



# Robot-assisted versus on-pump and off-pump coronary artery bypass grafting: single center cost-analysis of 30 days hospital claims and intraoperative costs

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## STUDY AIM

Assessing the economic impact on Dutch hospital resources after the introduction of RA-MIDCAB.

## BACKGROUND

Throughout Europe, the interest in implementing Robotic Assisted Minimally Invasive Direct Coronary Artery Bypass (RA-MIDCAB) has been growing. However, concerns about additional costs have emerged concurrently. In this analysis, we aim to provide a comparison of the cumulative perioperative costs of RA-MIDCAB, On-Pump Coronary Artery Bypass Grafting (CABG), and Off-Pump CABG (OPCAB).

## METHODS

We conducted a propensity score-matched analysis comparing patients undergoing RA-MIDCAB with those undergoing CABG or OPCAB at the University Medical Centre of Utrecht from January 2016 to December 2021. After matching, we analyzed combined intraoperative surgical costs and 30-day postoperative costs. We first compared RA-MIDCAB costs to CABG and then to OPCAB separately. Violin plots illustrated cost distribution among individual patients. Total cost uncertainty was estimated using 1000 bootstrapping iterations.

## STUDY POPULATION

Seventy-nine RA-MIDCAB patients were matched to 158 CABG patients, and 80 RA-MIDCAB patients were matched to 149 OPCAB patients.

Baseline characteristics and intraoperative data of patients undergoing CABG versus RA-MIDCAB, and OPCAB versus RA-MIDCAB, following propensity score matching.

|                                            | CABG        | RA-MIDCAB  | p-value | OPCAB       | RA-MIDCAB  | p-value |
|--------------------------------------------|-------------|------------|---------|-------------|------------|---------|
| N before propensity matching               | 684         | 80         |         | 350         | 80         |         |
| N after propensity matching                | 158 (100)   | 79 (100)   |         | 149 (100)   | 80 (100)   |         |
| Patient Characteristics                    |             |            |         |             |            |         |
| Male                                       | 139 (87.9)  | 69 (87.3)  | 0.78    | 129 (86.6)  | 70 (87.5)  | 0.84    |
| Age, mean ± SD, y                          | 60.8 ± 8.3  | 60.7 ± 8.7 | 0.89    | 60.7 ± 8.5  | 60.5 ± 8.8 | 0.86    |
| Hypertension                               | 73 (46.2)   | 45 (56.9)  | 0.19    | 92 (61.7)   | 46 (57.5)  | 0.53    |
| BMI mean ± SD, kg/m <sup>2</sup>           | 26.5 ± 3.3  | 26.7 ± 3.4 | 0.74    | 26.7 ± 3.1  | 26.7 ± 3.3 | 0.97    |
| Diabetes                                   | 18 (11.3)   | 13 (16.4)  | 0.28    | 27 (18.1)   | 14 (17.5)  | 0.91    |
| COPD                                       | 9 (5.7)     | 8 (10.1)   | 0.21    | 13 (8.7)    | 8 (10)     | 0.75    |
| NYHA class (III + IV)                      | 24 (15.2)   | 20 (25.3)  | 0.59    | 35 (23.5)   | 21 (26.2)  | 0.64    |
| LV Dysfunction (grade III + IV)            | 3 (1.9)     | 2 (2.5)    | 0.75    | 6 (4)       | 2 (2.5)    | 0.55    |
| Preoperative AMI                           | 23 (14.6)   | 12 (15.2)  | 0.90    | 24 (16.1)   | 12 (15)    | 0.83    |
| Preoperative Cardiac arrest                | 2 (1.2)     | 1 (1.2)    | 1.00    | 2 (1.3)     | 1 (1.2)    | 0.95    |
| Preoperative CVA                           | 7 (4.4)     | 2 (2.5)    | 0.47    | 6 (4)       | 2 (2.5)    | 0.55    |
| Preoperative AF                            | 5 (3.2)     | 3 (3.8)    | 0.80    | 4 (2.7)     | 3 (3.7)    | 0.65    |
| Preoperative Creatinine, mean ± SD, µmol/L | 84.1 ± 49   | 84.3 ± 24  | 0.97    | 92.6 ± 66.3 | 84.4 ± 24  | 0.29    |
| Dialysis                                   | 2 (1.3)     | 1 (1.3)    | 1.00    | 4 (2.7)     | 1 (1.2)    | 0.48    |
| Multivessel disease                        | 73 (46.2)   | 34 (43)    | 0.64    | 61 (41)     | 35 (43.7)  | 0.68    |
| Extracardiac arteriopathy                  | 9 (5.7)     | 1 (1.3)    | 0.11    | 14 (9.4)    | 1 (1.2)    | 0.18    |
| Beta-blockade usage                        | 114 (72.1)  | 53 (67.1)  | 0.54    | 110 (73.8)  | 54 (67.5)  | 0.31    |
| Intraoperative results                     |             |            |         |             |            |         |
| N of bypass mean                           | 2.6 ± 0.6   | 1.1 ± 0.3  | <0.001  | 3.4 ± 1     | 1.1 ± 0.3  | <0.001  |
| LITA use                                   | 158 (100)   | 79 (100)   | -       | 149 (100)   | 80 (100)   | -       |
| HCR                                        | NA          | 30 (37.9)  | -       | NA          | 30 (37.5)  | -       |
| Reverse HCR                                | NA          | 10 (12.6)  | -       | NA          | 10 (12.5)  | -       |
| CBP time mean ± SD, min                    | 74.4 ± 26.9 | 104 ± 11.6 | -       | NA          | 104 ± 11.6 | -       |
| Clamp time mean ± SD, min                  | 47.2 ± 18.3 | 0          | -       | NA          | 0          | -       |
| Sternotomy (conversion)                    | NA          | 2 (2.5)    | -       | NA          | 2 (2.5)    | -       |

Abbreviations: AF: atrial fibrillation; AMI: acute myocardial infarct; BMI: body mass index; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; COPD: chronic obstructive pulmonary disease; CVA: cerebrovascular accident; HCR: hybrid coronary revascularization; LITA: left internal thoracic artery; LV: left ventricular; NYHA: New York Heart Association; OPCAB: off-pump coronary artery bypass; RA-MIDCAB: robotic-assisted minimally invasive direct coronary artery bypass.

## RESULTS: Postoperative 30-day hospital stay and complications

Postoperative 30-day hospital stay and complications among patients undergoing CABG versus RA-MIDCAB and OPCAB versus RA-MIDCAB, following propensity score matching.

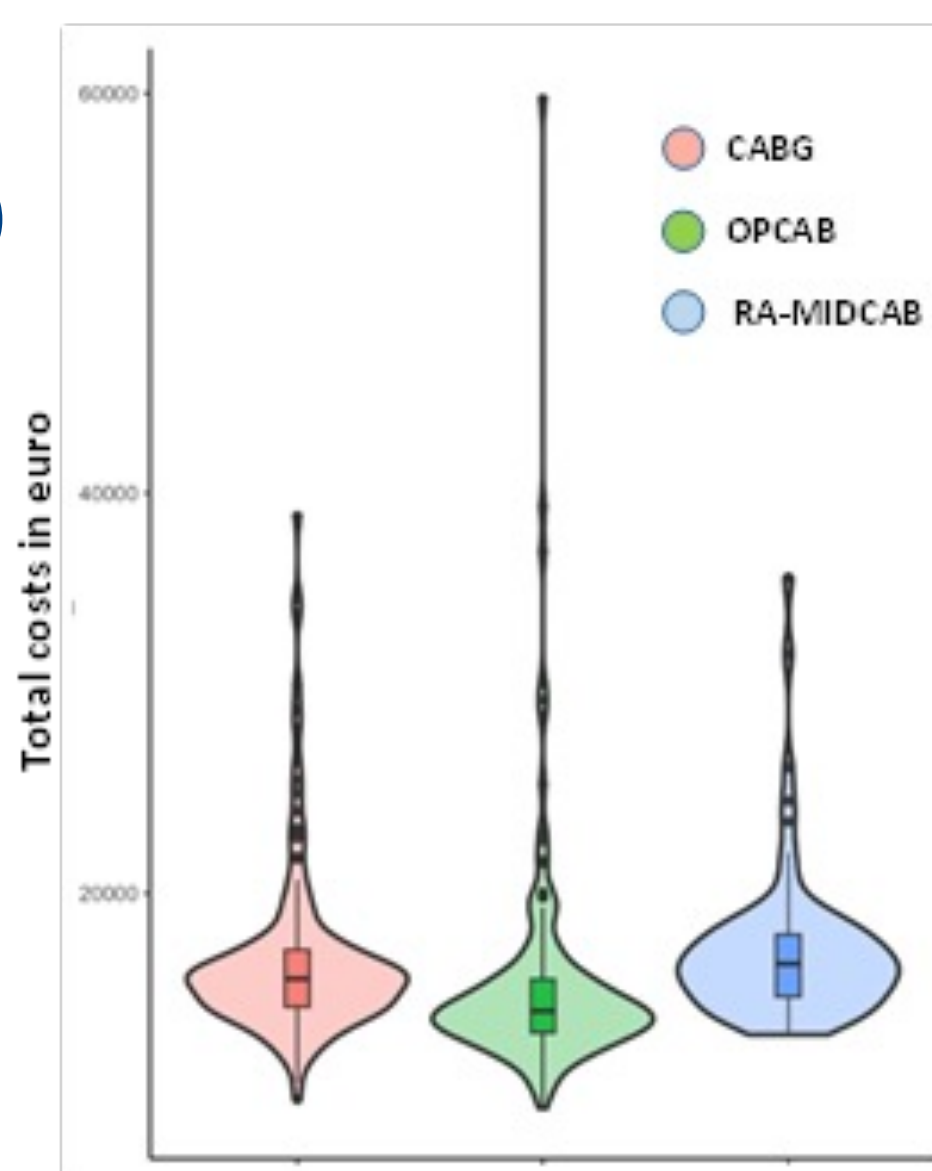
| 30-days Outcomes          | CABG      | RA-MIDCAB | p-value | OPCAB     |           | RA-MIDCAB | p-value |
|---------------------------|-----------|-----------|---------|-----------|-----------|-----------|---------|
|                           |           |           |         | 149 (100) | 80 (100)  |           |         |
| N (%)                     | 158 (100) | 79 (100)  |         |           |           |           |         |
| MACCE                     | 2 (1.3)   | 1 (1.3)   | 1.00    | 4 (2.6)   | 1 (1.2)   | 0.48      |         |
| CVA                       | 1 (0.6)   | 0         | 0.48    | 2 (1.3)   | 0         | 0.30      |         |
| AMI                       | 1 (0.6)   | 0         | 0.50    | 2 (1.3)   | 0         | 0.30      |         |
| Graft dysfunction         | 1 (0.6)   | 1 (1.3)   | 0.62    | 2 (1.3)   | 1 (1.2)   | 0.95      |         |
| Bleeding                  | 4 (2.5)   | 2 (2.5)   | 0.79    | 2 (1.3)   | 2 (2.5)   | 0.52      |         |
| Re-Thoracotomy            | 6 (3.2)   | 3 (3.8)   | 1.00    | 3 (2)     | 3 (3.7)   | 0.43      |         |
| Renal failure             | 1 (0.6)   | 0         | 0.48    | 2 (1.3)   | 0         | 0.30      |         |
| Dialysis                  | 0         | 0         | -       | 0         | 0         | -         |         |
| Cardiac arrest            | 1 (0.6)   | 0         | 0.48    | 0         | 0         | -         |         |
| Pneumonia                 | 7 (4.4)   | 1 (1.3)   | 0.20    | 3 (2)     | 1 (1.2)   | 0.67      |         |
| AF                        | 21 (13.3) | 9 (11.4)  | 0.70    | 18 (12.1) | 9 (11.2)  | 0.85      |         |
| UTI                       | 1 (0.6)   | 0         | 0.48    | 1 (0.7)   | 0         | 0.46      |         |
| Septicemia                | 2 (1.3)   | 0         | 0.31    | 0         | 0         | -         |         |
| Sternal infection         | 2 (1.3)   | 0         | 0.31    | 1 (0.7)   | 0         | 0.46      |         |
| Transfusion (RBC)         | 7 (4.4)   | 3 (3.8)   | <0.001  | 6 (4)     | 3 (3.7)   | 0.54      |         |
| Blood products            | 12 (7.6)  | 4 (5.1)   | 0.46    | 9 (6)     | 4 (5)     | 0.75      |         |
| ICU stay, mean, days      | 1 ± 0.4   | 0.6 ± 0.7 | <0.001  | 1.1 ± 0.7 | 0.6 ± 0.7 | <0.001    |         |
| Prolonged ventilation     | 1 (0.6)   | 0         | 0.48    | 5 (3.3)   | 0         | 0.17      |         |
| Re-admission ICU          | 4 (2.5)   | 0         | 0.15    | 3 (2)     | 0         | 0.20      |         |
| Re-Intubation             | 3 (1.9)   | 0         | 0.22    | 2 (1.3)   | 0         | 0.30      |         |
| Death (within 30 days)    | 0         | 0         | -       | 0         | 0         | -         |         |
| Death (within 120 days)   | 2 (1.3)   | 0         | 0.31    | 2 (1.3)   | 0         | 0.30      |         |
| Hospital stay, mean, days | 4.8 ± 2.7 | 4 ± 2     | 0.24    | 5.3 ± 3.6 | 4 ± 2     | 0.008     |         |
| Discharge home            | 61 (38.6) | 59 (74.7) | <0.001  | 56 (37.6) | 60 (75)   | <0.001    |         |

Numbers shown are counts (%) unless otherwise indicated.

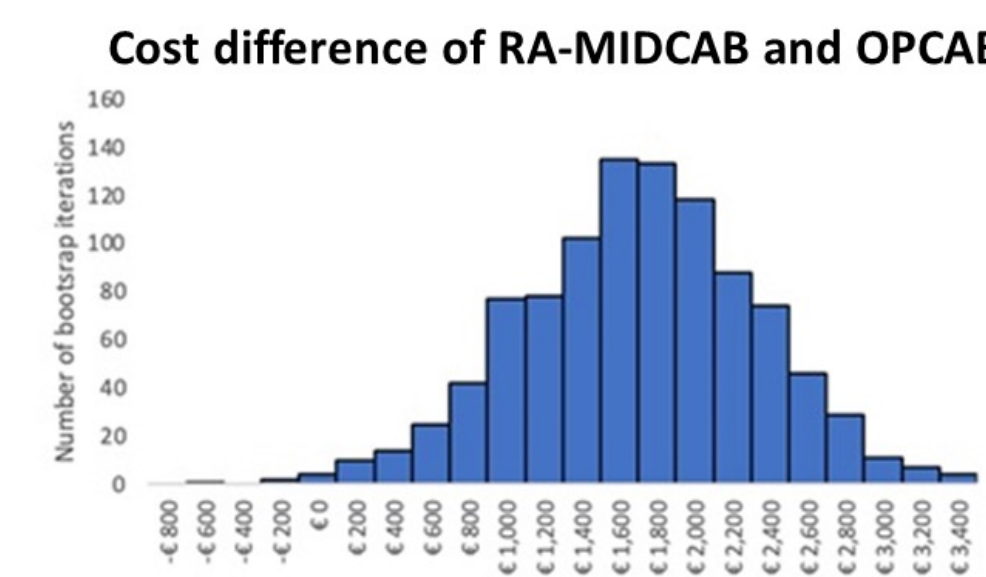
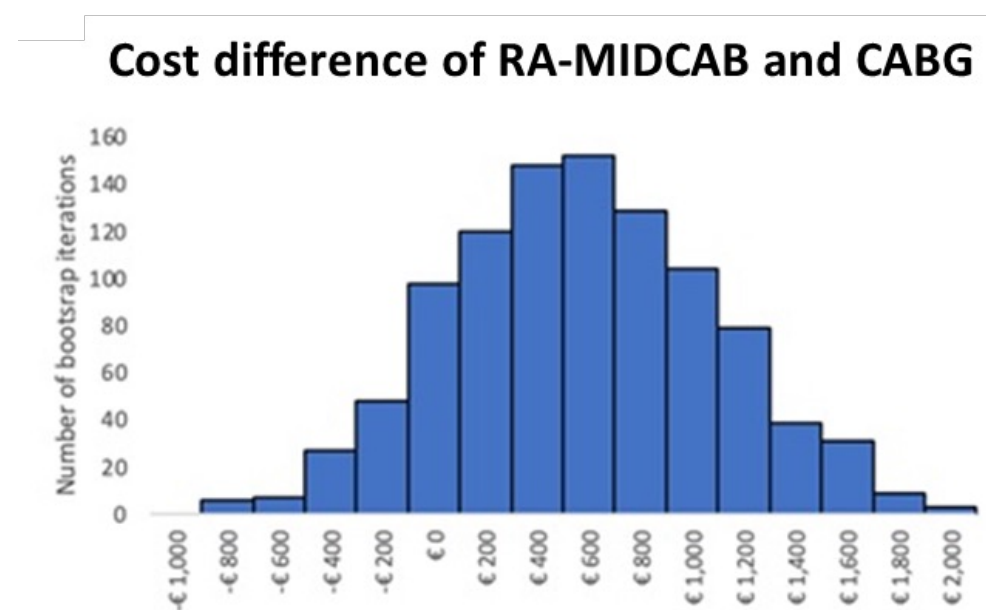
Abbreviations: AF: atrial fibrillation; AMI: acute myocardial infarction; CABG: coronary artery bypass grafting; CVA: cerebrovascular accident; ICU: intensive care unit; MACCE: major adverse cardiac and cerebrovascular accident; OPCAB: off-pump coronary artery bypass; RA-MIDCAB: robotic-assisted minimally invasive direct coronary artery bypass; UTI: urinary tract infection.

## TOTAL COSTS per patient per procedure and COST-DIFFERENCE per procedure in euro

Average cost per patient:  
RA-MIDCAB: €17,121 (€16,781- €33,294)  
CABG: €16,571 (€16,664 - €41,860)  
OPCAB: €15,463 (€10,895 - €57,867)



Violin plots showing the distribution of total costs for the patients that underwent RA-MIDCAB, CABG and OPCAB with on the y-axis the costs and the width of the violin representing the number of patients at each cost level.

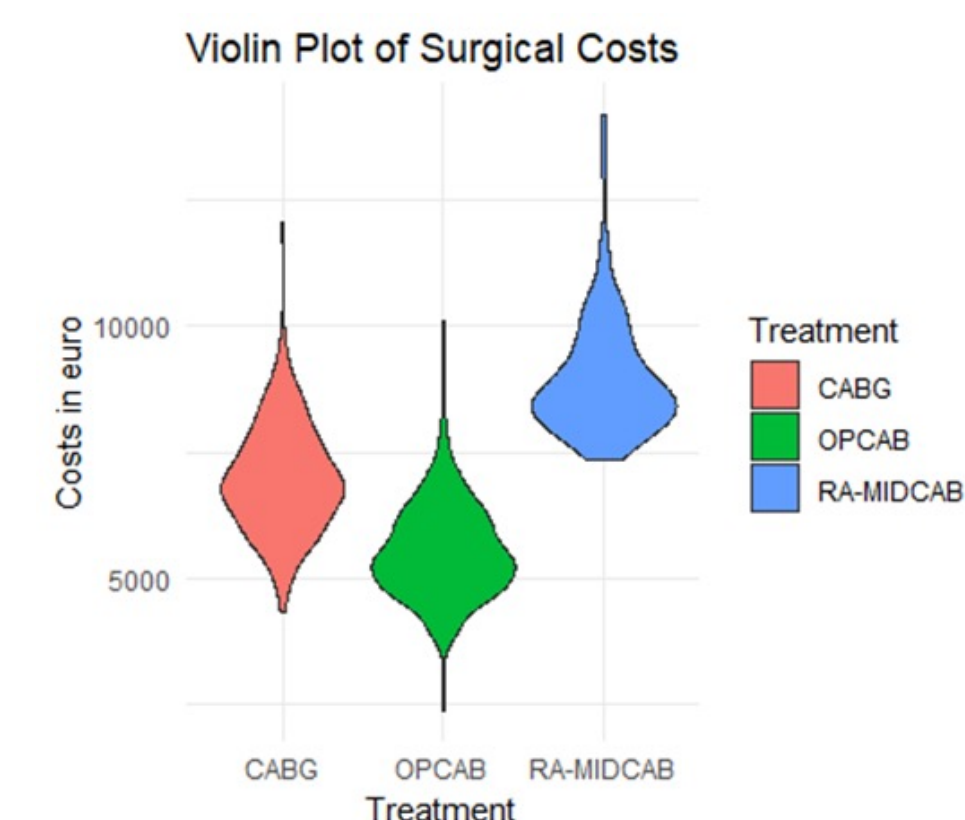


After bootstrap iterations, RA-MIDCAB was found to be €472 (2.8%) and €1,599 (10.3%) more expensive per patient than CABG and OPCAB, respectively

The number of bootstrapped iterations into categories of total cost-difference between RA-MIDCAB and CABG and OPCAB.

## OPERATIVE COSTS

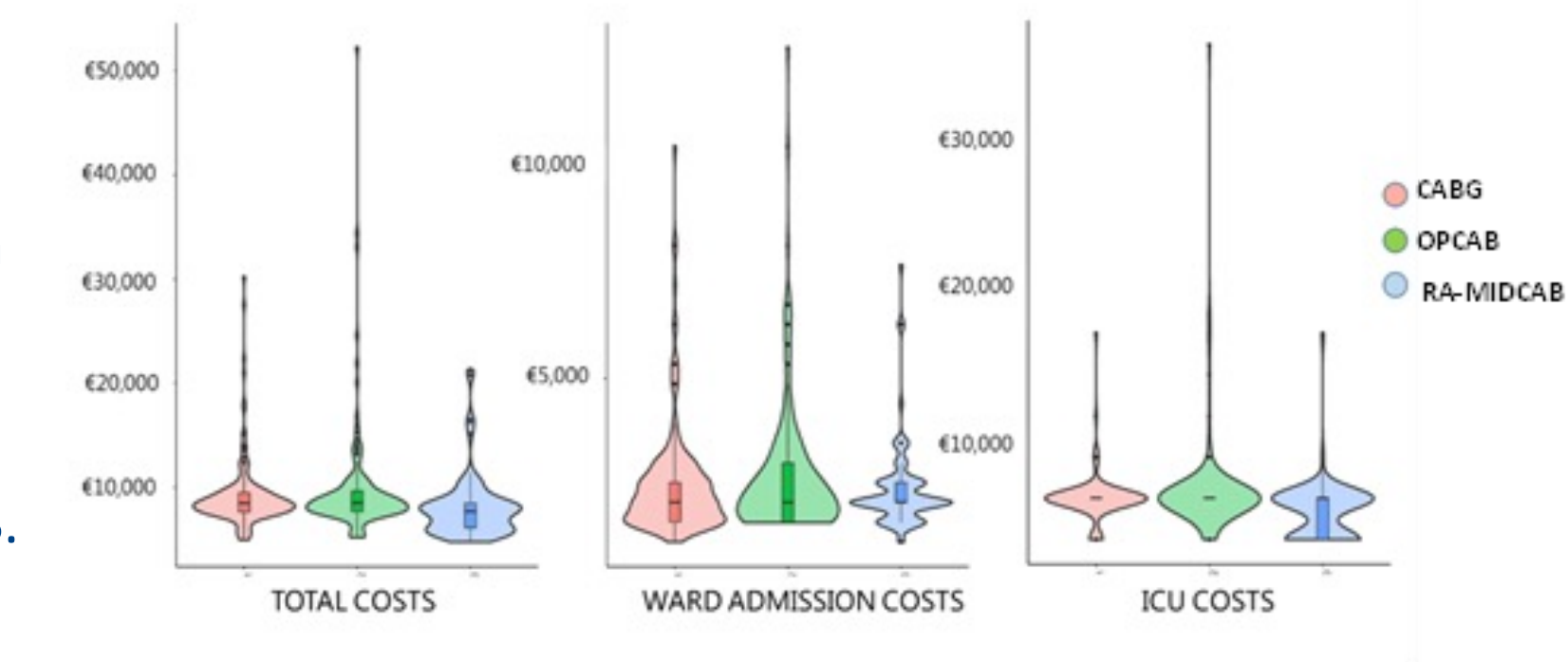
The average surgical costs for the different procedures were:  
RA-MIDCAB: €8,992 (SD± €1205). €5,254 ± €1109 due to operation time (238.8 minutes)  
CABG: €7,367 (SD± €1,588). €4,892 ± €1,588 due to operation time  
OPCAB: €5,690 (SD± €1,738). €4,334 ± €1,738 due to operation time



Violin plots showing the distribution of surgical costs for the patients that underwent RA-MIDCAB, CABG and OPCAB with on the y-axis the costs and the width of the violin representing the number of patients at each cost level. Robotic depreciation and maintenance costs are excluded in this figure.

## POST-OPERATIVE COSTS

RA-MIDCAB showed a larger proportion of patients having lower postoperative costs and a smaller proportion of outliers with higher costs than the patient's receiving CABG or OPCAB.



Violin plots showing the distribution of postoperative total costs, ward admission costs and ICU costs until 30 days after surgery for the patients that underwent RA-MIDCAB, CABG and OPCAB with on the y-axis the costs and the width of the violin representing the number of patients at each cost level.

## POST-OPERATIVE COSTS

When compared to CABG, the costs of the clinical outcomes within 30-days postoperatively after RA-MIDCAB were on average €1,075 per patient cheaper.

|                       | RA-MIDCAB N= 79 |         |          | CABG N = 158 |         |          | Difference in means | P-value |
|-----------------------|-----------------|---------|----------|--------------|---------|----------|---------------------|---------|
|                       | mean            | median  | min-max  | mean         | median  | min-max  |                     |         |
| Ward admissions       | € 2,281         | € 1,948 | € 974    | € 2,416      | € 1,948 | € 974    | -€ 136              | 0.43    |
| ICU admissions        | € 4,637         | € 5,593 | € 7,792  | € 5,628      | € 5,593 | € 10,714 | -€ 991              | <0.001  |
| Reoperations          | € 17            | € 0     | € 16,779 | € 58         | € 0     | € 2,797  | -€ 42               | 0.20    |
| Blood transfusion     | € 94            | € 0     | € 0      | € 205        | € 0     | € 1,320  | -€ 111              | 0.004   |
| Consultations         | € 80            | € 0     | € 0      | € 67         | € 0     | € 1,260  | € 13                | 0.56    |
| Expensive medication* | € 102           | € 0     | € 1,550  | € 10         | € 0     | € 1,131  | € 92                | 0.18    |
| Imaging               | € 275           | € 206   | € 82     | € 219        | € 165   | € 861    | € 55                | 0.01    |
| Lab tests             | € 373           | € 331   | € 1,078  | € 344        | € 281   | € 959    | € 29                | 0.38    |
| Other diagnostics     | € 260           | € 231   | € 182    | € 240        | € 231   | € 1,128  | € 20                | 0.28    |
| Other costs           | € 11            | € 0     | € 0      | € 17         | € 0     | € 46     | -€ 6                | 0.67    |
| Total costs           | € 8,130         | € 7,707 | € 21,308 | € 9,204      | € 8,505 | € 30,181 | -€ 1,075            | 0.02    |

\* One patient affected by hemophilia A, was treated by recombinant concentrate of clotting factor VII (Eloctate).

Costs of hospital procedures until 30 days after surgery for the RA-MIDCAB and CABG patients.

|                       | RA-MIDCAB N= 80 |         |          | OPCAB N = 149 |         |          | Difference in means | p-value |
|-----------------------|-----------------|---------|----------|---------------|---------|----------|---------------------|---------|
|                       | Mean            | median  | min-max  | mean          | median  | min-max  |                     |         |
| Ward admissions       | € 2,277         | € 1,948 | € 974    | € 2,644       | € 1,948 | € 1,450  | -€ 367              | 0.08    |
| ICU admissions        | € 4,614         | € 5,593 | € 7,792  | € 5,978       | € 5,593 | € 13,149 | -€ 1,364            | <0.001  |
| Reoperations          | € 17            | € 0     | € 16,779 | € 18          | € 0     | € 36,355 | -€ 1                | 0.94    |
| Blood transfusion     | € 93            | € 0     | € 0      | € 128         | € 0     | € 1,320  | -€ 35               | 0.32    |
| Consultations         | € 84            | € 0     | € 0      | € 90          | € 0     | € 1,476  | -€ 6                | 0.95    |
| Expensive medication* | € 101           | € 0     | € 1,550  | € 10          | € 0     | € 1,221  | € 90                | 0.20    |
| Imaging               | € 275           | € 206   | € 82     | € 243         | € 165   | € 1,078  | € 32                | 0.22    |
| Lab tests             | € 374           | € 334   | € 182    | € 380         | € 306   | € 1,461  | -€ 6                | 0.85    |
| Other diagnostics     | € 261           | € 231   | € 182    | € 252         | € 231   | € 134    | € 9                 | 0.47    |
| Other costs           | € 11            | € 0     | € 0      | € 30          | € 0     | € 3,141  | -€ 19               | 0.56    |
| Total costs           | € 8,106         | € 7,707 | € 21,308 | € 9,773       | € 8,540 | € 3,529  | -€ 1,667            | 0.03    |

\* One patient affected by hemophilia A, was treated by recombinant concentrate of clotting factor VII (Eloctate).

Costs of hospital procedures until 30 days after surgery for the RA-MIDCAB and OPCAB patients.

## CONCLUSIONS

In an era of financial constraints, this study has demonstrated that implementing robotic technology for minimally invasive revascularization in the Netherlands did not impose a negative financial burden on hospital resources. While there are high costs associated with robotic implementation during the intraoperative phase, postoperative costs appear to be lower compared to traditional CABG and OPCAB procedures. However, these postoperative cost comparisons may not hold true when the costs of complementary PCIs for HCR are included. Optimizing surgical time and awareness in the depreciation and maintenance fees of robotic technology is crucial to further enhance the cost-effectiveness of robotic procedures

## TAKE HOME MESSAGE

RA-MIDCAB's implementation had minimal impact on hospital resources relative to CABG, despite initial increased operative times due to the learning curve. The additional costs of robotic surgery were largely offset by reduced postoperative hospital stays.