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ORIGINAL RESEARCH

Impact of frequent testing on the transmission of HIV and *N. gonorrhoeae* among men who have sex with men: a mathematical modelling study

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ABSTRACT

Objectives To investigate the impact and efficiency of combined testing for HIV and other STIs on HIV and STI transmission among men who have sex with men (MSM) and to assess what subgroups of MSM should be targeted for frequent testing.

Methods We developed an agent-based transmission model that simulates infection with HIV or *Neisseria gonorrhoeae* (NG) among MSM. We examined scenarios with increased percentages of MSM getting tested six monthly, among all MSM or only specific subgroups of MSM (defined according to recent gonorrhoea, number of partners and engagement in condomless anal intercourse (CAI)) and scenarios with reduced intervals between HIV/STI tests.

Results The most efficient strategies were those with increased percentage of MSM getting tested every 6 months among MSM with a recent gonorrhoea diagnosis; or among MSM who had CAI and ≥ 10 partners; or MSM who had ≥ 10 partners. Over 10 years, these strategies resulted in 387–718 averted HIV infections and required 29–164 additional HIV tests per averted HIV infection or one to seven additional gonorrhoea tests per averted NG infection. The most effective strategy in reducing HIV transmission was the one where the intervals between tests were reduced by half, followed by the strategy with increased percentage of MSM getting tested every 6 months among all MSM. Over 10 years, these strategies resulted in 1362 and 1319 averted HIV infections, but required 663 and 584 additional HIV tests per averted HIV infection, respectively.

Conclusions Targeting MSM with recent gonorrhoea diagnosis or MSM with many partners is efficient in terms of HIV/STI tests needed to prevent new HIV or NG infections. Major reductions in HIV incidence can be achieved with consistent HIV/STI testing every 6 months among larger groups, including low-risk MSM. To impede HIV transmission, frequent testing should be combined with other prevention measures.

INTRODUCTION

HIV testing is essential to control HIV transmission, since it enables early diagnosis and timely initiation of combination antiretroviral therapy (cART), which diminishes HIV transmissibility and is

beneficial for the treated individuals.^{1–4} The WHO and the Joint United Nations Programme on HIV/AIDS (UNAIDS) support ‘Test and Treat’ as a global prevention strategy, which includes frequent HIV testing and immediate initiation of cART.⁵ In the UK and the USA, men who have sex with men (MSM) are recommended to have HIV tests at least annually and every 3 or 6 months if they are at increased risk for HIV infection.^{6,7} In the Netherlands, some organisations advise MSM to get tested for HIV and other STIs every 6 months,⁸ but no official national guidelines exist. Since HIV/STI coinfections are frequent among MSM, MSM seeking HIV testing at STI clinics are offered combined testing for HIV, gonorrhoea, chlamydia, syphilis and hepatitis B. Although some individuals, especially those without symptoms, may not be interested at first to have tests for other STIs, information and counselling about the importance of testing for the five more common STI infections among MSM in the Netherlands could result in high uptake of HIV/STI testing. Therefore, increased HIV testing could result in increased STI testing. That could affect the prevalence of other STIs and indirectly affect HIV transmission, since coinfection with HIV and another STI, such as gonorrhoea, can enhance the transmission potential of HIV.⁹ Consequently, the impact of increased HIV testing on HIV transmission could be underestimated, if STI testing and transmission are not taken into consideration.

Earlier modelling work has shown that increased HIV testing can result in substantial reductions in HIV incidence^{10–16} and that testing (or screening) for other STIs could reduce STI transmission.^{16–20} However, the impact of combined HIV/STI testing on the transmission of HIV and other STIs has not been investigated thus far. Moreover, it is unclear whether recommendations for frequent testing should be addressed to all MSM or only specific subgroups of MSM. These issues were addressed in this study. We considered infections with *Neisseria gonorrhoeae* (NG) as example of another STI, because that is the most frequent STI among MSM in the Netherlands.²¹ We used a transmission model to describe scenarios with increased testing among all MSM or targeted to specific risk groups. We calculated the HIV incidence rate, the prevalence of gonorrhoea and the numbers of HIV

and gonorrhoea tests needed to prevent one new HIV or NG infection.

METHODS

The transmission model

We developed an agent-based model that describes HIV and gonorrhoea transmission among MSM. The model simulates the formation of steady and casual sexual relationships in a stable population of sexually active MSM aged 15–64 years. MSM may acquire HIV and/or gonorrhoea via condomless anal intercourse (CAI). We distinguished two stages of HIV infection: acute and chronic HIV infection. After HIV diagnosis, persons living with HIV/AIDS (PLWHA) may enrol in HIV care and receive cART, which can reduce viral load to undetectable levels. We assumed that MSM with symptomatic gonorrhoea always seek testing and receive antibiotic treatment immediately when tested. MSM with asymptomatic gonorrhoea may get tested opportunistically, but they receive treatment after test results are available. The probability of HIV transmission from a man with HIV and NG coinfection is higher than that from a man with HIV and no NG infection. Model parameters were obtained from several data sources^{21–28} and from the literature (see online supplementary tables S1–S7). The model was fitted to data on HIV diagnoses in 2007–2014²⁴ and gonorrhoea positivity rate in 2009–2014.²¹ Details on the model are given in the online supplementary material. Results shown are medians and IQRs of 2000 simulations.

Current HIV/STI testing

In the model, we assumed that MSM get tested for HIV and gonorrhoea at the same time, except for diagnosed PLWHA who get tested only for gonorrhoea. The current testing rates (in 2017) were determined based on data from the national database of STI clinics in the Netherlands.^{21–26} We assumed that 20% of MSM do not get tested for HIV/STI,^{27–28} unless they have symptoms or they are notified by a partner. The remaining 80% of MSM get tested for HIV/STI every 5 years, every 2 years or every 6 months. The distribution of MSM across the three testing frequencies is determined by the number of casual partners men had in the preceding 6 months (which depends on age and having a steady partnership) and according to known HIV

serostatus (table 1A). This resulted in approximately 20% of MSM tested for HIV/STI every 6 months, 29% every 2 years and 51% every 5 years (the current testing uptake).

Increased percentage of MSM getting tested six monthly

We modelled a number of scenarios where the percentage of MSM getting tested consistently every 6 months was increased, compared with current testing uptake. We examined a moderate increase in testing uptake from approximately 20% getting tested six monthly (table 1A) to 50% (table 1B). This was implemented by increasing the percentages getting tested every 6 months (in each subgroup with specific HIV status and number of partners—table 1) and decreasing the percentages getting tested every 2 or 5 years. Subsequently, we examined scenarios where the increased testing rates (table 1B) were implemented in the following subgroups among MSM who are tested for HIV/STI:

- ▶ All MSM.
- ▶ MSM who had CAI in the preceding 12 months.
- ▶ MSM who had CAI in the preceding 12 months and ≥ 3 partners in the preceding 6 months.
- ▶ MSM who had CAI in the preceding 12 months and ≥ 10 partners in the preceding 6 months.
- ▶ MSM who had ≥ 10 partners in the preceding 6 months.
- ▶ MSM who had a gonorrhoea diagnosis in the preceding 12 months.

The scenarios with increased HIV/STI testing were implemented from 2018 onwards. As sensitivity analysis, we investigated also scenarios with a lower increase (from 20% to 30% among all MSM or in specific risk groups) and a higher increase (from 20% to 100% in specific risk groups) in the percentage of MSM getting tested six monthly. More details about these scenarios are given in the online supplementary material.

Reduced intervals between tests

We also examined two scenarios where the testing distributions were the same as with current testing (table 1A), but the time intervals between tests were halved:

- ▶ Half testing intervals: the time between tests among all MSM was reduced by 50%, such that MSM get tested every 2.5 years, every 1 year or every 3 months.

Table 1 HIV/STI testing distributions of MSM, according to known HIV status and number of partners in the preceding 6 months*

Testing distribution†	Known HIV status	Testing frequency	Number of partners in preceding 6 months				
			0–2	3–4	5–9	10–20	>20
(A) Current testing	HIV-negative and undiagnosed PLWHA	Every 5 years	66%	57%	50%	43%	40%
		Every 2 years	22%	27%	32%	33%	31%
		Every 6 months	12%	15%	18%	24%	29%
	Diagnosed PLWHA	Every 5 years	56%	46%	35%	32%	30%
		Every 2 years	26%	32%	36%	36%	36%
		Every 6 months	18%	23%	29%	32%	34%
(B) Increased six monthly testing	HIV-negative and undiagnosed PLWHA	Every 5 years	48%	38%	31%	24%	21%
		Every 2 years	16%	18%	20%	18%	16%
		Every 6 months	36%	44%	49%	58%	64%
	Diagnosed PLWHA	Every 5 years	33%	24%	17%	15%	13%
		Every 2 years	21%	23%	23%	22%	22%
		Every 6 months	46%	53%	60%	63%	65%

*HIV-negative MSM and undiagnosed persons living with HIV/AIDS (PLWHA) get tested for HIV and gonorrhoea; diagnosed PLWHA get tested only for gonorrhoea. Testing percentages are among the 80% of MSM testing for HIV; the remaining 20% of MSM are not tested. HIV status indicates the known status.

†The current testing distributions were based on data from the national database of STI clinics in the Netherlands. The distributions with increased percentage of MSM testing six monthly were calculated from the current distributions by increasing all percentages six monthly testing and decreasing the percentages testing every 2 or 5 years proportionately, such that the total percentage of MSM testing six monthly among MSM who test increased from 20% currently to 50%. MSM, men who have sex with men.

- Six monthly testing becomes three monthly: the time between tests was reduced by 50% only among MSM currently tested every 6 months.

Impact on transmission and efficiency

We calculated the HIV incidence rate (new HIV infections per 100 person-years (PY)), the numbers of averted HIV infections and NG infections and the gonorrhoea prevalence (percentage of MSM with NG infection on 31 December 2027). Further, we calculated the number of HIV tests. Since gonorrhoea testing may indirectly affect HIV transmission, we looked also at HIV/STI testing moments, which are all occasions at which MSM get tested (A) for HIV and gonorrhoea (HIV-negative MSM and undiagnosed PLWHA) or (B) only for gonorrhoea (diagnosed PLWHA). Next, we calculated the ratio of additional tests per averted infection, for example, the number of additional HIV tests per averted HIV infection was the ratio:

$$\frac{(\text{HIV tests with increased testing}) - (\text{HIV tests with current testing})}{(\text{HIV infections with current testing}) - (\text{HIV infections with increased testing})}$$

The numbers of additional tests and averted infections were cumulative over 2018–2027.

RESULTS

Increased percentage of MSM getting tested six monthly

With the current testing rates (20% testing six monthly among the 80% of MSM who get tested), the HIV incidence rate in 2027 was 0.300 infections (IQR: 0.186–0.431) per 100 PY. With increased six monthly testing among all MSM, the incidence was 0.188 (IQR: 0.115–0.286) per 100 PY in 2027 (figure 1A) and 1319 (IQR: 903–1839) new HIV infections were averted over 2018–2027 (table 2). Increasing six monthly testing only within specific groups of MSM resulted in higher HIV incidence than that with increased six monthly testing among all MSM. By targeting MSM who had CAI in the preceding 12 months, the HIV incidence rate was reduced almost as much as with increased testing among all MSM to 0.192 per 100 PY in 2027 (figure 1A). Targeting MSM who had CAI and ≥ 3 or ≥ 10 partners resulted in HIV incidence of 0.213 and 0.236 per 100 PY, respectively. Targeting only MSM who had a gonorrhoea diagnosis in the preceding 12 months resulted in the highest HIV incidence rate (0.264 per 100 PY) among the scenarios examined, but still lower incidence than that with the current testing rates. Gonorrhoea prevalence in 2027 was reduced from 1.25% with the current testing rates to 0.81% with increased six monthly testing among all MSM and varied between 0.88% and 1.11% with increased six monthly testing in one of the five risk groups (figure 1B). Similar observations were made with lower and higher increases in the percentage of MSM testing six monthly; the HIV incidence rate was reduced the most (reaching 0.059 infections per 100 PY) in the scenario where all MSM engaging in CAI had HIV/STI tests every 6 months (see online supplementary figure S1).

Reduced intervals between tests

By halving the time between tests among MSM who get tested, the HIV incidence rate was reduced to 0.178 per 100 PY by 2027 (figure 1A) and gonorrhoea prevalence to 0.70% (figure 1B). Halving the time between tests of six monthly testers only (such that they test every 3 months) resulted in an HIV incidence rate of 0.260 per 100 PY by 2027 and gonorrhoea prevalence of 0.9% (figure 1).

Efficiency of HIV/STI testing

The most effective scenarios in preventing HIV and NG transmission were the scenarios with (1) half-time intervals between

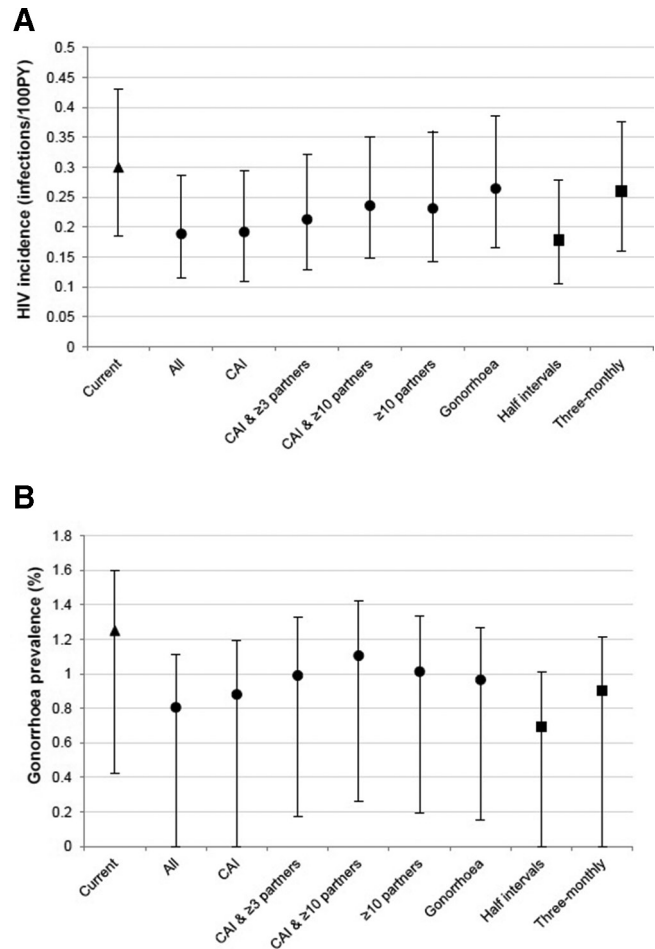


Figure 1 The impact of increased HIV/STI testing on HIV and *Neisseria gonorrhoeae* transmission among men who have sex with men (MSM) in the Netherlands. (A) The incidence of HIV, as number of new HIV infections per 100 person-years in 2027. (B) The prevalence of gonorrhoea as percentage of MSM on 31 December 2027. The symbols (triangular, circles, squares) show the medians and the line segments show the IQR of the 2000 simulations. The first line segment (with triangular) corresponds to the current testing rates. The next six line segments (with circles) are for the scenarios with increased percentage of six monthly testing among: all testing MSM, MSM who had condomless anal intercourse (CAI), MSM who had CAI and ≥ 3 partners, MSM who had CAI and ≥ 10 partners, MSM who had ≥ 10 partners or MSM who had a gonorrhoea diagnosis in the preceding 12 months. The last two line segments (with squares) are for the scenarios with reduced intervals between tests: all testing intervals reduced by 50% ('half intervals') or only six monthly reduced to three monthly. PY, person-years.

tests among all MSM who get tested, (2) increased percentage of six monthly testers among all MSM, or (3) only among MSM who had CAI (figure 2, table 2). However, these scenarios were the least efficient in terms of numbers of tests needed to prevent an infection. For instance, by halving the time between tests among all MSM, 1362 HIV and 42 151 NG infections were averted, but 901 962 additional HIV tests and 999 598 additional gonorrhoea tests were carried out. This resulted in 663 additional HIV tests (or 738 additional HIV/STI testing moments) per averted HIV infection. The scenario with increased six monthly testing among MSM who had gonorrhoea in the past year was the most efficient strategy with only 29 extra HIV tests (or 35 additional

Table 2 Median numbers (and IQRs) of additional tests, averted infections and additional tests per averted infection, cumulative over 2018–2027

	Additional tests*			Averted new infections			Additional tests per averted infection		
	HIV tests	HIV/STI testing moments	HIV	NG	HIV tests per HIV infection	HIV/STI testing moments per HIV infection	HIV/STI testing moments per NG infection		
Increased percentage of six monthly testing among MSM who get tested†:									
All testing MSM	773 748 763 491–789 575	846 469 837 959–853 285	1319 903–1839	33813 27 744–41 164	584 416–880	646 454–941	25 20–30		
≥10 partners	121 395 113 719–128 698	126 199 118 552–134 315	718 493–1058	19351 15 646–24 102	164 108–241	172 115–252	7 5–8		
Gonorrhoea	13 812 7527–20 711	14 954 8538–22 638	387 155–562	22 540 16 635–26 752	29 12–55	35 13–63	1 0–1		
CAI	518 924 507 440–535 618	577 334 566 209–588 772	1232 846–1698	28 844 24 169–34 930	423 291–625	478 329–680	20 16–24		
CAI and ≥3 partners	256 191 242 858–66 635	278 293 264 982–289 723	964 622–1368	20 307 16 344–25 519	269 184–423	289 200–449	14 11–17		
CAI and ≥10 partners	89 776 82 579–95 547	93 463 85 387–100 729	704 421–1003	12 448 9694–17 885	120 82–207	126 84–214	7 5–10		
Reduced intervals between tests‡:									
Half	901 962 883 328–917 585	999 598 990 510–1 007 397	1362 1011–1838	42 151 35 021–47 264	663 484–894	738 539–969	24 21–29		
Three monthly	490 557 478 667–501 538	552 801 544 433–557 221	461 238–696	26 126 20 713–16 723	905 587–1719	1022 675–1889	21 17–27		

* By the number of HIV tests, the tests for gonorrhoea were excluded. By the number of HIV/STI testing moments, every moment of either combined HIV/gonorrhoea testing (by HIV-negative MSM or undiagnosed PLWHA) or only-gonorrhoea testing (by diagnosed PLWHA) was counted as one testing moment. Additional number of tests was the number of tests with increased testing minus the number of tests with the current testing rates.

† Scenarios with increased percentage of six monthly testing among: all MSM who get tested; MSM who had ≥10 partners; MSM with gonorrhoea diagnosis in the preceding 12 months; MSM who had CAI in the preceding 12 months; MSM who had CAI and ≥3 partners; MSM who had CAI and ≥10 partners.

‡ Scenarios with reduced intervals between tests: the testing intervals among all MSM who get tested were reduced by 50% (half-testing intervals); or the testing intervals among MSM who get tested every 6 months were reduced by 50%, becoming three monthly testing.

CAI, condomless anal intercourse; MSM, men who have sex with men; NG, *Neisseria gonorrhoeae*; PLWHA, persons living with HIV/AIDS.

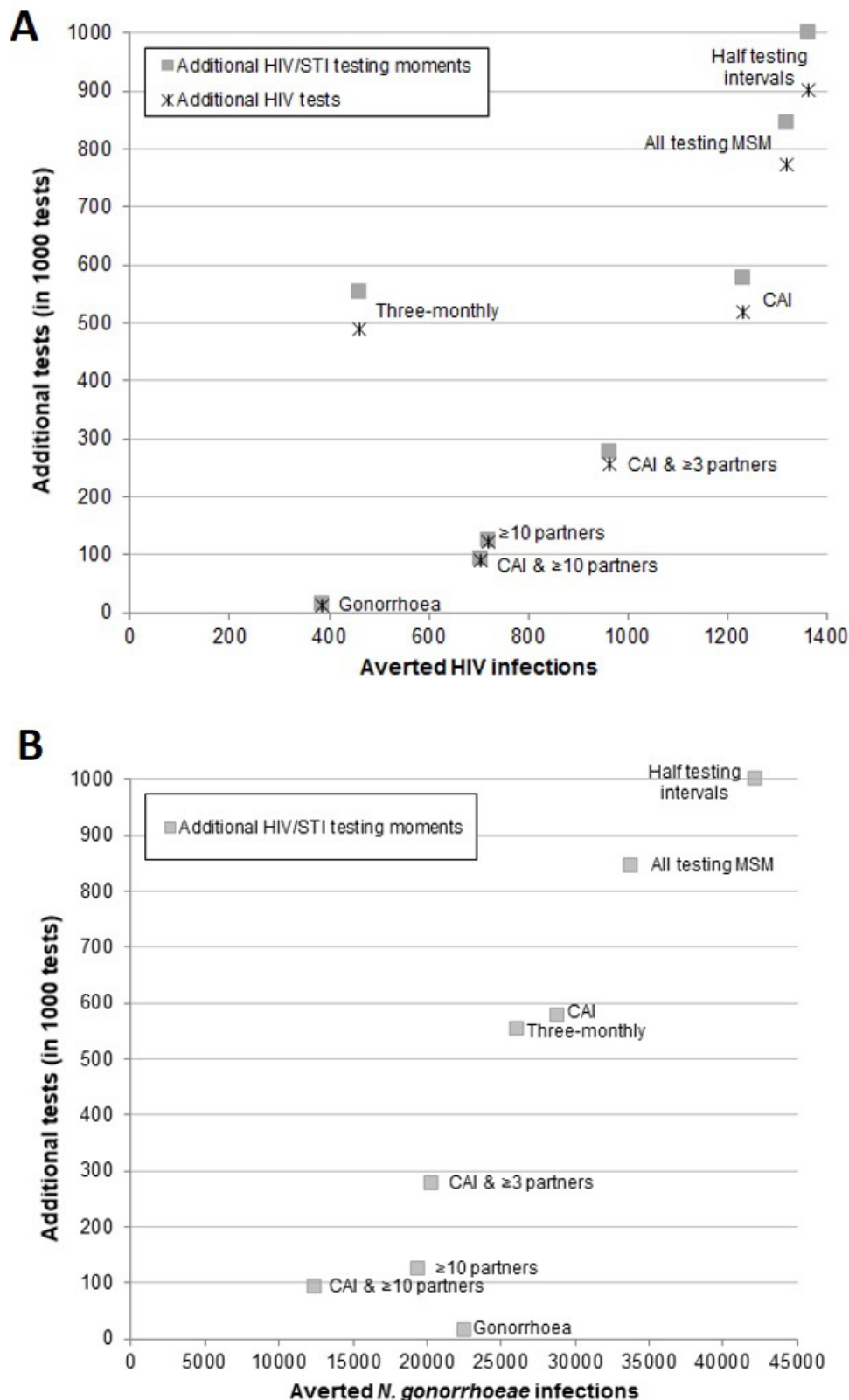


Figure 2 The number of additional tests and the number of averted infections due to increased testing compared with current testing, among men who have sex with men (MSM) in the Netherlands. The numbers shown are the medians of the cumulative numbers (of tests or infections) over the years 2018–2027. The following scenarios with increased percentage of six monthly testing are shown: among all testing MSM, MSM who had condomless anal intercourse (CAI), MSM who had CAI and ≥ 3 partners, MSM who had CAI and ≥ 10 partners, MSM who had ≥ 10 partners or MSM who had a gonorrhoea diagnosis in the preceding 12 months. Also, two scenarios are shown with reduced intervals between tests: all testing intervals reduced by 50% ('half testing intervals') or only six monthly reduced to three monthly. (A) The number of additional HIV tests and the number of averted HIV infections (horizontal axis). (B) The number of additional HIV/STI testing moments (vertical axis) versus the number of averted new *Neisseria gonorrhoeae* infections (horizontal axis).

HIV/STI testing moments) per averted HIV infection and one additional HIV/STI testing moment per averted NG infection. However, this strategy was the least effective in preventing HIV transmission (only 387 averted HIV infections in 2018–2027), but not the least effective in preventing NG transmission (22 540 averted NG infections). Similar observations were made with lower and higher increases in the percentage of MSM testing six monthly (see online supplementary table S7 and figure S2).

DISCUSSION

Increased HIV/STI testing can result in considerable reductions in HIV and NG transmission, but it can result in high numbers of additional HIV/STI tests needed to prevent a new HIV infection. Increasing the percentage of MSM tested every 6 months from the current 20% to 50% could have a major impact on HIV and NG transmission. Targeting MSM who had CAI in the preceding 12 months could be almost equally effective, since most MSM engage in CAI occasionally. Reducing intervals between tests by half among MSM who are already willing to get tested could result in substantial decline in HIV incidence. Targeting MSM with many casual partners (≥ 10 partners or those who had CAI and ≥ 3 or ≥ 10 partners) or those with a recent gonorrhoea diagnosis is more efficient in terms of number of tests needed to prevent an infection, but is less effective in limiting transmission.

We found that high numbers of infections were averted in the scenarios with high numbers of tests and high numbers of extra tests per averted infection. The only exception was the scenario where all MSM testing currently every 6 months switched to testing every 3 months. This resulted in the highest number of additional HIV tests per averted HIV infection, but in a relatively low number of averted HIV infections. Nevertheless, halving the time between tests of all MSM who get tested was one of the most effective strategies in reducing HIV transmission. The difference in the efficiency of the two scenarios with reduced intervals between testing can be explained by the fact that the group of six monthly testers is small (20% of MSM who get tested) and these men got tested on average 3 months earlier than with the current testing rates. Therefore, only a few HIV infections could be averted in 3 months. Interestingly, changing six monthly to three monthly testing was more efficient in reducing gonorrhoea transmission than in reducing HIV transmission, since more gonorrhoea infections occur (and could be averted) in 3 months than HIV infections.

Our findings are in agreement with earlier modelling work on the impact of testing on transmission of HIV^{10–16} or other STIs.^{16–20} For instance, a study among MSM in the UK found that higher levels of HIV testing (68% tested annually instead of 25%) in combination with immediate cART initiation could result in 62% lower incidence.¹⁰ Annual HIV testing in

combination with immediate cART initiation has been shown to result in 76% reduction in HIV infections after 10 years, among MSM in San Francisco.¹⁴ A study on gonorrhoea testing has shown that targeting MSM with many partners is effective in reducing NG transmission and efficient in terms of tests needed to prevent an NG infection.¹⁸ Three monthly testing, targeting MSM with > 10 partners and targeting MSM with prior syphilis have been found to be effective also in reducing syphilis transmission.^{19 20}

This is the first study, to our knowledge, that investigates the impact of increases in combined HIV/STI testing on the transmission of HIV, but also on the transmission of another STI, NG. Our study is also exceptional in that it evaluates the impact and the efficiency of targeting HIV/STI testing to specific subgroups of MSM: those with recent gonorrhoea diagnosis, MSM with many partners, MSM who had CAI or MSM who had CAI and many partners.

Nevertheless, our study has also its limitations. A number of simplifications were made, for example, we modelled a ‘combined’ testing moment for HIV and NG, although sometimes MSM get tested only for HIV or only for NG. Due to lack of data to inform relative parameters, testing for one infection was not included. We considered HIV and only one other STI, since including three or more infections in the model would have made it even more complex and it would be difficult to unravel the interactions between the infections. Moreover, we assumed that all the strategies we examined were equally feasible. However, the efficiency of a strategy depends also on the efforts needed to achieve the respective participation and possibly on necessary capacity extensions. The model does not account for sexual contacts of MSM with females. Since this occurs rarely in the Netherlands,²⁹ we expect that this omission would not have influenced the results. In the model, we did not include non-citizen MSM temporarily residing in the Netherlands, due to the model complexity and the lack of data to inform related parameters. Finally, the impact of testing was calculated in this study assuming no other alterations or other prevention measures, like pre-exposure prophylaxis (PrEP).

Following the vision of UNAIDS to get to ‘Zero New Infections’, a recent initiative in the Netherlands aims to reach ‘zero new HIV infections by 2030’.³⁰ Among the scenarios examined in this study, the scenario that was the ‘closest’ to this goal was the scenario where all MSM engaging in CAI had HIV/STI tests every 6 months. This scenario was extreme, in terms of testing coverage. After 10 years, 1.6 million more HIV tests were carried out than with the current testing rates, but HIV transmission still occurred (online supplementary figure S1 and table S7). Zero new HIV infections is an ambitious goal that would most likely demand extremely great efforts. In terms of efforts needed to prevent a new HIV infection, the most efficient strategy could be to increase HIV/STI testing among those with a recent gonorrhoea diagnosis, those with many partners and those who had CAI and many partners. This ‘high-risk’ group of MSM is small, but has a major role in HIV transmission, since they have a higher risk to acquire HIV and a higher risk to transmit HIV, compared with other (often called ‘low-risk’) MSM. Therefore, targeting strategies on high-risk MSM may need relatively little effort to prevent many infections. Nevertheless, the group of low-risk MSM is large and many infections (in absolute numbers) occur in this group, despite the low HIV incidence. Therefore, targeting high-risk MSM may be efficient in reducing HIV transmission, but not sufficient to stop HIV spread, if low-risk MSM are not also targeted.

Revealing the impact and efficiency of increased testing in specific subgroups can help public health authorities to focus

Key messages

- ▶ Mathematical modelling suggests that reducing the time intervals between HIV/STI tests could result in major reductions in HIV and gonorrhoea transmission among men who have sex with men (MSM).
- ▶ Six monthly HIV/STI testing among MSM with ≥ 10 partners or recent gonorrhoea was the most efficient strategy in terms of tests needed to avert an infection.
- ▶ To impede HIV transmission, also low-risk MSM should have HIV/STI tests every 6 months and frequent testing should be combined with other prevention measures.

their strategies in an optimal way: identifying strategies with high benefits and low efforts or choosing the strategies with the most benefits and being prepared for major efforts. We showed that increased HIV/STI testing among MSM with recent gonorrhoea or MSM with many partners is efficient in reducing HIV incidence. To impede HIV transmission, efforts should be made beyond what is efficient: motivating all MSM to get tested more frequently, or motivating MSM who engage in CAI to get tested every 6 months could help accomplish this goal, but healthcare facilities offering HIV/STI testing should be prepared for high workload and costs. Therefore, the optimal strategy depends on the objectives set forth. To reduce HIV incidence to zero in an efficient way, increased testing should be combined with other public health measures, such as PrEP, condom use, partner notification and linkage of PLWHA to care ensuring viral suppression.

Handling editor Katy M E Turner

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