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An economic analysis of varicella vaccination for health care workers

A. M. GRAY[1]*, P. FENN[2], J. WEINBERG[3], E. MILLER[4] AND A. McGUIRE[2]

[1] *Health Economics Research Centre, Institute of Health Sciences, University of Oxford*
[2] *Health Economics Group, Wolfson College, University of Oxford*
[3] *Public Health Laboratory Service, Communicable Disease Surveillance Centre, London*

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SUMMARY

A simulation model was constructed to assess the relative costs and cost-effectiveness of different screening and vaccination strategies for dealing with hospital incidents of varicella exposure, compared with current policies, using data from published sources and a hospital survey. The mean number of incidents per hospital year was 3·9, and the mean annual cost of managing these incidents was £5170. Vaccination of all staff would reduce annual incidents to 2·2 at a net cost of £48 900 per incident averted. Screening all staff for previous varicella, testing those who are uncertain or report no previous varicella, and vaccinating those who test negative for VZV antibodies, reduces annual incidents to 2·3 and gives net savings of £440 per incident averted. Sensitivity analyses do not greatly alter the ranking of the options. Some form of VZV vaccination strategy for health care workers may well prove a cost-effective use of health care resources.

INTRODUCTION

Varicella-zoster virus (VZV) infects almost everyone. Clinical varicella (chickenpox) occurs in almost 100 % of those when first infected, and some of these may at a later date develop zoster (shingles), a condition resulting from re-activation of latent virus. Individuals with varicella are infectious, and those without immunity can acquire varicella. Serious complications, including death, can occur with varicella, particularly amongst neonates and immunocompromised persons. As a consequence of these risks, policies to control VZV are necessary in certain environments such as hospitals, and the costs which can be incurred as a consequence of these policies have been estimated in a number of American studies and a recent British study [1–5], the results of which are summarized in Table 1. In all studies the main items of cost have included exclusion of staff from work, prophylactic immunoglobulin (VZIG) treatment, patient isolation, serological testing, and the time of infection control staff.

A live attenuated vaccine has been developed and has been widely used in Japan [6]. The main vaccine strategies which have been proposed are to focus on high-risk groups such as immunocompromised children, or to implement a routine programme for all healthy children. Economic evaluations of both strategies have been performed [7–10].

However, to date there have been no published studies of other strategies, in particular vaccination of health care workers (HCW), which might avert some of the costs of hospital incidents of nosocomial VZV exposure, an incident being any episode in which a possibly susceptible person is exposed to an infectious source of VZV. Such nosocomial exposure might arise from contact with staff, patients or visitors with either

* Author for correspondence: Dr Alastair M. Gray, Director, Health Economics Research Centre, University of Oxford, Institute of Health Sciences at Wolfson College, Oxford OX2 6UD.

Table 1. *Summary of studies of the costs associated with incidents of nosocomial VZV exposure in hospitals*

Costs estimated	Country	Cost	Ref.
VZV control in one hospital over 1 year	USA	$55934 (1986)	1
VZV control in one hospital over 1 year	USA	$41500 (1984)	2
Single VZV incident in one hospital	USA	$10000 (1984)	3
Single VZV incident in one hospital	USA	$19999 (1982)	4
VZV control in one hospital over 1 year	UK	£13204 (1994–5)	5

varicella or zoster. Vaccination of health care workers would prevent varicella in staff and would also prevent the consequences of exposure of staff to cases of varicella or zoster. This study reports such an evaluation, in which data on varicella incidents from a sample of British hospitals are combined with a simulation model to assess the relative costs and cost-effectiveness of alternative programmes for dealing with the problem of varicella in health care workers.

METHODS

Economic methodology

The study reports the costs and cost-effectiveness of four options for screening and vaccinating health-care workers in relation to a baseline represented by existing practices within the National Health Service to deal with incidents of varicella exposure. Existing practices are described in more detail below, based on the results of a hospital survey, and consist of some screening by history of varicella, some antibody testing of new recruits, and a variety of screening, testing, patient isolation and staff suspension/relocation procedures during incidents of varicella exposure. The alternative options considered represent a range of possible policies towards screening and vaccination. Within each option, different sizes of hospital, staff turnover rates and frequencies of varicella incidents are considered.

Results are reported in terms of: (i) the net cost of each strategy, (ii) the change in net total costs of each option compared with the baseline (current practice), and (iii) the net cost per incident of varicella exposure averted in comparison with existing practice. Items (i) and (ii) represent the results of a cost analysis, and item (iii) can be seen as a cost effectiveness result. We report this as it is likely that there are health consequences associated with incidents of varicella exposure, such as morbidity or mortality, which should be taken into account in any decision-making process but which are not represented in the net cost figures given in results (i) and (ii). This point is worth emphasizing, because the costs of incidents of varicella exposure in this study are measured in terms of the extent to which hospitals currently respond to these incidents. Hospitals which fail to detect, ignore or respond inadequately to incidents of varicella exposure will report low costs, but may nevertheless experience adverse health consequences.

Results are reported over a 10 year time perspective, in line with the minimum expected duration of clinical protection afforded by the vaccine [11]. All costs are defined from a health sector perspective, and following standard practice in economic evaluations [12] all costs are expressed in net present values using the Treasury-approved annual discount rate of 6%; other discount rates are considered in the sensitivity analysis. All costs are expressed in terms of 1995 value.

Options for screening and vaccination of health care workers

The effectiveness and cost-effectiveness of any vaccination strategy will be related to the probability of an incident of varicella exposure occurring, the likelihood that it is detected and the way in which the particular hospital currently responds to such incidents. The underlying probability of an infection occurring is unlikely to vary substantially among health care workers or general hospital patient populations. However, the probability that an incident is detected and responded to is likely to vary between hospitals, and between departments such as paediatric departments or departments with high proportions of immunocompromised patients.

Within the hospital or department, not all groups of staff are likely to be in contact with patients, and hence may not be appropriate subjects for vaccination. Here, it is assumed that the groups likely to be in routine contact with patients, including all doctors, nurses and paramedical staff, would be included; groups likely to be excluded would consist of

Table 2. *Screening and vaccination strategies examined in study*

Option	Take history of prior varicella?	Perform VZV antibody test?	Vaccinate?
Baseline	Selective	Selective	No
Option 2	No	No	All
Option 3	Yes	No	Negatives only
Option 4	Yes	Only if stated history is negative	Negatives only
Option 5	No	All	Negatives only

maintenance and office staff and those such as catering staff who do not go into patient areas.

Five different vaccination strategies are considered, representing different combinations of screening and vaccination, and these are set out in Table 2.

In *Option 1*, the baseline model which represents current practice, some occupational health departments ask health care workers for a history of prior varicella at recruitment, while others test health care workers for VZV antibody. The probabilities of these occurring, and the associated costs, were derived from a hospital survey and are reported below. In *Option 2*, every existing and new health care worker is vaccinated with no screening. In *Option 3*, screening by taking history of varicella only is performed, and those who are uncertain or report no previous varicella are vaccinated. In *Option 4*, screening by history of varicella is performed, followed by antibody tests on those who are uncertain or report no previous varicella. Those who test negative for VZV antibody are then vaccinated. Finally, in *Option 5* all staff receive an antibody test and those who test negative for VZV antibody are vaccinated.

In *Options 2–5*, it is assumed that the policy would be applied to all existing staff as well as new recruits in the first year of the programme, and thereafter would be applied to all new recruits. For the purposes of this model, it is assumed that the consent rate is 100%.

Each option has different associated direct resource requirements and hence costs, relating to screening, antibody tests and vaccination. In addition, each option will have different resource consequences, due to the differing likelihoods of Type I (false positive) or Type 2 (false negative) errors associated with each strategy and hence their impact on the number of incidents. Using results from a hospital staff screening study conducted during 1986 at St Bartholomew's Hospital, London [13], in which responses to the question 'Have you had chickenpox in the past?' were compared with the results of radioimmunoassays for 622 members of staff, we have assumed that 66% will reply 'yes', 12% will reply 'no', and 22% will not know or be uncertain. Amongst those replying 'yes', 99·3% will test positive for VZV antibody in a radioimmunoassay (RIA) and 0·07% will test negative; amongst those replying 'no' and those who are uncertain or don't know, 78·3% will test positive and 21·7% will test negative. The overall rate of VZV antibody negativity from this study was 7·9%, and this figure has been used in the model to estimate the baseline staff population at risk. Similar proportions of staff who recall clinical illness, and of those who do not or are unsure, have been reported in other studies [14], and there is little evidence of major differences in the epidemiology of VZV around the UK [15], hence we would not expect accuracy of recall to vary substantially.

In the vaccination strategies, it is assumed in the baseline analysis that a seroconversion rate of 90% will occur following two doses of attenuated vaccine given 2–3 months apart [11]. Alternative assumptions are also considered.

DESCRIPTION OF MODEL

A spreadsheet-based decision tree model was developed to compare the net costs of each of the options outlined above for managing varicella exposures in hospital.

Hospital size and probability of an incident of nosocomial exposure

The model begins by specifying parameters for the average number of staff employed in a hospital or department within a hospital, the average number of patient days per member of staff, and the expected frequency of incidents of varicella exposure in which the index case is a member of staff/family member of staff, or a patient/visitor (expressed in terms of staff incidents per member of staff at risk per annum; and patient incidents per patient day).

The baseline values of these parameters are derived from a hospital survey, further details of which are given below. These parameters can be varied to represent hospitals or departments with different staff and patient days; similarly, the likelihood of a staff or patient index case can be altered for any defined size of hospital. The model can therefore produce results for a range of provider units with differing expectations of incidents of varicella exposure. The sensitivity analysis addresses these issues.

Screening and vaccination policies

The next part of the model deals with the policies in place for screening and/or vaccinating health care workers to manage varicella exposures in hospitals. The baseline values, and the assumed values under different vaccination options, enable us to determine the numbers of staff who would be screened by history, antibody tested and vaccinated using each option, and the associated costs.

The effect of each option on the number of staff incidents is modelled by adjusting the baseline rate of incidents from the survey, taking into account the proportion of staff vaccinated, the seroconversion rate, and the Type I and 11 errors associated with each option.

If vaccinated individuals developed symptoms such as a localized vaccine related rash, it is possible that there would be some policy response such as exclusion from the clinical environment for a short period. However, these are rare events on which there is little information and no consensus at present, and hence are not incorporated in the model.

Management of nosocomial VZV exposures

The next part of the model deals with the way in which incidents of varicella exposure in hospitals are managed. Parameter values are used for the probability of different events with resource consequences occurring, such as placing a patient in isolation or laying off a member of staff, and for the unit costs associated with these resources. Separate parameter values are used for staff index case incidents and patient index case incidents.

The baseline parameter values for the probability of events occurring in response to an incident, and the associated unit costs, are taken from the responses to a hospital survey of recent incidents, described below. The combined probabilities and unit costs give the expected total cost of dealing with an incident of varicella exposure, and this combined with the probability of an incident gives the expected total cost of managing varicella exposures per hospital or department per year. Hence as the probability of an incident changes under different screening and vaccination strategies, so does the total expected annual cost of dealing with these incidents.

In addition, it is assumed that the way in which hospitals or departments respond to incidents of varicella exposure may change as a result of introducing a vaccination policy. In particular, it is assumed that it would no longer be necessary to evaluate staff for exposure, screen exposed staff, or perform staff serology tests. However, we have assumed that the index case will continue to be suspended from work with the same likelihood as at present.

Sensitivity analyses

All model parameters can be altered systematically to assess the sensitivity of the results to the parameter values. In the results, the main sensitivity analyses reported relate to the number of staff employed; the probability of staff index case incidents; the probability of patient index case incidents; the staff turnover rate; the discount rate; and the vaccine price.

Model results

The expected costs of each option over a 10 year period are derived from: (*a*) the numbers tested and vaccinated in each programme, and the cost of these; (*b*) the number of incidents of varicella exposure expected with each programme, and (*c*) the cost of responding to an incident in each programme.

When presenting the results, we express costs as (i) the net total cost of each option; (ii) the change in net total costs of each option compared with the baseline (current practice); and (iii) the net total cost per annual incident averted compared with baseline (i.e. the change in costs divided by the change in annual incidents).

DATA

Survey population

Data on the frequency and characteristics of hospital incidents of varicella exposure during the calendar year 1994, and on the resources and costs associated with the most recent incident, are based on in-

Table 3. *The cost of managing varicella exposures in hospital, using survey data from 39 hospitals*

Item	Index case: Patient or visitor	Index case: Staff or staff member's family
Percent of responding hospitals which		
Took history of prior varicella from patients	54%	33%
Took history of prior varicella from staff	92%	75%
Performed VZV antibody blood test amongst patients	31%	17%
Performed VZV antibody blood test amongst staff	85%	75%
Devoted nurse time to evaluating patient exposure	63%	44%
Devoted medical time to evaluating patient exposure	50%	47%
Devoted other staff time to evaluating patient exposure	22%	0
Devoted OHD time to evaluating staff exposure	92%	92%
Devoted other staff time to evaluating staff exposure	42%	50%
Initiated procedures to screen exposed staff	23%	25%
Suspended staff from work	39%	70%
Placed patients in isolation	77%	0
Used other resources (infection control staff, ZIG, etc)	55%	22%
Number (and cost, £s) of resources used per incident*		
Patient tests performed	2·75 (£16·0)	4·0 (£18·1)
Staff tests performed	4·7 (£27·9)	3·4 (£15·4)
Nurse hours	1·6 (£20·5)	7·5 (£97·2)
Medical hours	0·66 (£8·4)	2·7 (£33·8)
Other staff hours	3·0 (£38·9)	0
OHD hours	2·54 (£34·2)	3·1 (£43·2)
Other staff hours	2·8 (£35·1)	1·5 (£19·4)
Hours involved in screening	2·0 (£25·9)	1·7 (£21·6)
Staff days off work	18 (£1481·6)	28 (£1426·8)
Patient days in isolation	13 (£710)	0
Other resources used per incident	£112·5	£40·0

* At 1995 value.

formation obtained via a postal questionnaire sent to a sample of hospitals across the United Kingdom. The questionnaire was distributed by the National Association of Occupational Health Physicians (ANHOPS) to all occupational health departments on their mailing list. Questionnaires were sent to 160 general, teaching and specialist hospitals, and 44 responses were obtained. Of these five had no data available concerning incidents of varicella, and were excluded from the study. Of the remaining 39 hospitals, 31 did not routinely keep records of varicella incidents but were able to complete the questionnaire, and 8 did routinely keep records and were able to complete the questionnaire. Five hospitals also returned information on zoster incidents. However the remainder kept records only of varicella incidents, and so zoster incidents were not included in the analysis. This study therefore underestimates the annual incidence and cost of all nosocomial VZV exposures, a point returned to in the discussion.

Size of hospital

Medical and dental, nursing and midwifery, and allied professional whole time equivalent (WTE) staff numbers employed by each trust in 1994 were obtained from the Fitzhugh Directory of NHS Trusts 1995 edition [16]. The number of WTE staff was then converted into actual numbers employed using the ratio of WTEs to all nursing and midwifery staff in the NHS as a whole, of 1·206. Data on the number of in-patient days were obtained from the CIPFA database for 1994 [17]. The staff levels and in-patient numbers of responding and non-responding hospitals were not significantly different, suggesting that the response rate while low was not biased.

The probability of a hospital incident of varicella exposure

Forty-six percent of hospitals recorded no incidents of varicella during the 12 months 1 January–31 December 1994, and 54% reported at least one incident. Across all respondents the mean number of incidents over this period was 3·9. Amongst those reporting at least one incident, the mean number was 6·6.

The index case was known in 122 (88%) of the 139 incidents reported for 1994. In 62 (51%) of these cases the index case was a patient (59) or visitor (3) to the hospital, and in 60 (49%) of cases the index case was a member of staff (33) or the family of a member of staff (27). Relating these percentages back to the figure of 3·9 incidents/year gives a mean of 2·0 incidents/year in which the index case was a patient or visitor to the hospital, and 1·9 cases/year in which the index case was a member of staff or the family of a member of staff.

When hospitals were asked for further details concerning their most recent incident, the pattern of index cases remained very similar; of the 25 incidents for which detailed information was available, the index case was a patient or visitor to the hospital in 52% of cases (12 patients, 1 visitor), and a member of staff or the family of a member of staff in 48% of cases (5 members of staff, 7 family of member of staff).

Only 1 (3%) of the 39 hospitals providing information routinely performed antibody tests to screen new staff for antibodies to VZV; 24 hospitals (61%) did no antibody testing, and the remaining 14 (36%) did antibody testing on some groups of staff, particularly staff unsure of their VZV history who were likely to be in contact with high-risk patients. The proportion of staff tested in these hospitals has been estimated at 10%, and hence the baseline probability of a new member of staff being antibody tested has been set at 0·066 ($0{\cdot}36 \times 0{\cdot}1 + 0{\cdot}03$). Finally, when an incident occurred, the mean period from start to finish was 13·8 days.

Resources and costs associated with managing nosocomial VZV exposures in hospital

Table 3 summarizes the resources and costs associated with managing varicella exposures in hospital. In the analysis, patient and visitor index cases are grouped together, as are incidents where the index case was a staff member or a staff member's family. While none of the options considered here would actually prevent a family relative of a staff member from getting varicella, the hospital episode is still averted because the staff member is no longer susceptible and hence a range of resource consequences such as staff suspension/reallocation and testing can be avoided.

Table 4. *Baseline parameters of model*

Parameter	Value
Hospital population	
No. of staff	1540
Staff turnover per annum (%)	10%
No. of in-patient days per annum	255000
No. of in-patient days per staff per annum	165
Population at risk	
Probability (negative)	0·08
Number and probability of incidents	
Survey no. of staff incidents per annum	1·9
Survey no. of patient incidents per annum	2·0
Probability (staff incident/staff at risk)	0·02
Effectiveness of screening by history of varicella	
Probability (positive/screen)	0·66
Probability (test positive/screen not positive)	0·78
Probability (test negative/screen positive)	0·007
Vaccine seroconversion rate and duration	
Probability (immunity/vaccine)	0·9
Duration of programme (years)	10
Cost of vaccine*	
Screen by history of varicella cost	£1·10
Antibody test cost	£15·41
Vaccine cost (two doses)	£41·1

* At 1995 values.

From the probabilities of resource being used, their volumes and costs, it is possible to calculate that current hospital policies to manage incidents of nosocomial VZV exposure have a net cost/hospital/year of £5172, of which £200 is related to taking histories from new recruits, £203 to testing new recruits, £2169 in dealing with incidents where the index case was a member of staff or their family, and £2599 in dealing with incidents where the index case was a patient or visitor to the hospital. Based on an observed mean of 3·9 incidents/hospital/year, the mean cost per incident was therefore £1,319.

Model parameter values

Based on the data obtained above, it is possible to report the baseline parameters of the model, as set out in Table 4. The first set of parameters define the relevant population: that is, the staff numbers, staff turnover and patient throughputs of the hospital (or department within a hospital) which is considering the introduction of a vaccination programme for health care workers. The parameter for the underlying rate of VZV antibody negativity amongst health care

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workers, and hence the population at risk, and the parameters representing the effectiveness of screening of staff for a history of varicella and the incidence of Type I and Type 11 errors, come from the hospital staff screening study at St Bartholomew's Hospital, London described earlier [13]. The parameters which define the number and probability of incidents come from the hospital survey conducted as part of this study, as reported above. The parameter representing the seroconversion rate achieved by the vaccine following two doses is referenced above. The final set of parameters represent the costs associated with screening and vaccination. A cost of £1.10 has been assigned to the administration of the vaccine doses, based on 5 min of a Grade G nurse's time to explain the vaccine. The cost of the antibody test comes from the mean figure reported in the hospital survey, and the cost of the vaccine is based on the US vaccine price of \$35 per dose, with two doses converted into 1995 values at an exchange rate of \$1·7 = £1.

The model parameters representing the costs and probabilities associated with incidents of nosocomial VZV exposure are as set out in Table 3. If any vaccination option is introduced we assume that the hospital will withdraw some of these procedures. In particular, it is assumed that a hospital will not require to initiate procedures for evaluating staff exposure, for screening staff or for serological testing of staff in the event of an incident.

RESULTS

Comparison of vaccination strategies

Table 5 provides summary data on the costs and cost-effectiveness of each vaccination strategy for an average hospital with 1540 staff involved in the programme and 255000 patient bed-days/year. In the baseline situation, an annual average of 3·9 incidents are expected, with expected 10-year net costs of £37300 (discounted at 6% per annum). Under *Option 2*, all staff are vaccinated, and the average annual number of incidents falls from 3·9 to 2·2. Screening and testing costs fall to zero but vaccine costs are £110000. The costs associated with staff index cases fall by approximately 90%, but the costs associated with patient index case incidents fall only slightly. The net cost is £121000, equivalent to a cost per incident averted of £48900.

Under *Option 3*, all staff are asked about previous varicella, and those who are uncertain or report no previous varicella are then vaccinated. This substantially reduces vaccine costs compared with *Option 2*, but additional screening costs are incurred and a smaller reduction in incidents is achieved due to staff who falsely claim a positive history of varicella and consequently are not vaccinated. Net costs of this option are £51800 and the net cost per incident averted is £9000.

With *Option 4*, all staff are asked about previous varicella and those who are uncertain or report no previous varicella are antibody tested; those who test negative for VZV antibodies are then vaccinated. This increases test costs compared with *Option 3* but reduces vaccination costs, so the net cost falls to £36600, which is over £700 less than the baseline option. There is consequently a net financial saving to the NHS from this option.

Finally, under *Option 5* an antibody test is performed on all staff, and those who test negative for VZV antibodies are then vaccinated. Here the net cost is £60900 and the net cost per incident averted is £13800.

In summary, of the options considered, *Option 4* has lower net costs than any other option including the current policy: that is, it would give fewer incidents and would also produce net savings in comparison with the baseline situation.

Sensitivity analysis

A number of key parameters have been subjected to sensitivity analysis, holding all other parameters constant. Altering the number of staff involved, from the baseline of 1542, does not affect the relative position of the alternatives to the baseline situation, but costs steadily increase with size.

The parameter which has most influence on the outcome is the probability of a staff incident. Figure 1 shows this, where the probability of an incident is expressed in terms of incidents per 1000 staff each year. Thus in the baseline option the annual number of incidents per 1000 staff is 1·23, which equals a total of 1·9 incidents per annum for a hospital with 1542 staff, as observed in the survey. Figure 1 shows that the ranking of the various options changes as the probability of an incident changes. When the staff incident rate falls slightly from the baseline rate (where vaccinating after an antibody test on those indicating a negative history of varicella is the lowest cost option), the current policy becomes the cheapest option. As the staff incident rate increases, other

Table 5. *Costs and cost-effectiveness of vaccination strategies in a typical hospital**

	Option 1 Baseline	*Option 2* Vaccinate all	*Option 3* Vaccinate after screen for history of varicella	*Option 4* Vaccinate after antibody test on screen negatives	*Option 5* Vaccinate after antibody test on all staff
Annual number of					
Staff index case incidents	1·90	0·19	0·29	0·28	0·19
Patient index case incidents	2·01	2·01	2·01	2·01	2·01
All incidents	3·91	2·20	2·30	2·29	2·20
Expected 10 year cost of					
Screening (£)	1135	0	2677	2677	0
Testing (£)	1154	0	0	14027	41256
Vaccine (£)	0	110033	37411	8230	8739
Staff index case incidents	15882	1483	2259	2195	1483
Patient index case incidents	19128	9457	9457	9457	9457
Net total cost per hospital (£)	37300	120973	51805	36587	60935
Change in net cost compared with baseline (£)	0	83674	14506	−713	23635
Change in incidents compared with baseline	0·00	−1·71	−1·61	−1·62	−1·71
Net cost per incident averted compared with baseline (£)	—	48932	9007	−440	13822

* Costs in £ at 1995 value.

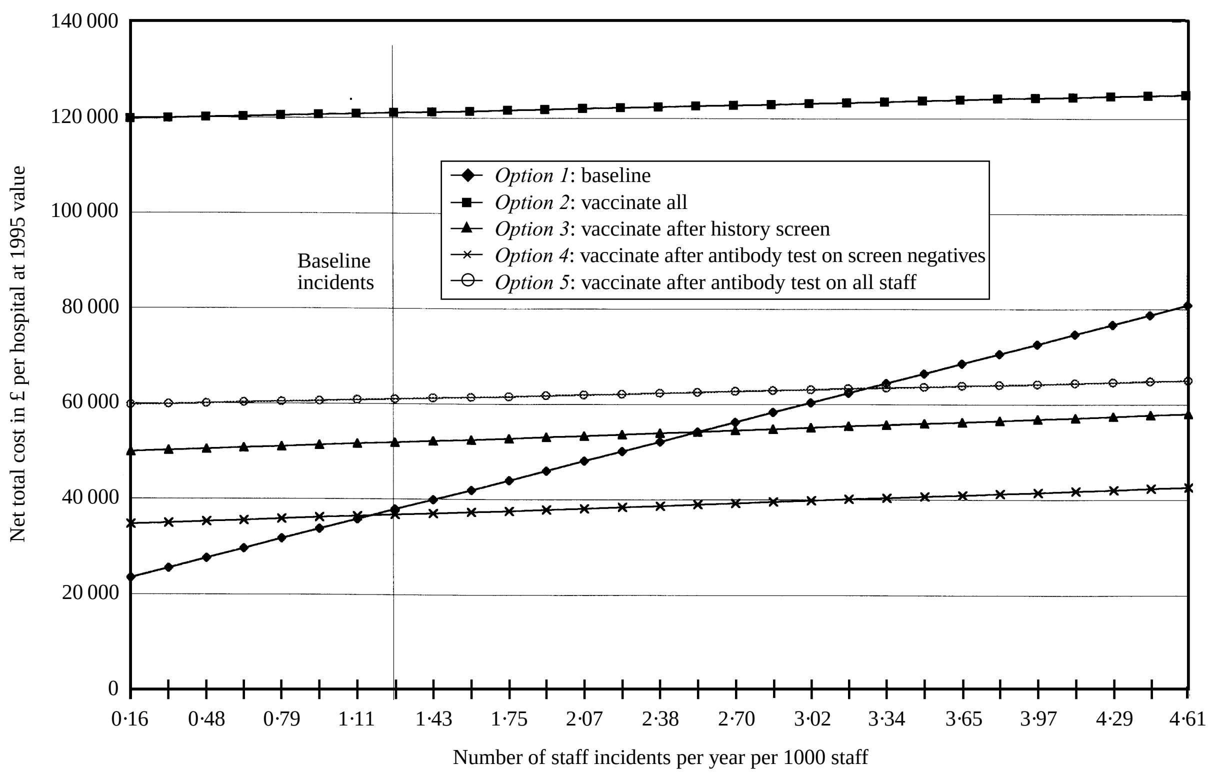

Fig. 1. Net total cost of different VZV vaccination strategies with varying probability of staff index case incidents: 10 year programme, costs in £ at 1995 values discounted at 6% p.a.

options come into contention against current policy: at an incident rate of 2·54 per 1000 staff per annum, *Option 3* becomes cheaper than the current policy, and when the incident rate rises to 3·2 per 1000 staff per annum, *Option 5* becomes cheaper than the current policy. However, *Option 2*, in which all staff are

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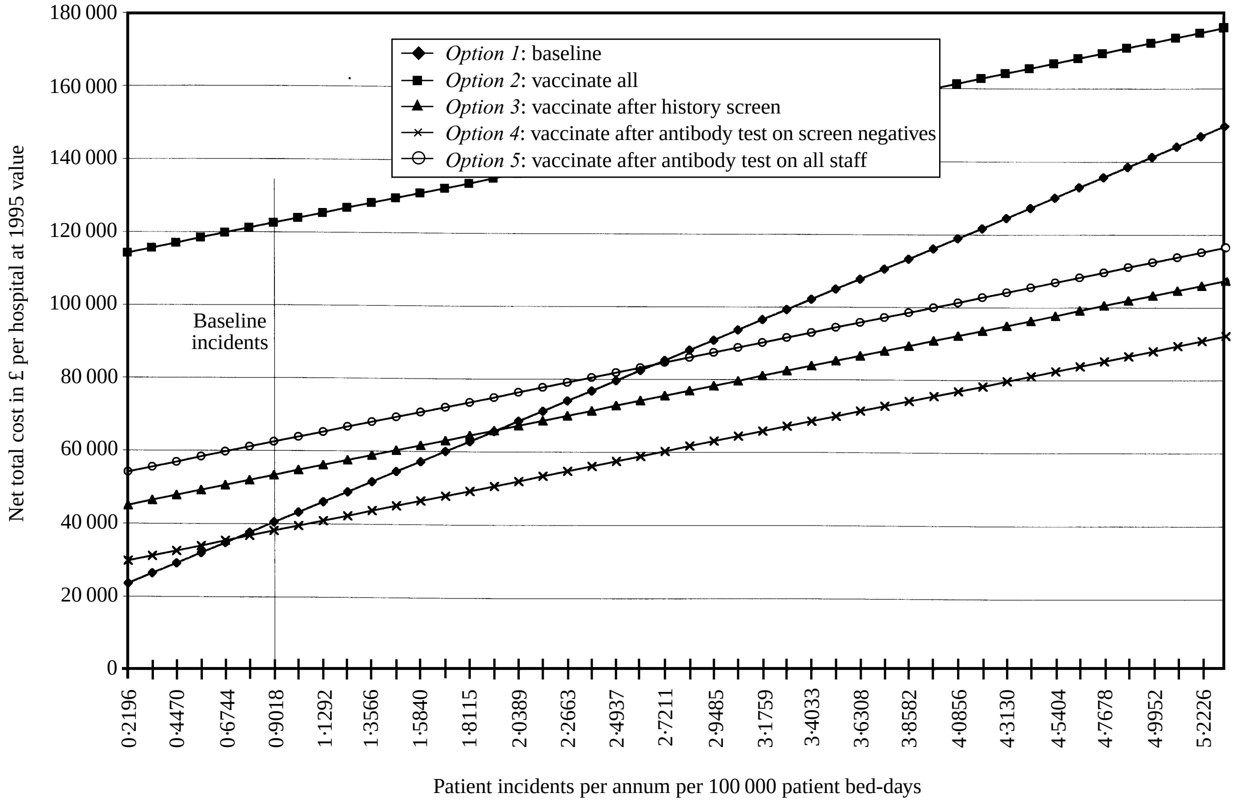

Fig. 2. Net total cost of different VZV vaccination strategies with varying probability of patient index case incidents: 10 year programme, costs in £ at 1995 values discounted at 6% p.a.

vaccinated, does not become cheaper than current policy even at the highest shown rates of staff incident. Finally, although a number of other options become less costly than current policy at higher incident rates, *Option 4* is always the least costly.

Figure 2 shows the influence of changes in the rate of patient incidents, where the probability of a patient incident is expressed in terms of incidents per 100000 patient bed-days per annum: thus in the baseline option the annual number of patient incidents per 100000 patient-bed-days is 0·79, which equals an average of 2·01 patient incidents per annum for a hospital with 255000 bed-days per annum, as observed in the survey. As with staff incidents, altering the rate of patient incidents changes the ranking of the various options under consideration: when the rate falls slightly from the baseline rate, the current policy becomes the cheapest option. When the rate rises from the baseline of 0·79 to 1·95 per 100000 bed-days, *Option 3* becomes less costly than the current policy, and at an incident rate of 2·65 per 100000 bed-days *Option 5* also becomes cheaper than the current policy. However, at all these higher incident rates *Option 4* still has lower net costs than any other option considered.

Figure 3 shows the effect on the net costs of each option of varying the vaccine price around the baseline figure of £41·1. It can be seen that, as the vaccine price rises above the baseline level, the current policy gradually becomes the cheapest option. As the vaccine price falls, the cost advantage of *Option 4* over baseline policy is increased, and at a price of around £20 per vaccination, *Option 3* becomes the lowest cost option. The policy in which all staff are vaccinated, *Option 2*, does not have equal costs to the current policy until the vaccine price falls to approximately £10, and even then is not the least cost option available.

In addition, sensitivity analyses were performed on the following: when the proportion of staff recalling a definite history of varicella is increased from the baseline of 66%, the cost advantage of *Option 4* increases, and when this proportion falls below 62% none of the vaccination options offers a cost saving compared with the baseline policy; when the efficacy rate of the vaccine falls from 90 to 85%, *Option 4* ceases to be a cost-saving option compared with current practice, compared with a saving of over £700 per hospital in the baseline case; when efficacy falls to 80% the additional cost of *Option 4* is £684, and when

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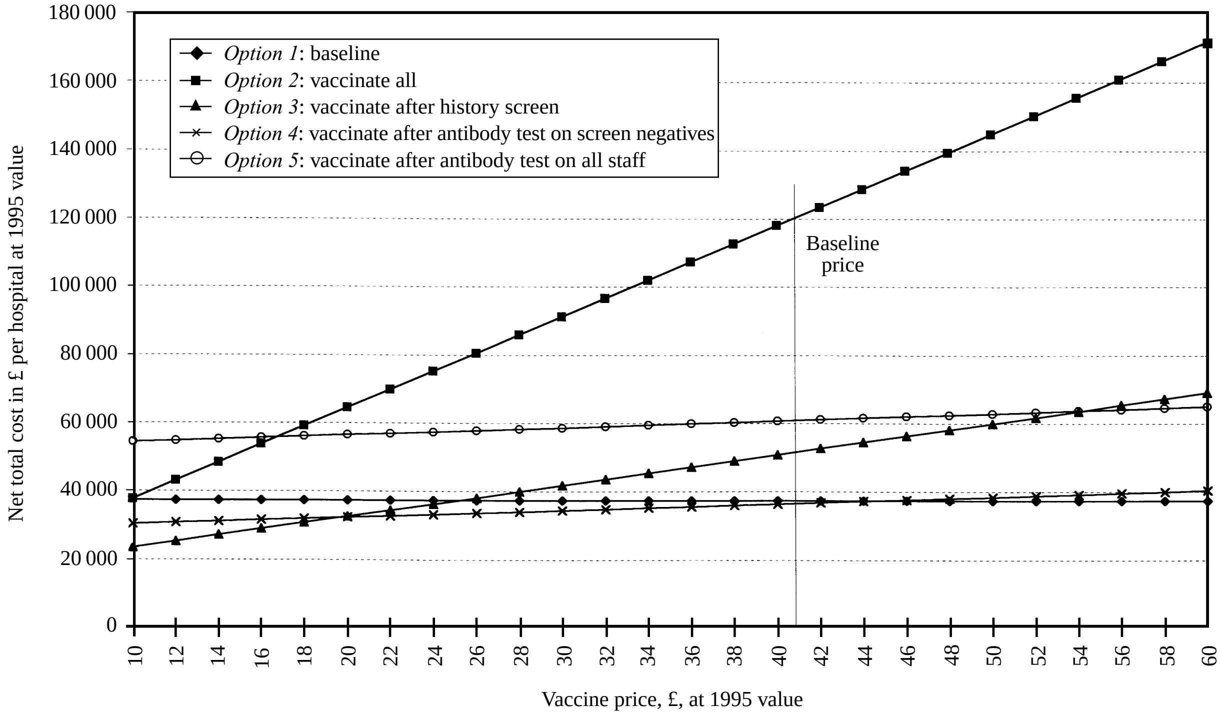

Fig. 3. Net total cost of different VZV vaccination strategies with varying vaccine price: 10 year programme, costs in £ at 1995 value discounted at 6% p.a.

efficacy rises to 100% the cost saving of *Option 4* increases to almost £2000; when the staff turnover rate is increased from the baseline value of 10% the difference in net cost between the various options gradually increases, and *vice versa*, but the rankings of the options remain the same; finally, varying the discount rate around the baseline value of 6% has very little effect on the results and leaves the rankings unaffected.

DISCUSSION

Evidence indicates that application of the currently recommended VZV control measures does not fully prevent transmission of VZV to patients or staff in hospital nosocomial incidents [14]. The analysis reported above indicates that introducing a policy of vaccinating health care workers after an antibody test on staff who answer 'no' or 'not sure' to a question about previous varicella would result in a reduction in net costs to the NHS compared with the present policies for dealing with incidents of nosocomial VZV exposure in hospitals. None of the other options considered would result in an actual reduction in net costs. This does not necessarily mean that the other options considered are cost-ineffective: the avoidance of VZV incidents in hospital may well have health benefits, for example, in terms of reduced morbidity or mortality, which would make an increase in net costs worthwhile compared to other uses of health care resources. However, due to the uncertainties and lack of information concerning these potential health benefits, the methodological framework adopted here is focused on costs.

The results are dependent on the baseline values used, which are based as far as possible on published literature and on empirical data from a sample of hospitals which responded to a questionnaire. It should be noted that these baseline values are averages across 39 different hospitals; consequently they are likely to reflect current practice and costs across a range of hospital types and settings, but may not represent an individual hospital's present position. Similarly, different hospitals may experience different costs and savings under each vaccination strategy considered: the results reflect the likely experience on average. Under most alternative assumptions *Option 4*, in which screening by history of varicella is performed, followed by antibody tests on those who are uncertain or report no previous varicella, and those who test negative for VZV antibody are then vaccinated, remains the favoured option. Nevertheless, the analysis shows that changes in these baseline values can affect the results and the ranking of options. The epidemiology of varicella is fairly uniform across the UK and other Northern European countries, and should not restrict the generalizability of the results. The broad framework used is also generalizable to other settings, if the required data are available.

The average cost of VZV control per hospital in the baseline results was £5172 per annum: in comparison, a recently reported study gives a figure of £13 204 per annum for control of varicella and zoster cases in Addenbrooke's Hospital, Cambridge [5]. The results reported here are therefore conservative, and are likely to understate the benefits of vaccination.

The results are particularly sensitive to the incident rate amongst staff. The incident rate used in the baseline analysis, of 1·9 staff index case incidents per hospital per year, is equivalent to one incident per 812 staff employed. This is a lower rate than that reported by Morgan-Capner and colleagues [18], who identified 9 staff index case incidents over 22 months in 3 major hospitals in Preston Health Authority with a total of 2815 staff in contact with patients, or 1 incident per year per 570 staff. At that incident rate, the net saving compared with current policies of introducing *Option 4* would rise from the baseline figure of just over £700 to around £6400 per hospital. The lower incident rate used in the present study reflects the fact that, as noted in the Data section, 46% of hospitals in our survey reported no episodes of varicella over the 12 months covered by the survey: this may be evidence that some hospitals are not looking or responding, rather than because the incidents do not exist. There is also some evidence of a significant upward trend in the incidence of varicella in young adults in England and Wales in recent years [19]: such a trend would strengthen the conclusions of this study. Finally, the results of this study do not include zoster exposures, which probably occur at a rate of one per two varicella exposures [14]; these would not be prevented by a vaccination strategy but their consequences for staff would be reduced, and therefore the cost savings shown in the model are likely to be conservative.

If a number of hospitals were concurrently operating a VZV vaccination policy over a period of years, it is likely that some vaccinated workers would be amongst the new recruits to an individual hospital. This would lower the costs attributed to the vaccination options in the model, which are all based on an assumption that all new recruits would be vaccinated. The effect of this would be equivalent to a reduction in the turnover rate: as the national pool of vaccinated staff increased, the number of new recruits having to be vaccinated would fall, and this would increase the cost savings associated with *Option 4* compared to current policies.

To assess the cost-effectiveness of different VZV vaccination strategies for health care workers, better information than currently exists will be required on the health consequences of incidents of nosocomial VZV exposure in hospital. However, given that at least one of the options considered here dominates the existing situation (i.e., has lower costs and fewer incidents) some form of VZV vaccination strategy for health care workers is likely to prove a cost-effective use of health care resources.

APPENDIX

Details of costings

Hospitals were asked to provide information where available on the resources associated with an incident (for example, numbers of serological tests, or hours of occupational health time) and the cost of these resources. Where a cost was provided this was used in the analysis; where the quantity of resources was reported but not the cost, the resources were valued using the mean cost from those hospitals that did report a cost. For example, 21 hospitals provided information on the number of serological tests performed on staff or patients, but only 10 hospitals provided information on the costs of serological tests, and the mean cost from these 10 hospitals was applied to the remainder.

For nursing time in the evaluation of patients, it was assumed in cases where no cost was given that a G grade nurse was used, at an average cost per hour in 1995 prices of £12.96 including employers' costs. For medical time in the evaluation of exposure of patients, it was assumed in cases where no cost was given that an SHO was used, at an average cost per hour in 1995 prices of £12·66 including employers' costs. For other time in the evaluation of exposure of patients, it was assumed in cases where no cost was given that an infection control G grade nurse was used, at an average cost per hour in 1995 prices of £12·96 including employers costs. For OHD and other time in the evaluation of exposure of staff, it was assumed in cases where no cost was given that a G grade nurse was used, at an average cost per hour in 1995 prices of £12·96 including employers costs.

Where staff were suspended from work but no cost was given, this was costed on the basis of the salary and

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employers cost at the midpoint of the relevant grade at 1995 pay rates. Student nurses were costed at nurse grade A. Where no nurse grade was given a grade E was assumed.

Three hospitals reported a patient in isolation but did not give the days in isolation. These missing values were replaced with a mean per patient from the other cases, of 6 days. Weber and colleagues [1] reported a cost of $45 per day in 1986. We have assumed that the difference between the cost per day of an isolation bed and the cost per day of an acute in-patient bed is £50.

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REFERENCES

1. Weber DJ, Rutala WA, Parham C. Impact and cost of varicella prevention in a university hospital. Am J Pub Health 1988; **78**: 19–23.
2. Krasinski K, Holzman RS, LaCouture R, Florman A. Hospital experience with varicella-zoster virus. Infect Control 1986; **7**: 312–6.
3. Miller PJ, Landry S, Searcy MA, Hunt E, Wenzel RP. Cost of varicella epidemic. Pediatrics 1985; **75**: 989–90.
4. Hyams PJ, Stuewe MCS, Heitzer V. Herpes zoster causing varicella (chicken pox) in hospital employees: cost of a casual attitude. Infect Control 1984; **12**: 2–5.
5. Wreghitt TG, Whipp J, Redpath C, Hollingworth W. An analysis of infection control of varicella-zoster virus infections in Addenbrooke's Hospital Cambridge over a 5-year period, 1987–92. Epidemiol Infect 1996; **117**: 167–71.
6. Asano Y, Suga S, Yoshikawa T, et al. Experience and reason: twenty year follow up of protective immunity of the Oka strain live varicella vaccine. Pediatrics 1994; **94**: 524–6.
7. Kitai IC, King S, Gafni A. An economic evaluation of varicella vaccine for pediatric liver and kidney transplant recipients. Clin Infect Dis 1993; **17**: 441–7.
8. Preblud SR, Orenstein WA, Koplan JP, Bart KJ, Hinman AR. A benefit-cost analysis of childhood varicella vaccination programme. Postgrad Med 1985; **61**: 17–22.
9. Lieu TA, Cochi SL, Black SB, et al. Cost-effectiveness of a routine varicella vaccination program for US children. JAMA 1994; **271**: 375–81.
10. Lieu TA, Black SB, Shinefield HR, et al. Routine childhood varicella vaccination. JAMA 1994; **271**: 1906.
11. Gershon AA, Steinberg SP, LaRussa P, Ferrera A, Hammerschlag M, Gelb L, and the NIAIA varicella Collaborative Study Group. Immunization of healthy adults with live attenuated varicella vaccine. J Infect Dis 1988; **158**: 132–7.
12. Drummond MF, Jefferson TO. Guidelines for authors and peer reviewers of economic submissions to the BMJ. BMJ 1996; **313**: 275–83.
13. Murray A, Kangro HO, Health RB. Screening hospital staff for antibodies to varicella-zoster virus. Lancet 1990; ii: 192.
14. Miller E, Marshall R, Vurdien J. Epidemiology, outcome and control of varicella-zoster infection. Rev Med Microbiol 1993; **4**: 222–30.
15. Fairley CK, Miller E. Varicella-Zoster virus epidemiology – a changing scene. J Infect Dis 1996; **175**: S314–S319.
16. Health Care Information Services. The Fitzhugh Directory of NHS Trusts: 1995. London: Health Care Information Services, 1995.
17. Chartered Institute of Public Finance and Accountancy. NHS Trust database. London: CIPFA, 1994.
18. Morgan-Capner P, Wilson M, Wright J, Hutchinson DN. Varicella and zoster in hospitals. Lancet 1991; i: 1960.
19. Miller E, Vurdien J, Farrington P. Shift in age in chickenpox. Lancet 1993; **341**: 308–9.