Cost-effectiveness of cervical cancer screening with primary human papillomavirus testing in Norway

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Cost-effectiveness of cervical cancer screening with primary human papillomavirus testing in Norway

EA Burger¹, JD Ortendahl², S Sy², IS Kristiansen¹ and JJ Kim*,²
¹Department of Health Management and Health Economics, University of Oslo, PO BOX 1089, Oslo 0137, Norway; ²Department of Health Policy and Management, Center for Health Decision Science, Harvard School of Public Health, 718 Huntington Avenue, 2nd Floor, Boston, MA 02115, USA

BACKGROUND: New screening technologies and vaccination against human papillomavirus (HPV), the necessary cause of cervical cancer, may impact optimal approaches to prevent cervical cancer. We evaluated the cost-effectiveness of alternative screening strategies to inform cervical cancer prevention guidelines in Norway.

METHODS: We leveraged the primary epidemiologic and economic data from Norway to contextualise a simulation model of HPV-induced cervical cancer. The current cytology-only screening was compared with strategies involving cytology at younger ages and primary HPV-based screening at older ages (31/34 years), an option being actively deliberated by the Norwegian government. We varied the switch-age, screening interval, and triage strategies for women with HPV-positive results. Uncertainty was evaluated in sensitivity analysis.

RESULTS: Current cytology-only screening was less effective and more costly than strategies that involve switching to primary HPV testing in older ages. For unvaccinated women, switching at age 34 years to primary HPV testing every 4 years was optimal given the Norwegian cost-effectiveness threshold ($83 000 per year of life saved). For vaccinated women, a 6-year screening interval was cost-effective. When we considered a wider range of strategies, we found that an earlier switch to HPV testing (at age 31 years) may be preferred.

CONCLUSIONS: Strategies involving a switch to HPV testing for primary screening in older women is expected to be cost-effective compared with current recommendations in Norway.


Keywords: cost-effectiveness; cervical cancer screening; HPV vaccination

Cytology-based screening programmes that have achieved comprehensive coverage have been credited with significant reductions in incidence of and mortality from invasive cervical cancer through early detection and treatment (Hakama and Hristova, 1997; Peto et al, 2004; Bray et al, 2005). Despite successful screening, cervical cancer is still among the three most frequent cancers for women 25–49 years of age in Norway, where incidence and mortality rates are 9.5 and 1.7 per 100 000 women-years, respectively (Cancer Registry of Norway, 2011). Since 1995, the Norwegian Coordinated Cervical Cancer Screening Program has invited women to cytology-based screening every 3 years. Recent clinical studies have reported that human papillomavirus (HPV) DNA testing has a higher sensitivity for detecting high-grade precancerous lesions (Arbyn et al, 2006), possibly resulting in more opportunities for early detection and treatment. In addition, data combined from six European countries suggests that the primary screening interval may be safely extended by using HPV DNA testing (Dillner et al, 2008).

In the autumn of 2009, vaccination against HPV was introduced as part of the childhood immunisation programme for preadolescent girls, free of charge. The HPV vaccine protects against two carcinogenic HPV types, 16 and 18, that cause ~70% of cervical cancers in Norway, as well as two non-carcinogenic types, 6 and 11, that cause the majority of genital warts. HPV vaccination of older women has not been implemented, and screening will continue to remain the main source of prevention against cervical cancer for the current population of Norwegian women who are past the vaccination target age, as well as those who do not receive the vaccine in adolescence. Importantly, screening will also continue to be critical among those vaccinated to prevent the 30% of cancer cases that are not attributable to the vaccine types.

Given the availability of HPV vaccines and highly sensitive HPV DNA tests (Franco, 2003; Arbyn et al, 2006; Cuzick et al, 2006a,b), countries around the world are evaluating new screening algorithms that use HPV DNA testing for primary screening; however, determining the optimal approach to cervical cancer prevention is quite complex and involves multiple tradeoffs. For example, despite the higher sensitivity of the HPV DNA test for high-grade cervical intraepithelial neoplasia (CIN), health officials have concerns with regard to the low clinical specificity of the test, which may result in over referrals (i.e., excess burden for women and health services). This limitation may be minimised by an algorithm that relies more heavily on identifying HPV persistence rather than immediately subjecting women directly to colposcopy/biopsy, a diagnostic procedure that may be associated with
increased anxiety compared with routine testing. The use of decision-analytic methods to synthesise and extrapolate clinical, epidemiological, and economic evidence beyond the capacity of empirical trials, may aid decisions regarding the optimal secondary prevention strategies under various scenarios of uncertainty (Goldie, 2003). Such models can estimate the lifetime risk of dying from cervical cancer, life expectancy, and lifetime costs related to screening and treatment of cervical cancer. These data are then used to estimate the additional costs and life years saved of a particular screening strategy, compared the current recommended strategy. In Norway, the health benefit of an intervention or strategy is considered to be good value for money if the additional life year costs < 500 000 Norwegian Kroner (NOK; $83 000). In this study, we use a decision-analytic model to assess the impact of adopting recently proposed cervical cancer prevention strategies involving primary HPV DNA testing (Cancer Registry of Norway, 2011) in order to inform policy recommendations in Norway. Specifically, our analysis addresses whether women who have been vaccinated against HPV can be screened efficiently using primary HPV DNA testing and whether the optimal strategy may differ for those women who have not been vaccinated.

**MATERIALS AND METHODS**

**Analytic approach**

We adapted an existing mathematical model to reflect the natural history of HPV-induced cervical cancer in Norway (Goldhaber-Fiebert et al., 2007; Kim et al., 2007; Kim and Goldie, 2008). The model was adjusted to the Norwegian context using primary clinical and cost data from Norway to project the health and economic outcomes associated with different scenarios of screening. We compared the currently recommended cytology-based programme with alternative screening strategies that use HPV DNA testing for women who have been either vaccinated or not vaccinated against HPV-16 and HPV-18 in pre-adolescence. Outcomes included lifetime risk of cancer, life expectancy, and lifetime costs. Incremental cost-effectiveness ratios (ICERs), calculated as the additional dollar ($) for each additional year of life saved of a strategy compared with the next most costly strategy, was used as a performance indicator. Strategies that were more costly and less effective (dominated) or less costly and less cost-effective (weakly dominated) were removed from the cost-effectiveness calculations. The ‘most cost-effective’ intervention is not necessarily the one that has the lowest ratio as society may be willing to pay more for health benefit. We used the proposed willingness-to-pay threshold of 500 000 NOK (≈ $83 000) per YLS to signify the amount below which an intervention would be considered ‘good value for money’ (Norwegian Directorate of Health, 2007). We adopted a societal prospective, including all costs and benefits regardless to whom they accrue, and discounted costs and benefits by 4% per year, as recommended in Norway costs and benefits regardless to whom they accrue, and discounted.

**Epidemiologic data**

Baseline transition parameter values describing the natural history of disease were based on the best available empirical data and assume that the underlying mechanism of cervical carcinogenesis does not vary across epidemiological settings. However, risk factors, such as sexual behaviour, and cervical cancer incidence rates differ between countries; therefore, country-specific data are needed to adjust baseline inputs to account for variations in progression and regression rates. We leveraged empirical data from Norway and used a likelihood-based algorithm to identify candidate sets of parameter values that achieve good-fit to epidemiological outcomes observed in the Norwegian population. Specifically, Norwegian data used for calibration included age-specific prevalence of HPV-16, HPV-18 (Mari Nygaard, personal communication) and of CIN2 in Norwegian women (Molden et al., 2005, 2006); the relative contributions of HPV-16, HPV-18 and other high-risk HPV types in CIN2 and cervical cancer (Steinar Thoresen, personal communication), and pre-screening (1953–1969) cancer incidence rates were obtained from the Cancer Registry of Norway. The parameterisation and likelihood-based calibration process have been described previously (Goldhaber-Fiebert et al., 2007; Kim et al., 2007; Kim and Goldie, 2008); details of the Norwegian-specific calibration for the current analysis are included in the Supplementary Appendix. All analyses were conducted with 50 statistically indistinguishable (i.e., good-fitting) parameter sets to incorporate the effect of uncertainty surrounding the natural history of cervical cancer. Results were reported as the mean of outcomes across the 50 parameter sets, and ICERs were calculated as the incremental mean costs divided by the incremental mean effects of two strategies (Stinnett and Paltiel, 1997). Screening test characteristics (i.e., sensitivity and specificity) were based on published studies and varied in sensitivity analyses (Franco, 2003; Sherman, 2003; Solomon, 2003; Arbyn et al., 2006; Cuzick et al, 2006a, b).

**Cost data**

Direct medical and non-medical costs associated with screening, vaccination, and treatment were estimated using a combination of official Norwegian guidelines (Norwegian Medical Association, 2010a) and expert opinion. All costs were measured in 2010 NOK and converted to US dollars (US $) using the average annual 2010 exchange rate (US $1 = NOK6.05) (Federal Reserve, 2011). Direct medical costs for screening, diagnosis, and treatment of dysplasia and invasive cervical cancer were based on Norwegian Diagnosis Related Groups (DRGs) and the Fee Schedules for General Practitioners and Specialists (Norwegian Directorate of Health, 2010; Norwegian Medical Association, 2010b, c; Table 1). Screening laboratory costs were adjusted to reflect potential discrepancies between published reimbursement rates and true economic costs (additional details in the Supplementary Appendix). We based HPV vaccination costs on a published report from the Norwegian
Medicines Agency and assumed a three-dose regimen administered over the course of 6 months (Norwegian Medicines Agency, 2010).

Direct non-medical costs were estimated to account for the production loss and the transportation costs associated with screening and treatment. We used the average 2010 gross monthly income of Norwegian women obtained from Statistics Norway (2011) and adjusted the wage to include social benefits paid by employers. Travel time and transportation costs associated with screening and follow-up visits were estimated from a prospective study of colorectal screening in Norway (Aas, 2009). The time spent travelling to a hospital to receive cervical cancer treatment was estimated from a health survey conducted by the Statistics Norway for the World Health Organization (2003). We attributed zero production loss or transportation costs for the children or their parents to receive the HPV vaccination, as it is given as part of the school administered vaccination programme for girls in the 7th grade. Additional details and costing assumptions can be found in the Supplementary Appendix. The costs of cancer treatment, CIN treatment, screening test, colposcopy, and office visits were varied widely (50 and 200% of base case values) in one-way sensitivity analyses.

### Strategies

The current Norwegian screening strategy involves triennial cytologic evaluation of cervical cells (i.e., cytology) followed by repeat cytology in combination with HPV testing for atypical squamous cells of undetermined significance or low-grade squamous intraepithelial lesion (LSIL) 6 months later (herein referred to as ‘cytology-based screening’). Women with high-grade squamous intraepithelial lesions are referred directly to colposcopy/biopsy. The proposed strategy involves switching older women (age ≥ 34 years) from the current strategy to primary HPV DNA testing with liquid-based cytology (LBC) triage for women found to be positive for hrHPV types (herein referred to as ‘HPV with reflex LBC’). For women who are HPV-positive and cytology-negative (HPV + /Cyt–), the strategy uses a period of intensified screening to identify women who are persistently HPV + /Cyt–, requiring three additional HPV + /Cyt– results each with 12 months apart before receiving a referral for colposcopy/biopsy.

Our primary analysis included 24 variations of the strategy specified by the Norwegian proposal and immediately relevant for Norwegian policy decisions (Figure 1). We compared variations of the strategy that differed by routine screening interval, the number of persistent HPV + /Cyt– results, and the month interval between repeat testing required prompting colposcopy. We then conducted a secondary analysis, which included the same strategies but allowed the age at which women switch from cytology to primary HPV testing (i.e., 31 or 34 years) to vary. In addition, we allowed younger women with LSIL to be referred directly to colposcopy, as recommended in other settings (Wright et al, 2007). The secondary analysis also included a strategy of pre-adolescent vaccination only without screening. For all analyses, we held the screening start and stop ages constant and maintained the 3-year screening interval for younger women (pre-switch). We evaluated the optimal strategies for two sub-groups of women: those who had been vaccinated and those who had not been vaccinated in pre-adolescence.

Screening compliance was assumed to be 100% to allow comparison of the maximum benefit for each strategy; however, this assumption was varied in sensitivity analysis. For this variation, we assumed that the risk is equally distributed across attenders and non-attenders and there was no change in future screening behaviour. For strategies that incorporate vaccination, we assumed that: (1) the vaccination is given to sexually naive girls at the age of 12 years; (2) all girls receive the recommended three doses of the vaccine; (3) vaccination is 100% effective in preventing HPV-16, HPV-18, but does not give any protection against contracting other high-risk HPV types (i.e., no cross-protection); and (4) duration of vaccine immunity is lifelong (see Supplementary Appendix for additional assumptions).

In addition to varying costs, we varied the test characteristics of cervical cytology and evaluated the impact of uncertainty around herd immunity, vaccine efficacy, and waning vaccine protection in sensitivity analyses. To explore the impact of screening coverage, we applied a distribution of screening frequencies across the cohort. For this we assumed 15% were non-screeners, 70% complied with the specified interval, and the remaining 15% were screened less frequently (1 year delay each screening round). Although simplified, these assumptions are consistent with estimates documented by the Norwegian Cancer Registry (Cancer Registry of Norway, 2009). Last, we conducted a probabilistic sensitivity analysis by using the 50 good-fitting parameter sets.

### RESULTS

Analysis including currently proposed Norwegian strategies only

In the primary analysis and regardless of vaccination status, the current cytology-based screening strategy was less effective and
more costly (i.e., strongly dominated) than proposed strategies that involve switching to primary HPV testing at 34 years of age. For unvaccinated women, the optimal (cost-effective) strategy involves switching at age 34 years to primary HPV DNA testing with a 4-year screening interval. For women HPV+/Cyt−, optimal management involves three additional persistent HPV+/Cyt− results 6 months apart, before colposcopy referral. This strategy is associated with a cost-effectiveness ratio of $83 000 per YLS, compared with the next best strategy and yields an expected reduction in lifetime cervical cancer risk of 65%, compared with no screening (Figure 2A). By comparison, the current cytology-based screening programme gives an expected cancer risk reduction of ~55%.

For vaccinated women, the preferred screening strategy involves extension of the screening interval to every 6 years after the switch-age of 34 years with the same follow-up of HPV+/Cyt− women as for unvaccinated women. This strategy had a cost per YLS of $76 000, compared with the next best strategy and an expected cancer risk reduction of 85.7% (Figure 2B); nearly the same expected reduction as screening women every 3 years with the current strategy, but for a lower lifetime cost. If vaccinated women followed the same strategy that is optimal for unvaccinated women (i.e., screening every 4 years after age 34 years), the ICER would be well over what is considered good value for the cost. On the other hand, if older, unvaccinated women were screened every 6 years (as recommended for vaccinated women), rather than every 4 years, they would be forgoing an additional 8% absolute reduction in cancer, compared with no intervention.

Analysis including additional strategies

Switching unvaccinated women to primary HPV DNA testing at age 31 years was always preferred over strategies that involved switching at the proposed age of 34 years. Switching at a younger age provided equal or greater reductions in cervical cancer and could cost up to 24% less over a woman’s lifetime compared with the current screening strategy (Table 2). The optimal strategy, with an ICER of $76 000 per YLS, entails switching at age 31 years to primary HPV DNA testing every 4 years with reflex LBC (Table 2; top panel). This strategy requires women who are HPV+/Cyt− to have three persistent results 12 months apart, before colposcopy referral. This strategy, compared with the optimal strategy, identified by our primary analysis has similar benefits, but would be expected to cost ~5% less per woman over her lifetime. Variants of this screening strategy were less attractive. If a 3-year screening interval was maintained for older women using HPV DNA testing and the most intensive follow-up of HPV+/Cyt− women, we estimated that it provides nominal life expectancy gains at a cost of approximately $513 000 per YLS, compared with the next best strategy.

For women vaccinated during adolescence, switching at an earlier age to HPV DNA testing may also provide similar benefit at a lower cost per woman compared with switching at age 34 years. The optimal strategy involved a 6-year screening interval after the switch-age of 31 years and requires two additional HPV+/Cyt− results 12 months apart, before colposcopy referral (Table 2; bottom panel). Compared with switching women to 6-yearly HPV screening at age 34 years and the current cytology-based programme, vaccinated women may achieve similar cancer risk reductions by switching at the earlier age but could reduce the cost per woman over her lifetime by an additional 5% and 18%, respectively.

Sensitivity analysis

Overall results were not sensitive to cancer and CIN treatment costs or the imperfect screening compliance scenarios. Results
Figure 2  Efficiency frontiers showing the trade-off of costs and benefits. Discounted life expectancy, lifetime costs, reduction in lifetime risk of cancer, and ICERs for alternate cervical cancer screening strategies for women 34 years and older from the ‘primary analysis’ (see the Results for details) for either unvaccinated (A) or vaccinated (B) women. Strategies lying on the efficiency curve are either less costly and more effective (i.e., strongly dominant) or more costly but more cost-effective (i.e., weakly dominant) than those lying to the right of the curve. The slope of the efficiency curve (also the inverse of the ICER) will be steeper when the net gain in the life expectancy per dollar is greater. Abbreviations: HPV = human papillomavirus; HPV+/Cyt− = HPV-positive and cytology-negative result; ICER = incremental cost-effectiveness ratio; LBC = liquid-based cytology.

were moderately influenced by screening costs, colposcopy costs, and vaccine efficacy. For example, if the cost of a colposcopy/biopsy doubled ($674 rather than the $337 assumed in the base case), the optimal primary screening interval for vaccinated women remained constant, but the follow-up strategy requires HPV+/Cyt− results rather than requiring three persistent results. Additional sensitivity analysis results are included in the Supplementary Appendix.

We used the 50 good-fitting natural history parameter sets to estimate the probability that the optimal strategies in the primary analysis are cost-effective according the Norwegian cost-effectiveness threshold. For unvaccinated women 34 years or older, switching to primary HPV DNA testing with a 4-year screening interval was found optimal in the majority of the simulations (58%), whereas a 6-year screening interval was never preferred. The analogous results for vaccinated women indicated that a 6-year screening interval was never preferred. The analogous results for vaccinated women indicated that a 6-year screening interval was never preferred. The analogous results for vaccinated women indicated that a 6-year screening interval was never preferred.

**DISCUSSION**

With the advent of new HPV diagnostics, secondary preventative strategies have the potential to further reduce the burden of
cervical cancer. For countries that have implemented the HPV vaccination, two distinct risk groups will emerge as cohorts of vaccinated girls become eligible for screening. Model-based analyses can assist decision-makers faced with choosing new vaccination strategies, for both vaccinated and unvaccinated women. For women who are not vaccinated, our primary analysis projected that the optimal strategy for primary screening involves cytology for younger women and HPV DNA testing with reflex LBC every 4 years for women aged 34 years and older. The algorithm requires additional HPV+ results to prompt colposcopy, while holding all else constant, yielded relatively minimal changes to cost-effectiveness. We acknowledge the incremental cost-effectiveness ratio; HPV+/Cyt-: HPV-positive, cytology-negative result. For vaccinated women, the primary screening interval for older women could be extended to 6 years with the same follow-up for HPV+/Cyt- women. Our expanded secondary analysis concluded warranted the same primary screen–follow-up intervals of 6 or 12 months and number of persistent HPV+/Cyt- results required to prompt colposcopy, while capitalising on the additional benefit of HPV testing without the colposcopy resource constraints and preference to minimise false-positive results. The proposed management approach attempts to minimise the potential excess burden on resources and use a risk management strategy that identifies only the women at increased risk (i.e., those with persistent HPV infection) who have not developed dysplasia detectable by cytology. As we varied follow-up intervals of 6 or 12 months and number of persistent HPV+/Cyt- results required to prompt colposcopy, while holding all else constant, yielded relatively minimal changes to cancer risk reduction; our analysis suggests that it is rarely attractive to refer women to colposcopy after one additional HPV+/Cyt- result. We found that switching to primary HPV DNA testing at age 31 dominated switching at age 34, one screening episode earlier than suggested by the Norwegian proposal. This is likely because the prevalence of high-risk HPV does not substantially change from 31 to 34 years, allowing women to capitalise on the additional benefit of HPV testing without the system incurring excess costs from a large number of transient infections. Determining the optimal switch age is inherently dependent on the natural history of HPV in older women. Our analysis has clear limitations, many of which have been described previously (Goldhaber-Fiebert et al., 2007; Kim et al., 2007; Kim and Goldie, 2008). We chose to use a detailed simulation model that accommodates complex screening strategies and individual history at the expense of explicitly modelling herd immunity. In sensitivity analysis, we tried to simulate the indirect effects (herd immunity) that HPV vaccination may have on the individual history at the expense of explicitly modelling herd immunity. In sensitivity analysis, we tried to simulate the indirect effects (herd immunity) that HPV vaccination may have on the

### Table 2: Cost-effectiveness results for the analysis including additional strategies

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<th>Screening start age</th>
<th>Screening frequency, pre-switch (years)</th>
<th>Pre-switch</th>
<th>Screening switch age</th>
<th>Screening frequency, post-switch (years)</th>
<th>Pre-switch</th>
<th>Primary screening test, post-switch</th>
<th>Primary screening test, post-switch</th>
<th>Wait time for rescreening HPV+/Cyt- results (months)</th>
<th>No. of additional HPV+/Cyt- results to colposcopy</th>
<th>Vaccine</th>
<th>Absolute reduction in cancer (%)</th>
<th>Total cost per woman ($)</th>
<th>Total LE ICER ($/YLS)</th>
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<td>Unvaccinated women</td>
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| Vaccinated women    |                                        |            |                     |                                        |            |                                   |                                   |                                               |                                        |          |                                  |          |                      |
|---------------------|----------------------------------------|------------|---------------------|----------------------------------------|------------|-----------------------------------|-----------------------------------|                                               |                                        |          |                                  |          |                      |
| 25                  |                                        |            |                     |                                        |            | Cytology+                          | None                              | 25                                            | 3                                      | 6        | HPV                              | 12       | 2                         | Yes                  | 85.38    | 1267 32.9568 80 000      |
|                     |                                        |            |                     |                                        |            |                                   |                     6               | 1c                              | Yes                  | 85.85    | 1279 32.9572 80 000      |
| 25                  |                                        |            |                     |                                        |            | Cytology+ | 31                     | 5                              | HPV                               | 6        | 3                         | Yes                  | 86.89    | 1339 32.9573 185 000     |
| 25                  |                                        |            |                     |                                        |            | Cytology+                          | 31                  | 4                               | HPV                              | 6        | 3                         | Yes                  | 88.48    | 1439 32.9577 229 000     |
| 25                  |                                        |            |                     |                                        |            | Cytology+                          | 31                  | 4                               | HPV                              | 6        | 2                         | Yes                  | 88.50    | 1442 32.9577 390 000     |
| 25                  |                                        |            |                     |                                        |            | Cytology+                          | 31                  | 3                               | HPV                              | 6        | 0                         | Yes                  | 90.25    | 1609 32.9581 418 000     |
| 25                  |                                        |            |                     |                                        |            | Cytology+                          | 31                  | 3                               | HPV                              | 6        | 1                         | No                   | 90.36    | 1625 32.9582 544 000     |
| 25                  |                                        |            |                     |                                        |            | Cytology+                          | 31                  | 3                               | HPV                              | 6        | 1                         | No                   | 90.39    | 1636 32.9582 707 000     |

Abbreviations: HPV = human papillomavirus; LE = discounted life expectancy; ICER = incremental cost-effectiveness ratio; HPV+/Cyt+: HPV-positive, cytology-positive result. *Discounted at 4% per year. All costs are expressed in 2010 US dollars (US$ = NOK6.05). aCombo test triage (HPV/cytology) 6 months later for atypical squamous cells of undetermined significance (ASCUS) and low-grade squamous intraepithelial lesion results. bHeld constant for all combo strategies for younger women. cCombo test triage (HPV/cytology) 6 months later for ASCUS results only.
CONCLUSION

Our objective was to provide quantitative insight to policy makers about the trade-offs between different screening strategies, which use new screening technology in the context of HPV vaccination. We highlight the importance of alternative screening strategies that are conditional on vaccination status and age. The optimal strategies for vaccinated women determined by this analysis are very similar to the strategy that has been proposed for pilot testing in Norway (Cancer Registry of Norway, 2011). We shed light on the potential benefits of switching to HPV DNA testing at an earlier age and considering different screening recommendations for those women who have not been vaccinated. Given a cost-effectiveness threshold of $83,000, it may be more efficient to screen unvaccinated women, more frequently than those women who were vaccinated during adolescents. We conclude that in Norway, strategies involving a switch to primary HPV testing in older women is expected to be cost-effective compared with the current cytology-based screening programme.

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Disclaimer

Our work was independent of the funders and the funding sources had no involvement in the study design or conduct of the study; collection, management, analysis or interpretation of the data; or preparation, review or approval of the manuscript.

Supplementary Information accompanies the paper on British Journal of Cancer website (http://www.nature.com/bjc)

REFERENCES


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