; willing to be tested for syphilis	Venous blood for HIV, syphilis	Yes	Face to face	1	9	3	Yes	3	\$6.50	\$3.50	425	160	13	24	No
2005																
Brazil, Porto Alegre [28]	Male/female/ transgender; engaged in commercial sex in past month; age ≥ 18 ; work in Porto Alegre	None	Yes	Face to face	NR	13	1	Yes	3	\$5.00	\$5.00	381	190	6	20	No
Brazil, Santos [29]	Female; engaged in commercial sex in past month in Santos; age ≥ 18 ; willing to give blood for HIV testing	Venous blood for HIV	Yes	Face to face	3	10	2	Yes	3	\$5 in food stamps	\$5 in food stamps	200	303	5	20	Yes
China, Yangiang [19]	Female; reported being commercial sex worker at time of study; age ≥ 18 ; live in Yangiang	Venous blood for HIV	Yes	Face to face	1	NR	NR	NR	3	\$6.66	None	400	NR	NR	20	Yes
Papua New Guinea, Goroka (Yeka et al. 2006) [26]	Female; received money/ goods/services in exchange for sex in past 12 months; age ≥ 16 ; not drunk at time of interview	None	Yes	Face to face	1	6	5	No	3	\$3.00	\$1.50	200	249	NR	3	NR

Table 4 continued^a

Country, city, author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed		Primary	Secondary	Desired	Actual			
Papua New Guinea, Port Moresby (Yeka et al. 2006) [26]	Female; received money/goods/services in exchange for sex in past 12 months; age ≥ 16 ; not drunk at time of interview	None	Yes	Face to face	1	8	6	No	\$6.00	\$3.00	200	245	NR	2.5	NR
Serbia, Belgrade (Simic et al. 2006) [12]	Male/female; exchanged sex for drugs/money/other goods in past month; ≥ 18 ; live and/or work in Belgrade	DBS for HIV, HBV, HCV, syphilis	Yes	ACASI	1	15	3	Yes	\$14.30	\$7.15	400	209	8	8	Yes
2004															
Vietnam, Hai Phong (Johnston et al. 2006) [30]	Female; exchanged sex for money in past month; age ≥ 18 ; live and/or work in Hai Phong	Oral fluid for HIV	No	Face to face	3	20	5	No	\$3.00	\$1.00	200	215	6	12	Yes
Vietnam, Ho Chi Minh City (Johnston et al. 2006) [30]	Female; exchanged sex for money in past month; age ≥ 18 ; live and/or work in Ho Chi Minh City	Oral fluid for HIV	No	Face to face	4	20	4	No	\$4.00	\$1.50	400	413	7	12	Yes

^a Reported through October 1, 2007

Published references are in parentheses; numbers in square brackets refer to Appendix

Key: ACASI = audio computer-assisted structured interview; CT = Chlamydia trachomatis; DBS = dried blood spot; HBV = hepatitis B virus; HCV = hepatitis C virus; HIV = human immunodeficiency virus; HSV-2 = herpes simplex virus, type 2; I&E = information and educational materials; MG = Mycoplasma genitalium; NG = Neisseria gonorrhoeae; NR = not reported; TV = Trichomonas vaginalis; BV = bacterial vaginosis

Table 5 HIV biological and behavioral studies that used RDS, high-risk heterosexual men, 2006^a

Country, city author reference	Inclusion criteria	Biological sample	Formative research	Type of interview	Sites (N)	Seeds		Maximum referrals	Incentives		Sample size		Waves	Duration (weeks)	Equilibrium reached
						Total	Failed		Primary	Secondary	Desired	Actual			
2006															
South Africa, Western Cape (Johnston et al. 2008; Chopra et al. 2007) [31]	≥1 female sex partner <24 or ≥5 years younger in past 6 months; age ≥18; live and/or work in Khayelitsha	DBS for HIV	Yes	Face to face	2	20	6	Yes	\$8.87 phone card	\$2.96 phone card	430	421	9	16	Yes

^a Reported through October 1, 2007

Published references are in parentheses; numbers in square brackets refer to Appendix

Key: DBS = dried blood spot; HIV = human immunodeficiency virus

Table 6 Operational characteristics of HIV biological and behavioral studies that used RDS by study group, 2003–2007^a

	Injecting drug users (N = 65)			Men who have sex with men (N = 39)			Sex workers (N = 18)		
	Reported studies	Range	Mean (SD)	Median (IQR)	Reported studies	Range	Mean (SD)	Median (IQR)	Reported studies
Total seeds	59	2–28	9.4 (6.48)	8.0 (4.0–15.0)	22	5–32	11.1 (7.07)	9.5 (8.0–11.0)	16
Failed seeds	52	0–14	1.0 (2.61)	0 (0–1)	19	0–19	2.3 (4.65)	0 (0–4)	14
Failed/total seeds	51	0–0.9	0.1 (0.18)	0 (0.0–0.05)	19	0.0–0.6	0.1 (0.20)	0 (0.0–0.27)	14
Participants/seed/week	57	0.5–25	7.9 (5.55)	7.5 (3.10–11.11)	19	0.3–12.5	4.0 (3.04)	3.6 (2.06–6.03)	16
Actual/desired sample size	61	0.7–1.1	1.0 (0.59)	1 (1.0–1.02)	35	0.1–1.3	9.94 (0.22)	1.0 (1.00–1.01)	16

^a Studies conducted outside the United States only; excludes one study conducted in high-risk heterosexual men

outside the United States. The studies were conducted in 28 countries in five continents and had an average sample size of 273 participants. Over 32,000 IDUs, MSM, SWs and HRH men were surveyed in these 123 studies. We are also aware of at least 18 additional HIV biological and/or behavioral studies that, as of October 1, 2007, are being conducted around the world.

We found substantial methodological heterogeneity among the studies. The majority of the studies used formative research, face-to-face interview formats, three referrals per participant, a single interview site for data collection and biological specimens collected from participants, mostly for HIV but also for other sexually and parenterally transmitted infections. Types of sites, number of seeds and types of incentives varied. During data collection, some studies added seeds if recruitment slowed or seeds failed to recruit any peers. The use of some incentive was relatively constant across the studies, consistent with standard RDS methods.

Notably, we found that RDS has been somewhat more successful in IDU studies in terms of recruitment efficiency, as measured by the number of new participants referred per seed for week. Our findings show that RDS studies took 9 weeks to complete on average, but in some cases studies took as long as several months. This variation, however, can be explained; these studies had many differences (e.g., sample sizes, number of seeds, target populations) that would most likely affect the length of the study. Furthermore, investigators can manipulate the process to accelerate or slow recruitment for operational reasons (Johnston et al. 2007).

Our review is subject to several limitations. Like any systematic review, ours is limited by how complete our search was and how complete the reports were once we identified them. Although there may be a few studies that we were unable to find, we believe our search was comprehensive and complete to the greatest extent possible. We also found that many reports were missing key data, which introduced uncertainty into our calculations of average number of initial and added seeds, size of a design effect (if used), desired and recruited sample sizes, number of recruitment waves and sampling duration. Finally, our findings can be affected by multiple RDS studies using the

same RDS protocol but conducted in different cities within one country, such as occurred in Ukraine and India (Appendix: references 6, 8).

To assess whether any of these studies generated representative data, detailed information about the implementation and analytical characteristics of each RDS study is needed. In the future it may prove useful to establish certain key data that should be reported for each RDS study, as has been done for randomized controlled trials (Moher et al. 2001) and observational (Von Elm et al. 2007) and qualitative studies (Tong et al. 2007). In general, we suggest that RDS studies should report the following items: (1) whether formative research was conducted, the quality and quantity of such research, and whether the population under study was found to be socially networked; (2) comprehensive description of eligibility criteria; (3) how initial and replacement seeds were selected and how they were found; (4) the maximum number of allowable referrals per participants; (5) whether the recruiter–recruit relationship was tracked; (6) whether a design effect was used during calculation of sample size and the size of the design effect; (7) the sample size calculated versus the sample size attained; (8) the maximum number of recruitment waves attained; (9) length of time needed for data collection; (10) whether equilibrium was reached and for which variables; (11) how the sizes of participants' social networks were measured; and (12) whether survey data were adjusted using RDSAT or a similar software program.

Our review shows that RDS has been used widely for HIV prevalence and risk behavior surveillance in most-at-risk populations. When designed and conducted correctly, RDS is a valuable method for monitoring trends, better understanding epidemic dynamics and evaluating the effect of public health programs.

Acknowledgments **Disclaimer** The findings and conclusions in this paper are those of the authors and do not necessarily represent those of donor agencies. We would like to thank the individual investigators and organizations that generously shared their information with us or assisted in locating principal investigators (Appendix). We would like to extend our special gratitude to Family Health International; Centers for Disease Control and Prevention, Global AIDS Program; and the Eastern Mediterranean Regional Office of World Health Organization, which contributed to this project through sharing information from several studies.

Appendix

Resources used for Tables 2–5

Reference number	Data sources	Principal investigator or contact person	Organization/contact information	Related documents
1	Co-author personal involvement, study protocol, personal communication	Valerio Bacak	Knowledge Hub for Capacity Building in HIV/AIDS Surveillance, Andrija Stampar School of Public Health, University of Zagreb, Croatia	Protocol: Procjena prevalence HIV-a, HCV-a, HBV-a, sifilisa i rizičnog ponašanja u populaciji intravenoznih korisnika droga u Sarajevu, Banja Luci i Zenici. (2007). UNICEF BiH
2	Personal communication	Anneli Uusküla	Department of Public Health, University of Tartu, Estonia	Uusküla, A., Kals, M., Rajaleid K., Abel K., Talu, A., et al. (2008) High-prevalence and high-estimated incidence of HIV infection among new injecting drug users in Estonia: need for large scale prevention programs. <i>Journal of Public Health</i> . Advance Access published Feb. 28, 2008. pp. 1–7
3	Personal communication, unpublished paper	Guy Morineau	Family Health International, Jakarta, Indonesia	Platt et al. (2006) Cambodian studies were reported in: Morineau, G., Pisani, E., Neal, J. J., and Saphonn, V. (2007). Respondent driven sampling of men who have sex with men in Cambodia: is the bang worth the buck? Unpublished paper MSM studies in 2007 were conducted under: “Dr. Sigit Priohutomo, Centers for Disease Control and Prevention, Ministry of Health (MOH), Government of Indonesia, # 29, Pecetakan Negara, Jakarta, Indonesia
4	Co-author personal involvement, field notes, surveillance report	Mohammed J. Dahoma	Zanzibar AIDS Control Program, Ministry of Health and Social Welfare, Zanzibar, Tanzania	Protocol: Protocol for sampling sex workers, injection drug users and males who have sex with other males using respondent driven sampling in Zanzibar, Tanzania. (2007). Zanzibar, Tanzania: Zanzibar AIDS Control Programme, Ministry of Health and Social Welfare; Atlanta: Centers for Disease Control and Prevention, Global AIDS Program; New Orleans: Tulane University, School of Public Health and Tropical Medicine
5	Conference presentation, personal communication	Sherine Shawky	PI: Dr Nasr El Sayed Egyptian Ministry of Health and Population, Cairo, Egypt Dr. Sherine Shawky: Social Research Center, American University, Cairo, Egypt	Presentation: Behavioral and social sciences research on HIV/AIDS in the Middle East and North Africa. The Biological and Behavioral Surveillance Survey: The first round experience in Egypt (PowerPoint presentation). Tunis, Tunisia, May 1–3, 2007
6	Co-author personal involvement, personal communication	Ramesh Paranjap	National AIDS Research Institute, Bhosari, Pune, India	Protocol: Mapping, size estimation and integrated behavioral and biological assessment (IBBA) in high HIV prevalence settings in India. (2006)
7	Co-author personal involvement, field notes, study protocol	Mohsen Malekinejad	Iranian Research Center for HIV/AIDS (IRCHA), Tehran University of Medical Sciences, Tehran, Iran. Institute for Global Health, University of California, San Francisco, and University of California, Berkeley, School of Public Health, CA, USA	Protocol: HIV Prevalence and Risk Behavior among Injection Drug Users in Tehran, Iran. (2006). Eastern Mediterranean Regional Office of World Health organization. ID number: SGS06/67, EMRO/TDR Web Site: http://www.emro.who.int/tdr Malekinejad, M., Mohraz, M., Razai, N., Khairandish, P., McFarland, W., et al. (2008). Enhancing HIV surveillance capacity in Iran: Lessons learned from implementation of respondent-driven sampling (RDS) among injecting drug users. <i>Unite For Sight, Fifth Annual International Health Conference, Building Global Health For Today and Tomorrow</i> . Yale University, New Haven, Connecticut, USA. April 12–13, 2008

Appendix continued

Reference number	Data sources	Principal investigator or contact person	Organization/contact information	Related documents
8	Personal communication, final report	Olga Balakireva	Ukrainian Institute for Social Research, Kiev, Ukraine	Protocol: Risk and protective factors in the initiation of injecting drug use: report of a respondent driven sampling study and strategy paper on preventing the initiation of injecting drug use among vulnerable adolescents and young people. (2006). Olexander Yaremko Unkranian Institute for Social Research, Kiev, Ukraine
9	Personal communication	Vivian Hope	London School of Hygiene and Tropical Medicine, UK Matthew Hickman, University of Bristol, UK	
10	Surveillance report, personal communication	Roland Bani	National AIDS Program, Tirana, Albania	The Implementing AIDS Prevention and Care Project (IMPACT). (2005). 2005 Albania Behavioral and Biological Surveillance Study Report. I. Arlington, VA: Family Health International. Available at: http://www.fhi.org/en/HIV/AIDS/pub/surveys/res_BioBSS_Albania2005.htm . Access date: November 29, 2007
11	Published paper	Simon D. Frost	Department of Pathology and Antiviral Research Center, University of California, San Diego, CA, USA	Stromer et al. (2006) Frost et al. (2006) Pollini, R.A., Brouwer, C.B., Lozada, R.M., Ramos, R., Cruz, M.F. (2008) Syringe possession arrests are associated with receptive syringe sharing in two Mexico-US border cities. <i>Addiction</i> . 103: 101–108
12	Co-author personal involvement, personal communication, published paper, protocol	Lucy Platt, Tim Rhodes	Centre for Research on Drugs and Health Behavior, Department of Public Health and Policy, London School of Hygiene and Tropical Medicine, London, UK	Platt et al. (2006); Simic et al. (2006) Tkatchenko-Schmidt, E. (2006). Knowledge for Action in HIV/AIDS in the Russian Federation. London: Institute for Health and Human Development, University of East London. Available at: http://www.uel.ac.uk/ihhd/programmes/RussiaKP.htm . Access date: November 29, 2007
13	Personal communication, personal notes, brief conference abstract	Laxmi Bilas Acharya	Family Health International, Katmandu, Nepal	Acharya, L.B., Dhungel, N., and Ross, J.L. (2004). Factors associated to HIV prevalence among male IDUs in the Eastern Terai of Nepal? [Abstract C11318]. International AIDS Conference, Bangkok, Thailand, July 11–16, 2004
14		Zinaida Bodanovskaia	St-Petersburg Non-Governmental Organization of Social Projects "Stellit", St. Petersburg, Russia	Stromer et al. (2006)
15	Surveillance report	Trinh Quan Huan	Ministry of Health. Hanoi, Vietnam	Ministry of Health. (2006). Results from the HIV/STI Integrated Biological and Behavioral Surveillance (IBBS) in Vietnam 2005–2006. Hanoi, Vietnam: National Institute of Hygiene and Epidemiology; Arlington, VA: Family Health International
16	Published paper	Wantanee Wattana	Bangkok Metropolitan Administration, Bangkok, Thailand	Wattana et al. (2007)
17	Co-author personal involvement, final report	Aire Trummal	National Institute for Health Development, Tallinn, Estonia	Final report: Trummal, A., Johnston, L.G., & Lohmus L. (2007). Men having sex with men in Tallinn: pilot study using respondent driven sampling. Final study report. National Institute for Health Development. Tallinn, Estonia

Appendix continued

Reference number	Data sources	Principal investigator or contact person	Organization/contact information	Related documents
18	Co-author personal involvement, field notes, published paper	Tasnim Azim	HIV/AIDS Programme, ICDDR,B, Dhaka, Bangladesh	Johnston et al. (2007)
19	Personal communication and published paper	Jinkou Zhao	Centers for Disease Control and Prevention Global AIDS Program, Beijing, China. Also, Dr. Willi McFarland at San Francisco Department of Public Health, San Francisco, CA, USA	Ma et al. (2007)
20	Co-author personal involvement, personal communication	Ivana Bozicevic	Andrija Stampar School of Public Health, University of Zagreb, Zagreb, Croatia	Bozicevic et al. (2008) Stulhofer et al. (2007)
21	Co-author personal involvement, personal communication, final report	Morales-Miranda Sonia	Centers for Disease Control and Prevention, Global AIDS Program, Office for Central America and Panama, Guatemala City, Guatemala	Reporte final: Estudio centroamericano de vigilancia de comportamiento sexual y prevalencia de VIH/TTS en poblaciones vulnerables: hombres que tienen sexo con hombres. (2007). Guatemala City, Guatemala: Centers for Disease Control and Prevention, Global AIDS Program, Office for Central America and Panama
22	Personal communication		Chinaglia, MLM, Reprolatina Solucoes Inovadoras em Saude Sexual e Reprodutiva Rua Maria Tereza da Silva, 740, Campinas 13083-820 Brazil	
23	Personal communication, final report	Edona Deva	Bio-BSS Principal Investigator and Kosovo AIDS Committee, Ministry of Health, Pristina, Kosovo, Serbia	The Implementing AIDS Prevention and Care Project (IMPACT). (2006). Behavioral and Biological Surveillance Study Kosovo, February 2006–July 2006. Arlington, VA: Family Health International. Available at: http://www.fhi.org/en/HIV/AIDS/pub/res_IMPACT+Kosovo+Final+Report.htm . Access date: November 29, 2007
24	Personal communication, study protocol (Campinas, Brazil)	Maeve Mello	Oswaldo Cruz Foundation – FIOCRUZ, Rio de Janeiro, Brazil; Programa Nacional de DST/Aids, Brasilia, Brazil; Centers for Disease Control and Prevention, Global AIDS Program, Brasilia, Brazil	Protocol: Risk factors for HIV infection in the MSM and transgender populations in the Metropolitan Area of Campinas city, Brazil, using Respondent-Driven Sampling (Sept 2005–Feb 2007)

Appendix continued

Reference number	Data sources	Principal investigator or contact person	Organization/contact information	Related documents
25	Co-authors personal involvement, field notes, unpublished paper	Ligia Regina Franco Sansigolo Kerr	Federal University of Ceará, Medical School, Fortaleza, Brazil; Programa Nacional de DST/Aids, Brasília, Brazil; Centers for Disease Control and Prevention, Global AIDS Program, Brasília, Brazil	Kendall, C., Kerr, L.R.F.S., Gondim, R.C., Werneck, G.L., Hermelinda, R., et al. (2007). An empirical comparison of respondent-driven sampling, time location sampling, and snowball sampling for behavioral surveillance in men who have sex with men, Fortaleza, Brazil. Unpublished paper
26	Published paper, personal communication	Geraldine Maibani	Papua New Guinea Institute of Medical Research, Goroka, Papua New Guinea	Yeka et al. (2006)
27	Co-author personal involvement, published paper	Willi McFarland	San Francisco Department of Public Health, San Francisco, CA, USA	Kajubi et al. (2007)
28	Personal communication	Cíntia Germany	Centro de Estudos de Aids/DST do Rio Grande do Sul, Porto Alegre, Brazil; Programa Nacional de DST/Aids, Brasília, Brazil; Centers for Disease Control and Prevention, Global AIDS Program, Brasília, Brazil	
29	Personal communication	Neide Gravato da Silva	Associação Santista de Pesquisa Prevenção e Educação em DST/Aids, São Paulo, Brazil; Programa Nacional de DST/Aids, Brasília, Brazil; Centers for Disease Control and Prevention, Global AIDS Program, Brasília, Brazil	Johnston et al. (2006)
30	Co-author personal involvement, field notes, unpublished and published papers, conference abstract (IDU, 2004)	Luu Thi Minh Chau	Ministry of Health, Hanoi, Vietnam, and Centers for Disease Control and Prevention, Global AIDS Program, Hanoi, Vietnam	Johnston, L.G., Huong, P.T., Hien M.T., Chau L.M., Hau D.H. HIV prevalence and risk factors among injecting drug users in Ho Chi Minh City, Vietnam. 16th Annual International Conference for the reduction of Harm among Injecting Drug Users. Abstract 910, p. 111 March, 2005, Belfast, Ireland
31	Co-author personal involvement, field notes, unpublished paper	Mickey Chopra	Medical Research Council, Cape Town, South Africa	Johnston, L.G., O'Bra, H., Chopra, Mathews, C., Townsend, L., Sabin, K., Tomlinson M., Kendall, C. (2008). The associations of HIV risk perception and voluntary counseling and testing acceptance to HIV status and risk behaviors among men with multiple sex partners in a South African township. AIDS and Behavior [in press] Chopra et al. (2007)

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