Exploring The Relative Costs of Contact Tracing for Increasing HIV Case Finding in Sub-Saharan Countries

Benjamin Armbruster, PhD, Stephane Helleringer, PhD,† Linda Kalilani-Phiri, PhD, MBChB,‡ James Mkandawire, BSN,§ and Hans-Peter Kohler, PhD||*

Background: Contact tracing (CT) has rarely been used to improve HIV case finding in sub-Saharan Africa because of concerns regarding privacy protection and possibly high costs.

Methods: We estimate the relative cost of identifying an undiagnosed HIV infection through CT compared with client-initiated voluntary counseling and testing (VCT) and door-to-door provider-initiated testing (PIT). We used data from the Likoma Network Study, a study of sexual networks and HIV infection conducted on the small island of Likoma in northern Malawi, to inform these calculations.

Results: In Likoma, the probability that partners of HIV index cases could be traced and that they would consent to HIV testing and counseling was high and varied by partner type. HIV prevalence ranged from 48.1% to 66.7% among the partners who were tested. CT is rarely a cheaper casefinding approach than VCT in populations with HIV prevalence > 5%. In populations with HIV prevalence < 5%, CT is an attractive case-finding approach relative to VCT when few HIV-infected individuals are aware of their status. Compared with door-to-door PIT, CT is almost always preferred when the population prevalence is below 10%, unless CT costs are prohibitively high. When HIV prevalence is >10%, providing CT for current spouses of index cases remains an attractive approach to HIV case finding.

Conclusions: CT could complement client-initiated VCT or door-to-door PIT in a large number of sub-Saharan populations affected by generalized epidemics of varying magnitudes.

Key Words: contact tracing, cost analysis, HIV prevention, HIV testing, Malawi, screening

(*J Acquir Immune Defic Syndr* 2011;58:e29–e36)

Received for publication March 24, 2011; accepted June 22, 2011.

From the *Department of Industrial Engineering and Management Sciences, Northwestern University, Evanston, IL; †Columbia University Mailman School of Public Health, New York, NY; ‡Division of Community Health, University of Malawi College of Medicine, Blantyre, Malawi; §Population Studies Center, University of Pennsylvania, Philadelphia, PA; and ||University of Malawi College of Medicine, Blantyre, Malawi.

Supported through the National Institute of Child Health and Development (grant nos. RO1 HD044228 and RO1 HD/MH41713), National Institute on Aging (grant no. P30 AG12836), the Boettner Center for Pensions and Retirement Security at the University of Pennsylvania, and the National Institute of Child Health and Development Population Research Infrastructure Program (grant no. R24 HD-044964), all at the University of Pennsylvania.

The authors S.H. and H.P.K. designed the study; B.A., S.H. analyzed the data; S.H. and J.M. collected data for the study; B.A. and S.H. designed and conducted mathematical modeling; J.M. supervised HIV testing procedures; B.A. and S.H. produced first draft of the article; H.P.K., J.M., and L. K.P. reviewed, edited, and approved the article; S.H. guarantor.

The authors have no conflicts of interest to disclose.

The Likoma Network Study was approved by the ethical review boards of the University of Malawi College of Medicine (COMREC) and the University of Pennsylvania. All study participants provided informed consent before participation.

The study sponsors did not play any role in the design, implementation, and analysis of the study.

Correspondence to: Stephane Helleringer, PhD, Columbia University Mailman School of Public Health, New York, NY (e-mail: sh2813@columbia.edu).

INTRODUCTION

Despite a significant scale-up of HIV testing and treatment services,[1–5] the majority of HIV-infected individuals in sub-Saharan Africa (SSA) remain unaware of their infection.[6] Current approaches to increasing the capacity to detect undiagnosed HIV infections consist of expanding access to client-initiated voluntary counseling and testing (VCT[7,8]), and provider-initiated approaches such as routine testing in clinical settings[9–11] and door-to-door HIV testing.[12–15] All these strategies involve encouraging all members of a target population to get tested, even in the absence of signs of the disease. Contact tracing (CT, also known as provider-initiated partner notification) is another approach to increasing HIV case finding. During CT, a health provider first elicits the number and location of the sexual partners of HIV index cases (ICs), and then seeks to inform locatable partners about their possible exposure to infection and the need for HIV testing and counseling, prevention and possibly treatment. In developed settings with concentrated HIV epidemics, CT is frequently conducted by health services,[16,17] but it has generally not been practiced in SSA.

This has been the case because of (1) concerns about privacy and potential for harm for CT participants, (2) lack of proven interventions to reduce HIV transmission among couples reached through CT,[18] and (3) perceptions of CT as possibly expensive in settings of intense migration, where partners may be difficult to trace due to lack of specific contact information (eg, no street names). The former 2 obstacles to the use of CT are increasingly being eroded in SSA. Recent work in ethics has placed emphasis on the responsibilities of sexual partners to inform each other about potential exposures to lethal diseases.[19–21] Effective approaches to preventing HIV transmission have also recently become available. In particular, HIV transmission is considerably reduced (if not interrupted) in serodiscordant couples when ICs are put on antiretroviral treatment.[22] Two recent pioneering trials of CT conducted in Malawi[23] and Cameroon[24] further indicate that obstacle (3) may also have been exaggerated. Both trials found that CT was feasible, acceptable, generated few adverse events, and increased the number of HIV diagnoses.

It remains however unknown whether the resources (human and material) needed to conduct CT in SSA populations are commensurate to the benefits of CT.[25] CT likely requires investments in time and training of health personnel and upgrading of health information systems to guarantee confidentiality of patient information. By identifying additional undiagnosed HIV infections, it also leads to increased treatment costs. On the other hand, CT could also generate large savings by averting new HIV infections. Whereas estimates of the cost of existing testing strategies are widely available for sub-Saharan countries,[13] at present, there are no data available on the costs of a CT program for HIV in SSA.[25] As a result, a full assessment of the cost-effectiveness of CT is not feasible.

In this article, we thus do not consider treatment costs and potential benefits due to infections averted through CT. Instead, we focus on the costs incurred by health services to detect a single previously undiagnosed HIV infection (case finding). CT could be a cheaper case-finding approach in SSA than existing strategies, if its costs are low or its "yield", that is, the proportion of newly diagnosed HIV cases among the partners of an IC sought by a health provider, is high. The yield of CT is a function of the probability that a sexual partner is infected and has yet to be diagnosed. It also depends on the ease of locating that partner and the provider's ability to gain consent for testing from him/her. Unfortunately, outside of the 2 recent trials of CT, the data on such parameters is lacking for sub-Saharan populations, particularly in more remote rural areas.

We use simple calculations to investigate the relative costs of CT versus other testing approaches in detecting undiagnosed HIV cases in SSA populations, under a broad range of epidemiological and service provision conditions.

METHODS

Cost Calculations

General Approach

We examine the relative costs of CT compared with (1) client-initiated VCT and (2) provider-initiated testing (PIT) in identifying an undiagnosed HIV infection. Among PIT strategies, we only consider the case of door-to-door testing, in which health providers attempt to visit every household in a population to offer HIV testing and counseling.[12–14,26] We conduct cost calculations from a provider's perspective. We define the yield of CT (noted q) as the proportion of initiated partners who become newly diagnosed HIV cases.[27] The yield is a function of the probability of successfully locating (ie, tracing) a partner ("tracing probability" thereafter, noted t), the probability that the traced partner will accept to be tested ("testing probability" thereafter, noted h), the prevalence of HIV among tested partners ("partner prevalence" thereafter, noted i) and the proportion of traced partners already aware of their possible infection, noted a_{CT}. As a result,

$$q = t \cdot h \cdot i \cdot (1 - a_{CT}) \tag{1}$$

We call C the unit cost of tracing and providing HIV testing and counseling to a sexual partner. Thus the cost of finding an undiagnosed HIV infection through CT is C/q.

In a population with prevalence p, the prevalence of undiagnosed HIV infection among users of other testing services (eg, PIT or VCT) is

$$p' = (1 - a_T) \cdot \delta(p) \tag{2}$$

where a_T is the proportion of infected users already aware of their infection and δ corrects for the selective use of testing services in the population (see below). The average cost of finding an undiagnosed infected person through other testing strategies is S/p', where S is the cost of providing testing services to 1 client.

As mentioned above, S and C do not include treatment costs and savings generated from prevented infections. We estimate t, h, and i from the Likoma Network Study (LNS) data (see below). In the LNS, a is unknown and we treat a as a varying parameter. Identifying an undiagnosed infection through CT is cheaper than doing so through other testing strategies when $C/q < S/p'$. Thus at the break-even point, the relative cost of contact tracing, C/S equals q/p'. We conduct these calculations for each type of sexual partner: current spouses, former spouses, and nonmarital partners. We plot the break-even relative cost of contact tracing, C/S, as a function of q and p. Below the curve, CT is cheaper, and above, it is more expensive.

Contact Tracing Versus Client-Initiated Testing

In comparing CT with client-initiated VCT, we assume that previously diagnosed HIV cases do not seek VCT again after diagnosis, ie, $a_T = 0$ (we ignore possible confirmatory testing of a previous diagnosis). On the other hand, $a_{CT} \neq 0$. We thus consider 2 scenarios: a high awareness scenario in which 80% of HIV-infected individuals are aware of their infection ($a_{CT} = 0.8$) and a "low awareness scenario" in which 20% of HIV-infected individuals are aware of their infection ($a_{CT} = 0.2$). Individuals in SSA tend to seek VCT once they have shown signs of the disease or after they have taken particular risks. As a result, the prevalence of HIV among users of testing services can be significantly larger than in the general population. We use data from Menzies et al[13] to estimate $\delta(p)$. In this study, the odds of HIV infection among VCT clients were 4.4 times larger than among the general population. Thus we define $\delta(p)$ so that $\delta(p)/(1-\delta(p)) = 4.4 \cdot p/(1-p)$.

Contact Tracing Versus Provider-Initiated Testing

In comparing CT with door-to-door PIT, we assume for simplicity that $\delta(p) = p$, that is, that the prevalence of HIV among those who test reflects the underlying population prevalence. In door-to-door PIT, health workers will also contact clients who are already aware of their infection. We thus assume that $a_{CT} = a_T$, i.e., the proportion of HIV-positive partners/clients contacted during CT or PIT who are aware of their infection is the same. As a result, the relative costs of CT versus PIT in detecting undiagnosed infections do not depend on the proportion of infected population members who are aware of their status.

Contact Tracing Parameters in a Remote Sub-Saharan Setting

Data Source

We use data collected on Likoma—a remote island of Lake Malawi—[28,29] to estimate some of the parameters in equation 1. The data analyzed in this article were collected in 2007/2008. They were not collected in a public health setting, but the LNS data collection emulates the steps of the CT process with some notable differences (see below). We first constructed a roster of the adult population of Likoma during a census. Inhabitants aged 18–49 were then asked to provide the names and characteristics of up to 5 of their most recent sexual partners (starting with the most recent) during audio computer–assisted interviews. Based on this information, we attempted to locate each nominated partner in the preestablished rosters of the island population. Home-based HIV testing and counseling was offered to island inhabitants aged 18–49 years old.

Parameter Estimates

We refer to all HIV+ respondents identified during the course of the LNS as "ICs". Some nominated sexual partners of ICs were not "initiated",[27,30]—that is, we did not attempt to locate them in the island roster—because the IC reported that their partner was dead, was outside of the 18–49 years old range, or resided outside of the LNS study area. All other partners were initiated. The partner of an IC was "traced" when s/he was identified in the island roster.

Based on this information, we measure the tracing probability (t) as the number of traced partners divided by the total number of initiated partners. We then estimate the testing probability (h) as the proportion of traced partners consenting to HIV testing and counseling during the LNS. Finally, we estimate partner prevalence (i) as the proportion of partners who tested positive among all partners tested during the LNS.

The LNS data differ from data on CT conducted in public health settings in several key ways. First, some partners elicited during the LNS would not be elicited during CT (eg, deceased partners). Second, in the LNS, sexual partners are not contacted directly by health workers on the basis of information provided by ICs. Instead, they are approached by the study team solely because they reside in study villages.[29] We obtain linked partner data, only indirectly, by matching nominations made by ICs to the island population roster.

Covariates

The LNS survey measured several characteristics of respondents, partners, and their relationships. Respondent characteristics included age (younger than 30 years, 30–39, 40 years old and older), marital status (never married, currently married, widowed, divorced/separated), self-rated health (measured as a score ranging from 1 = excellent to 5 = poor), alcohol consumption (1 = consumes alcohol more than once a week, 0 = consumes alcohol only once a week or less), and self-reported antiretroviral (ARV) treatment. Sexual partners were classified into current spouses, former spouses, and nonmarital partners on the basis of reports from the IC. Relationship characteristics analyzed included date of last sex with a given partner (within last month > 1 month but < 1 year ago, and > 1 year ago), reported partnership concurrency (whether the IC or the partner had other partner(s) at the time of the relationship), and coresidence of partners in the same household. Partnership concurrency was assessed directly[31,32] by asking ICs whether themselves or their partner had other partners at any time during the course of their relationship.

TABLE 1. Characteristics and Behaviors of HIV-Infected Respondents Reporting at Least One Sexual Partner

	Women (n = 138)	Men (n = 56)
Background characteristics		
First tested positive by the LNS* in		
2005/06	33 (23.9%)	6 (10.7%)
2007/08	105 (76.1%)	50 (89.3%)
Age		
<30 years old	54 (39.1%)	13 (23.2%)
30–39 years old	59 (42.8%)	20 (35.7%)
≥40 years old	25 (18.1%)	23 (41.1%)
Marital status		
Never married	21 (15.1%)	8 (14.3%)
Currently married	69 (49.6%)	43 (76.8%)
Divorced/separated	25 (18.0%)	2 (3.6%)
Widowed	22 (15.8%)	3 (5.3%)
Number of reported sexual partners		
Number of reported current spouses		
0	84 (60.9%)	22 (39.3%)
1	54 (39.1%)	32 (57.1%)
2	—	2 (3.6%)
Number of reported former spouses		
0	79 (57.3%)	41 (73.2%)
1	54 (39.1%)	13 (23.2%)
2	5 (3.6%)	1 (1.8%)
3	—	1 (1.8%)
Number of reported nonmarital sex partners		
0	62 (44.9%)	23 (41.1%)
1	44 (31.9%)	15 (26.8%)
2	19 (13.8%)	10 (17.9%)
3	9 (6.5%)	6 (10.7%)
4	4 (2.9%)	2 (3.6%)
Health and risk behaviors		
General health		
Average score (1 = excellent, 5 = poor)	2.41 (1.38)	2.24 (1.28)
Alcohol consumption		
Several times a week	15 (10.8%)	23 (41.1%)
ARV treatment		
Reports being on ARV treatment	15 (10.8%)	8 (14.3%)

*First HIV diagnosis could have taken place earlier.
Source: Likoma Network Study (2007–2008).

RESULTS

Descriptive Statistics

We interviewed 194 HIV cases during the LNS in 2007/2008 (Table 1). Most HIV ICs were women, and first tested positive during the LNS in 2007/2008. The average age of female ICs was lower than that of male ICs. Male ICs were more likely to report having a current marital partner, whereas female ICs were more likely to report having former spouses (due to divorce or widowhood). Polygamy was uncommon among male ICs (2 of 56, 3.6%). Finally, males were more likely to report nonmarital partners. Female ICs were less likely to report frequent alcohol consumption. Between 10% and 15% of ICs reported being on ARV treatment.

ICs reported 357 relationships, with 343 unique partners (Table 2). Ninety-one relationships were with current spouses (25.5%), 82 were with former spouses (23.0%), and 184 were nonmarital relations (51.5%). More ICs had sexual intercourse recently with their current spouses than with other types of partners. Partnership concurrency was prevalent in all types of partnerships, with 20.2% of ICs and close to 30% of partners reported to have been engaged in concurrency at the time of the relationship. ICs resided with 73% of their current spouses, whereas only 3.6% of divorced spouses and 2.4% of nonmarital partners lived in the IC's household.

CT Parameters

Twenty-seven (32.9%) former spouses and 14 (7.6%) nonmarital partners were not initiated because they were reported as deceased (lower panels of Table 2). Virtually, no current spouses resided outside of the island, but this was the case for 18.3% and 34.2% of former spouses and nonmarital partners, respectively. Between 7% and 12% of partners were not initiated because they were not eligible for HIV testing due to age restrictions. In total, 90.1% (82 of 91) of current spouses were initiated versus 46.3% (38 of 82) and 53.3% (98 of 184) of former spouses and nonmarital partners, respectively. Among those initiated, the tracing probability was highest for current spouses and was lowest for nonmarital partners: only 2.4% (2 of 82) of current spouses initiated by the study team could not be traced compared with 38.8% (37 of 98) of nonmarital partners. The testing probability was high among all traced partners, with 68.9%–83.3% of partners consenting to HIV testing and counseling when offered by the study team.

Partner prevalence was also high in all types of relationships (Fig. 1): 42 of the 63 current spouses of HIV infected respondents (66.7%), 13 of the 27 former spouses (48.1%) and 24 of the 44 non-marital partners (54.5%) were themselves infected with HIV. The prevalence of HIV among tested partners did not vary by gender of the IC except in non-marital relations: 16 out of 22 tested non-marital partners of male ICs vs. 8 out of 23 non-marital partners of female ICs were infected with HIV ($p = 0.02$ according to Fisher's exact test).

Cost Calculations

In all the scenarios and comparisons, we consider (Fig. 2), the attractiveness of CT as a case-finding approach is highest for current spouses followed by former spouses and

TABLE 2. Characteristics of Relationships Reported by HIV-Infected Respondents

	All Partners (n = 357)	Current Spouses (n = 91)	Former Spouses (n = 82)	Nonmarital Relations (n = 184)
Characteristics of the relationship				
Date of last sexual intercourse				
Within last month	114 (32.0%)	71 (78.9%)	12 (14.6%)	31 (17.0%)
Within last year	63 (17.7%)	9 (10.0%)	21 (25.6%)	33 (18.1%)
More than a year ago	177 (49.7%)	10 (11.1%)	49 (59.8%)	118 (64.8%)
Partnership concurrency				
IC	72 (20.2%)	23 (25.3%)	13 (15.8%)	36 (19.6%)
Partner	105 (29.6%)	30 (33.0%)	15 (18.3%)	60 (33.0%)
Residence of the partner				
Same household as respondent	73 (23.0%)	67 (73.6%)	2 (3.6%)	4 (2.4%)
CT outcomes				
Not initiated because deceased	41 (11.5%)	—	27 (32.9%)	14 (7.6%)
Not initiated because does not reside on the island	79 (22.1%)	1 (1.1%)	15 (18.3%)	63 (34.2%)
Not initiated because not eligible for LNS	19 (5.3%)	8 (8.8%)	2 (2.4%)	9 (4.9%)
Total initiated	218 (61.1%)	82 (90.1%)	38 (46.3%)	98 (53.3%)
Total traced (tracing probability*, t)	172 (78.9%)	80 (97.6%)	31 (81.6%)	61 (62.2%)
HIV testing and counseling outcome of the partner†				
Tested and counseled (testing probability†, h)	127 (78.9%)	60 (75.0%)	25 (83.3%)	42 (68.9%)
Counseled but refused test	3 (1.7%)	—	—	3 (4.9%)
Refused HIV testing and counseling	19 (11.0%)	10 (12.5%)	1 (3.2%)	8 (13.1%)
Absent at time of visit(s)	23 (13.4%)	10 (12.5%)	5 (16.1%)	8 (13.1%)

For some variables, missing data implies that the counts do not sum up to the total in the column header.
*Among initiated partners.
†Among traced partners.
Source: Likoma Network Study (2007–2008).

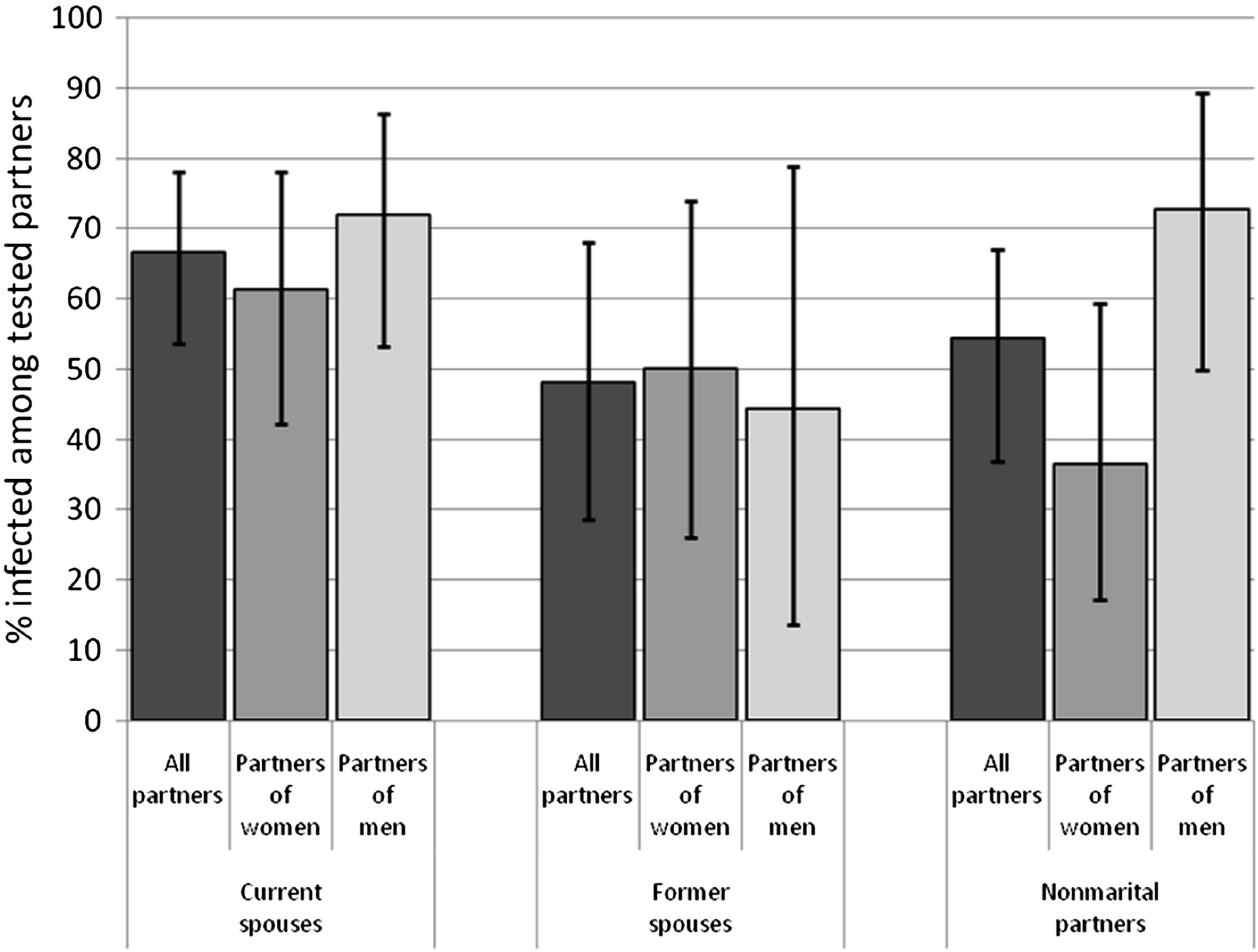

FIGURE 1. HIV prevalence among traced partners of HIV-seropositive respondents, Source: Likoma Network Study, 2007–2008. Error bars show 95% CI.

nonmarital partners. It also decreases when the prevalence of HIV in the population increases. Compared with VCT (solid lines), providing CT is rarely the cheapest case-finding approach in populations with high HIV status awareness, at any level of HIV prevalence. In populations with low HIV status awareness, on the other hand, the relative costs of CT versus VCT increase sharply when the prevalence of HIV declines below 5%. In a population with 2% HIV prevalence and low HIV status awareness, for example, CT would be the cheaper case-finding approach even if its costs were up to 2–4.5 times higher than the costs of providing VCT, depending on the type of partner to be traced.

Compared with door-to-door PIT, CT is much more commonly an attractive option for HIV case finding. Below 5% prevalence in the population, CT is almost invariably preferred to PIT unless its costs are more than 4–9 times higher than the costs of PIT. In a population with HIV prevalence $\approx$ 10%, CT would be a cheaper case-finding approach than door-to-door PIC even if CT costs were up to 2–5 times larger than the costs of PIC. In populations with prevalence above 10%, providing CT remains an attractive approach for current spouses, even at high levels of relative costs ($>$2). Providing CT for nonmarital partners and former spouses would be a cheaper case-finding approach than PIT only if the relative costs of CT versus door-to-door PIC are below 2.

DISCUSSION

Using parameter estimates derived from the LNS, in conjunction with simple calculations, we showed that CT could be a cheaper approach to detecting an undiagnosed HIV infection than both client-initiated VCT and door-to-door PIT strategies in a large number of rural sub-Saharan populations affected by generalized epidemics. This was particularly true in populations with low to moderate HIV prevalence (ie, countries of western, central, and eastern Africa). In these settings, CT would be cheaper than PIT unless the costs of CT

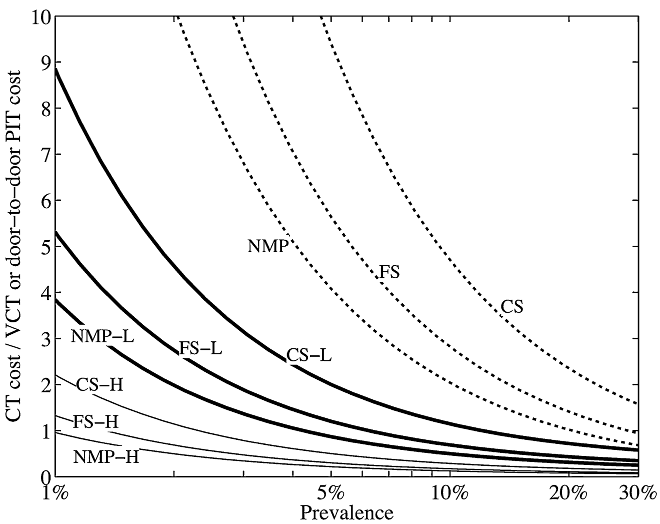

FIGURE 2. Relative cost of providing contact tracing for different types of sexual partners. Below the curve, CT is cheaper than VCT or PIT; above the curve, CT is more expensive. The dotted curves represent PIT (eg, door-to-door testing); the thick solid curve represent low awareness scenarios of VCT; and the thin solid curves represent high awareness scenarios of VCT. CS, current spouse; FS, former spouse; and NMP, nonmarried partners, respectively.

TABLE 3. Strategies Available to Improve HIV Case Finding

In Seeking Undiagnosed HIV Patients	Health Providers are Passive	Health Providers are Active
HIV IC are passive	Stand-alone VCT (spontaneous presentation)	Door-to-door testing routine "opt-out" testing
HIV ICs are active	Partner disclosure couples' counseling and testing	CT (provider-initiated partner notification)

are prohibitively high. CT would also be cheaper than VCT in settings where awareness of HIV status is low. In the most afflicted populations (eg, southern Africa), CT is unlikely to be a cheaper case-finding approach than VCT unless CT costs are comparable with (or even lower than) the costs of VCT. CT remains a cheaper case-finding approach than provider-initiated strategies, even at high costs levels, when it is offered for current spouses of HIV ICs. CT could thus complement existing strategies used by health services for HIV case finding.

Our results suffer from important limitations. First, our analysis does not constitute an assessment of the cost-effectiveness of CT. It does not take into account treatment costs associated with increased case finding or potential savings stemming from averted infections. Even if partners are traced only after they have already been infected by the IC, CT can lead to identifying undiagnosed HIV cases earlier than waiting for infected persons to spontaneously present for testing. This aspect is not considered in our calculations. Second, our estimates of CT parameters were obtained using research data rather real-life data obtained in a public health setting. In the LNS, partners of HIV ICs were not directly approached by health workers, but rather their location and HIV status were indirectly obtained by data linking procedures.[29] The effectiveness of CT in public health settings could be significantly lower if (1) health workers have less information on the members of their catchment population than was available to LNS researchers; (2) health workers elicit systematically lower numbers of partners from their patients because they cannot use audio computer–assisted interview techniques or do not have time to establish trust and rapport with them during the provision of care; or (3) health workers have less time to devote to CT than LNS study team members. However, the effectiveness of CT in a public health setting could also be higher if health workers can employ more aggressive tracing strategies based on local inquiries with neighbors and relatives, use of mobile phones, etc. In the LNS, if a nominated partner could not be identified in the preestablished island roster using information reported by respondents, no further inquiries were made.[29]

Third, we did not consider that the potential effectiveness of CT in identifying undiagnosed infections could be lower if ICs preferentially refer to testing their partners who have already been tested elsewhere and are aware of their HIV status. There are unfortunately no data on this parameter in the LNS or in the study of Brown et al in Lilongwe.[23] Fourth, because the study was conducted in a remote island setting, it may also have overestimated the proportion of partners who are actually traceable. In more accessible mainland settings, individual sexual networks may extend well beyond neighboring villages and a smaller proportion of one's partners may thus be locatable. Because the estimated relative costs of CT versus both client-initiated and PIT were often highly favorable to CT, it is however likely that our findings translate to a large number of mainland populations, particularly where the prevalence of HIV is moderate.

Fifth, the cost calculations we conducted relied on strong assumptions. In particular, we assumed that the prevalence of HIV among partners of ICs is independent of the population-level prevalence; in doing so, we ignored the possibility that the partner of an IC was infected by someone other than the IC. This implies that we slightly underestimate the break-even cost of CT versus other testing strategies when the population prevalence is high and overestimates it when the prevalence is low. More detailed models of CT can relax this assumption.[33,34] Sixth, our analysis only considered relative costs per newly diagnosed infection. It did not address (possibly more) important outcomes such as the total number of new infections diagnosed through CT versus client or PIT strategies. For example, while the unit cost of using VCT to diagnose new infections may often be lower than those of CT (and PIT), VCT only permits detecting a small total number of new infections. This outcome depends on the uptake of CT services among HIV ICs and their partners (ie, whether 10% or 90% of ICs choose to have health workers assist them in notifying their partners of HIV exposure). Unfortunately, there are no available data on the uptake of CT in SSA to inform such calculations.

Our results nonetheless have important implications for strategies of HIV control, particularly those relying on "test and treat" approaches to HIV prevention.[35–37] In seeking to increase HIV case finding, current strategies employed in sub-Saharan countries mobilize patients and health providers independently (Table 3). Strategies mobilizing patients have aimed to encourage partner disclosure but have systematically failed to raise the rate of partner notification and referral to HIV services.[38–43]

On the other hand, strategies mobilizing health providers may not always significantly increase case-finding rates in the general population,[44] may come at high costs,[13] or may threaten the functioning of weak health systems.[35] Because it mobilizes patients and providers simultaneously, CT could help achieve better case-finding outcomes with more limited resources. In addition, CT is a highly transferable capacity, which can be usefully mobilized in epidemiological investigations of outbreaks of other diseases besides HIV (eg, other sexually transmitted infections such as syphilis, or diseases transmitted by nonsexual contacts such as tuberculosis or meningitis) or in improving patient retention in chronic care programs (eg, ARV treatment). We thus strongly support the call for further operational studies of the use of CT in sub-Saharan settings.[25]

REFERENCES

1. Access to HIV treatment improves. *AIDS Patient Care STDS*. 2008;22:535–536.
2. De Cock K, Grubb I. Towards universal access: WHO's role in HIV prevention, treatment and care. *Bull World Health Organ*. 2006;84:506.
3. El-Sadr WM, Abrams EJ. Scale-up of HIV care and treatment: can it transform healthcare services in resource-limited settings? *AIDS*. 2007;21(suppl 5):S65–S70.
4. Loubiere S, Boyer S, Protopopescu C, et al. Decentralization of HIV care in Cameroon: increased access to antiretroviral treatment and associated persistent barriers. *Health Policy*. 2009;92:165–173.
5. Reid A, Scano F, Getahun H, et al. Towards universal access to HIV prevention, treatment, care, and support: the role of tuberculosis/HIV collaboration. *Lancet Infect Dis*. 2006;6:483–495.
6. World Health Organization. *Towards Universal Access: Scaling Up Priority HIV/AIDS Interventions in the Health Sector*. Geneva, Switzerland: World Health Organization; 2010.
7. Sweat M, Morin S, Celentano D, et al. Community-based intervention to increase HIV testing and case detection in people aged 16–32 years in Tanzania, Zimbabwe, and Thailand (NIMH Project Accept, HPTN 043): a randomised study. *Lancet Infect Dis*. 2011;7:525–532.
8. Mbopi-Keou FX, Ongolo-Zogo P, Angwafo F III, et al. High impact of mobile units for mass HIV testing in Africa. *AIDS*. 2007;21:1994–1996.
9. Centers for Disease Control and Prevention. Introduction of routine HIV testing in prenatal care—Botswana, 2004. *MMWR Morb Mortal Wkly Rep*. 2004;53:1083–1086.
10. Cockcroft A, Andersson N, Milne D, et al. Community views about routine HIV testing and antiretroviral treatment in Botswana: signs of progress from a cross sectional study. *BMC Int Health Hum Rights*. 2007;7:5.
11. Topp SM, Chipukuma JM, Chiko MM, et al. Opt-out provider-initiated HIV testing and counselling in primary care outpatient clinics in Zambia. *Bull World Health Organ*. 2011;89:328A–335A.
12. Were W, Mermin J, Bunnell R, et al. Home-based model for HIV voluntary counselling and testing. *Lancet*. 2003;361:1569.
13. Menzies N, Abang B, Wanyenze R, et al. The costs and effectiveness of four HIV counseling and testing strategies in Uganda. *AIDS*. 2009;23:395–401.
14. Helleringer S, Kohler HP, Frimpong JA, et al. Increasing uptake of HIV testing and counseling among the poorest in sub-Saharan countries through home-based service provision. *J Acquir Immune Defic Syndr*. 2009;51:185–193.
15. Negin J, Wariero J, Mutuo P, et al. Feasibility, acceptability and cost of home-based HIV testing in rural Kenya. *Trop Med Int Health*. 2009;14:849–855.
16. Centers for Disease Control and Prevention. Recommendations for partner services programs for HIV infection, syphilis, gonorrhea, and chlamydial infection. *MMWR Recomm Rep*. 2008;57:1–83; quiz CE81–CE84.
17. Mackellar DA, Hou SI, Behel S, et al. Exposure to HIV partner counseling and referral services and notification of sexual partners among persons recently diagnosed with HIV. *Sex Transm Dis*. 2008.
18. Cassell MM, Surdo A. Testing the limits of case finding for HIV prevention. *Lancet Infect Dis*. 2007;7:491–495.
19. Dixon-Mueller R. The sexual ethics of HIV testing and the rights and responsibilities of partners. *Stud Fam Plann*. 2007;38:284–296.
20. Dixon-Mueller R, Germain A. HIV testing: the mutual rights and responsibilities of partners. *Lancet*. 2007;370:1808–1809.
21. Dixon-Mueller R, Germain A, Fredrick B, et al. Towards a sexual ethics of rights and responsibilities. *Reprod Health Matters*. 2009;17:111–119.
22. Donnell D, Baeten JM, Kiarie J, et al. Heterosexual HIV-1 transmission after initiation of antiretroviral therapy: a prospective cohort analysis. *Lancet*. 2010;375:2092–2098.
23. Brown L, Miller W, Kamanga G, et al. HIV partner notification is effective and feasible in sub-Saharan Africa: opportunities for HIV treatment and prevention. *J Acquir Immune Defic Syndr*. 2011;56:437–442.
24. Tih PM, Forgwei G, Welty T, et al. Integrated HIV contact tracing and partner notification in Cameroon: a feasible HIV infection risk reduction intervention for resource-poor settings. Presented at: IAS Conference on HIV Pathogenesis, Treatment and Prevention; July 19–22, 2009; Cape Town, South Africa.
25. Potterat JJ. Puzzling observations in a trial of HIV partner notification in Sub-Saharan Africa. *J Acquir Immune Defic Syndr*. 2011;56:384–392.
26. Bunnell R, Cherutich P. Universal HIV testing and counselling in Africa. *Lancet*. 2008;371:2148–2150.
27. Brewer DD. Case-finding effectiveness of partner notification and cluster investigation for sexually transmitted diseases/HIV. *Sex Transm Dis*. 2005;32:78–83.
28. Helleringer S, Kohler HP. Sexual network structure and the spread of HIV in Africa: evidence from Likoma Island, Malawi. *AIDS*. 2007;21:2323–2332.
29. Helleringer S, Kohler HP, Chimbiri A, et al. The Likoma Network Study: context, data collection, and initial results. *Demogr Res*. 2009;21:427–468.
30. Golden MR, Gift TL, Brewer DD, et al. Peer referral for HIV case-finding among men who have sex with men. *AIDS*. 2006;20:1961–1968.
31. Nelson SJ, Manhart LE, Gorbach PM, et al. Measuring sex partner concurrency: it's what's missing that counts. *Sex Transm Dis*. 2007;34:801–807.
32. Maughan-Brown BG, Venkataramani AS. Measuring concurrent partnerships: potential for underestimation in UNAIDS recommended methods. *AIDS*. 2011;25:1549–1551.
33. Armbruster B, Brandeau ML. Contact tracing to control infectious disease: when enough is enough. *Health Care Manag Sci*. 2007;10:341–355.
34. Armbruster B, Brandeau ML. Who Do You Know? A Simulation Study of Infectious Disease Control Through Contact Tracing. International Conference on Health Sciences Simulation; January 14–18, 2007; San Diego, CA.
35. Garnett GP, Baggaley RF. Treating our way out of the HIV pandemic: could we, would we, should we? *Lancet*. 2009;373:9–11.
36. Granich RM, Gilks CF, Dye C, et al. Universal voluntary HIV testing with immediate antiretroviral therapy as a strategy for elimination of HIV transmission: a mathematical model. *Lancet*. 2009;373:48–57.
37. De Cock KM, Crowley SP, Lo YR, et al. Preventing HIV transmission with antiretrovirals. *Bull World Health Organ*. 2009;87:488–488A.
38. Brou H, Djohan G, Becquet R, et al. When do HIV-infected women disclose their HIV status to their male partner and why? A study in a PMTCT programme, Abidjan. *PLoS Med*. 2007;4:e342.
39. Makin JD, Forsyth BW, Visser MJ, et al. Factors affecting disclosure in South African HIV-positive pregnant women. *AIDS Patient Care STDS*. 2008;22:907–916.
40. Medley A, Garcia-Moreno C, McGill S, et al. Rates, barriers and outcomes of HIV serostatus disclosure among women in developing countries: implications for prevention of mother-to-child transmission programmes. *Bull World Health Organ*. 2004;82:299–307.

41. Ndiaye C, Boileau C, Zunzunegui MV, et al. Gender-related factors influencing HIV serostatus disclosure in patients receiving HAART in West Africa. *World Health Popul*. 2008;10:43–54.
42. Varga CA, Sherman GG, Jones SA. HIV-disclosure in the context of vertical transmission: HIV-positive mothers in Johannesburg, South Africa. *AIDS Care*. 2006;18:952–960.
43. Wong LH, Rooyen HV, Modiba P, et al. Test and tell: correlates and consequences of testing and disclosure of HIV status in South Africa (HPTN 043 Project Accept). *J Acquir Immune Defic Syndr*. 2009;50:215–222.
44. Pope DS, Deluca AN, Kali P, et al. A cluster-randomized trial of provider-initiated (opt-out) HIV counseling and testing of tuberculosis patients in South Africa. *J Acquir Immune Defic Syndr*. 2008;48:190–195.

