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Putting National Institute for Health and Clinical Excellence guidance into practice: A cost minimization model of a national roll-out of liquid based cytology in England

Boyka Stoykova
Brunel University and Wyeth UK

Georgi Kuzmanov
University of Surrey

Robin Dowie
Brunel University

Objectives: In 2003, the National Institute for Health and Clinical Excellence (NICE) advised that liquid based cytology (LBC) should be adopted for cervical screening in England. The aim of this study was to explore the cost implications of implementing the NICE guidance in cytology laboratories. The ThinPrep® technology was used as the case study.
Methods: An optimization model was developed to analyze options for leasing alternative LBC processing machines with different capacities. Variables entered in the model included: the cost of the contract with the supplier, the laboratory labor cost, and inter-laboratory transport costs. All costs referred to the 2005–06 financial year. A simulation program calculated mileages within laboratory networks. Alternative strategies for contracting by laboratories acting independently and by Quality Assessment Regional Centres (QARC) were analyzed.
Results: Centralizing the processing of specimens in "hub and spoke" laboratory networks was the least costly strategy. Total annual costs for England using existing transport links were £14,807,000 for 5-year contracts. If all laboratories installed processors, the annual cost for 5-year contracts placed by QARCs was £14,941,000 compared with £16,359,000 if the laboratories placed their own contracts. Three-year contracts averaged an additional £1 million: £15,912,000 for networks and £17,304,000 for independent laboratory contracts.
Conclusions: Deciding on the mode of implementation of a NICE guidance can be challenging for decision makers. These cost minimization appraisal techniques are equally applicable to national screening programs in general and to other health technologies for which there are significant cost implications associated with innovative policy directives.

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Keywords: Cervical screening, LBC, Cost minimization, Cytology laboratories, Guidelines

Screening for diseases is a specific form of public health service that affects large populations and usually involves a simple and rapid test to identify individuals with a high probability of having a disease at an early stage when there may be no obvious symptom. Further tests may be needed to confirm the diagnosis. Policy makers increasingly demand evidence of the effectiveness, cost effectiveness and feasibility of potential screening strategies. However, economic analyses designed to assess the cost effectiveness of alternative screening strategies are often based on the assumption that the strategy considered to be acceptable by policy makers would be rolled out nationally without much variation in current practice.

In 2003, the National Institute for Health and Clinical Excellence (NICE) (7) advised that the National Health Service Cervical Screening Programmes (NHS CSP) for England and Wales should adopt liquid based cytology (LBC) as the primary means of collecting and processing cervical samples. NICE had concluded, following a comprehensive consultation process, that the LBC method was likely to be cost effective compared with the conventional Papanicolaou (Pap) method despite its higher associated costs. The LBC guidance was accompanied by an Advice to the Service statement (3) that suggested 5 years as the time needed to complete the implementation process nationally. Thus, it would take a few years for the new technology to be rolled out in the local CSPs.

Each new guidance from NICE typically is associated with additional expenditure, thus the UK Government's Secretary of State for Health requires that the NHS in England should provide funding and resources for the recommended treatment within 3 months of the publication date, although extensions may be granted on advice by NICE (2). Decision makers responsible for implementation can benefit from generic and guidance-specific implementation tools available at the Institute's Web site http://www.nice.org.uk/. However, the Audit Commission observed in 2005 that "NHS bodies do not routinely identify costs and savings associated with guidance, or do not use robust costing methodologies, making it more difficult to assess financial impact and affordability" (1).

Cervical samples are processed and screened in cytology laboratories that form part of the pathology services provided by NHS acute hospital trusts. The purpose of this study, therefore, is to explore what the impact could be on laboratory configurations when rolling out the NICE guidance on LBC under a range of "efficiency" assumptions. A cost minimization analysis was carried out to identify the most efficient decisions within the context of the national CSP in England. ThinPrep® is the LBC technology used as the case study in the model.

METHODS

The Setting: The NHS Cervical Screening Programme

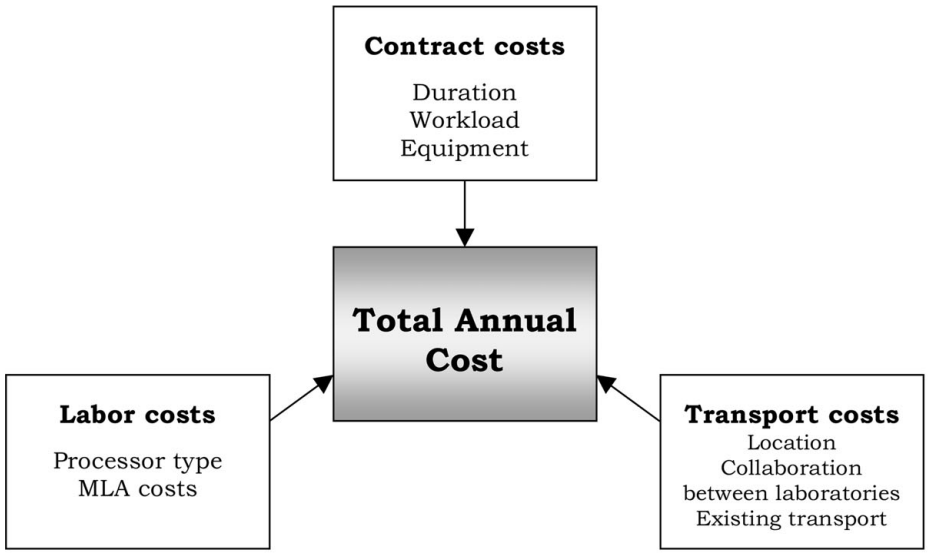
The national NHS CSP for England is coordinated through a system of regional Quality Assurance Reference Centres (QARC). In addition to quality assurance, QARCs advise on the implementation of cervical screening policies based on the guidance from the NHS CSP and professional bodies (8). The QARC regional boundaries are co-terminus with the boundaries of the Strategic Health Authorities, and the QARC regions are geographically divided into subregions, ranging between two and five in number. Cytology laboratories are normally sited within the pathology departments of district general hospitals or teaching hospitals located in cities and towns across the regions. Over the years, the laboratories have independently dealt with the workload of cervical samples collected from the local population, and contracting for equipment and supplies has been undertaken by their respective NHS trust.

There were nine QARCs (see Supplementary Figure 1, which can be viewed online at www.journals.cambridge.org/thc) with twenty-eight subregions and a total of 139 cytology laboratories in England with a total workload of 4,022,269 slides in 2004–05 (9). Laboratories varied in size and the number of slides screened. Two laboratories screened 80,000 slides or more, while 117 (84 percent) had a workload of 40,000 slides or less.

The LBC Technology

Liquid based cytology involves a complex slide preparation technique. Cellular material obtained from the cervix of a woman using a spatula/collection device is placed in a vial with preservative fluid to generate a suspension of cells, and the vial is sent to a laboratory. A sample of the suspension is extracted from the vial and placed in an automated processor machine which deposits a thin layer of cells on a slide. The cells are then stained ready for the slide to be examined. The LBC processing technique is believed to be better than the technique for processing conventional Pap smears, because it produces a more representative sample of cells from a cervical specimen and reduces contamination by blood cells, pus and mucus (7).

Two alternative LBC technologies were evaluated in a pilot study (6) that informed the NICE guidance: SurePath® and ThinPrep®. However, NICE concluded that there was insufficient comparative evidence available from the pilot study or from other sources to recommend one LBC process over the other. ThinPrep® was selected for this case study because it was the technology being used in Manchester for a large-scale randomized controlled trial evaluating the



Objective of the optimization:

$$\text{Minimize: } C = \sum_{j=1}^{n} (C_j + L_j + T_j)$$

$$\text{Subject to: } 40{,}000 * X_j + 60{,}000 * Y_j \geq W_j$$

Model parameters:

n = Number of contracts
X = Number of T2000 machines
Y = Number of T3000 machines
W = Yearly workload
C = Total annual costs
C_j = Total cost of contract (including value added tax)
L_j = Labor costs
T_j = Transport costs

Figure 1. Optimization model: diagram and mathematical model.

role of human papillomavirus testing in cervical screening (the ARTISTIC trial) (4). Cytyc Corporation manufactures two types of ThinPrep® machines for processing cervical specimens and producing slides: the T2000 machine and the T3000 machine. The optimum capacity per year for a T2000 is 40,000 samples, and for a T3000, around 60,000 samples. In addition, the T2000 is less automated, thus, more labor intensive than the T3000. It can also be used as a backup machine to the T3000 if necessary. Activities associated with the processing machines are normally performed by medical laboratory assistants (MLAs). One full time equivalent (FTE) MLA is required to man a T2000 processor daily, while the automated T3000 requires approximately 0.2 FTE of an MLA (See Table 1).

The Model

An optimization model was developed to assess the financial impact of decisions over LBC implementation in England and to identify an optimal strategy (5). Refer to Figure 1 for a graphical and mathematical definition of the model. The model incorporated costs that were directly dependent on decisions as to how the LBC guidance might be implemented. Thus, the total annual cost in the model comprises: the cost of the contract with the supplier of the processing machines, the laboratory labor cost for the processing activities, and transport costs that may be relevant should laboratories collaborate in the use of LBC processors. Costs that would be incurred irrespective of the terms of the contract with the supplier were not considered, for example the

Table 1. Model Inputs and Sources

Model inputs	Value(s)	Source
Contract costs	In confidence	Agreements with supplier
Labor costs (MLA):		
• Annual salary	£15,446	Agenda for Change[a]
• National Insurance	12.8%	NI Contributions[b]
• Pension Scheme	14%	NHS Pension Scheme[c]
Optimal processor capacity (slides per year)		
• T2000	40,000 slides	Agreements with supplier
• T3000	60,000 slides	
MLA staff (full-time equivalent)		
• T2000	1 FTE	Assumption based on product description and interviews with cytology laboratory staff
• T3000	0.2 FTE	
Workload of laboratories	various	National statistics for 2004–05 (9)
Distances between laboratories in each QARC	various	Multimap.com based on postcodes from www.nhs.uk
Frequency of transport services between laboratories per year	24 – 100 return journeys	Assumption
Cost of transport (£/mile)	£0.20 – £0.80	Assumption

[a]NHS Employers. Agenda for Change: NHS terms and conditions of service handbook. January 2005. Available at: http://www.nhsemployers.org/; Accessed 30 January 2007.
[b]National Insurance Contributions: http://www.hmrc.gov.uk/nic/.
[c]NHS Pension Scheme: http://www.nhspa.gov.uk.
MLA, medical laboratory assistant; FTE, full time equivalent; NI, national insurance.

cost of taking a smear, or staining of the slides and screening by cytoscreeners.

The model assumed that contracting decisions were made either by QARCs and applied to single laboratories or to "hub and spoke" networks of laboratories in their subregions, or else by laboratories acting independently. We modeled the cost of leasing rather than purchasing the processors as that was the preferred type of contract at the time of the analysis.

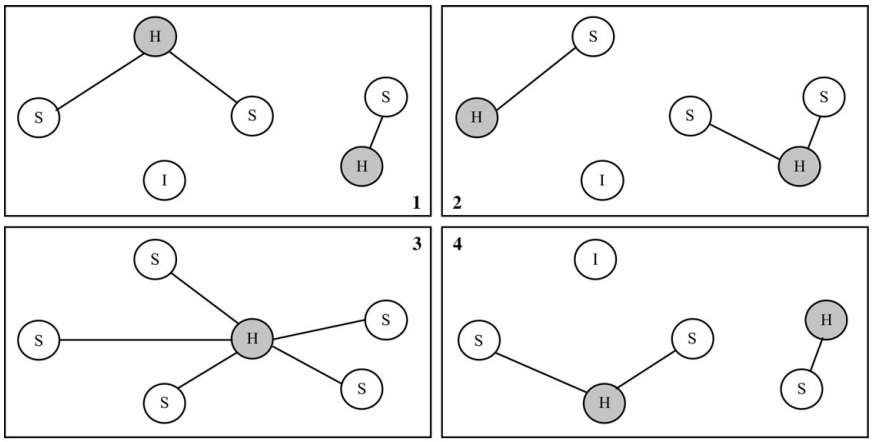
In a network, local laboratories would receive LBC vials from general practices and clinics and transfer them to a central laboratory for processing. They would then be sent the prepared slides for screening. QARCs would decide on the number of processors to be leased and their type (T2000 and/or T3000), their location (the hub laboratories), and the laboratories they would serve (the spokes). Individual laboratories, in contrast, needed only to choose the type of processor(s) to install and the duration of the contract. We assumed that the availability of a labor force of MLAs to operate the equipment was not a constraint. Transport costs covered costs of spoke-to-hub transport of vials for processing, and hub-to-spoke transport of prepared slides.

The cost of a contract negotiated with the supplier was a function of (i) the duration of the contract, (ii) the number of T2000 processors (X), (iii) the number of T3000 processors (Y), and (iv) the yearly workload (W). Contracts also covered other services, such as the installation and maintenance of processors, and operator training.

The inputs to the model are summarized in Table 1. Labor costs borne by the NHS consisted of the employees' annual salaries, the national insurance payments and contributions to the NHS Pension Scheme. All reported costs refer to the 2005–06 financial year.

Microsoft® Office Excel 2003 was used to calculate the contract and labor costs for a range of options with various numbers of T2000 and/or T3000 processors. Transport costs were calculated as the product of the distances between laboratories identified as hubs and their spokes and a fixed mileage rate. The frequencies of return journeys between laboratories were varied from twice monthly to twice weekly.

To calculate mileages within laboratory networks, the laboratories in each subregion of each QARC were partitioned into nonoverlapping subsets such that each laboratory was a member of one subset only (see Figure 2). The simulation software for the model was a Perl script that considered a brute force enumeration (10): a technique that systematically enumerated all possible ways of partitioning each QARC subregion and checked whether each candidate partition satisfied the inclusion criterion. Partitions were rejected if they contained a subset with a total laboratory workload below 15,000 slides per year (the lower threshold capacity of a standalone T2000 processor). It computed the transport distances between the hub and the spoke(s) for each subset comprising the partition. If there were three or more laboratories in a subset the hub was selected according to the shortest distances between the laboratories. The enumeration of all partitions of a set was done using the algorithm implemented by the Algorithm::Combinatorics CPAN module. The input CSV files were read using the Text::CSV_XS



Abbreviations: H – hub laboratory; S – spoke laboratory; I – individual laboratory.

Figure 2. Four example partitions in a subregion with six laboratories. H, hub laboratory; S, spoke laboratory; I individual laboratory.

CPAN module. Further details about the simulation are available from the authors.

RESULTS

The simulation model identified 28,394 partitions complying with the constraints of the model. Sixty percent of the partitions were in the Surrey and Sussex subregion (in the South East QARC) where there are nine cytology laboratories. The subregions of Cheshire and Merseyside (in the North West QARC), and Birmingham and the Black Country (in the West Midlands QARC) had eight laboratories each and they accounted for another 29 percent of the partitions. The remaining 11 percent of the partitions were spread across twenty-five subregions, five of which had 4 partitions and the other twenty had between 10 and 4,139 partitions.

In the context of the national NHS CSP for England, we explored alternative strategies for contracting LBC technologies at regional (QARC) and laboratory levels according to different road transport arrangements. We varied the main parameters of the model that determined the contract cost: duration of contract (3 or 5 years), number of T2000 processors, and number of T3000 processors, given the reported national workload of slides in 2004–05 (9). Labor costs were adjusted according to the type of processor and workload. The alternative transport arrangements were: continuation of current practice (hospital vans running between laboratories) with no additional costs, or new road transport links with additional costs.

Model Outputs with No Transport Costs (Table 2)

Option 1: QARC-Placed Contracts on Behalf of Single Laboratories. Independent laboratories could benefit from the discounts of contracts signed at a QARC level to acquire their own processors to prepare LBC slides on site. The lowest total annual cost of this option would be £14,941,000 if contracts were signed for 5 years, and £15,886,000 for the shorter 3-year contract. Because four-fifths of laboratories in England process fewer than 40,000 slides annually, the total number of processors needed would be ten T3000s and 181 T2000s (including backup machines for the T3000s). On average, the 191 processors would be used at 51 percent of their capacity and MLA labor costs would be based on eighty-eight FTEs.

If there were insufficient MLAs to staff the various processors, the least labor intensive arrangement would be the installation of a T3000 processor in each laboratory as well as a T2000 back up machine—adding another £1,503,000 and £1,976,000 to the 5-year and 3-year costs, respectively. The used capacity of the processors would now be 29 percent, but the labor needed would be reduced to fourteen FTEs.

Option 2: Single Laboratory-Placed Contracts. This option assumes that contracts were signed individually by laboratories (or their NHS trusts) thus contract costs in the model differed from Option 1 and were set by the supplier. The total annual cost would be £16,359,000 and £17,304,000 according to contract duration. If every laboratory used a T3000 processor backed up by a T2000, an extra £1.5 million per year would be needed for both 5-year and 3-year contracts.

Option 3: QARC-Placed Contracts on Behalf of Laboratory Networks, Base Case. This scenario assumes there are hub-and-spoke(s) networks in subregions and in the base-case they rely upon existing transport links between laboratories. The total annual cost of contracts for each QARC would be £14,807,000 for 5 years, and £15,912,000 for 3 years. These costs would cover sixty-three T3000 and

Table 2. Model Strategies

Laboratory configuration	Duration of contract (years)	T3000 only	Total annual cost (£ '000)	Number of T3000	Number of T2000	Labor (FTE)
Option 1: QARC-placed contracts on behalf of single laboratories						
139 laboratories	5		14,941	10	181	88
139 laboratories	3		15,886	10	181	88
139 laboratories	5	√	16,444	140	140	14
139 laboratories	3	√	17,862	140	140	14
Option 2: Single laboratory-placed contracts						
139 laboratories	5		16,359	10	181	88
139 laboratories	3		17,304	10	181	88
139 laboratories	5	√	17,862	140	140	14
139 laboratories	3	√	18,808	140	140	14
Option 3: QARC-placed contracts on behalf of laboratory networks, base case with no additional transport costs						
28 hub-and-spoke networks	5		14,807	63	75	19
28 hub-and-spoke networks	5	√	14,890	71	71	13.5
28 hub-and-spoke networks	3		15,912	63	75	19
28 hub-and-spoke networks	3	√	16,131	71	71	13.5
	Distance (miles)	Transport costs (£)	Total annual cost (£'000)	Number of T3000	Number of T2000	Labor (FTE)
Option 3: QARC-placed contracts on behalf of laboratory networks – scenarios with additional transport costs						
28 hubs / 111 spokes (5 yr)	2540	101,600	14,907	63	75	19
28 hubs / 111 spokes (3 yr)	2540	101,600	16,014	63	75	19
28 hubs / 111 spokes (5 yr, T3000 only)	2540	101,600	14,992	71	71	13.5
28 hubs / 28 spokes / 83 singles (5 yr)	412	16,480	15,009	14	124	83
40 hubs / 96 spokes / 3 singles (5 yr)	2623	104,920	14,957	45	112	42

Note. Transport costs are based on 50 round journeys per annum at £0.40 per mile.
√ Indicates that each processing laboratory would be equipped with a T3000 machine.

seventy-five T2000 processors staffed by nineteen FTEs, and operating at almost 60 percent of their capacity. If all hub laboratories installed T3000 and T2000 processors, that would add a further £83,000 or £219,000 to the costs for the respective contract periods.

The lowest total processing cost per slide would be £3.68 for all QARCs. However, its two components—"contract cost per slide" and "labor costs"—would vary across QARCs depending on workload and type of equipment (see also Supplementary Figure 1, which can be viewed online at www.journals.cambridge.org/thc). The usage of the machines would remain the same.

The Role of Transport Costs (Table 2)

This variation of Option 3 incorporates hypothetical transport costs and demonstrates how they could be contained if networks optimized the mileage between hub and spoke laboratories and the annual frequency of return journeys.

If, for each subregion in England, the laboratories were organized in a single network, there would be twenty-eight hub-and-spoke configurations with a total distance between spokes and hubs of 2,540 miles (ranging between 16 miles for the South West London subregion, to 330 miles for the Norfolk, Suffolk & Cambridgeshire subregion in the East QARC). The specimens from 111 laboratories (spokes) would be transported to twenty-eight hubs for processing and slides returned for (staining and) reading, thus approximately 83 percent of all vials and slides would be conveyed every year. The overall contract and labor cost per slide for all QARCs would be the lowest available (as described in the base case option 3), but transport costs need to be factored in the total annual cost. Assuming fifty round journeys per year per spoke at £0.40 per mile, the estimated transport cost would be approximately £101,600 and the total annual cost would increase to £14, 907,000 (see Table 2).

The concentration of vial processing in twenty-eight hubs in England would mean that T3000 processors could be used more efficiently (economies of scale). Seventy-one T3000 processors and a similar number of T2000 back up machines would be needed, increasing the total costs by £83,000. The more automated T3000s could be operated at nearly 100 percent of capacity by MLAs, whose total time spent on these activities would be equivalent to 13.5 FTEs.

In the simulation model some partitions had total hub-and-spoke distances that were shorter than in the scenario described above and hence had lower expected transport costs. The partitions with the shortest distances in each subregion had a total mileage of 412 miles (equivalent to approximately £16,500 per year), so under this twenty-eight-hub scenario (see Table 2), fourteen instead of sixty-three T3000s would be needed, because eighty-three laboratories would process their own slides. As a result, the total annual cost would be £15,009,000. The total annual cost of the scenario with the longest possible distance (2,623 miles) was similar at £14,957,000. It incorporated forty hubs each with two or three spokes and only three single laboratories.

DISCUSSION

In this study, we explored the impact of a new slide preparation technology on the cervical screening program in England. LBC differs from the conventional technology by using equipment with processing capacities that far exceeded the individual workloads of the majority of cytology laboratories in 2004–05. We carried out an optimization modeling exercise to assess the potential variations in costs related to the NICE guidance on the implementation of LBC. The results suggest that to achieve an efficient use of resources requires careful planning of equipment leasing policies from an early stage, which will pay off in the long-run. Total annual costs ranged between £14,807,000 and £18,808,000, thus up to £4 million per year could be saved if a robust cost methodology were used to support the decision-making process.

Contracts placed by QARCs are more economical than contracts negotiated by laboratories. If laboratories independently processed their slides, a QARC-based contract would save £0.5 million a year, although such an arrangement would result in the more labor intensive T2000 processors being used and more staff used as MLAs to reach the target of eighty-eight FTEs needed. Laboratories within close proximity might decide to collaborate in the use of the bigger T3000 processors. The logistics of such operational collaborations may seem complex, but the real complexity is in the identification and costing of all possible laboratory configurations within a geographical area followed by the selection of the most efficient installation option. In the simulation to identify optimal transportation linkages, five of the twenty-eight subregions had only four partitions, but the model identified more than 17,000 possible configurations in the Surrey and Sussex subregion where there were nine laboratories. The partitions in the remaining subregions ranged from dozens to thousands, thus the use of suitable software programs to model viable permutations would be inevitable. NICE could provide such a tool to support local decision making.

The centralization of cervical sample processing in twenty-eight or more hubs is the most efficient way of organizing services in the English NHS CSP. However, transport logistics and associated journey costs should be taken into account. Transport costs could be contained by using existing road transport arrangements between laboratories and choosing configurations that optimize journey distances. Locally, there may be other factors that would determine transport decisions. We reported the costs of several scenarios which demonstrated that being a spoke (or a hub) laboratory can be less costly than working independently even when transport costs are factored in the total annual cost. Moreover, for some QARC regions there were several contract options that attracted the lowest cost per slide. Four QARCs—East, North West, South East and London—had two contract options each attracting the lowest cost per slide, but at a national level the second of the two options would have resulted in fewer T3000 processors (sixty-one), more T2000s (seventy-seven) and greater labor costs—twenty-two FTEs. In regions where it is difficult to recruit MLAs the equipment selection may favor greater automation. However, because of the physical size of the T3000 processor, a lack of available space for installing the machine in a small laboratory may be a constraint.

Our model could not reflect all available options and all the complexities of the real world. We used one LBC technology, ThinPrep®, as a case study, but there are other technologies on the market. The benefits from decision modeling of implementation options at a regional level may be even greater for other brands of LBC processors with larger capacities than the two types of ThinPrep® processors. Although the model focused on lease options, a purchase option is also available and the methodology for the corresponding cost minimization analysis would be similar. Another limitation to the model was that simulations were run at subregional level, but QARCs may wish to explore options for laboratory networks that are not confined specifically to subregions.

What have we learned? Our findings suggest that decision makers in the national NHS CSP, particularly in the regional QARCs, would benefit from having access to dedicated implementation tools both when introducing LBC in the national screening program and later when equipment contracts have to be renewed. Otherwise, the Audit Commission may re-iterate its criticism about service inefficiencies when putting NICE guidance into practice. The appraisal techniques described here are equally applicable to national screening programs in general, and to other health technologies for which there are significant cost implications associated with innovative policy directives.

CONCLUSION

With the introduction of LBC in the NHS CSP, the screening for cervical cancer in England has the potential to offer enhanced benefits to the population of women. Responsibility

for the efficient use of NHS resources during the rolling out of the new technology is in the hands of policy makers in regional QARCs and local CSPs, and they deserve to receive decision analytical assistance with this task. Other countries considering the wider use of LBC in their national screening programs may face similar challenges in identifying the most efficient model of service delivery.

CONTACT INFORMATION

Boyka Stoykova, MD MSc (boyka.stoykova@brunel.ac.uk), Health Economics Research Group, Brunel University, Kingston Lane, Uxbridge UB8 3PH, UK; Health Economist, Department of Health Outcomes, Wyeth UK, Huntercombe Lane South, Taplow SL6 0PH, UK
Georgi Kuzmanov, BA (georgi_kuzmanov@yahoo.co.uk), Senior Software Administrator, School Computing Services, University of Surrey, Guildford GU2 7XH, UK
Robin Dowie, PhD (robin.dowie@brunel.ac.uk), Senior Research Fellow, Health Economics Research Group, Brunel University, Uxbridge, Middlesex, UB8 3PH, UK

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