Cost-effectiveness analysis of 64-slice computed tomography vs. cardiac catheterization to rule out coronary artery disease before non-coronary cardiovascular surgery

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Aims

To explore the cost-effectiveness of two alternative strategies to rule out significant coronary artery disease (CAD) in the pre-operative evaluation of non-coronary cardiovascular surgery: initial pre-operative coronary 64-slice computed tomography angiography (CCTA) vs. invasive coronary angiography (ICA).

Methods and results

These diagnostic strategies are compared from the clinical and payee’s perspective, on the basis of the results of four European studies including 490 patients, by an analytic model of a decision tree in terms of the cost-effectiveness as the percentage of catheterizations, complications, and deaths avoided. These studies show that 71.2% of the ICA and 3.56% of the post-ICA complications could have been avoided by an initial pre-operative CCTA with a saving of €411/patient. The sensitivity analysis did not find relevant differences in terms of the cost-effectiveness when we established the indication of ICA vs. CCTA in relation to the amount of coronary calcium and when ICA was always performed by radial access. However, the lack of team experience in CCTA increased the economical and biological cost due to involving an ICA and the exposure to double ionizing radiation sources.

Conclusion

In experienced groups, the diagnostic strategy with initial pre-operative CCTA is better than the strategy with initial ICA because it is capable of ruling out significant CAD avoiding ICA and post-ICA morbidity-mortality, with an important saving in the cost of the diagnostic process.

Keywords

Cost-effectiveness analysis • Non-coronary cardiovascular surgery • Coronary 64-slice computed tomography angiography • Invasive coronary angiography

Introduction

The exclusion of significant coronary artery disease (CAD) is necessary in most of the patients requiring non-coronary cardiovascular surgery (NCCS) to avoid the deleterious consequences in the peri- and post-operative prognosis.1 Hence, the European Society of Cardiology2 (ESC) and the American College of Cardiology/American Heart Association3 (ACC/AHA) guidelines recommend carrying out an invasive coronary angiography (ICA) in the pre-operative assessment of patients with valvular heart disease in the majority of cases.

Nowadays, multidetector coronary computed tomographic angiography (CCTA) is a reliable technique to exclude significant CAD with a proven high negative predictive value, particularly in patients with low or intermediate pre-examination probability4 of CAD and proximal or middle stenosis that can be treated with a coronary bypass during a cardiac/aortic wall surgery. In the European context, several studies5–8 have shown the potential of CCTA for avoiding the pre-operative ICA for NCCS (Table 1). Both the ESC2 and ACC/AHA3 accept that ICA can be omitted if the CCTA rules out significant CAD. However, the economic impact of this change in the diagnostic strategy has not yet been evaluated.

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Currently, the public and private health systems have to consider not only technological innovation, but also the opportunity cost and its sustainability because of the evident limitations of financial resources. Therefore, we set out to develop an exploratory analytic model of decision-making to perform a cost-effectiveness assessment of the change in this diagnostic strategy prior to NCCS.

Methods

Decision model
A mathematical decision model\textsuperscript{10} was developed to assess the cost-effectiveness of CCTA vs. ICA as the diagnostic strategy to exclude significant CAD in the pre-operative evaluation of patients undergoing NCCS. This model was elaborated on the basis of the probabilities and expected values estimated from the four European studies mentioned;\textsuperscript{5–8} the most relevant randomized and multi-centre trials, and meta-analysis on cardiac catheterization. The decision tree model was performed using standard software (TreeAge Pro, Williamstown, MA, USA) (Figure 1).

This decision tree begins with a decision node (the square box) in which either CCTA or ICA is chosen. The CCTA could be: (i) diagnostic (the image is of sufficient quality to rule out coronary stenosis $\geq 50\%$ or to establish a clear coronary obstruction $\geq 50\%$) or (ii) non-diagnostic (it is not of sufficient quality to definitely discriminate between significant/non-significant CAD). These two possibilities are represented by a probabilistic node (a circle) and their outcome is governed by the probabilities derived from the literature\textsuperscript{5–8} (Tables 1 and 2).

In the first situation the patients without significant CAD (coronary stenosis $<50\%$) can undergo surgery without any other test and the remaining patients will have to undergo an ICA. The ICA is considered as the ‘gold standard’ test to exclude significant CAD and it can be performed with or without complications as is shown by a new probabilistic node and its probabilities have been obtained from previous studies.\textsuperscript{8,11–13} (Table 2). The possibilities of death or resolution after a complication are displayed by a new encircling node and their probabilities are considered from the preceding publications.\textsuperscript{11,12} The end of each branch is represented by a triangle, terminal node, and the final outcome of the diagnostic process in relation to its cost and effectiveness expressed in terms of catheterizations, complications, and deaths avoided.

Population
The base-case model consisted of a hypothetical cohort of pre-operative patients evaluated by CCTA to rule out significant CAD before NCCS. The probabilities of every branch were estimated from the four European studies published,\textsuperscript{5–8} which reported 490 pre-operative patients evaluated by CCTA prior to NCCS during 2005–2010 in central and southern Europe (Tables 1 and 2) and previous ICA studies.\textsuperscript{11–13}

Cost
The fees were obtained from the 2009 financial schedule of the Community of Madrid and the private health insurance companies (Table 3). These prices are very similar to the 2009 national average. The hospital fees for cardiac catheterization and some specific catheters used for the femoral/radial catheterization were not available in the 2009 financial schedule of the Community of Madrid and have been provided by the Economic Management Department of Ramón y Cajal University Hospital.

Table 1
Studies performed in Europe with 64-slice computed tomography coronary angiography to rule out significant coronary disease in patients referred for non-coronary cardiovascular surgery

<table>
<thead>
<tr>
<th>Study</th>
<th>Country</th>
<th>Patients (n = 490)</th>
<th>Age (years)</th>
<th>Surgical cardiac diseases</th>
<th>AF (%)</th>
<th>CS (median) (range)</th>
<th>Diagnostic CCTA (%)</th>
<th>Control</th>
<th>Unnecessary ICA (%)</th>
<th>Non-SCAD (median) (range)</th>
<th>Diagnostic CCTA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meijboom et al.</td>
<td>The Netherlands</td>
<td>70</td>
<td>63 ±11</td>
<td>Valvular</td>
<td>214 (0–1397)</td>
<td>94</td>
<td>69</td>
<td>6</td>
<td>ICA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheffel et al.</td>
<td>Switzerland</td>
<td>50</td>
<td>54 ±14</td>
<td>Chronic AR</td>
<td>136</td>
<td>278a (0–1207)</td>
<td>94</td>
<td>70</td>
<td>4</td>
<td>ICA</td>
<td></td>
</tr>
<tr>
<td>Bettencourt et al.</td>
<td>Portugal</td>
<td>237</td>
<td>67 ±10</td>
<td>Valvular</td>
<td>105 (0–6617)</td>
<td>90</td>
<td>73</td>
<td>9</td>
<td>ICA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Catalan et al.</td>
<td>Spain</td>
<td>133</td>
<td>65 ±11</td>
<td>Congenital disease</td>
<td>51 (0–3956)</td>
<td>81</td>
<td>70</td>
<td>3</td>
<td>Clinical monitoring (median: 20 months)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AF, atrial fibrillation; CS, calcium score (Agatston); CCTA, coronary CT angiography; SCAD, significant coronary artery disease ($\geq 50\%$ stenosis); ICA, invasive coronary angiography.

aMean ± standard deviation.

bDiagnostic CCTA: an accurate determination of the presence or absence of SCAD by CCTA.
cUnnecessary ICA on the basis of the CCTA outcome (due to the misdiagnosis of coronary artery stenosis by CCTA).
An analysis of the economic impact of radial vs. femoral access for ICA was performed as follows: (i) for radial access, the sum comprised the costs of the diagnostic procedure, half the in-patient hospital stay, and the incremental cost of the radial catheter (€1061, €270, and €18, respectively) with a final outcome of €1343, (ii) for femoral access, the sum comprised the costs of the diagnostic procedure and a full in-patient hospital stay (€1061 and 540, respectively) with an outcome of €1601. As 45% of the cases were by radial access in Spain during 2009, the average cost per catheterization was €1485. The possibility of including the costs of femoral access, vascular closure device, and half in-patient hospital stay (€1061 + €182 + €270 = €1513) was not considered for the sensitivity analysis because of the irrelevant economic difference with femoral access and full in-patient hospital stay. The value for a unit of post-ICA complication was estimated for the most common: peri-procedural vascular complication at the access site. The cost interval (€1000–6000) tries to show the broad range of possibilities on this topic (Table 3).

**Sensitivity analysis**

**Confidence interval of the tree probabilities, CCTA, and ICA costs**

The cost-effectiveness analysis for the European population was performed by the base-case decision tree model developed with the lower and higher limits of the confidence interval (CI) of the tree probabilities estimated from the European studies shown in Table 1 and prior ICA studies. The lower and higher limits of CI of the CCTA and ICA costs were obtained from previously reported values (Table 3).

**Agatston score**

The sample considered was divided in groups on the basis of coronary calcium expressed as the Agatston score (600, 1000, 1500, and 2000), outstanding marker of prevalence of significant CAD and probability for a non-diagnostic CCTA. A decision tree model was performed with the probabilities obtained (Table 2) and the results were estimated for every previously mentioned the Agatston score group in which ICA was directly considered for patients with values higher than 600, 1000, 1500, and 2000, respectively (Figure 2).

**Training of the diagnostic team for the acquisition and interpretation of CCTA**

The concept ‘enough training’ of the diagnostic team was defined by performing an exploratory decision tree model to estimate the percentage of CCTA with an indication of ICA that involves the global outcome in favour of the initial ICA strategy. This approach assumes that the higher the prevalence of significant CAD in the population, the more relevant is the better training of the diagnostic team. This high standard of training in CCTA reduces the possibility of an under-diagnosis with deleterious consequences for the clinical prognosis of the patients’ and from the economic perspective for society. On the other hand, over-diagnosis requires an ICA with more economic costs and unnecessary radiation exposure for the patient and the health-care staff.

The **best clinical setting and incidence rate of vascular complications for ICA**

From the clinical and payee’s perspective, the femoral access for cardiac catheterization and its potentially higher complications also involve an increase in the costs if the CCTA does not rule out significant CAD or ICA is performed as the initial test. Therefore, we explored this subject with a decision tree model including the probabilities of the best possible clinical context for ICA: all patients by radial access with the lowest incidence rate of vascular complications reported (0.7% from the centres with the highest experience for radial access in the RIVAL study).

**Results**

**Base-case analysis**

Under base-case conditions the cost-effectiveness analysis of the hypothetical cohort of patients undergoing NCCS is shown as results of the decision tree model (Figure 1 and Table 4). As can be seen, the initial CCTA strategy dominates the initial ICA alternative, because the CCTA strategy had lower costs (€1149 CCTA vs. €1560 ICA strategy with a saving of €411/patient evaluated for ruling out significant CAD before NCCS) and better clinical outcomes with 71.2 and 3.56% of ICA and post-ICA complications avoided, respectively.

**Sensitivity analysis**

The results of this sensitivity analysis are summarized in Table 5 and Figure 3.

All the clinical settings evaluated showed a better cost-effectiveness outcome for the initial CCTA vs. ICA strategy except for the highest limit CCTA cost, the lowest limit ICA cost, and the experience variable when the diagnostic team was incapable of avoiding at least 50% of ICA. A population prevalence of 20 or 30% of significant CAD (as the European studies considered) would require a percentage of 57% or 65%, respectively, of diagnostic CCTA. Otherwise, there would be an incremental cost of about €100/patient for every 10% of decrease in diagnostic CCTA, besides the biological over-cost of exposing the patients to a double radiation source if finally they require both diagnostic tests.

Figure 3 shows a tornado diagram allowing us simultaneously to compare one-way sensitivity analysis for the most relevant input variables and a single output variable, the differential cost of the initial CCTA vs. ICA strategy. This graph shows the most sensitive variable or that with the highest impact at the top of the chart followed by other variables in the descending order of impact to the bottom for the least sensitive variable. Thus, we can see that the variable with the highest impact over the differential cost of the pre-operative diagnostic strategy after CCTA and ICA costs is the experience of the diagnostic team, followed by the calcium coronary burden, the percentage of CCTA without significant CAD, the best ICA setting, and the catheterization complications. The vertical line at €411 represents the difference in the expected pay-off when all the input variables take their base value (base-case conditions).

**Discussion**

The CCTA is currently considered an alternative to ICA in patients with low- or intermediate-pre-test probability of significant CAD. This is the case of the patients referred for NCCS in which it can provide outstanding information for the surgical intervention. However, the cost-effectiveness impact of this change of pre-operative diagnostic strategy has not been yet addressed.
Our cost-effectiveness analysis demonstrates that, with an experienced diagnostic team, a pre-operative CCTA strategy is better than the strategy with ICA as the initial test, because of its capability in obtaining better results in terms of avoiding ICA and morbidity-mortality. There is a saving of €411/patient without deleterious consequences in the post-operative prognosis.8

To investigate the macroeconomic impact of this change in the pre-operative strategy, this exploratory study assumes that in most cases the current developments in echocardiography and cardiac magnetic resonance imaging avoid invasive haemodynamic evaluation.2,3 Therefore, the exclusion of significant CAD is the only reason for conventional ICA. If the 9683 patients reported15 with valvular disease and ICA in Spain during 2009 had undergone prior CCTA, with the percentage of avoided catheterization procedures in the four European studies,5– 8 there would have been a saving of almost three million euros for both the public and private health-care systems. In addition, the potential complications related to the invasive strategy, which these patients present at a higher rate than patients with only CAD,11 would have been avoided. However, these hypothetical results collide with clinical practice that, without a significant increase in the incidence of valvular heart disease in Spain during 2010, has reported an increase of 1898 ICA in this type of patients.

The sensitivity analysis performed with the confidence interval values of the probabilities estimated for the variables presented in Table 2, CCTA, and ICA costs (Table 3) shows that the initial ICA strategy was dominated by the CCTA strategy in terms of effectiveness, with 71.2 and 3.56% of ICA and post-ICA complications avoided, respectively. However, there was a maximum incremental cost of €211 in cases with the lowest ICA cost. The major saving in the cost of the CCTA strategy (€881) was obtained with the lowest cost of CCTA reported19 (Table 5).

The indication of ICA on the basis of the calcium coronary burdens shows that the economic benefit decreases slightly with the higher calcium coronary burdens. However, these benefits remain, although to a lesser degree, even with scores ≤2000. Therefore, the indication of ICA on the basis of a determined Agatston score, although a marker of probability of a diagnostic/non-diagnostic CCTA, is not more cost-effective in practice for an experienced diagnostic team. Consequently, we consider that for this clinical context the determination of the Agatston score should not be carried out due to the small number of patients with a very high calcium score. This involves a saving of 1–2 mSv in the biological cost.

These positive results for initial CCTA strategy contrast with those obtained when considering the experience of the diagnostic team in CCTA. If the team is incapable of avoiding a sufficient number of catheterization procedures, the final cost of the diagnostic process will be increased from the economical and biological cost perspectives. The main scientific societies have established the requirements for the team of the acquisition and interpretation of the CCTA.20,21 Our results establish for the European setting
that a diagnostic team can be considered as experienced, when it is capable of avoiding at least 50% of ICA in unselected patients (without exclusion for atrial fibrillation or the calcium score) undergoing NCCS. From the clinical and payee perspective, this variable has always to be considered because too many non-diagnoses or overestimated coronary stenoses by CCTA will involve an ICA that causes a negative influence in the accumulated costs of the diagnostic process as well as in the total radiation that the patient will receive. On the other hand, the possibility of under-estimating the coronary stenoses can involve negative consequences in the prognosis of the patients undergoing cardiac surgery and thus cause a clinical and economic over-cost for patients and the society due to a peri- or post-operative complications.

Therefore, we should ponder the benefit–risk relationship for the patient if the team training is not carried out in centres with accredited technical and scientific solvency for the quality of its work and publications. In addition, experience has been shown to be a variable that permits obtaining a CCTA with lower doses of radiation. Experience is essential for the implementation of the new protocols for the acquisition of CCTA with only a 1–4 mSv effective dose of radiation, far below other ionizing diagnostic techniques used in Cardiology.

The higher risk of post-ICA vascular complications of candidates for NCCS has been demonstrated by previous studies. This risk must be taken into account in the pre-operative diagnostic strategy. Therefore, the rate of vascular complications considered for the base-case analysis was 5%, as has been reported in the only study that shows these data in the setting of pre-operative evaluation of NCCS. On the other hand, radial access for the catheterization seems to have reduced vascular complications in the context of the acute coronary syndrome (ACS) and costs due to shortened hospital stays. However, this aforementioned decrease in vascular complications in the ACS may not be extrapolated to the candidates for NCCS. Then, radial access implies a process of learning, the appropriate patient selection (preferably ≤70 years), a higher time of catheterization room occupancy, and an increase in radiation to the patient and health-care staff of up to 23%. In addition, this implementation should be done parallel to the allocation of ‘short stay units’ for effective cost reduction by avoiding the occupancy of beds in the conventional

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Summary of probabilities used in the model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Base-case estimated</td>
</tr>
<tr>
<td>Base-case estimations (%)</td>
<td></td>
</tr>
<tr>
<td>Diagnostic CCTA</td>
<td>89</td>
</tr>
<tr>
<td>Non-SCAD</td>
<td>80</td>
</tr>
<tr>
<td>CCTA</td>
<td></td>
</tr>
<tr>
<td>Catheterization complications</td>
<td>5</td>
</tr>
<tr>
<td>Catheterization deaths</td>
<td>0.1</td>
</tr>
<tr>
<td>Sensitivity analysis (%)</td>
<td></td>
</tr>
<tr>
<td>Catheterization complications</td>
<td>0.7</td>
</tr>
<tr>
<td>Diagnostic CCTA</td>
<td>57</td>
</tr>
<tr>
<td>Diagnostic CCTA</td>
<td>65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Values for unit and range costs of model inputs (cost for 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test</td>
<td>Unit cost (€)</td>
</tr>
<tr>
<td>Calcium score (Agatston)</td>
<td>117</td>
</tr>
<tr>
<td>CCTA</td>
<td>700</td>
</tr>
<tr>
<td>ICA (all patients by femoral access)</td>
<td>1601</td>
</tr>
<tr>
<td>ICA (45% radial access)</td>
<td>1485</td>
</tr>
<tr>
<td>ICA (all patients by radial access)</td>
<td>1343</td>
</tr>
<tr>
<td>Post-ICA complication</td>
<td>1500</td>
</tr>
<tr>
<td>Post-ICA death</td>
<td>6000</td>
</tr>
</tbody>
</table>

CCTA, coronary computed tomography angiography; ICA, invasive coronary angiography; PI, private insurances.
hospitalization area. Nonetheless, the best clinical setting for ICA was considered for the sensitivity analysis with a saving of €264/patient for the initial CCTA strategy.

Limitations of the study
The determination of the public prices through the related diagnostic groups (GRD) does not always agree with the large and complex clinical reality. The proof of this is the possibility of considering the cost of catheterization for this population the difference between the GRD 104 (procedures on heart valves with cardiac catheterization) and GRD 105 (same procedure without cardiac catheterization), which in the Community of Madrid is €6454. However, we have considered that €1485 estimated as the average cost of the catheterization (as was indicated in the methodology) is a better reflection of the clinical reality and is in agreement with previous reported costs. On the other hand, the considered base-case cost of CCTA (€700) on the basis of the prices of private health insurance companies in Spain

Figure 2  Decision tree model structure in relation with the Agatston score for deciding an initial ICA strategy.
The induced effects of radiation exposure were not quantified in this pilot study; however, they have been considered from a global perspective. Table 5 provides a sensitivity analysis of cost-effectiveness, showing the average CCTA costs, the cost difference over the ICA strategy, and the percentage of complications and deaths avoided. The costs of transitory suppression of oral anticoagulation, quite common in NCCS patients for the femoral access in ICA, were not considered due to the exploratory character of this analysis. The induced effects of radiation exposure were not quantified in this pilot study; however, they have been considered from a global perspective.
perspective and for controlling during the pre-operative evaluation of patients undergoing NCCS.

This economic evaluation has been made on the basis of data from four European studies carried out in 490 patients by 64-slice CT. Provided that the included patients and the practical development of these studies are representative of the usual practice, this cost-effectiveness assessment will be of greater external validity. On the other hand, we believe it is essential to publish more of the clinical and financial results made in our European healthcare environment, which if corroborated by further studies will facilitate managerial decision-making.

Conclusions

The initial CCTA strategy for the pre-operative evaluation of NCCS in experienced groups represents not only a more comfortable diagnostic strategy for the patient, but is also more cost-effective than the conventional ICA strategy. It produces a saving of €411/patient as well as a benefit due to the possibility of avoiding potential complications and post-ICA death.

Acknowledgements

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Conflict of interest: none declared.

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14. Orden D/2009, de 31 de agosto, por la que se fijan los precios públicos por la prestación de los servicios de naturaleza sanitaria de la red de la Comunidad de Madrid (BOCM de 10 de septiembre de 2009).
Incidental finding of partial anomalous pulmonary venous drainage

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A 56-year-old man with locally advanced gastric carcinoma underwent echocardiography prior to commencing chemotherapy to assess the left ventricular systolic function. Echocardiography disclosed a severely dilated right heart, with preserved right ventricular systolic function and a normal predicted pulmonary artery systolic pressure. The inter-atrial septum was intact and no other structural cardiac abnormality was found.

A review of the staging CT (Siemens Definition AS 64-slice scanner) scan showed no left pulmonary veins connected to the left atrium. Reformating of the images showed anomalous left pulmonary venous drainage. The superior and inferior pulmonary veins on the left formed a common left pulmonary vein which then drained via the left innominate vein into the superior vena cava and right atrium. Two normal right pulmonary veins were seen connected to the left atrium.

(Panel A and B and Supplementary data online, video clip. IV, innominate vein; MPA, main pulmonary artery; SVC, superior vena cava; CLPV, common left pulmonary vein; RPV, right pulmonary vein; Ao, ascending aorta).

A diagnosis of partial anomalous pulmonary venous drainage was made, and as he was asymptomatic, surgical correction was considered following treatment of his cancer.

This case highlights the role of contrast-enhanced chest MDCT with volume-rendered reconstructions in providing accurate information of pulmonary vein anatomy and intra-cardiac shunts in patients with right ventricular enlargement. CT is widely accessible, and with its wide field of view and high spatial resolution, clearly depicts the great vessels and any abnormal connections.

Supplementary data are available at European Heart Journal – Cardiovascular Imaging online

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