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Is primary angioplasty cost effective in the UK?
Results of a comprehensive decision analysis

Yolanda Bravo Vergel, Stephen Palmer, Christian Asseburg, Elisabeth Fenwick, Mark de Belder, Keith Abrams and Mark Sculpher

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Is primary angioplasty cost effective in the UK? Results of a comprehensive decision analysis

Yolanda Bravo Vergel, Stephen Palmer, Christian Asseburg, Elisabeth Fenwick, Mark de Belder, Keith Abrams, Mark Sculpher

Effective and cost-effective management of coronary heart disease in the UK is an NHS priority. In particular, the timely and efficient management of acute myocardial infarction (AMI) comprises the cornerstone of the Coronary Heart Disease National Service Framework. Although the management of AMI has improved in the UK, with an associated 16% reduction in mortality between 1999 and 2001, reducing the gap in death rates between this country and others in Europe, many of these deaths are still considered to be potentially preventable.

Thrombolysis remains the predominant reperfusion strategy for ST-segment elevation myocardial infarction in the UK, but its use has limitations. In particular, normal coronary flow is restored in only 25–50% of patients, depending on the choice of thrombolytic drug. The increased use of primary angioplasty has been suggested as one approach to improve further the management of patients with AMI. However, the question of whether primary angioplasty should become the first-line treatment in the UK is still the subject of considerable debate.

The Department of Health and the British Cardiac Society have recently set up the National Infarct Angioplasty Project (NIAP), a study to assess the feasibility of implementing a national primary angioplasty service in 10 NHS pilot centres across England. Apart from the logistic and economic implications derived from any structural change in healthcare provision, one possible reason for the limited use of primary angioplasty in the UK NHS is the lack of evidence about its cost effectiveness: no studies have been published relating to UK angioplasty in the UK NHS.

The increased use of primary angioplasty associated 16% reduction in mortality between 1999 and 2001 mainly explained by the superior mortality benefit and the prevention of non-fatal outcomes associated with primary angioplasty for delays of up to this length.

**METHODS**

**Overview**

A probabilistic decision analytic model was constructed. A systematic review was conducted to update the most comprehensive meta-analysis in this area, and Bayesian statistical methods were used to synthesise the effectiveness evidence from 22 randomised control trials. The model was developed as a comprehensive decision analysis, where the individual components of the decision modelling were dealt with simultaneously and evaluated using a Markov Chain Monte Carlo simulation implemented in the specialist software WinBUGS. QALYs were used as the measure of health outcome. The structure of the decision analytic model and its underlying assumptions were developed in discussion with a group of clinical advisors, all experienced consultant cardiologists from the UK. The model considered the costs from the perspective of the NHS, using 2003–4 prices, with costs and benefits discounted at 3.5% a year.

Details of the updated systematic review and evidence synthesis are presented in a companion paper to this. Full technical details of all methods can be found in a technical report (available at http://heart.bmj.com/supplemental).

**Model structure**

The decision model comprised two main elements: a decision tree that captured the short-term events and costs associated with treatment of AMI and a Markov gambling model of long-term effectiveness. The model was built using a WinBUGS model file to simulate the natural history of AMI and the effectiveness of primary angioplasty for AMI. Costs from a health service perspective and outcomes measured as quality-adjusted life years (QALYs) were used as the measure of health outcome. The model was developed as a comprehensive decision analysis, where the individual components of the decision modelling were dealt with simultaneously and evaluated using a Markov Chain Monte Carlo simulation implemented in the specialist software WinBUGS. QALYs were used as the measure of health outcome. The structure of the decision analytic model and its underlying assumptions were developed in discussion with a group of clinical advisors, all experienced consultant cardiologists from the UK. The model considered the costs from the perspective of the NHS, using 2003–4 prices, with costs and benefits discounted at 3.5% a year.

Details of the updated systematic review and evidence synthesis are presented in a companion paper to this. Full technical details of all methods can be found in a technical report (available at http://heart.bmj.com/supplemental).

**Abbreviations:** AMI, acute myocardial infarction; CRI, credible interval; GPAs, glycoprotein IIb/IIIa antagonists; ICER, incremental cost-effectiveness ratio; MI, myocardial infarction; NIHAR, Nottingham Heart Attack Registry; NIAP, National Infarct Angioplasty Project; OR, odds ratio; QALYs, quality-adjusted life years
Cost effectiveness of primary angioplasty

Figure 1 Overview of the model structure. IHD, ischaemic heart disease; MI, myocardial infarction; RCTs, randomised controlled trials.

Table 1 Clinical effectiveness measures based on the evidence synthesis results

<table>
<thead>
<tr>
<th>Probability of an event with thrombolysis</th>
<th>Base-case value</th>
<th>Low CrI</th>
<th>High CrI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>0.07</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>Non-fatal reinfarction</td>
<td>0.06</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td>Non-fatal stroke</td>
<td>0.02</td>
<td>0.01</td>
<td>0.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Odds ratios—primary angioplasty effect</th>
<th>Average time delay (54 min)</th>
<th>Base-case value</th>
<th>Low CrI</th>
<th>High CrI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>0.70</td>
<td>0.42</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td>Non-fatal reinfarction</td>
<td>0.33</td>
<td>0.20</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Non-fatal stroke</td>
<td>0.26</td>
<td>0.08</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>30 Minutes’ delay</td>
<td>0.54</td>
<td>0.29</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>0.30</td>
<td>0.14</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>Non-fatal reinfarction</td>
<td>0.47</td>
<td>0.05</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>Non-fatal stroke</td>
<td>0.77</td>
<td>0.44</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>60 Minutes’ delay</td>
<td>0.39</td>
<td>0.21</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Non-fatal reinfarction</td>
<td>0.56</td>
<td>0.09</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Non-fatal stroke</td>
<td>1.15</td>
<td>0.49</td>
<td>2.36</td>
<td></td>
</tr>
<tr>
<td>90 Minutes’ delay</td>
<td>0.55</td>
<td>0.29</td>
<td>1.27</td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>0.79</td>
<td>0.08</td>
<td>1.43</td>
<td></td>
</tr>
</tbody>
</table>

Results are posterior mean distributions and 95% credible interval (CrI).

Long-term event rates and costs
The long-term implications of two short-term ("prognostic") events were modelled over the long term: non-fatal MIs and non-fatal strokes. In the absence of long-term trial evidence on the prognosis of these patients after primary angioplasty or thrombolysis, UK registry data were used to calculate long-term event rates and associated costs. This "extrapolation modelling" assumed no
continued treatment effect difference between thrombolysis and angioplasty beyond 6 months. The Nottingham Heart Attack Registry (NHAR)\textsuperscript{23} was used to estimate resource use and transition probabilities for the long-term model. NHAR was selected because extensive follow-up data had been collected (5-years’ follow-up) and provided detailed information on both the frequency and timing of recurrent events as well as resource utilisation. Transition probabilities were calculated from the NHAR data using survival analysis techniques. Although non-cardiac mortality was recorded in the NHAR, the probability of non-cardiac mortality was based on UK life tables owing to the small number of these events.\textsuperscript{2}

### Quality adjustment

To estimate QALYs, it is necessary to quality adjust the period of time the average patient is alive within the model using an appropriate utility or preference score. In the absence of utility data from the trials and the NHAR, external estimates of utility data were sought in order to differentiate between the health status of patients according to the different states of the model. A literature review was undertaken to obtain estimates of utilities for the different long-term health states. A single utility score for patients with a stroke was applied, which was weighted by the probability that this event was disabling or not.\textsuperscript{24}

---

**Table 2: Summary of other variables associated with the base-case model**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Base-case value</th>
<th>Low CrI</th>
<th>High CrI</th>
<th>Distribution</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Probabilities of further revascularisations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary angioplasty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repeated angioplasty</td>
<td>0.054</td>
<td>–</td>
<td>–</td>
<td>Beta ($\alpha = 19, \beta = 219$)</td>
<td>Systematic review\textsuperscript{1, 27}</td>
</tr>
<tr>
<td>CABG</td>
<td>0.054</td>
<td>–</td>
<td>–</td>
<td>Beta ($\alpha = 18, \beta = 290$)</td>
<td>Systematic review\textsuperscript{1, 27}</td>
</tr>
<tr>
<td>Thrombolysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angioplasty (rescue and routine)</td>
<td>0.281</td>
<td>–</td>
<td>–</td>
<td>Beta ($\alpha = 27, \beta = 69$)</td>
<td>Systematic review\textsuperscript{1, 27}</td>
</tr>
<tr>
<td>CABG</td>
<td>0.071</td>
<td>–</td>
<td>–</td>
<td>Beta ($\alpha = 18, \beta = 222$)</td>
<td>Systematic review\textsuperscript{1, 27}</td>
</tr>
<tr>
<td><strong>Transition probabilities\textsuperscript{†}</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From IHD state to non-fatal event (year 1)</td>
<td>0.059</td>
<td>0.041</td>
<td>0.077</td>
<td>Log normal</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>From IHD to non-fatal event (≥2 years)</td>
<td>0.027</td>
<td>0.019</td>
<td>0.036</td>
<td>Log normal</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>From IHD to CV death (year 1)</td>
<td>0.038</td>
<td>0.024</td>
<td>0.055</td>
<td>Log normal</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>From IHD to CV death (≥2 years)</td>
<td>0.032</td>
<td>0.023</td>
<td>0.041</td>
<td>Log normal</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>From non-fatal event to CV death (year 1)</td>
<td>0.260</td>
<td>0.180</td>
<td>0.352</td>
<td>Log normal</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>From non-fatal event to CV death (≥2 years)</td>
<td>0.048</td>
<td>0.021</td>
<td>0.084</td>
<td>Log normal</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>Recurrent non-fatal event in the MI state</td>
<td>0.087</td>
<td>0.049</td>
<td>0.134</td>
<td>Posterior distribution</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>Recurrent non-fatal event in the stroke state</td>
<td>0.038</td>
<td>0.017</td>
<td>0.182</td>
<td>Posterior distribution</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>Recurrent stroke</td>
<td>0.498</td>
<td>0.295</td>
<td>0.906</td>
<td>Posterior distribution</td>
<td>NHAR\textsuperscript{23}</td>
</tr>
<tr>
<td>Hospital length of stay after acute MI (days)</td>
<td>10</td>
<td>–</td>
<td>–</td>
<td>Fixed</td>
<td>HES\textsuperscript{24}</td>
</tr>
<tr>
<td><strong>Utilities associated with health states</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MI state (year 1)</td>
<td>1614</td>
<td>–</td>
<td>–</td>
<td>Fixed</td>
<td></td>
</tr>
<tr>
<td>MI state (≥2 years)</td>
<td>1614</td>
<td>–</td>
<td>–</td>
<td>Fixed</td>
<td></td>
</tr>
<tr>
<td>Combined stroke</td>
<td>0.612</td>
<td>–</td>
<td>–</td>
<td>Fixed</td>
<td></td>
</tr>
</tbody>
</table>

---

\textsuperscript{1}Mean and 95\% CrI reported.
\textsuperscript{2}All annual costs adjusted by average number of days spent in each state based on NHAR dataset.
\textsuperscript{3}Price year 2003–4; all costs updated using HCHS \textsuperscript{20}.
\textsuperscript{4}Hazard rates obtained from survival analysis, converted to probabilities.

\textsuperscript{a}Angioplasty (rescue and routine) 0.281 \textsuperscript{*} Mean 0.027 \textsuperscript{95\% CrI} 0.077 \textsuperscript{Log normal} NHAR\textsuperscript{23}.

\textsuperscript{b}From IHD state to non-fatal event (year 1) 0.059 \textsuperscript{*} Mean 0.019 \textsuperscript{95\% CrI} 0.077 \textsuperscript{Log normal} NHAR\textsuperscript{23}.

\textsuperscript{c}From IHD state to non-fatal event (≥2 years) 0.059 \textsuperscript{*} Mean 0.019 \textsuperscript{95\% CrI} 0.077 \textsuperscript{Log normal} NHAR\textsuperscript{23}.

\textsuperscript{d}From IHD state to CV death (year 1) 0.059 \textsuperscript{*} Mean 0.019 \textsuperscript{95\% CrI} 0.077 \textsuperscript{Log normal} NHAR\textsuperscript{23}.

\textsuperscript{e}From IHD state to CV death (≥2 years) 0.059 \textsuperscript{*} Mean 0.019 \textsuperscript{95\% CrI} 0.077 \textsuperscript{Log normal} NHAR\textsuperscript{23}.
Analytical methods

The model was run probabilistically and the uncertainty in the individual measures was fully characterised using the probability distributions summarised in table 2. The results of the model are presented in two ways. First, mean lifetime costs and QALYs for both strategies are reported and their cost effectiveness presented using incremental cost-effectiveness ratios (ICERs).

RESULTS

Clinical effectiveness

The full clinical results from the evidence synthesis have been published. Briefly, the results showed that for the average time delay (54 minutes) the mean event probabilities were lower for primary angioplasty for all outcomes. Mortality within 6 months was 5.5% after angioplasty and 7.7% after thrombolysis (OR = 0.70; 95% credible interval (CrI) 0.42 to 1.18). For non-fatal re-infarction, the OR was 0.33 (95% CrI 0.20 to 0.67); and for non-fatal stroke 0.26 (95% CrI 0.08 to 0.72). For all outcomes, the benefit of angioplasty decreased with longer treatment initiation delay (table 1).

Cost effectiveness: base-case analysis

Table 3 presents the base-case results. Primary angioplasty is the most expensive option (mean lifetime costs £12 760 vs £10 080), but it was also associated with a mean lifetime QALY gain of 0.29 (7.12 vs 6.83). The ICER associated with primary angioplasty compared with thrombolysis was £9241 for each additional QALY, hence primary angioplasty will be the optimal treatment provided that the NHS is prepared to pay at least this amount. The probability that primary angioplasty is cost effective is around 0.55 for a cost-effectiveness threshold of £10 000, increasing to almost 1 for a threshold of £30 000 per QALY.

Cost effectiveness: alternative scenarios

Reducing the time delay to 30 minutes improves the estimate of cost effectiveness, with a reduction of the ICER to £6850 per QALY. Furthermore, the probability that this strategy is cost effective is 0.82 at a threshold of £10 000, increasing to close to 1 for a threshold of £20 000 and above. These results are explained by a higher mortality benefit at 30 minutes (OR = 0.54; 95% CrI 0.29 to 0.92) and a slightly higher prevention of non-fatal re-infarction than those estimated based on the average time delay.

As expected, results at 60 minutes were similar to those for average time delay, but increasing the time delay up to 90 minutes resulted in a sevenfold increase in the base-case ICER (£64 750 per QALY) and a substantial reduction in the
probability that primary angioplasty was considered cost effective at conventional thresholds considered to represent value for money in the NHS. This is explained by the fact that no additional mortality benefit is apparent with primary angioplasty for 90 minutes' delay in starting treatment.

The alternative setting with lower length of initial hospitalisation with primary angioplasty (3.76 days compared with 12.12 days for the thrombolytic strategy) showed an improvement in the estimate of cost effectiveness, with a reduction of the ICER for all time delays. In this setting, even for a delay up to 90 minutes, primary angioplasty was the optimal strategy for a threshold of £30 000.

The cost-effectiveness results presented here are based on the assumption that centres already have the necessary infrastructure to provide primary angioplasty. Figure 2 presents a threshold analysis showing the impact of additional investment costs in new facilities for primary angioplasty that may be necessary in some centres. This represents an “up front” capital investment allocated per patient for primary angioplasty. This demonstrates that, in cases where the additional investment costs are up to the equivalent of £9000 per patient and when the additional time delay associated with primary angioplasty over thrombolysis, no higher than 60 minutes, the cost effectiveness of primary angioplasty would be in the region of £20 000 to £40 000 per QALY. In those cases where additional investment cost per patient is higher than £9000, thrombolysis is the optimal strategy.

**DISCUSSION**

Several studies have looked at the economics of primary angioplasty. For decision making in the UK NHS, however, a cost-effectiveness analysis should have some key features. These include the incorporation of all relevant trial evidence on clinical effects, the expression of outcomes as QALYs for comparison across clinical areas and the use of UK costs. Some studies have been based on systematic reviews of clinical effects, two used QALYs and one UK costs, but we are not aware of any existing study with all these features.

Despite hitherto limited evidence for its cost effectiveness, widening the use of primary angioplasty in the UK NHS is already being considered. Findings from the NIAP project, due in 2008, will inform policy on the provision of primary angioplasty as a first treatment for patients who have a heart attack. Results from the analysis presented here suggest that primary angioplasty is cost effective based on the cost-effectiveness thresholds used by the National Institute for Health and Clinical Excellence (£20 000 to £30 000 per additional QALY). This conclusion, however, is sensitive to the additional time delay associated with primary angioplasty. The results from the different scenarios suggest that primary angioplasty may not be cost effective for an additional delay somewhere within the region of 60 to 90 minutes. An additional analysis was undertaken to identify the time at which primary angioplasty no longer seems to be cost effective compared with thrombolysis. At a cost-effectiveness threshold of £20 000 per QALY, primary angioplasty appears cost effective for delays of less than 79 minutes (and 84.5 minutes at £30 000 per QALY). The cost effectiveness of primary angioplasty may also be sensitive to the set-up costs of the service.

The comprehensive decision modelling methods used in the analyses presented here allow both evidence synthesis and decision analytical models to be combined within a single coherent modelling framework, which not only allows all sources of uncertainty to be appropriately propagated throughout the analysis, and consequently included in the overall cost-effectiveness estimates, but also allows appropriate consideration of the correlation induced when the same evidence source contributes to multiple components of the decision model. The Bayesian approach also enables the inclusion of complex data structures and networks of evidence without the need to make distributional assumptions about model inputs.

In addition to handling the uncertainty in the evidence, it is also important to reflect variation—for example, in clinical context and practice, resource use and costs between hospitals. Analyses of various scenarios have been used here to assess the implications of additional time delay in providing angioplasty, differential lengths of hospital stay and additional investment cost in new facilities. These show the likely boundaries of the cost effectiveness of primary angioplasty. Each input into the analysis is estimated with uncertainty but, using probabilistic methods, the analysis shows that, for most settings, primary angioplasty has the highest probability of being cost effective even at lower cost-effectiveness thresholds. However, the remaining decision uncertainty may indicate that further primary research into the costs and effects of primary angioplasty would be good value.

As is often the case in evaluating medical interventions, technologies advance more rapidly than the evidence base. Since the majority of the trials informing this analysis were undertaken, medical practice for the delivery of thrombolysis and primary angioplasty has changed. For example, a large proportion of patients undergoing primary angioplasty today will have stents and GPAs as adjuvant drugs. Where possible, assumptions have been used which are conservative with respect to primary angioplasty (ie, tend to underestimate its cost effectiveness). For example, the use of stents and GPAs has been included as part of the cost of the primary angioplasty procedure, although only a proportion of patients in the most recent trials included in our review used them, and thus their influence on the overall estimated effectiveness was low. A sensitivity analysis (not reported here) has been undertaken using the price of streptokinase and including trials using only fibrin-specific thrombolytic agents, with no major changes in the results. Moreover, an increasing proportion of patients undergoing thrombolysis will later receive “rescue” percutaneous coronary intervention to achieve reperfusion or revascularisation before discharge. This would probably affect the cost and effectiveness of a strategy of initial thrombolysis. This is also likely to be true for a large proportion of patients receiving pre-hospital thrombolysis.

The lack of individual patient data from the trials precludes an analysis of how the relative effectiveness and cost effectiveness of angioplasty varies between subgroups of patients defined by their clinical and sociodemographic factors, so cost effectiveness is presented for the “average” patient reflected in the evidence. Our analysis should not be used to determine whether an individual patient should or should not receive primary angioplasty, but may reflect how cost effective a primary angioplasty service might be, depending on mean call-to-balloon times for the population being served. Furthermore, it has to be recognised that patients in routine practice are likely to show some differences from those included in trials. There is some conflicting evidence on whether primary angioplasty will be more or less effective in routine practice.

Some limitations to the analysis should be noted. First, the time between patients contacting emergency services and receiving thrombolysis is a predictor of efficacy. However, this likely source of variability in cost effectiveness could not be explicitly included in the analysis owing to inconsistent reporting in the trials. Therefore, results presented here represent average time-to-needle (54.3 minutes), which is similar to the mean time-to-needle in the UK of 67 minutes (personal communication, Dr John Birkhead, UK Myocardial Infarction National Audit Project). Second, given that our
systematic review was an update of a previously published meta-analysis,39 neither the effect of publication bias nor study quality were formally assessed. Third, ideally the analysis would have compared the full range of reperfusion strategies, including different thrombolytic agents, alternative modes of administration and the use of rescue or facilitated angioplasty.39 40 These analyses represent significant extensions of the work presented here.

In conclusion, the analysis suggests that primary angioplasty is cost effective for the treatment of AMI, on the basis of threshold values used in the NHS, for a time delay of up to about 80 minutes.

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A supplementary technical report is available on the Heart website—http://heart.bmj.com/supplemental

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Keith Abrams, Centre for Biostatistics and Genetic Epidemiology, Department of Health Sciences, University of Leicester, UK

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Competing interests: Mark Sculpter and Mark de Belder have received research funding and consultancy fees from various manufacturers of medical devices such as coronary stents. No other authors have competing interests to declare.

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