Original article

Cost-effectiveness of the National Health Service abdominal aortic aneurysm screening programme in England

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Background: Implementation of the National Health Service abdominal aortic aneurysm (AAA) screening programme (NAAASP) for men aged 65 years began in England in 2009. An important element of the evidence base supporting its introduction was the economic modelling of the long-term cost-effectiveness of screening, which was based mainly on 4-year follow-up data from the Multicentre Aneurysm Screening Study (MASS) randomized trial. Concern has been expressed about whether this conclusion of cost-effectiveness still holds, given the early performance parameters, particularly the lower prevalence of AAA observed in NAAASP.

Methods: The existing published model was adjusted and updated to reflect the current best evidence. It was recalibrated to mirror the 10-year follow-up data from MASS; the main cost parameters were re-estimated to reflect current practice; and more robust estimates of AAA growth and rupture rates from recent meta-analyses were incorporated, as were key parameters as observed in NAAASP (attendance rates, AAA prevalence and size distributions).

Results: The revised and updated model produced estimates of the long-term incremental cost-effectiveness of £5758 (95 per cent confidence interval £4285 to £7410) per life-year gained, or £7370 (£5467 to £9443) per quality-adjusted life-year (QALY) gained.

Conclusion: Although the updated parameters, particularly the increased costs and lower AAA prevalence, have increased the cost per QALY, the latest modelling provides evidence that AAA screening as now being implemented in England is still highly cost-effective.

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Introduction

The UK Multicentre Aneurysm Screening Study (MASS) investigated the effects of offering population screening for abdominal aortic aneurysm (AAA) to men aged 65–74 years. The results of this randomized trial[1], first reported at 4 years of follow-up in 2002, demonstrated that invitation to a one-time ultrasound screen and follow-up of identified aneurysms was effective in reducing AAA-related mortality. This clinical finding has been confirmed by longer-term follow-up from MASS[2–4], and reinforced by systematic reviews[5,6] of evidence including other relevant trials. Based on the initial MASS results it was evident that screening in the context of the UK was likely to be cost-effective in the long-term[7]. This expectation was confirmed by a formal model that extrapolated from the 4-year follow-up data to estimate the long-term incremental cost per quality-adjusted life-year (QALY) for a screening programme of 65-year-old men, using the same screening methods and rescanning intervals for detected aneurysms as in MASS[8]. This estimated the incremental cost per QALY gained for those invited to screening compared with those not invited as £2970 (95 per cent uncertainty interval £2030 to £5430).

In the light of this clinical and cost-effectiveness evidence, and a positive review of all its criteria for a new screening programme, the UK National Screening Committee recommended that a National Health Service (NHS) AAA screening programme (NAAASP) be introduced. Phased implementation began in March 2009 with the aim to cover the whole of England by March 2013[9,10]. Implementation is also under way in Wales, Scotland and Northern Ireland.

Early information from the NAAASP is now available, and it has been noted particularly that the prevalence of AAA at screening is considerably lower than that found in MASS (1·5 per cent compared with 4·9 per cent for MASS)[1,10]. This paper re-estimates the cost-effectiveness of AAA screening as operationalized in England using the most up-to-date available data. The changes to the model reflect: a recalibration to take account of the 10-year follow-up of MASS, using individual patient data; incorporation of updated cost parameters reflecting the current costs of screening, rescans and procedures, including allowance for the introduction of elective endovascular aneurysm repair (EVAR); the use of more robust estimates of AAA growth and rupture rates based on recent meta-analyses[11,12] of individual patient data; and key parameters observed in NAAASP to date (attendance rates, AAA prevalence and aortic size distribution).

Methods

Original model

This re-estimation of the long-term cost-effectiveness of offering AAA screening used the cost-effectiveness model reported in 2007[8]. The underlying Markov model structure is shown in *Fig. 1* and remained unchanged in this reanalysis. The two populations (those invited to AAA screening and those not invited) are modelled using 3-month cycles; each arrow in *Fig. 1* represents a possible transition. The original model incorporated information from a range of sources to chart the detection, growth and treatment of AAAs over time for these populations, using the 4-year follow-up data from MASS as its prime source. It allowed estimation of 30-year costs and benefits of a programme offering a one-off screen to men aged 65 years with repeat scanning annually for aneurysms with a diameter of 3·0–4·4 cm (small AAA) and every 3 months for those with a diameter of 4·5–5·4 cm (medium AAA). Men with aneurysms over 5·4 cm (large AAA) would be referred for consideration for elective surgery. The model adopted an NHS perspective of costs.

Revalidation and recalibration

The original model had been validated against the 4-year MASS data and shown to perform satisfactorily[13]. Using the longer 10-year follow-up data reported for MASS[3], a revalidation exercise was undertaken to assess how well the model predicted the longer-term observed data and to inform recalibration where necessary. Numbers of key events and cost-effectiveness (at 2008–2009 prices)

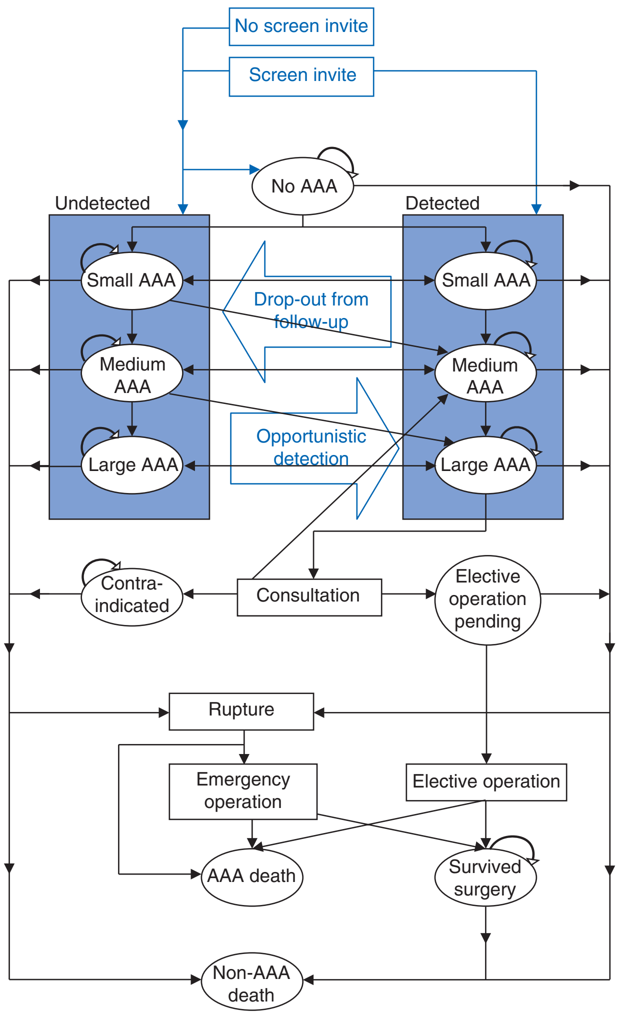

Fig. 1 Markov model structure. AAA, abdominal aortic aneurysm. Reproduced from Kim *et al*.[8], with permission from *Journal of Medical Screening*

observed in the trial were compared with results from the model.

To account for any emerging time trends in observed parameters, regression methods were used to derive time-dependent transition probabilities. Based on MASS, 10-year data probabilities were estimated for each 3-monthly cycle, determining transitions between states in the model. Recalibrations of parameter estimates for the rate of opportunistic detection and the rupture rate in large undetected AAAs were also carried out. These parameters cannot be estimated directly from MASS data; hence estimates were chosen to fit the observed data, with a focus on calibration to reflect best the incremental cost-effectiveness ratio (ICER) at 10 years based on observed follow-up. Rates were adjusted to minimize disparity in

Table 1 Unit costs: original estimates from the Multicentre Aneurysm Screening Study, costs inflated to 2010–2011 prices, re-estimated unit costs, cost distributions applied in probabilistic sensitivity analysis, and source

Cost component	Original cost 2000–2001 (£)	MASS cost inflated to 2010–2011 (£)	Re-estimated unit cost (£)	Distribution*	Source
Invitation to screen	1·31	1·84	1·70	Normal(1·7, 0·17)†	NAAASP
Cost of first scan	19·08	26·80	32·20	Normal(32·2, 3·22)†	NAAASP
Surveillance scan	46·04	64·67	68·00	Normal(68·0, 6·80)†	NAAASP
Presurgical assessment	309·88	435·25	435·25	Normal(435·25, 87·05)‡	MASS
Elective repair	6909·00	9704·24	12 806·21	Normal(12 806, 2561)‡	Thompson *et al.*[14]
Emergency repair	11 176·00	15 697·59	19 984·75	Normal(19 985, 3996)‡	Thompson *et al.*[14]

*Normal(μ, σ); standard deviation (σ) †10 per cent and ‡20 per cent of point estimate. MASS, Multicentre Aneurysm Screening Study; NAAASP, National Health Service abdominal aortic aneurysm screening programme.

the modelled and observed differences between arms in key events. A previously published *Health Technology Assessment* monograph[14] deals with this process more comprehensively.

Re-estimation of unit costs

Following the model calibration, input parameters were updated to reflect contemporary costs. The unit cost estimates used in the original modelling related to the costs of screening as undertaken in MASS, and to contemporaneous estimates of the costs of elective and emergency procedures[7]. They were originally estimated at 2000–2001 prices, and in subsequent analyses were simply uplifted to account for general health service inflation. In this updated analysis, costs have been re-estimated and are presented at 2010–2011 price levels. Unit cost data for the screening itself were obtained from NAAASP[14]. Data from MASS[7], the EVAR-1 trial[15] and the National Vascular Database[16] were used to re-estimate the cost of surgical procedures. *Table 1* shows the original aneurysm repair costs, together with the updated unit costs. A fuller account of this re-estimation has been published elsewhere[14].

Clinical data

The majority of probabilistic parameters that determine transitions between states in the Markov model have been updated using the 10-year follow-up data from MASS[3] (*Table 2*). The postcalibration model was also updated to reflect available data from the current NAAASP. Data for attendance rates at screening (75 per cent *versus* 80 per cent in MASS), AAA prevalence (1·5 per cent *versus* 4·9 per cent in MASS) and the size distribution of aneurysms at initial screening (similar in NAAASP and MASS)[10] were incorporated (*Table 2*). Sensitivity analysis around the 30-day surgical mortality rate was also conducted. The mortality rate after elective intervention for a screen-detected AAA observed in the NAAASP was lower (1·6 per cent *versus* 3·0 per cent in MASS), but based on few deaths, so it was deemed inappropriate to use it in the base case. Given the trend of an observed fall in the prevalence rate, a threshold analysis was also conducted to estimate the rate at which the modelling suggests the ICER would rise above £20 000 per QALY.

Growth and rupture rate estimates

The postcalibration model also included improved estimates of aneurysm growth and rupture rates which were derived from the meta-analyses of individual patient data from 18 longitudinal studies of AAA screening surveillance programmes, undertaken as part of the RESCAN Collaboration[11]. The statistical methods used in these meta-analyses have been described elsewhere[11,19], as has their incorporation into the modelling[14].

Implementation of the model

As before, the model was implemented in Microsoft® Excel (Microsoft, San Diego, California, USA), and a 30-year time horizon was adopted (essentially constituting a lifetime for the 65-year-old men considered). Long-term cost and life-years accrued in populations invited to, and not invited to, screening are the outcomes of interest, both discounted at 3·5 per cent per annum. As in previous versions of the modelling, QALYs are estimated by adjusting life-year estimates by EQ-5D™ (EuroQol Group, Rotterdam, The Netherlands) utility values for UK-relevant population age norms[20]. No further adjustment was made, based on the lack of differences in quality of life of those with an AAA[1]. Age-specific death rates from causes other than AAA were taken from UK national statistics[18].

The results are presented as an ICER of invitation to the screening programme compared with no invitation to screening. Probabilistic sensitivity analysis was undertaken

Table 2 Clinical parameters: point estimate used in the model, distribution applied in probabilistic sensitivity analysis, and source

	Estimate	Distribution*	Source
Proportion reinvited to screening	0·1360	Beta(4602, 29 237)	MASS
Prevalence of AAA at first screen			
Attenders	0·0151	Beta(1619, 105 432)	NAAASP
Non-attenders	0·0151	Beta(1619, 105 432)	NAAASP
Non-visualized AAA	0·0151	Beta(1619, 105 432)	NAAASP
Proportion of scans non-visualized	0·0121	Beta(329, 26 818)	MASS
Proportion of screen-invited attending	0·750	Beta(93 170, 31 022)	NAAASP
Proportion of small AAAs at first screen	0·789	Dirichlet(1278, 193, 148)	NAAASP
Proportion of medium AAAs at first screen	0·119		NAAASP
Proportion of large AAAs at first screen	0·091		NAAASP
Transition probabilities (3-monthly)			
Grow from no AAA to small AAA	0·00207	Gamma(27, 7·66 $\times$ 10^{-5})	Scott *et al.*[17]
Grow from small to medium AAA	TDTP‡	Multiplier ~ Normal(1, 0·1)	RESCAN
Grow from medium to large AAA	TDTP§		RESCAN
Probability of drop-out from surveillance	0·0142	Gamma(330, 4·34 $\times$ 10^{-5})	MASS
Rupture			
No AAA	0	n.a.	Assumption
Small AAA	TDTP¶	Multiplier ~ Normal(1, 0·35)	RESCAN
Medium AAA	TDTP#		RESCAN
Detected large AAA	0·0125	Gamma(23, 0·00055)	MASS
Undetected large AAA†	0·0282	n.a.	Calibrated
Contraindicated for surgery	0·0282	Gamma(19, 0·0015)	MASS
Opportunistic detection	0·0114	n.a.	Calibrated
Emergency surgery after rupture	0·368	Beta(193, 331)	MASS
Death after emergency surgery	0·342	Beta(66, 127)	MASS
Proportion of large AAAs having surgery	0·681	Dirichlet(481, 156, 69)	MASS
Proportion of large AAAs returned to screening	0·221		MASS
Proportion of large AAAs contraindicated for elective surgery	0·0977		MASS
Death after elective surgery			
Screen-detected AAA	0·0298	Beta(15, 503)	MASS
Opportunistically detected AAA	0·0717	Beta(18, 251)	MASS
All-cause mortality			
Contraindicated for surgery	0·0599	Gamma(41, 0·0015)	MASS
Age-specific	Age-specific	n.a.	Office for National Statistics[18]

*Beta(α, β); Gamma(α, β); Dirichlet($\alpha_1 \ldots \alpha_k$); Normal(μ, σ). †Cannot be observed directly; value chosen during recalibration exercise. ‡Mean 0·016; §mean 0·077; ¶mean 0·00076; #mean 0·0064. MASS, Multicentre Aneurysm Screening Study; AAA, abdominal aortic aneurysm; NAAASP, National Health Service abdominal aortic aneurysm screening programme; TDTP, time-dependent transition probability; RESCAN, RESCAN Collaboration; n.a., not available.

to allow for parameter uncertainty, providing 1000 simulated ICER values. The distributions used for the uncertainty around the point estimate of each variable are detailed in *Tables 1* and *2*. For the updated time-dependent growth and rupture rates, a normally distributed multiplier (with mean 1 and based on a conservative approximation of the standard deviation from the mean of the pooled rates) was defined and sampled from, in order to increase or decrease all growth or rupture rates over time by a constant factor.

Results

The revalidation process showed that the original model did not perform particularly well in predicting the observed MASS 10-year data. There were a number of discrepancies that together led to a substantial difference in the estimate of the 10-year ICER (*Table 3*). Recalibration attempted to minimize the discrepancy in the estimated ICER. The recalibrated model predicted a 10-year ICER of £8900, compared with an ICER based on the 10-year observed data of £7600 per life-year.

The updated 2010–2011 costs for screening and rescans were considerably higher than the 2000–2001 figures originally derived from MASS (*Table 1*). Although this increase reflects general health service inflation, most of these specific costs have increased more rapidly. For example, the cost of elective repair now reflects the proportion of cases in which EVAR is used, leading to a cost that was 32 per cent higher than the inflated value

Table 3 Abdominal aortic aneurysm screening model: validation and recalibration of results using original cost estimates inflated to 2008–2009 prices for consistency

	Observed in MASS*	Original model†	Model after recalibration to MASS 10-year follow-up data‡
Control group			
Elective operations	226	256	213
Emergency operations	141	140	168
AAA deaths	296	305	385
Non-AAA deaths	10 185	10 139	10 148
Life-years (mean)	7·509	7·291	7·282
Mean cost (£)	108	118	124
Invited group			
Elective operations	552	607	539
Emergency operations	62	88	97
AAA deaths	155	202	248
Non-AAA deaths	10 119	10 185	10 189
Mean life-years	7·523	7·297	7·293
Mean cost (£)	208	233	225
Difference between arms			
Elective operations	326	351	326
Emergency operations	−79	−52	−71
AAA deaths	−141	−103	−137
Non-AAA deaths	−66	46	41
Mean difference in life-years	0·013	0·006	0·011
Mean difference in cost (£)	100	115	101
ICER (£)			
Life-years	7600	18 000	8900
QALYs	9700	23 000	11 400

*Key events and cost-effectiveness observed in Multicentre Aneurysm Screening Study (MASS) at 10-year follow-up. †Key events and cost-effectiveness results of modelling, using time-constant parameter estimates from MASS 10-year follow-up. ‡Key events and cost-effectiveness results of modelling, with time-dependent parameter estimates from MASS 10-year follow-up and after recalibration exercise. AAA, abdominal aortic aneurysm; ICER, incremental cost-effectiveness ratio; QALY, quality-adjusted life-year (adjusted using population norms).

of the original estimate. The estimate for an emergency repair was also 27 per cent higher.

The new estimates of life-years, costs and cost-effectiveness results, over a 30-year time horizon, for an AAA screening programme are shown in *Table 4*. The ICER is now £5758 (95 per cent confidence interval £4285 to £7410) per life-year gained and £7370 (£5467 to £9443) per QALY gained.

When presented on the cost-effectiveness plane (*Fig. 2*), the 1000 iterations of the probabilistic sensitivity analysis show that, in all cases, the intervention provides additional QALYs but costs more. The figure demonstrates the low level of remaining uncertainty and that all estimates fall below the £20 000 threshold, as used by the National Institute for Health and Care Excellence (NICE)[21]. Furthermore, for any threshold value of a QALY over

Table 4 Abdominal aortic aneurysm screening model: 30-year cost-effectiveness results at 2010–2011 prices for the current National Health Service abdominal aortic aneurysm screening programme

	Control group	Invited group	Difference
Life-years†	12·719	12·727	0·0084
QALYs†	9·921	9·928	0·0067
Costs (£)	269	316	47
ICER (£)‡			
Life-years		5758 (4285, 7410)	
QALYs		7370 (5467, 9443)	

Values in parentheses are 95 per cent confidence intervals. Modelling after recalibration, incorporating Multicentre Aneurysm Screening Study (MASS) 10-year follow-up data, growth and rupture rates from meta-analysis of patient-level data, National Health Service abdominal aortic aneurysm screening programme (NAAASP) data on attendance, prevalence and abdominal aortic aneurysm size at initial screen and updated costs. †Life-years and costs discounted at 3·5 per cent. ‡Estimated from the mean of incremental cost-effectiveness ratios (ICERs) produced by 1000 probabilistic sensitivity analysis iterations. QALY, quality-adjusted life-year.

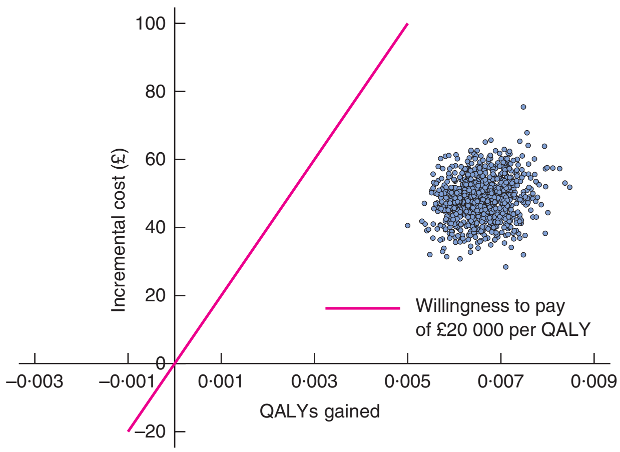

Fig. 2 National Health Service abdominal aortic aneurysm screening programme (NAAASP) cost-effectiveness estimates (30 years); 1000 probabilistic sensitivity analysis iterations. QALY, quality-adjusted life-year

£10 000, there is at least a 99 per cent probability that the programme is cost-effective.

The probabilistic sensitivity analysis incorporated the uncertainty around the postsurgical mortality observed in MASS; a one-way sensitivity analysis using the lower mortality rate observed in NAAASP, based on limited data, reduced the latter ICER by approximately £300. One-way sensitivity analysis suggests that the cost-effectiveness ratio would rise above the NICE £20 000 threshold at a prevalence of AAA in 65-year-old men of 0·35 per cent, compared with the observed 1·5 per cent.

Discussion

To assess the cost-effectiveness of many interventions, particularly screening where the bulk of costs are upfront, but benefits are accrued over time, long-term modelling is essential. It is rare to be able to revisit a model originally constructed using short-term (4-year) trial evidence and compare modelled results with more robust mid-term (10-year) trial data. Such models may not, however, as here, predict well over the medium term. The efforts to recalibrate the model confirmed that the cost-effectiveness estimates are more sensitive to the modelled differences between arms in costs and outcomes (incremental costs and QALYs) than the absolute values in each arm. For that reason, the focus of calibration should be on these differences that drive the cost-effectiveness ratio. The revalidation exercise undertaken demonstrates that economists should be cautious in the use of models based on relatively short-term data[13], given that they may not extrapolate well to medium- or long-term outcomes.

These new analyses have not simply been updated to reflect longer-term trial data. Data from recent meta-analyses of aneurysm rupture and growth rates were used to estimate the growth and rupture rates over the long term. New unit cost estimates for the screening procedure and for AAA surgery that reflect current practice in the UK were incorporated. The new cost estimates demonstrate that, although simple adjustment using relevant price indices may be adequate for some unit costs, for some the procedure costs need to be re-estimated to reflect changes in the costs of particular resources, and changes in the process of care.

Most importantly from a policy perspective, the model incorporates key parameters from the first years of NAAASP: attendance, AAA prevalence and size distribution at first screen. The combined changes do mean that the estimated 30-year ICER of £7370 per QALY gained has increased; the original model estimated an ICER of £2970 per QALY gained[8]. The increase in the estimated ICER reflects the incorporation into the modelling of the much lower AAA prevalence found by NAAASP (1·5 per cent) compared with MASS (4·9 per cent). It also reflects, as might be expected, the fact that the cost of screening has increased since the first costing exercise was conducted in 2001. The costs of elective and emergency AAA repair have increased well above general health service inflation, in part due to the use of more expensive EVAR procedures.

Despite the increase in the estimated ICER, the new modelling demonstrates with confidence that AAA screening remains highly cost-effective, with an ICER well below the lower limit of NICE's acceptable cost-effectiveness range of £20 000–30 000 per QALY gained. The probabilistic sensitivity analysis suggests that, even at a level of £10 000 per QALY, the probability that NAAASP is cost-effective is 99 per cent, thus providing strong support for cost-effectiveness of the current screening programme in the UK.

Although early estimates of the cost-effectiveness of AAA screening predating the publication of results from randomized trials were very variable[22], and precise estimates of cost-effectiveness are necessarily country-specific, there is now a growing international consensus that one-off ultrasound screening in men at around age 65 years is cost-effective. This conclusion for the UK is paralleled by studies relating to Canada[23], Denmark[24,25], The Netherlands[26], Norway[26], Northern Ireland[27] and Italy[28], with only one recent contrary estimate, also from Denmark[29].

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