# Impact of screening and antiretroviral therapy on anal cancer incidence in HIV-positive MSM

Nello Blaser[a,b,*], Barbara Bertisch[a,c,d,*], Roger D. Kouyos[e], Alexandra Calmy[f], Heiner C. Bucher[g,h], Matthias Cavassini[i], Janne Estill[a,d], Olivia Keiser[a,d,*], Matthias Egger[a,j,*], for the Swiss HIV Cohort Study

**Background:** The incidence of anal cancer is high in HIV-positive MSM. We modeled the impact of screening strategies and combination antiretroviral therapy (cART) coverage on anal cancer incidence in Switzerland.

**Methods:** Individual-based, dynamic simulation model parameterized with Swiss HIV Cohort Study and literature data. We assumed all men to be human papillomavirus infected. $CD4^+$ cell count trajectories were the main predictors of anal cancer. From 2016 we modeled cART coverage either as below 100% (corresponding to 2010–2015) or as 100%, and the following four screening strategies: no screening, yearly anal cytology (Papanicolaou smears), yearly anoscopy and targeted anoscopy 5 years after $CD4^+$ count dropped below 200 cells/μl.

**Results:** Median nadir $CD4^+$ cell count of 6411 MSM increased from 229 cells/μl during 1980–1989 to 394 cells/μl during 2010–2015; cART coverage increased from 0 to 83.4%. Modeled anal cancer incidence peaked at 81.7/100 000 in 2009, plateaued 2010–2015 and will decrease to 58.7 by 2030 with stable cART coverage, and to 52.0 with 100% cART coverage. With yearly cytology, incidence declined to 38.2/100 000 by 2030, with yearly anoscopy to 32.8 and with $CD4^+$ cell count guided anoscopy to 51.3. The numbers needed to screen over 15 years to prevent one anal cancer case were 384 for yearly cytology, 313 for yearly anoscopy and 242 for $CD4^+$ cell count-dependent screening.

**Conclusion:** Yearly screening of HIV-positive MSM may reduce anal cancer incidence substantially, with a number needed to screen that is comparable with other screening interventions to prevent cancer.



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[a]Institute of Social and Preventive Medicine (ISPM), University of Bern, Bern, Switzerland, [b]Department of Mathematics, University of Bergen, Bergen, Norway, [c]Checkpoint Zurich, Zurich, [d]Institute of Global Health, University of Geneva, Geneva, [e]Division of Infectious Diseases and Hospital Epidemiology, University Hospital Zurich, Zurich, [f]Division of Infectious Diseases, University of Geneva, Geneva, [g]Division of Infectious Diseases and Hospital Epidemiology, University of Basel, [h]Basel Institute for Clinical Epidemiology & Biostatistics, University Hospital Basel, Basel, [i]Division of Infectious Diseases, Department of Medicine, University Hospital of Lausanne, University of Lausanne, Lausanne, Switzerland, and [j]Centre for Infectious Disease Epidemiology and Research (CIDER), University of Cape Town, Cape Town, South Africa.

Correspondence to Prof. Matthias Egger, Institute of Social and Preventive Medicine (ISPM), University of Bern, Finkenhubelweg 11, CH-3012 Bern, Switzerland.

Tel: +41 31 631 35 11; fax: +41 31 631 35 20; e-mail: matthias.egger@ispm.unibe.ch

[*] Nello Blaser, Barbara Bertisch, Olivia Keiser and Matthias Egger contributed equally to the article.

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## Introduction

Anal cancer is caused by infection with high-risk types of human papillomavirus (HPV) [1–3]. In HIV-negative MSM, the incidence of anal cancer is around five per 100 000 person-years, which is about five times higher than in the general population [1,2]. In HIV-positive MSM, the incidence ranged between 78 and 168 per 100 000 person-years in studies from the era of combination antiretroviral therapy (cART) [1,4–7]. The main risk factor for anal cancer is a history of infection with high-risk types of HPV which is very frequent in HIV-positive MSM [1–3,8]. Another important risk factor is immunosuppression, characterized by low nadir $CD4^+$ cell counts [4–6,9] or a long duration of exposure to low $CD4^+$ cell counts [10,11]. An analysis of the Swiss HIV Cohort Study (SHCS) found that the strongest predictor was a low $CD4^+$ cell count 6–7 years before diagnosis [12]. Other potential risk factors include smoking [2,12] and presence of antibodies against high-risk HPV proteins [12].

Anal intraepithelial neoplasia (AIN) grades 2 or 3, the precursors of anal cancer [2,3,13], are found in 24–50% of HIV-positive MSM [1–3]. The progression from AIN 2/3 to anal cancer is estimated to range from 1.3 to 5.6% over 5 years [1,3,13,14]. Screening for AIN 2/3 and treatment of lesions can prevent progression to anal cancer. Cytology based on Papanicolaou (Pap) smears of the anal canal is inexpensive, but with 67–90% the sensitivity is low in HIV-positive persons [15]. High-resolution anoscopy and histology requires dedicated equipment and training and is substantially more expensive than cytology, but sensitivity is close to 100% [16]. Electrocautery and infrared (IR) coagulation are the most effective treatments for intraanal AIN 2/3 [2]. Burgos *et al.* [17] found that 1 year after treatment 49% of patients were free of AIN 2/3; other studies showed comparable or better results [18–20]. Although only around half of men were free of AIN 2/3 after 1 year, the treatment prevented progression to anal cancer in all of them [18–20].

cART substantially decreases the risk of opportunistic infections and cancers such as Kaposi sarcoma or non-Hodgkin lymphoma [8,21], and similar decreases were expected for anal cancer. However, studies suggest that anal cancer incidence increased even after the widespread introduction of cART [4,7–9]. For example, an analysis of 13 cohorts from North America found that the incidence of anal cancer continued to raise during the early years of cART (1996–1999) and plateaued in the 2000s [7]. In the Netherlands, a slight decrease was observed after 2006 [6].

The effectiveness of different screening strategies for anal cancer is unclear and a matter of ongoing debate [1–3,7]. We developed a mathematical model and parameterized it with data from the SHCS and the literature. We used the model to study the impact of increasing the coverage of cART, and of different screening strategies on the incidence of anal cancer.

## Methods

### Structure of mathematical model

We developed an individual-based mathematical simulation model to predict anal cancer incidence in HIV-positive MSM in Switzerland, 1980–2030. We assumed that all HIV-positive MSM were HPV-infected and immunodeficiency (measured as trajectories of the $CD4^+$ positive lymphocyte cell count per μl) was the main risk factor for anal cancer [12]. The model is a stochastic, dynamic model and consists of a $CD4^+$ cell count layer and an anal cancer layer, which depends on the $CD4^+$ cell count layer (Fig. 1).

The $CD4^+$ cell count layer of the model is a Markov model, and the anal cancer part is a stochastic compartmental model, where transition probabilities are non-Markovian. In the $CD4^+$ cell count layer, the $CD4^+$ trajectories of MSM are modeled across five $CD4^+$ cell count states (<100, 100–199, 200–349, 350–499 and ≥500 cells/μl). The anal cancer layer includes four states of anal cancer progression (no precursor lesion, AIN 1, AIN 2/3 and anal cancer). In the $CD4^+$ cell count layer, all transition times are piecewise exponentially distributed. In the anal cancer layer, the rate of progression from no lesion to AIN 1 is a function of the $CD4^+$ cell count $\left[ f(\mathrm{CD4}^+) = \beta_0 \times \beta_1^{-\mathrm{CD4}^+/100} \right]$. The hazards of transitions from AIN 1 to AIN 2/3 and from AIN 2/3 to anal cancer are Weibull distributed. The hazard functions are, thus, of the form $(k/\lambda)(t/\lambda)^{k-1}$, in which $k$ is the shape parameter and $\lambda$ the scale parameter. For the MSM who regressed from AIN 2/3 to AIN 1, the time to regression was assumed to be 1 year after detection

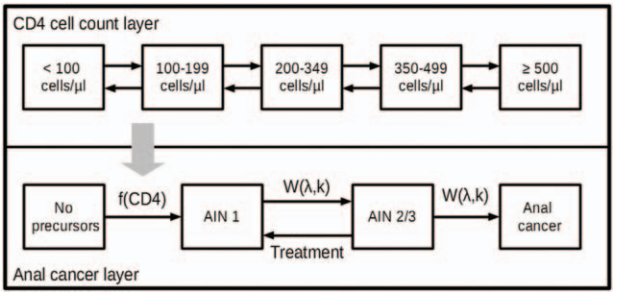


**Fig. 1. Model structure with $CD4^+$ cell count and anal cancer layers.** The model is a stochastic, dynamic model. The $CD4^+$ cell count layer of the model is a Markov model and the anal cancer layer a stochastic compartmental model, where transition probabilities are non-Markov. AIN, anal intraepithelial neoplasia.

of AIN 2/3 and successful treatment. We compared the predicted anal cancer incidence with the incidence observed in MSM in the SHCS. For each of the interventions described below, we simulated 10 000 000 HIV-positive MSM who were followed from 1980 to 2030.

We analyzed the SHCS to determine the parameters for the $CD4^+$ cell count layer, including probabilities of transition between $CD4^+$ cell count states and mortality. From 2016 onward, we used the parameters of 2010–2015. We used published estimates for the anal cancer layer.

## Analyses of Swiss HIV Cohort Study data

The SHCS is a prospective longitudinal study that includes about 45% of all HIV-positive adults living in Switzerland, and about 70% of all patients living with AIDS [22]. Socio-demographic, behavioral, clinical, laboratory data and use of cART regimens are recorded at study entry and semiannual follow-up visits. We included all MSM who had at least three $CD4^+$ cell counts. Follow-up started at estimated HIV infection date [23]. We split follow-up into periods before cART initiation and on cART. cART was defined as at least three antiretroviral drugs from at least two drug classes. We further split follow-up on cART into periods of successful cART (viral load <1000 copies/ml) and failing cART (viral load ≥1000 copies/ml). Within each calendar period, we monotonically smoothed $CD4^+$ trajectories using a general additive model and predicted $CD4^+$ cell counts eight times a year. We fit a multistate model with states determined by $CD4^+$ cell counts (<100, 100–199, 200–349, 350–499 and ≥500/μl) to six calendar periods (1980–1989, 1990–1994, 1995–1999, 2000–2004, 2005–2009 and 2010–2015). We used the same calendar periods and $CD4^+$ cell count states to parameterize the mortality rates of the MSM in our model.

## Parameter estimates from literature

We chose the transition rate from no precursors of anal cancer to AIN 1 in the baseline $CD4^+$ category of 100–199 cells/μl so that model simulations corresponded to the anal cancer incidence of 78 per 100 000 person-years reported by Machalek *et al.* [1]. We simulated the model 1000 times with 10 000 HIV-positive MSM and used linear regression to identify the rate that matched this incidence best. This rate was 0.15 per person-year ($\beta_0 = 0.15$ in the equation for the hazard function $f$ above). We assumed that the rate of transition from no lesion to AIN 1 increased by 2.04 per 100 000 for every 100/μl decrease in $CD4^+$ cell count ($\beta_1 = 2.04$), based on estimates from the SHCS [12]. We fit a Weibull distribution to the cumulative incidence observed by Mathews *et al.* [14]. In their study progression from AIN 2/3 to anal cancer was 2.1% [95% confidence interval (CI) 1.3–2.8] after 2 years, and 3.9% (95% CI 2.1–5.6) after 5 years. We found no published estimates for the progression from AIN 1 to AIN 2/3. We, therefore, fit a Weibull distribution to the progression from AIN 1 to AIN 2/3, so that the progression from AIN 1 to anal cancer lasted approximately 6–7 years, in line with observations from the SHCS [12]. The shape parameters ($k$) and scale parameters ($\lambda$) of these distributions and all other literature-derived parameters are shown in Table 1.

## Interventions

We examined the effect of 100% cART coverage and screening for AIN 2/3 and treatment on anal cancer

**Table 1. Parameter values progression and regression between precursor states and anal cancer.**

| Progression/regression | | | | | |
|---|---|---|---|---|---|
| From | To | Parameter | Value | Source | Reference |
| AIN 0 | AIN 1 | Rate per person-year with 100–199 $CD4^+$ cells/μl | 0.15[a,b] (0.1–0.2) | Systematic review and meta-analysis of longitudinal studies in MSM | [1] |
| AIN 0 | AIN 1 | Increase in rate per person-year per 100 cells/μl $CD4^+$ cell count decrease | 2.04 (1.44–2.88) | Case-control study nested within Swiss HIV Cohort Study, data from MSM | [12] |
| AIN 1 | AIN 2/3 | Weibull shape | 2[b] (1–4) | Idem | [12] |
| AIN 1 | AIN 2/3 | Weibull scale | 7[b] (5–10) | Idem | [12] |
| AIN 2/3 | Anal cancer | Weibull shape | 0.69[b] (0.53–0.77) | Cytology-based screening cohort, overall data (78% MSM) | [14] |
| AIN 2/3 | Anal cancer | Weibull scale | 551.13[b] (201.2–7395.9) | Idem | [14] |
| AIN 2/3 | AIN 1 | Sensitivity of anal cytology (Pap smears) %) | 81 (69–93) | Systematic review of test accuracy studies in MSM and other populations | [24] |
| AIN 2/3 | AIN 1 | Treatment efficacy 1 year after treatment (in %) | 48.1[b] (39.7–57.8) | Retrospective cohort study of MSM treated in surgical practice | [17] |

AIN, anal intraepithelial neoplasia; Pap, Papanicolaou.
[a]Identified through model simulations (see text).
[b]Calculated from data presented in cited publication.

**Table 2. Characteristics of cohorts of MSM enrolled in the Swiss HIV Cohort Study, by follow-up period.**

| Follow-up period | No. of men | $CD4^+$ cells/μl (median, IQR) | Nadir $CD4^+$ cells/μl (median, IQR) | Age (median, IQR) | Current smoking (%) | cART coverage (%) |
|---|---|---|---|---|---|---|
| 1980–1989 | 762 | 340 (140–545) | 228.5 (60.0–440.0) | 36.2 (29.9–43.5) | n.a. | 0 |
| 1990–1999 | 3018 | 283 (126–469) | 120.0 (20.0–288.8) | 38.5 (32.7–46.4) | n.a. | 45.5 |
| 2000–2009 | 4087 | 467 (351–613) | 257.0 (165.0–373.5) | 41.7 (36.1–48.4) | 50.4 | 78.2 |
| 2010–2015 | 4538 | 576 (451–727) | 394.0 (283.0–524.8) | 46.4 (38.9–53.0) | 44.3 | 83.4 |

cART, combination antiretroviral therapy; IQR, interquartile range; n.a., not assessed.

incidence in MSM. In the base scenario with cART coverage below 100% and no screening, we assumed that the cART coverage achieved in 2010–2015 continued 2016–2030. We implemented the 100% cART coverage scenario by parameterizing the model with the estimates from patients on cART. We considered four different screening strategies, combined with cART below 100%: no screening, yearly cytology screening, yearly anoscopy screening and a $CD4^+$ cell count-dependent strategy. In the $CD4^+$ cell count-dependent strategy, we assumed that only those MSM were screened who had had a $CD4^+$ nadir below 200 cells/μl; they underwent anoscopy 5 years after their $CD4^+$ cell count had dropped below 200 cells/μl. We assumed that cytology had a sensitivity of 81% (95% CI: 69–93%) based on the study by Chiao *et al.* [24], and that anoscopy, including the histological examination of suspicious lesions, was 100% sensitive. We assumed a response rate of 49% 1 year after treatment initiation for electrocautery or IR coagulation [17–19, 25]. We assumed that treated patients who reverted back to AIN 1 subsequently had the same probability of developing AIN 2/3 as untreated men with AIN 1. For each strategy, we recorded the number of anal cancer diagnoses and the number of screening tests. We then calculated the number of anal cancers prevented compared with the no screening strategy and the number of people who needed to be screened (NNS) to prevent one anal cancer [26]. In all simulations, we introduced the screening intervention in 2016.

### Sensitivity analyses

We performed a multivariate probabilistic sensitivity analysis. We sampled all model parameters 10 000 times from a log-normal distribution and simulated a population of 10 000 HIV-positive MSM for each sampled parameter set. We used the percentage of anal cancers prevented in each screening scenario as the main outcome variable and calculated Pearson correlation coefficients between all parameter values and outcomes to identify the parameters to which the model was most sensitive. Results are presented as incidence rates per 100 000 person-years, with 95% CI. In an additional sensitivity analysis, we tested the assumption of stationary $CD4^+$ trajectories. We simulated anal cancer incidence between 1980 and 2015 based on the observed $CD4^+$ trajectories in the SHCS.

## Results

We analyzed 6411 MSM with at least three $CD4^+$ cell counts who were followed in the SHCS between February 1983 and August 2015. Men had between three and 170 $CD4^+$ cell counts, totaling 175 827 measurements. Table 2 shows the characteristics of the cohorts of MSM followed in the different calendar periods. Coverage with cART increased from 0% in 1980–1989 to 83.4% in 2010–2015. There were marked increases over time in rates of transition from low to higher $CD4^+$ cell count states (Supplemental Digital Content Table S1, http://links.lww.com/QAD/B109). For example, the rate of transition from $CD4^+$ cell count less than 100 cells/μl to at least 100 cells/μl increased from 5.3 (95% CI 4.3–6.4) per 100 person-years in 1980–1989 to 122.9 (95% CI 120.8–124.9) per 100 person-years in 2010–2015. As expected, mortality rates increased with decreasing $CD4^+$ cell counts and were higher in earlier calendar years than in later years (Supplemental Digital Content Table S2, http://links.lww.com/QAD/B109).

### Anal cancer incidence

Under the base scenario of cART coverage remaining at the level reached in the period 2010–2015 (Table 2) and with no screening, the simulated anal cancer incidence rates increased until 2009, plateaued between 2010 and 2015 and decreased from 2015 onward. The highest rate was simulated for 2009, at 81.7 new cases per 100 000 person-years. The rate declined by 28.2% to 58.7 per 100 000 person-years in 2030 (Fig. 2 and, for a version with 95% CIs, Supplemental Digital Content Fig. S1, http://links.lww.com/QAD/B109).

The simulated anal cancer rate was broadly consistent with the incidence rate observed in the SHCS. Between 1997 and 2003, the observed incidence in the SHCS was higher than the simulated rates, but estimates were based on small numbers of cases and CIs were wide. The simulated rates matched the observed rates closely from 2003 onward (Supplemental Digital Content Fig. S2, http://links.lww.com/QAD/B109).

### Impact of combination antiretroviral therapy coverage and screening

When modeling anal cancer incidence under the assumption of 100% cART coverage from 2016 onward,

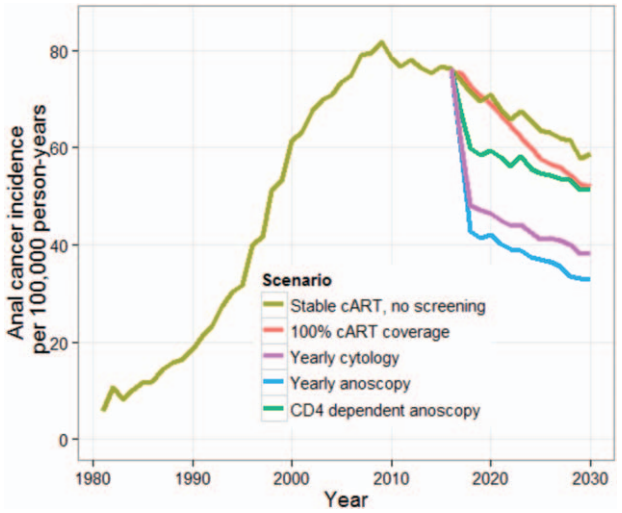


**Fig. 2. Simulated anal cancer incidence assuming different intervention scenarios.**

the incidence decreased to 52.0 per 100 000 person-years by 2030, rather than to 58.7 per 100 000 person-years with the base scenario (Fig. 2), corresponding to a relative reduction of 11.4% compared with the base scenario. Yearly anoscopy and subsequent treatment decreased anal cancer incidence to 32.8 per 100 000 person-years in 2030, for a reduction of 44.1% compared with the base scenario. Yearly cytology decreased anal cancer incidence to 38.2 per 100 000 person-years in 2030, for a reduction of 34.9%. Finally, $CD4^+$ cell count-dependent anoscopy decreased anal cancer incidence to 51.3 per 100 000 person-years in 2030, for a reduction of 12.6%. The decrease in anal cancer incidence was substantial in the first year after introducing screening. Afterwards the slope was similar to the one observed with the base scenario (Fig. 2).

Table 3 shows the number of expected anal cancer cases, the number of screening tests, the number of cancer cases prevented and the NNS of MSM to prevent one cancer in a hypothetical cohort of 10 000 MSM followed up 2016–2030. With yearly Pap screening, 384 MSM would need to be screened for 15 years to prevent one case. Similarly, with the yearly anoscopy strategy, 313 MSM would need to be screened for 15 years to prevent one new case of anal cancer. With $CD4^+$ cell count-dependent screening, 242 MSM would need to be screened once to prevent one anal cancer, but the percentage of cases prevented would be smaller than with the other strategies.

### Sensitivity analyses

The results of the sensitivity analyses are shown in Supplemental Digital Content Figs. S3 and S4, http://links.lww.com/QAD/B109. All strategies were sensitive to the efficacy of electrocautery or IR coagulation treatment (Pearson correlation $r = 0.46$ for yearly anoscopy, $r = 0.38$ for yearly cytology and $r = 0.20$ for $CD4^+$-dependent anoscopy). The benefit of the $CD4^+$ cell count-dependent anoscopy screening strategy was most sensitive to the relationship between the risk of transition from AIN 0 to AIN 1 and the $CD4^+$ cell count ($r = 0.55$). The benefit of yearly cytology was also dependent on the sensitivity of cytology screening ($r = 0.23$). The shape parameter of the Weibull distribution used in the transition from AIN 2/3 to anal cancer correlated with the percentage of anal cancers prevented in all three screening strategies ($r = 0.13$, 0.09, 0.09, respectively). Other correlations, including all correlations with transitions between $CD4^+$ cell count states (Supplemental Digital Content Fig. S4, http://links.lww.com/QAD/B109) were weak, with correlation coefficients below 0.1. In the sensitivity analysis using observed $CD4^+$ trajectories the same pattern was evident, with simulated anal cancer incidence rates increasing until 2007 and then plateauing. However, the peak of the incidence was somewhat higher than in the simulation with stationary $CD4^+$ trajectories (Supplemental Digital Content Fig. S5, http://links.lww.com/QAD/B109).

## Discussion

This modeling study based on data from the SHCS predicted that anal cancer incidence in HIV-positive MSM peaked in 2009 at around 80 new cases per 100 000, plateaued in subsequent years and will decrease to about

**Table 3. Comparison of anal cancer screening strategies in a cohort of 10 000 MSM, followed from 2016 to 2030.**

| Strategy | No. of expected invasive cancer cases | No. of screening tests | No. of cancers prevented | No. of men needed to be screened to prevent one cancer | Percentage of cases prevented | No. of screening tests to prevent one cancer |
|---|---|---|---|---|---|---|
| No screening | 81.7 (65–100) | 0 | 0.0 | NA | 0% | NA |
| Yearly cytology | 56.5 (42–72) | 118 150 | 25.2 (16–35) | 384 (347–422) | 30.9% (30.0–31.8%) | 4684 (4586–4782) |
| Yearly anoscopy | 50.8 (37–65) | 118 066 | 30.9 (21–42) | 313 (279–347) | 37.9% (36.9–38.8%) | 3817 (3722–3913) |
| $CD4^+$ cell count-dependent anoscopy[a] | 71.1 (55–88) | 2562 | 10.6 (5–17) | 242 (212–272) | 13.0% (12.3–13.6%) | 242 (212–272) |

Results from mathematical modeling study over 15 years (2016–2030). Estimates with 95% confidence intervals are shown.
[a]Men are screened 5 years after their $CD4^+$ cell count fell below 200 cells/μl; 25.6% of men were eligible for $CD4^+$ cell count-dependent screening.

60 per 100 000 by 2030 in the absence of screening. Universal cART coverage from 2016 onward would reduce incidence further, to around 50 per 100 000 by 2030. Annual screening with Pap smears or anoscopy would reduce anal cancer incidence substantially, to below 40 per 100 000, and targeted screening of MSM based on the $CD4^+$ cell count nadir to about 50 per 100 000. The NNS of MSM over 15 years to prevent one case were 384 for yearly cytology, 313 for yearly anoscopy and 242 for $CD4^+$ cell count-dependent screening.

To our knowledge, this is the first study to predict the incidence of anal cancer in HIV-positive MSM over many years, taking into account cART coverage and individual $CD4^+$ cell count trajectories. We used a dynamic stochastic simulation model to estimate anal cancer incidence, based on changes in $CD4^+$ trajectories following the introduction of cART and allowing for nonconstant rates in progression to anal cancer. Previous studies of the effect of screening for precancerous anal lesions and cancer did not consider the time-dependent effect of $CD4^+$ cell count on the risk of anal cancer [27,28]. The $CD4^+$ cell count layer of the model was parameterized with data from the SHCS, one of the longest-running HIV cohort studies worldwide [22,29]. The anal cancer layer was parameterized with data from the literature but reproduced the incidence observed in the Swiss cohort.

Our findings are consistent with several earlier studies from Europe and the United States which reported that during the first 10 years of cART anal cancer incidence continued to rise [4,5,9]. Our results are also in line with an analysis of North American cohorts which found that anal cancer incidence plateaued beyond 10 years of cART [7] and with findings from a Dutch cohort that observed a slight decrease after 2006 [6]. Of note, rates of anal cancer were higher in the North American and Dutch cohorts than in our study. In the sensitivity analysis using the observed instead of simulated $CD4^+$ trajectories, we also noted higher anal cancer incidence rates, but the overall pattern was similar. Our study offers a possible explanation for these trends, namely that during the early study period many HIV-positive MSM initiated cART at very low $CD4^+$ cell counts, had already progressed to AIN 1, and then lived long enough to develop anal cancer.

Our study has several limitations. Smoking status was not consistently recorded in the SHCS before the year 2000 and could, therefore, not be included in the model. Furthermore, although we simulated follow-up of patients until death, we did not explicitly model the effect of aging. The rate of anal cancer increases with age [2,7,8], but the effect of older age may be less important in HIV-positive MSM, in whom anal cancer is seen at younger ages than in other populations [4,9]. Our model did not take effects of screening and treatment on HPV transmission into account. The applicability of our results to other countries and settings is unclear. It would be of great interest to reparameterize our model in the context of a different cohort of MSM. The shape of the epidemic curve of anal cancer in HIV-positive MSM will likely be similar in other countries where cART was introduced rapidly, but the peak incidence reached, and the year of the peak might differ. We did not include HPV clearance in the model. Most anal cancers in MSM are caused by HPV type 16 [1] and clearance of HPV type 16 is reduced in HIV-positive individuals [30,31]. Also, integration of HPV into the host genome of squamous cells [32] may happen before HPV clearance.

We did not formally model cost-effectiveness. Goldie *et al.* used a state-transition model to estimate the cost-effectiveness of anal Pap screening in HIV-positive MSM in the United States. The authors concluded that with an incremental cost-effectiveness ratio of $13 000 (1997 US dollars, 2-yearly screening in early stage of HIV) per quality-adjusted life year (QALY) gained, such screening offered 'quality-adjusted life expectancy benefits at a cost comparable with other accepted clinical preventive interventions' [27]. Czoski-Murray *et al.* [33] developed decision-analytical models to evaluate the cost-effectiveness of anal Pap screening in HIV-positive and HIV-negative MSM in the United Kingdom. The authors found little evidence that screening 'would generate health improvements at a reasonable cost'. The incremental cost-effectiveness ratio in MSM, regardless of HIV status, was over £44 000 (2007 pounds sterling) per QALY gained. These discrepant findings are probably due to different assumptions regarding the rate of progression from AIN 2/3 to invasive cancer: the British study [33] assumed that the rate of progression was relatively low, and identical in HIV-positive and HIV-negative persons. Although we did not model this explicitly, it becomes clear from our study that the benefit of a screening program would be greatest now and decrease over time as fewer MSM have low nadir $CD4^+$, and more MSM have been vaccinated against HPV.

How does screening for anal cancer in HIV-positive MSM compare with screening for cervical cancer, which is recommended by The United States Preventive Services Task Force [34] and public health agencies in many other countries? There are no randomized controlled trials of cervical screening in Western countries, and comparisons between women participating and not participating in screening programs are prone to bias [35]. Raffle *et al.* [36] analyzed cervical screening in the west of England 1976–1996 and estimated rates of invasive cancer in the absence of screening based on historical data: about 1800 women were needed to be screened every 5 years during this period to prevent one case of invasive cancer. In rural India, a cluster randomized trial compared the effectiveness of a single round of screening: the number of women needed to be screened to prevent one cancer (stage II or higher) was

1258 for cytology and 684 for HPV testing [37]. Little data are available on the effectiveness of screening in HIV-positive women. A cost-effectiveness analysis based on simulated practice in the United States showed that screening with annual Pap smears was cost-effective [38], and a simulation study of a cohort of HIV-positive women in Cameroon concluded that 262 women will need to be screened at cART initiation to prevent one cervical cancer death [39]. Screening for colorectal cancer and breast cancer is also widely recommended. An Independent UK Panel on Breast Cancer Screening concluded that 180 women would need to be screened every 5 years from age 55 years to age 79 years to prevent one breast cancer death [40]. Finally, a systematic review and meta-analysis concluded that 377–515 asymptomatic adults will need to undergo guaiac fecal occult blood testing annually or biannually over 18 years to prevent one colorectal cancer death [41].

In conclusion, our modeling study predicts substantial reductions in anal cancer incidence in MSM in the next 15 years, even in the absence of screening and without further increases in cART coverage. The model also predicts that the introduction of yearly anal Pap screening or anoscopy screening, or $CD4^+$ cell count guided anoscopy screening would reduce anal cancer incidence further. It is noteworthy that NNS to prevent one invasive anal cancer in MSM appear to be lower than the NNS to prevent one invasive cervical cancer in HIV-negative women, in whom screening is well established [42], and that it may be similar to the NNS in HIV-positive women. Clearly, further research on the cost-effectiveness and acceptability of different strategies for anal cancer screening is warranted. In the meantime, increasing cART coverage further, in MSM and the HIV-positive population in general, remains an important priority in Switzerland and globally.

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### Conflicts of interest

There are no conflicts of interest.

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