Prevention of poultry-borne salmonellosis by irradiation: costs and benefits in Scotland

B. F. Yule, 1 J. C. M. Sharp, 2 G. I. Forbes, 3 & A. F. MacLeod 4

Poultry-borne salmonellosis is the most common foodborne infection in Scotland for which the vehicle can be identified. The cost of the disease to society in terms of health service use, absence from work, morbidity, and mortality is substantial. The study estimates the total cost of poultry-borne salmonellosis in Scotland and compares it with the cost of a single preventive measure: the irradiation of poultry meat. The results suggest that the public health benefits exceed irradiation costs. This conclusion is, however, sensitive to assumptions made in the analysis, particularly those related to the cost of unreported cases of salmonellosis.

The increasing incidence of salmonella infections in industrialized countries in recent years, together with rising awareness of their economic cost, has intensified the search by public health authorities for control measures (1). In Scotland, salmonellosis is the most commonly reported foodborne disease. Since the implementation of a ban on the sale of untreated milk in 1983, poultry has become the food vehicle most frequently implicated in such outbreaks (2). Poultry-borne salmonellosis accounted for 374 non-fatal cases and two fatalities per year, on average, over the period 1980–85 (3), excluding known sporadic, unreported, and unidentified cases. The economic cost associated with this morbidity and mortality is largely, if not wholly, preventable. Preventive policies themselves incur costs, however, that need to be weighed up against the costs of the disease to society.

Here, we discuss the costs and benefits of one such control measure: the irradiation of poultry meat. The potential contribution of irradiation to the prevention of salmonellosis is generally recognized (4, 5), and two North American studies reported that irradiation of poultry was economically viable (6, 7). However, it is important to ascertain whether this conclusion applies also in other countries and whether it is sensitive to differences in assessment methods. The issue is a particularly important one in the United Kingdom following the recommendations of the Advisory Committee on Irradiated and Novel Foods (5) to legalize the irradiation of food up to an average dose of 10 kGy (4, 7).

The present study does not seek to quantify all the costs and benefits of irradiation, but focuses rather on two key factors: the cost of irradiating poultry meat and the benefit gained from preventing salmonellosis. However, by treating the problem in the context of a cost–benefit analysis, the study provides a framework within which policy-makers can weigh up the relative importance of quantified and unquantified factors.

MATERIALS AND METHODS

Cost–benefit analysis

Cost–benefit analysis attempts to express in monetary terms all the advantages and disadvantages of a procedure, in this case poultry irradiation, so that they can be compared directly (8). Potential benefits from such irradiation include the public health benefit of eliminating salmonella and other poultry-borne pathogenic organisms, e.g., campylobacter, and commercial benefits such as the increased shelf-life of the irradiated product. The study attempts to measure public health benefits in terms of reduced salmonellosis only. If irradiation can be justified on this ground alone, any additional benefits may be viewed

1 Research Fellow, Health Economics Research Unit, University of Aberdeen, Foresterhill, Aberdeen AB9 2ZD, Scotland. Requests for reprints should be sent to this author.
2 Consultant Epidemiologist, Communicable Diseases (Scotland) Unit, Glasgow, Scotland.
3 Senior Medical Officer, Scottish Home and Health Department, Edinburgh, Scotland.
4 Community Medicine Specialist, Lothian Health Board, Edinburgh, Scotland.
as desirable extras.

As far as costs are concerned, we considered only the cost of the irradiation process. Other possible costs, such as any deterioration in the nutritional or taste qualities of the irradiated poultry meat or any outlays required to assure consumers of the safety and wholesomeness of the product, were omitted.

**Estimating benefits**

Benefits were measured in terms of the cost due to the disease that would be averted by irradiation. In order to estimate the cost of poultry-borne salmonellosis in Scotland, data from the following two studies were used: the costing of a community outbreak of milkborne salmonellosis in 1981 (9) and that of a hospital outbreak of poultry-borne infection in 1985 (10). Both studies used the same methodology. Account was taken of the costs to the health services, the loss of productive output, the "pain, grief and suffering" of victims and their families, and the value of lives lost. Health service inputs were valued at their market prices on the assumption that these approximate the opportunity costs (8). Economic losses caused by absence from paid employment were proxied by gross employment costs (11), and in the community outbreak allowance was made for the loss of housewives' output (9).

The monetary valuation of "pain, grief and suffering" and of lives lost is problematic; however, decision-making procedures in many areas of public policy currently assign values to such items, albeit often implicitly (12). Both Scottish studies referred to above make use of existing monetary valuations of "intangibles". Since the resulting estimates are inevitably crude, sensitivity analysis was used—that is, a range of values was taken so that the sensitivity of the results to alternative assumptions could be assessed. Allowances for "pain, grief and suffering" were centred around an estimate used to calculate the cost of occupational accidents and diseases in Great Britain (11).

Two economic approaches to valuing life were used. The first of these, the human-capital method, has the advantage that it yields an objective figure, but since it is based on individuals' productive capacities, rather than on a wider notion of their value to society, we used it as a lower bound in the study. The second approach, the willingness-to-pay method, which is based on individual valuations of reductions in the risk of death, is more attractive theoretically, but produces a wide range of estimates in practice. The most reliable of these to date was used in the study as an upper bound (13).

The costs thus obtained were applied to epidemiological data for Scotland to estimate the total cost of poultry-borne salmonellosis. The reported number of cases of this disease in Scotland is undoubtedly an underestimate of the true incidence. For example, a large number of salmonella outbreaks occur each year for which no vehicle can be identified. Together with an unquantifiable number of sporadic cases, many of which, on the epidemiological evidence available, are almost certainly due to poultry-borne infection.

Detailed investigation of salmonella outbreaks in North America suggests that only around 3% of cases are reported, on average, although in several large outbreaks this proportion has been as low as 1% (14). Comparable problems of under-reporting probably exist in Scotland. For example, since the self-certification period for sickness-related absence from work is five working-days, many mild or self-limiting cases do not come to the attention of a general practitioner; and, even if they do, salmonellosis may not be diagnosed since stool samples are not routinely taken in all instances of diarrhoeal illness. Uncertainty surrounding the number of unreported cases was dealt with by using sensitivity analysis. In this way, separate estimates were made of the cost of reported cases, unreported cases, and known fatalities.

**Estimating costs**

We assumed in the study that all poultry produced in Scotland would be irradiated in a single plant. In view of the dominance of the poultry market by one producer in Scotland, and the substantial economies of scale in the irradiation process (15), this assumption is plausible. In countries where poultry production is more dispersed geographically, however, a single centralized irradiation plant might not be practicable. As a result, some of the cost advantages of large-scale operation could be lost, and the cost per unit irradiated would be higher than in the present case. Irradiation at an average dose of 3 kGy eliminates salmonella contamination from poultry (16). Hence we assume that all costs of poultry-borne salmonellosis in Scotland would be avoided. Scotland is a net exporter of poultry. Any costs of salmonellosis caused by the small volume of imported poultry would therefore be more than offset by the benefits from exporting a salmonella-free product to the rest of the United Kingdom.

**Discounting**

The cost of irradiation equipment is heavily concentrated in the initial period of its operation, with much lower year-to-year operating expenses thereafter (15). By contrast, the benefits in terms of disease prevention are more evenly spread over time. In order to allow for these differences in the time profiles of costs and benefits, it is essential that both be discounted to their present values (8). Discounting em-
bodies the general principle that society values more highly the benefits that it receives now rather than in the future and that it prefers to pay costs later rather than now. Here, we use the discount rate of 5% recommended by the United Kingdom Treasury for appraising public projects (17), and recently suggested for universal adoption in cost–benefit studies (18).

RESULTS

Cost of reported cases

For reported (non-fatal) cases of salmonellosis, the costs per person affected comprise those borne by the health services (hospitalization, use of primary care, laboratory testing, and outbreak control), work output lost due to illness, and the "pain, grief and suffering" associated with illness. The ranges of average costs per case for these elements from the two previously mentioned studies of milk-borne and poultry-borne salmonellosis (9, 10) are shown in Table 1. Cost estimates for the hospital outbreak are substantially higher than those for the outbreak in the community for two main reasons: the more stringent control measures applied in the hospital outbreak because of the high-risk population affected (staff and geriatric patients), and the higher proportion of employed victims (hospital staff) (10). Together, however, these studies indicate the potential range of costs that apply to other outbreaks of the disease in Scotland.

Cost of unreported cases

For unreported cases of salmonellosis, the main costs incurred are lost work output, "pain, grief and suffering", and/or the cost of contacts with a general practitioner. Table 1 shows the range of costs per case for these factors taken from the two Scottish studies referred to above (9, 10). Since many unreported cases are likely to be less severe than reported cases, these costs need to be scaled down.

Table 2 shows estimates of the total cost of unreported cases of poultry-borne salmonellosis in Scotland under various assumptions about the cost of reported cases, i.e., whether the community or institutional outbreak is used as the cost basis, the cost of unreported relative to that of reported cases, and the number of unreported relative to reported cases. Uncertainty surrounding these variables gives rise to a very wide range of cost estimates.

Cost of fatalities

If the human-capital approach to valuing life is used, the mean value of a single life lost is US$ 268 850 (£207 400) at 1985 prices (11), compared with US$ 3 020 400 (£2 330 000) for the willingness-to-pay method (13). However, most deaths from salmonellosis occur among the elderly and chronic sick, who have below average life expectancy. Assuming life expectancies of 10% of normal for such individuals (9) reduces the range to US$ 26 855–302 040 (£20 740–£233 000) per life lost.

Total cost of poultry-borne salmonellosis

Table 3 collates the various components of the cost of poultry-borne salmonellosis in Scotland (for reported cases, total costs per case from Table 1 are used). Taking the middle estimate of cost per person from the community outbreak as a lower bound and the corresponding estimate from the hospital episode as an upper bound places the cost range of the 374

| Table 1. Estimated cost (at 1985 prices) per non-fatal case of salmonellosis in Scotlanda |
|---------------------------------------------|-------------------|-------------------|-------------------|
|                                  | Cost bracket (£ sterling)b                |
|                                  | Lower | Middle | Upper |
| **Community**                    |       |        |       |
| Total cost, excluding fatalities | 245   | 329    | 430   |
| General practitioner services, lost output, and "pain, grief and suffering" only | 159   | 241    | 324   |
| **Institutional**                |       |        |       |
| Total cost, excluding fatalities | 571   | 670    | 769   |
| General practitioner services, lost output, and "pain, grief and suffering" only | 437   | 536    | 635   |

a Based on data in ref (9) and (10).
b £1 = US$ 1.30
Table 2. Sensitivity analysis of middle cost (at 1985 prices) per case (see Table 1) of unreported cases of salmonellosis in Scotland

<table>
<thead>
<tr>
<th>Cost base*</th>
<th>Relative cost b</th>
<th>Relative frequency c</th>
<th>Cost of unreported cases (£ sterling)d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community outbreak</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>10%</td>
<td>5%</td>
<td></td>
<td>180 268</td>
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<td>30%</td>
<td>5%</td>
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<td>540 804</td>
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<td>2 704 020</td>
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<td>50%</td>
<td>1%</td>
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<td>4 506 700</td>
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<tr>
<td>Institutional outbreak</td>
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<tr>
<td>10%</td>
<td>5%</td>
<td></td>
<td>400 928</td>
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<td>30%</td>
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<td>1 202 784</td>
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<td>2 004 640</td>
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<tr>
<td>10%</td>
<td>3%</td>
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<td>688 213</td>
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<td>2 004 640</td>
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<td>3 341 067</td>
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<td>2 004 640</td>
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<td>6 013 920</td>
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<tr>
<td>50%</td>
<td>1%</td>
<td></td>
<td>10 023 200</td>
</tr>
</tbody>
</table>

* Middle estimate of relevant costs per case (see Table 1) are used.
  
  ** Relative cost = Cost of unreported cases - cost of reported cases
  
  b Relative frequency = No. of reported cases - No. of unreported cases
  
  c £1.00 = US$ 1.30

reported non-fatal cases per year in Scotland at US$ 159 510–US$ 324 830 (£123 046–£250 580). Also, from Table 2, the cost of unreported cases is US$ 233 680 (£180 268) under the most optimistic assumptions about the relative cost and relative frequency of unreported versus reported cases, and US$ 12 993 070 (£10 023 200) under the most pessimistic set of assumptions; these provide low and high estimates, respectively, for the cost of unreported cases. For fatalities, the human-capital approach to valuing life gives a minimum, and the willingness-to-pay approach, a maximum value. If it is assumed that the life expectancy of salmonella victims is 10% of that of normal, the estimated cost of two fatalities per year in Scotland is between US$ 53 770 (£41 480) and US$ 604 080 (£466 000).

Under these assumptions, the total cost of poultry-borne salmonellosis in Scotland was estimated to be US$ 446 960–US$ 13 921 980 (£344 794–£10 739 780) per year (Table 3), which is also a

Table 3. Estimated annual costs (at 1985 prices) of poultry-borne salmonellosis in Scotland

<table>
<thead>
<tr>
<th>Cost bracket (in £ sterling)a</th>
<th>Lower</th>
<th>Middle b</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reported cases</td>
<td>123 046</td>
<td>186 813</td>
<td>250 580</td>
</tr>
<tr>
<td>Unreported cases</td>
<td>180 268</td>
<td>5 101 734</td>
<td>10 023 200</td>
</tr>
<tr>
<td>Loss of life</td>
<td>41 480</td>
<td>253 740</td>
<td>466 000</td>
</tr>
<tr>
<td>Total annual cost</td>
<td>344 794</td>
<td>5 542 287</td>
<td>10 739 780</td>
</tr>
</tbody>
</table>

* £1.00 = US$ 1.30.
  
  ** Taken as the average of the lower and upper estimates.
measure of the potential benefit to be realized by irradiating poultry to prevent salmonellosis. It should be noted, however, that by far the most important element in this calculation is also the least certain—the cost of unreported cases.

Irradiation costs

In 1985, the total weight of poultry produced in Scotland was around 91,000 tonnes (19). The cost of irradiating this quantity in a single facility, which in the first year would be around US$ 6.5 million (£5 million—capital costs, £4.24 million; fixed overheads, £366 200; variable operating expenses, £155 100) would fall subsequently to around US$ 650 000 (£500 000) per annum (I. Green, personal communication, 1986). This excludes any additional transport and cold-storage costs incurred as a result of irradiating the poultry. These would be minimized by locating the irradiation plant close to the existing centre of poultry production. The largest single item in both the initial and recurrent outlays is the cost of the cobalt-60 radionuclide source and its replacement.

Combining costs and benefits

In the comparison of costs and benefits both were discounted at 5% over a 15-year period, as a conservative estimate of the life-span of an irradiation plant. We assumed that the benefits and recurrent costs of irradiation do not vary from year to year, though clearly alternative assumptions could be made. At the low projection of the benefits from irradiation, the net present value (benefits minus costs) from the facility is negative (US$ 8.0 million (US$ 6.2 million)). In other words, the irradiation process would incur more costs than it saved by preventing poultry-borne salmonellosis. However, the net present values for the middle (US$ 48.4 million (US$ 50.5 million)) and upper (US$ 138.8 million (US$ 107 1 million)) estimates of the benefits (discounted at 5% over 15 years) exceed costs, and there is an economic case to be made for poultry irradiation on public health grounds.

Discussion

In the study no attempt has been made to quantify all the costs and benefits of irradiation. We have considered only the benefits derived from eliminating poultry-borne salmonellosis, omitting any beneficial effects from the reduction of other pathogens present in the poultry, e.g., campylobacter, and from its increased shelf-life. Furthermore, we have assumed that irradiation produces no adverse effects on the quality and wholesomeness of the product and have ignored any costs associated with achieving consumer acceptance of the process. Nevertheless, the study provides a framework within which the relevant factors can be weighed up by policy-makers.

In Scotland, irradiation of poultry meat is justified on public health grounds, and our findings suggest that it could also be justified for economic reasons. However, this conclusion is sensitive to the assumptions made about the cost of poultry-borne salmonellosis, which indicates that efforts to improve the precision of these estimates would be worthwhile. The main factors that contribute to the wide range of benefit estimates are the absence of a universally accepted methodology for valuing “pain, grief and suffering” and loss of life as well as uncertainty about the number and cost of unreported cases of poultry-borne salmonellosis in Scotland. Further study of the magnitude of these variables would help to refine the results we have reported here.

It is important to recognize that irradiation of poultry meat is not the only means of achieving a reduction in poultry-borne salmonellosis. Alternatives include measures to improve the hygiene practices of producers and consumers and the irradiation of poultry feed. Since we have assumed as the objective the complete eradication of poultry-borne salmonellosis, irradiation of the final product is probably the only practicable means of attaining this. Other measures could produce the same result, if at all, only at exceptionally high cost. There is scope, however, for further economic analysis to assess the optimal degree of prevention and the least costly means of achieving this, both in Scotland and in other countries.

Acknowledgements

We are grateful to David Cohen of the Polytechnic of Wales, Anne Ludbrook and John Henderson of the Health Economics Research Unit, University of Aberdeen as well as referees for comments on earlier drafts of this paper. Thanks are also due to John Deffenbaugh and Ian Green for their assistance. Financial support from the Scottish Home and Health Department is acknowledged.

Footnotes:

- See footnote b, p 753
- See footnote a, p 753
RÉSUMÉ

PRÉVENTION DE LA SALMONELLOSE TRANSMISE PAR LA VIande DE VOLAILLE: COûTS ET AVANTAGES DE L'IRRADIATION EN ECOSSE

En Ecosse, la salmonelle transmise par la viande de volaille est la plus fréquente des toxiques alimentaires dont le mode de transmission est connu. Les coûts sociaux de cette maladie sont importants, mais ils pourraient être considérablement réduits par des mesures préventives. Toutefois, la prévention aussi son propre coût qui doit être inférieur à celui de la salmonelle pour que l'opération soit économiquement justifiée.

L'étude décrite ici visait à évaluer les coûts et avantages d'une méthode de prévention, à savoir l'irradiation de toute la viande de volaille produite en Ecosse. Les avantages ont été évalués en déterminant le coût des cas de salmonelle évités. On n'a pas tenu compte d'avantages supplémentaires tels que la réduction du nombre des autres micro-organismes pathogènes (ex: campylobacter) dans la viande de volaille, ou l'intérêt commercial d'une meilleure conservation de la viande irradiée. Côté dépenses, seul le coût du procédé d'irradiation a été déterminé et il n'a pas été tenu compte du coût d'une éventuelle détérioration des qualités nutritionnelles ou gustatives de la viande irradiée, ni des moyens à mettre en œuvre pour convaincre les consommateurs de la qualité et de la salubrité de la volaille ainsi traitée.

Pour estimer le coût annuel total de la salmonelle transmise par la volaille, on a exploité les données recueillies lors de deux flambées de cette maladie en Ecosse. Il a été tenu compte des coûts des services de santé, des pertes de production dues à la maladie, du pratum d salmonella des victimes et de leurs familles et du coût économique des vires perdues. Lorsque l'ordre de grandeur des variables était incertain, on a procédé à une analyse de sensibilité, afin d'obtenir une gamme de valeurs correspondant à différentes hypothèses. Les avantages estimés ont été comparés au coût d'une installation nationale d'irradiation; pour permettre cette comparaison, les avantages et les coûts ont été actualisés en fonction du temps.

Les résultats montrent que les avantages du point de vue de la santé publique l'emportent sur les coûts de l'irradiation, mais la validité de cette conclusion dépend des hypothèses retenues, notamment en ce qui concerne le coût des cas d'infection non signalés. L'irradiation de la volaille n'est qu'un des moyens de réduire le nombre des cas de salmonelle. D'autres mesures possibles consisteraient à favoriser une meilleure hygiène chez les producteurs et les consommateurs et à irradier les aliments pour la volaille. Il serait utile d'entreprendre des analyses économiques analogues pour examiner le rapport coût/avantages des autres mesures de lutte, tant en Ecosse que dans d'autres pays.

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