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Public Health Benefits of Routine Human Papillomavirus Vaccination for Adults in the Netherlands: A Mathematical Modeling Study

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Background. Expanding routine human papillomavirus (HPV) vaccination to adults could be an effective strategy to improve prevention of HPV infection and cervical cancer.

Methods. We evaluated the following adult vaccination strategies for women only and for both women and men in addition to the current girls-only vaccination program in the Netherlands, using the established STDSIM microsimulation model: one-time mass campaign, vaccination at the first cervical cancer screening visit, vaccination at sexual health clinics, and combinations of these strategies.

Results. The estimated impact of expanding routine vaccination to adult women is modest, with the largest incremental reductions in the incidence of HPV infection occurring when offering vaccination both at the cervical cancer screening visit and during sexually transmitted infection (STI) consultations (about 20% lower after 50 years for both HPV-16 and HPV-18). Adding male vaccination during STI consultations leads to more-substantial incidence reductions: 63% for HPV-16 and 84% for HPV-18. The incremental number needed to vaccinate among women is 5.48, compared with 0.90 for the current vaccination program.

Conclusions. Offering vaccination to adults, especially at cervical cancer screening visits (for women) and during STI consultations (for both sexes), would substantially reduce HPV incidence and would be an efficient policy option to improve HPV prevention and subsequently avert cervical and possibly male HPV-related cancers.

Keywords. human papillomavirus; modeling; vaccination; cervical cancer.

Human papillomavirus (HPV) vaccination, targeting the most-oncogenic HPV types for cervical cancer, HPV-16 and HPV-18 [1,2], has been implemented in many countries. Vaccination programs using either the bivalent or quadrivalent vaccine focus mainly on young girls (and, in some countries, also boys) prior to sexual debut. The United Kingdom has had a relatively high vaccination coverage (about 86% among girls) [3], but most countries experience suboptimal coverage levels, varying from 32%, in the United States, to about 70%, in Australia [4]. The low uptake, together with the limited target age group, has led to HPV transmission control not reaching its full potential in most countries. Recent findings from the multinational Vaccine Immunogenicity and Efficacy (VIVIANE) study showed that the bivalent vaccine is efficacious against HPV-16/18 infections in women aged >25 years [5], sparking the debate about whether adult women should also be offered HPV vaccination to further improve cervical cancer prevention [5–8]. In addition, recent findings of the Mid-Adult Males (MAM) study indicated that the quadrivalent vaccine is safe and induces HPV antibodies in vaccinated men aged 27–45 years [9]. Vaccination strategies also targeting adults could therefore improve HPV transmission control, especially in cohorts too old to have been covered by current vaccination programs or those in countries with poor coverage [5–8].

Thus far, it has not been studied how adult vaccination should be implemented. An effective and efficient strategy to roll out HPV vaccination for adult women could be by using existing public health programs, in particular cervical cancer screening and sexual health services [6, 10, 11]. In addition, a one-time mass campaign could target women who were too old for vaccination when the current girls-only program was initiated. Inclusion of boys and men in HPV vaccination strategies could further improve transmission control, with the additional benefit of protecting them against HPV-related cancers that can affect males [11–13].

Here, we used the established STDSIM model to estimate the impact of extending the current girls-only Dutch vaccination program with vaccination for women and men up to 45 years of age. We previously used this model to estimate the impact of the current Dutch vaccination strategy and found that the incidence of HPV-16 and HPV-18 infection will eventually decline by 64% and 58%, respectively, compared with the prevaccination incidence [13]. In the current study, we extended this model to

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simulate different HPV vaccination strategies integrated within existing public health services for cervical cancer screening and sexual health in the Netherlands, as well as a one-time mass vaccination campaign for adults.

METHODS

Model Structure and Quantification

STDSIM simulates the life course of individuals in a dynamic heterosexual network, in which sexually transmitted infections (STIs) such as HPV can spread. Same-sex partnerships are not included in our model. Each individual has characteristics that are either constant (eg, date of birth and sex) or subject to change (eg, number of sexual partners and infection status). Events are determined by probability distributions and can lead to new events (eg, birth leads to a future event of becoming sexually active) or to the cancellation of future events (eg, a death cancels all scheduled events concerning sexual activity for this person). STDSIM can simulate several interventions simultaneously.

We have previously quantified STDSIM to reproduce sexual behavior dynamics and the spread of HPV-16 and HPV-18 in the Netherlands [14]. Briefly, we reproduced the Dutch population and its sexual network, using demographic data [15, 16] and national sexual behavior surveys [17–19]. To validate the modeling of sexual risk behavior in the model, we simulated the transmission of chlamydia and compared our results to prevalence data from the Chlamydia Screening Implementation study [20]. We then introduced HPV-16 and HPV-18 in the simulated population to estimate the transmission probabilities and acquired immunity dynamics necessary to reproduce the observed age-specific HPV-16 and HPV-18 prevalences [21–23]. Complete information of the model structure can be found elsewhere [14, 24], and the parameter quantification and model validation for the Dutch setting is described in detail by Matthijsse et al [13, 14] and are briefly described in Supplementary Materials 1*A*–1*D*.

Assumptions About Vaccine Efficacy

We used the same assumptions for the impact of HPV vaccination of girls and boys in the Netherlands as in our previous study [13]. Efficacy of vaccination for girls aged <25 years was set to 94.7% for HPV-16 and 92.3% for HPV-18 [1] and modeled as a lifelong reduced susceptibility to infection [25]. Efficacy for boys was assumed to be equal to the recently reported quadrivalent vaccine efficacy for boys (ie, 78.7% for HPV-16 and 96.0% for HPV-18) [26].

Vaccine efficacy for women aged >24 years was obtained from the VIVIANE study, which showed an efficacy of 77.4% for both HPV types [5]. This efficacy is thus 18.3% lower for HPV-16 and 16.1% lower for HPV-18, compared with that for young girls. We used the same relative reductions to men aged >24 years, resulting in a vaccine efficacy of 64.5% for HPV-16 and 80.6% for HPV-18. We simulated vaccine efficacy to be independent of HPV status at the time of vaccination, as vaccine efficacy is still substantial in women previously exposed to HPV-16 and HPV-18 [5, 13, 27]. Infection clearance is not accelerated by the vaccine in our model.

Vaccination Strategies

We first modeled the current vaccination program as implemented in the Netherlands: a mass campaign for 13–16-year-old girls in 2009 with a coverage of 50% and annual vaccination of 12-year-old girls at 60% coverage [13, 28, 29]. We then simulated the addition of several adult vaccination strategies to the current girls-only strategy from 2016 onward. In strategies targeting both men and women, routine vaccination for boys was included from 2016 onward, assuming the same target age groups and uptake as for girls. The following 5 individual strategies were simulated (Supplementary Figure 5), as well as various combinations of these strategies.

Mass Campaign (Females)

This is a one-time mass campaign conducted in 2016 for women aged 24–45 years to capture those who fell outside the age ranges of the original catch-up campaign in 2009. Coverage rates are equal to the age-specific attendance rates of the Dutch cervical cancer screening program [30].

Screening (Females)

Vaccination is offered to all 30-year-old women attending cervical cancer screening for the first time from 2016 onward [30]. We assumed that all women accepted the vaccination, but they were not offered a new vaccination if they had already been vaccinated in the past.

STI Consultation (Females)

All girls and women aged 15–29 years attending sexual health clinics for STI testing are offered HPV vaccination. Attendance rates were derived from Statistics Netherlands [15] and the National Public Health Compass [31]. In the model, we tuned the clinic visit rates to reproduce the observed attendance rates in the Netherlands, and we assumed that women with ≥2 recent sex partners are 3 times more likely to go for a consultation than women with 1 recent sex partner. The resulting visit rates in the model were 2.75%, 5.10%, and 2.15% for ages 15–19 years, 20–24 years, and 25–29 years, respectively, for those with 1 recent sex partner and 8.25%, 15.30%, and 6.45%, respectively, for those with ≥2 recent sex partners. We assumed that all girls and women at the sexual health clinics accepted vaccination, but they did not receive another vaccination if they had already been vaccinated in the past.

Mass Campaign (Females and Males)

This is a one-time mass campaign for men and women aged 24–45 years in 2016, assuming the same coverage rates for men as for women [32] in the first strategy involving a mass campaign for females only.

STI Consultation (Females and Males)

Males and females aged 15–29 years attending sexual health clinics for STI testing from 2016 onward are offered HPV vaccination.

Similar to the third strategy, consisting of STI consultation for females only, we tuned the visit rates in the model to reproduce the attendance rates derived from Statistics Netherlands and the National Public Health Compass [15, 31]. For men aged 15–19 years, 20–24 years, and 25–29 years, the resulting visit rates are 1.50%, 2.80%, and 1.65%, respectively, for those with 1 recent sex partner and 4.50%, 8.40%, and 4.95%, respectively, for those with ≥2 recent sex partners. We assumed that all adults at the sexual health clinics accepted vaccination, but they did not receive another vaccination if they had already been vaccinated in the past.

Impact Calculations

The impact of strategies was calculated by estimating the relative reduction in the incidence of HPV-16 and HPV-18 infection in all women 10, 20, 50, and 70 years after the introduction of the vaccination program. In addition, we compared the efficiency of the programs by determining the incremental number needed to vaccinate (NNV) to prevent 1 new infection in all women from 2008–2029 and 2008–2079.

Sensitivity Analysis

In contrast to the base case analysis, we also ran the model assuming that the vaccine has no protective effect in individuals with an HPV infection at the time of vaccination. We further varied the vaccine efficacy for adults by using the limits of the 95% confidence interval of the VIVIANE study, resulting in vaccine efficacies for women ranging from 49.7% to 91.1% for both HPV types [5]. For men, we used the same relative reduction percentages, leading to an efficacy of 41.3% for HPV-16 and 51.7% for HPV-18 as lower bounds, and 75.7% and 94.8%, respectively, as upper bounds. Also, as an alternative scenario, we varied the expected uptake of the vaccination strategies, assuming that only half of the attending adults would accept the vaccine (instead of all attending adults). Finally, Huijsmans et al [33] recently showed that HPV prevalence in the Netherlands could be twice as high as the earlier data our model fit was based upon [22]. Therefore, we reanalyzed the impact of our most efficient strategies in a model with doubled HPV prevalence prior to vaccination. The overall prevalence among women was doubled in the model by increasing sexual risk behavior.

RESULTS

For all strategies, most of the incidence reduction has occurred within 50 years following vaccination (Table 1), and after approximately 70 years equilibrium is reached (Supplementary Figures 3 and 4). For strategies concerning only women, the most substantial incidence reductions over time are achieved through a combined strategy of offering vaccination to adult women at the first cervical cancer screening visit and during STI consultations (Table 1). The incidences of both HPV-16 and HPV-18 are then reduced by approximately 20% as compared to the incidence under the current vaccination program. While strategies including a one-time mass campaign generate substantial incremental reductions 10 years after the introduction of the current vaccination program (eg, 15% for HPV-16), the effects wear off over time, and the incidence is about the same as under the current program in the long run. Including also boys and men is projected to lead to substantial incremental reductions in HPV infection incidence among women in all strategies, especially for HPV-18 (Table 1).

Table 1. Incident Human Papillomavirus 16 (HPV-16) and HPV-18 Infections for All Women 10, 20, 50, and 70 Years After the Introduction of the Current Vaccination Program (in 2009) Under Different Adult Vaccination Strategies (All Starting by 2016)

	Incident Infections Per 100 Life-Years, by HPV Type[a]							
	HPV-16				HPV-18			
Vaccination Strategy (Sex)	10 y	20 y	50 y	70 y	10 y	20 y	50 y	70 y
Current vaccination program	0.84	0.58	0.44	0.41	0.24	0.17	0.14	0.13
Inclusion of women								
Mass campaign (F)	0.72 (15)	0.53 (9)	0.43 (1)	0.41 (0)	0.20 (18)	0.15 (10)	0.14 (2)	0.14 (0)
Screening (F)	0.81 (3)	0.52 (9)	0.38 (12)	0.36 (13)	0.23 (4)	0.15 (11)	0.12 (14)	0.11 (15)
STI consultations (F)	0.81 (3)	0.54 (6)	0.40 (9)	0.37 (10)	0.23 (3)	0.16 (5)	0.13 (8)	0.12 (8)
Mass campaign + STI consultations (F)	0.69 (17)	0.50 (14)	0.39 (11)	0.37 (11)	0.19 (20)	0.14 (16)	0.13 (10)	0.12 (8)
Screening + STI consultations (F)	0.79 (6)	0.50 (14)	0.35 (20)	0.32 (22)	0.23 (6)	0.14 (15)	0.11 (21)	0.10 (23)
Screening + mass campaign (F)	0.70 (16)	0.49 (15)	0.38 (13)	0.36 (13)	0.20 (19)	0.14 (18)	0.12 (16)	0.11 (15)
Inclusion of women, boys and men								
Mass campaign (F + M)	0.64 (24)	0.40 (30)	0.26 (40)	0.24 (41)	0.15 (36)	0.09 (49)	0.06 (61)	0.05 (62)
STI consultations (F + M)	0.75 (10)	0.44 (24)	0.24 (45)	0.20 (50)	0.20 (19)	0.10 (38)	0.05 (65)	0.04 (71)
Mass campaign + STI consultations (F + M)	0.62 (27)	0.37 (35)	0.23 (48)	0.20 (50)	0.15 (38)	0.08 (53)	0.04 (69)	0.04 (71)
Screening (F) + STI consultations (F + M)	0.73 (13)	0.40 (31)	0.19 (56)	0.15 (63)	0.19 (22)	0.09 (47)	0.04 (75)	0.02 (84)
Screening (F) + mass campaign (F + M)	0.63 (25)	0.37 (36)	0.21 (52)	0.18 (56)	0.15 (37)	0.08 (54)	0.04 (74)	0.03 (80)

HPV-16 and HPV-18 infection incidence prior to vaccination was 1.16 and 0.32 infections/100 life-years, respectively. The corresponding incidence graphs are shown in Supplementary Figures 3 and 4.

Abbreviation: STI, sexually transmitted infection.

[a] The relative percentage reduction in incidence as compared to the current vaccination program (girls only) is shown between parentheses (%).

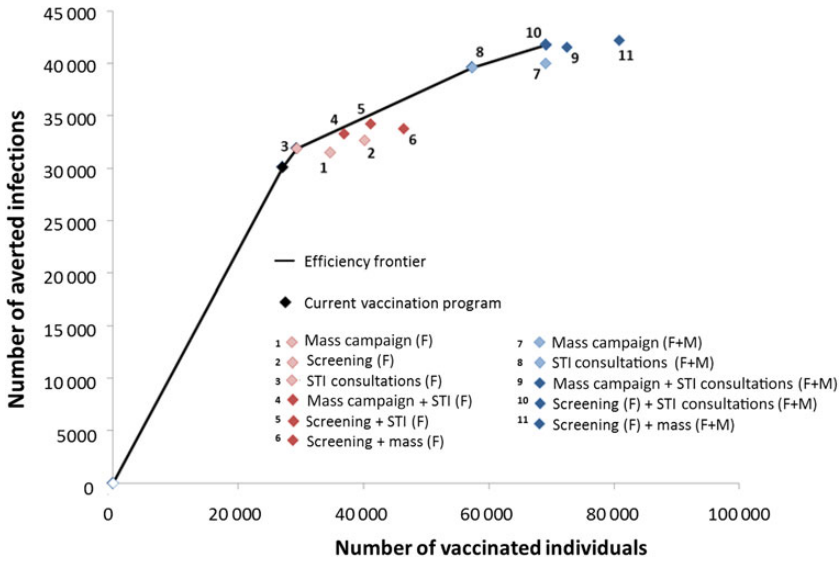

Figure 1. Estimated cumulative number of averted infections and vaccinated individuals for the current vaccination program and all adult vaccination strategies considered from 2008–2079 in the Netherlands. In strategies targeting both men and women, routine vaccination for boys was included from 2016 onward. Numbers are scaled to a simulated population of 100 000 people in 2016. Values of the corresponding number needed to vaccinate are given in Supplementary Table 1. Abbreviation: STI, sexually transmitted infection.

A combined strategy of offering vaccination to women at their first cervical cancer screening visit and to both men and women at STI consultations would lead to the largest incidence reductions over time (63% for HPV-16 and 84% for HPV-18).

The NNV to prevent 1 infection for the current vaccination program as compared to no vaccination is 0.90, when considering 2008–2079 (Figure 1 and Supplementary Table 1). The most efficient adult vaccination strategies are vaccination during STI consultations for women alone (incremental NNV, 1.27), vaccination during STI consultations for both men and women (incremental NNV, 3.63), and the combination of vaccination during the first cervical cancer screening visit and STI consultations for both men and women (incremental NNV, 5.48). Estimated trends in HPV-16 and HPV-18 infection incidence under these most efficient strategies are shown in Figure 2. Less efficient are the strategies of mass campaigns and cervical cancer screening, offered either individually or combined. When considering a shorter time frame, 2008–2029, the incremental NNVs are obviously higher, but the order of efficiencies is similar (Supplementary Table 1).

The sensitivity analysis shows that reductions in the incidence of HPV infection are only slightly lower as compared to the base case when assuming that vaccination is ineffective in HPV-positive women, yet the order of effective strategies remains the same (Table 2 and Supplementary Table 2). Assuming lower and higher vaccine efficacies for adults particularly affects the incidence reductions in strategies that incorporate vaccination at the first cervical cancer screening visit (Table 2 and Supplementary Table 2). The maximum difference in incidence reduction is 9 percentage points (ie, the HPV-18 incidence is reduced by 6% as compared to the current vaccination program, instead of 15%). In all other strategies, vaccine efficacy has a limited impact on the estimated incidence reduction. Assuming lower vaccine acceptability affects mostly the incidence reduction under the combined strategy of vaccination at the first cervical cancer screening and at STI consultations for both men and women, with a difference of about 10 percentage points. The incidences of HPV-16 and HPV-18 are still estimated to decrease by 53% and 75%, respectively (instead of 63% and 84%, respectively, compared with the current vaccination program (Table 2 and Supplementary Table 2). When the prevalences of HPV-16 and HPV-18 are twice as high prior to vaccination, the estimated relative reductions in incidence are slightly higher, compared with our base case analysis (Supplementary Table 3).

DISCUSSION

Using STDSIM and vaccination efficacy estimates from the VIVIANE study, we have presented the first estimations of the impact of extending routine HPV vaccination to adult women, boys, and men through existing public health programs. Compared with the current, girls-only program, the incidences of HPV-16 and HPV-18 infection are estimated to decrease in the long run by 63% and 84%, respectively, when offering vaccination both at the first cervical cancer screening visit for women (aged 30 years) and at STI consultations for men and women (aged 15–29 years). For this strategy, the incremental NNV to prevent 1 HPV infection is 5.48, which is 6 times higher than the NNV of 0.90 for the current program.

There are 3 important limitations associated with these results. First, there is still large uncertainty about the vaccine

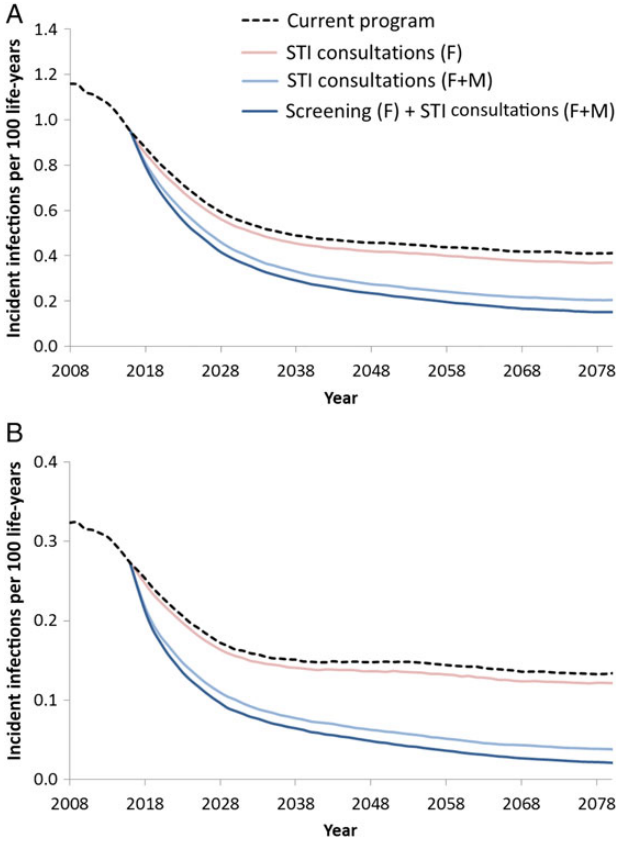

Figure 2. Model-estimated trends in incident human papillomavirus type 16 (HPV-16; *A*) and HPV-18 (*B*) infections for all women for the period 2008 (before vaccination) until 2080 when vaccinating adults under the 3 most efficient vaccination strategies by 2016. Abbreviation: STI, sexually transmitted infection.

efficacy for adults, yet the sensitivity analysis in which we varied the efficacy shows that this hardly affects our main findings. Still, observational studies are needed to determine the efficacy of the bivalent vaccine for adult men. Second, we made rather simple assumptions regarding vaccine uptake levels for adults based on cervical cancer screening and STI consultation rates, which might be too optimistic. However, while halving vaccine acceptability would lead to lower estimated incidence reductions, significant incremental benefits are still to be expected. Furthermore, an HPV prevalence of approximately 5% is rather low as compared to that in other countries and to recent results by Huijsmans et al [33], possibly affecting the generalizability of our study. Our sensitivity analysis showed that doubling HPV prevalences as compared to the base case resulted in a slightly higher impact of the most efficient strategies, yet differences were small. Finally, we did not include cervical intraepithelial neoplasia (CIN), cervical cancer, and treatment of women with CIN or cervical cancer in our model. By removing precancerous lesions, treatment could shorten the duration of the underlying HPV infection. However, this is to some extent taken into account in our model because we calibrated the natural history of HPV on prevalence data from a screened population [14, 22].

We appreciate that a 70-year time horizon might be less relevant for policy makers as uncertainties of predictions are increased with longer time horizons, owing to the emergence of factors such as new technical developments (better vaccines) or development of resistance. However, our results emphasize the need to consider both short- and long-term predictions in assessing HPV vaccination strategies. Our short-term incidence reductions (10 years and 20 years after the start of the current program) indicate that a one-time mass campaign for adults will have the largest incremental impact on HPV infection incidence. However, this impact diminishes over time as the vaccinated cohort ages, whereas the strategies with a relatively modest short-term impact are predicted to become more effective after 50 and 70 years since implementation.

Three other studies have modeled the impact of vaccinating women outside the age range of the vaccination program [34–36]. However, these models were limited by not considering natural immunity [35] and herd immunity [34–36], both important factors in determining the effects of interventions on sexually transmitted infections [37]. Still, consistent with Bogaards et al [34], we found that the mechanism of vaccine efficacy with regard to HPV status at the time of vaccination does not influence the effectiveness estimates of HPV vaccination. This could be due to the low observed HPV prevalence in older age groups, so that assumptions about effectiveness in HPV-positive women have a minor impact on model predictions.

Our results clearly suggest that implementing adult vaccination by using the most efficient of our selected strategies for women only or for women, boys, and men will have a substantial impact on HPV incidence and thus cervical cancer incidence. Starting from the observation that 62.5% and 17.2% of cervical cancers are caused by HPV-16 and HPV-18, respectively [38], and using the reported average lag time of 20 years between acquiring an HPV infection and developing cervical cancer, cervical cancer incidence would decline by about 51% when vaccinating adult women at STI consultations and by 69% when vaccinating women at cervical cancer screening and both sexes at STI consultations, compared with 48% under the current vaccination program (for details on the underlying calculations, see the article by Matthijsse et al [13]). In addition, vaccination will also offer some protection against vaginal and oropharyngeal cancer, against anal and penile cancers when boys and adult men will be included [12], and against genital warts if the quadrivalent vaccine is used [26]. While the new nonavalent vaccine would protect against 5 additional high-risk HPV types [39], the estimated cervical cancer reductions would only slightly increase, as the extra genotypes in the nonavalent vaccine are less oncogenic than HPV-16 and HPV-18 [38] and will therefore protect against relatively fewer cancers.

Table 2. Incident Human Papillomavirus Type 16 (HPV-16) Infections for All Women 70 Years After the Introduction of the Current Vaccination Program in the Sensitivity Analyses

Vaccination Strategy (Sex)	Incident HPV-16 Infections Per 100 Life-Years[a]				
	Base Case	Ineffective in Infected Individuals	Lower Vaccine Efficacy[b]	Higher Vaccine Efficacy[c]	Reduced Vaccine Acceptability[d]
Inclusion of women only					
Mass campaign (F)	0.41 (0)	0.41 (0)	0.41 (0)	0.41 (0)	0.41 (0)
Screening (F)	0.36 (13)	0.37 (11)	0.39 (5)	0.33 (21)	0.39 (6)
STI consultations (F)	0.37 (10)	0.37 (9)	0.37 (10)	0.37 (10)	0.39 (5)
Mass campaign + STI consultations (F)	0.37 (11)	0.37 (10)	0.37 (10)	0.37 (10)	0.39 (5)
Screening + STI consultations (F)	0.32 (22)	0.33 (19)	0.35 (15)	0.29 (29)	0.36 (12)
Screening + mass campaign (F)	0.36 (13)	0.37 (11)	0.39 (5)	0.32 (21)	0.39 (6)
Inclusion of also boys and men					
Mass campaign (F + M)	0.24 (41)	0.24 (41)	0.24 (41)	0.24 (42)	0.24 (41)
STI consultations (F + M)	0.20 (50)	0.20 (50)	0.20 (50)	0.20 (50)	0.22 (46)
Mass campaign + STI consultations (F + M)	0.20 (50)	0.20 (50)	0.20 (50)	0.20 (50)	0.22 (46)
Screening (F) + STI consultations (F + M)	0.15 (63)	0.16 (62)	0.18 (56)	0.13 (69)	0.19 (53)
Screening (F) + mass campaign (F + M)	0.18 (56)	0.19 (54)	0.21 (48)	0.16 (62)	0.21 (48)

Results for HPV-18 are shown in Supplementary Table 2.

Abbreviation: STI, sexually transmitted infection.

[a] The relative percentage reductions as compared to the estimated HPV-16 infection incidence per 100 life-years (0.41) under the current vaccination program in the base case are shown in parentheses.

[b] Vaccine efficacy was reduced to 49.7% for HPV-16 in women (instead of 77.4%) and to 41.3% in men (instead of 64.5%).

[c] Vaccine efficacy was increased to 91.1% and 75.7% for HPV-16 in women and men, respectively.

[d] Vaccine acceptability was reduced by 50%.

Most modeling studies have estimated that HPV vaccination of preadolescent girls is cost-effective, as presented in 3 overviews [40–42]. One modeling study concluded that girls-only vaccination in the Netherlands would not be cost-effective [43], yet it was performed using the previous recommendations of 3 vaccine doses instead of 2 and before the vaccine price reductions. Although the health gain associated with HPV vaccination of boys mainly consists of reduced cervical cancer risk for women, boys can still benefit substantially through reductions in other HPV-related cancers [12]. This would especially be the case for men who have sex with men, who would benefit marginally from reduced transmission in the general population. The incremental NNV of offering vaccination to women at sexual health clinics in our study is 1.27, only slightly higher than the NNV of the current vaccination program. This indicates that HPV vaccination of adults is less efficient than HPV vaccination of girls. However, since vaccinating girls is cost-effective, even slightly less efficient adult vaccination strategies are likely to still satisfy the usual criteria for cost-effectiveness. Also, modeling studies usually assume lifelong vaccine protection. If this protection would not last for a lifetime, vaccination of adults could provide the necessary booster for the vaccine, thereby reinforcing the cost-effectiveness of adult vaccination. Cost-effectiveness may be further enhanced if the recommended number of vaccine doses could be reduced, especially when the similar protection recently found after only 1 dose as compared to the full 3-dose vaccination schedule would also apply for a longer time horizon than the current follow-up of 4 years [44, 45]. Finally, the additional reductions in cervical cancer incidence due to extending the eligible age range for HPV vaccination warrant reevaluation of the current cervical cancer screening program, possibly leading to cost savings if fewer screenings turn out to be sufficient for a similar population effect.

The use of existing public health programs to provide HPV vaccination, as we assumed for most strategies, offers 2 important advantages. First, the need for large upfront investments is reduced by using existing infrastructures. Second, the familiarity of existing public health programs might enhance acceptability of the vaccine. Most women aged >26 years have positive attitudes about receiving HPV vaccination [32], and a recent study among women aged 26–77 years showed that many would want to be vaccinated against HPV, even if they had to pay for the vaccine out of pocket [46]. This might even become less of an obstacle now that vaccine prices are decreasing. A meta-analysis of 22 studies examining HPV vaccine acceptability among men found a moderate level of acceptance [47]. Most influential correlates of acceptability that can be targeted in campaigns are perceived HPV vaccine benefits and healthcare provider recommendation [47].

We conclude that rolling out adult HPV vaccination within existing public health infrastructures is likely to be an effective and efficient strategy to further and more quickly reduce HPV infection incidence in the Netherlands, as an addition to the current girls-only vaccination program. In particular, offering

vaccination to women at the first cervical cancer screening visit and to both men and women during STI consultations seems a very promising strategy to improve HPV transmission control, specifically for cohorts too old to have been covered by current vaccination programs or in countries with suboptimal coverage. Future research should study vaccine acceptability among adults in different public health settings. In any case, even with modest adult vaccination uptake in the general population, incremental and especially faster benefits can be achieved, and our results strongly suggest that the Netherlands, as well as other countries with routine HPV vaccination, should consider rolling out adult vaccination to further enhance cervical cancer prevention.

Supplementary Data

Supplementary materials are available at http://jid.oxfordjournals.org. Consisting of data provided by the author to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the author, so questions or comments should be addressed to the author.

Notes

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