Short-Term and Mid-Term Clinical Outcomes Following Hybrid Coronary Revascularization Versus Off-Pump Coronary Artery Bypass: A Meta-Analysis

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Abstract

Background: Off-pump coronary artery bypass grafting (OPCAB) is one of the standard treatments for coronary artery disease (CAD) while hybrid coronary revascularization (HCR) represents an evolving revascularization strategy. However, the difference in outcomes between them remains unclear.

Objective: We performed a meta-analysis to compare the short-term and mid-term outcomes of HCR versus OPCAB for the treatment of multivessel or left main CAD.

Methods: We searched the PubMed, EMBASE, Web of Science and Cochrane databases to identify related studies and a routine meta-analysis was conducted.

Results: Nine studies with 6121 patients were included in the analysis. There was no significant difference in short-term major adverse cardiac and cerebrovascular event (MACCE) rate (RR: 0.55, 95% CI: 0.30–1.03, p = 0.06) or mortality (RR: 0.51, 95% CI: 0.17–1.48, p = 0.22). HCR required less ventilator time (SMD: -0.36, 95% CI: -0.55– -0.16, p < 0.001), ICU stay (SMD: -0.35, 95% CI: -0.58 – -0.13, p < 0.01), hospital stay (SMD: -0.29, 95% CI: -0.50– -0.07, p < 0.05) and blood transfusion rate (RR: 0.57, 95% CI: 0.49–0.67, p < 0.001), but needed more operation time (SMD: 1.29, 95% CI: 0.54–2.05, p < 0.001) and hospitalization costs (SMD: 1.06, 95% CI: 0.45–1.66, p < 0.001). The HCR group had lower mid-term MACCE rate (RR: 0.49, 95% CI: 0.26–0.92, p < 0.05) but higher rate in mid-term target vessel revascularization (TVR, RR: 2.20, 95% CI: 1.32–3.67, p < 0.01).

Conclusions: HCR had similar short-term mortality and morbidity comparing to OPCAB. HCR decreased the ventilator time, ICU stay, hospital stay, blood transfusion rate and increased operation time and hospitalization costs. HCR has a lower mid-term MACCE rate while OPCAB shows better in mid-term TVR. (Arq Bras Cardiol. 2018; 110(4):321-330)

Keywords: Coronary Artery Disease/surgery; Coronary Artery Bypass, Off-Pump; Myocardial Revascularization/trends; Meta-Analysis; Database Bibliographic.

Introduction

Surgical revascularization still plays an essential role in the treatment of coronary artery disease (CAD) even in the era of widely prevalent percutaneous coronary intervention (PCI). As the most classical and widespread procedure for revascularization, coronary artery bypass grafting (CABG) has been considered the gold standard therapy in the past decades. In order to be safe and less disruptive, hybrid coronary revascularization (HCR) and off-pump coronary artery bypass grafting (OPCAB) which combines an off-pump technique with total arterial grafting. Recent years, more and more cardiac centers in the world have adopted OPCAB and HCR. It has been intensively discussed whether OPCAB is superior for CAD compared with on-pump CABG, but it remains uncertain. A recent randomized controlled trial (RCT) including 4752 patients found that the outcomes of death, stroke, myocardial infarction, renal failure or repeat revascularization at 5-year follow-up were similar among patients who underwent OPCAB or on-pump CABG. Another research investigated 3445 patents with a 13-year follow-up and drew conclusions that both OPCAB and on-pump CABG were safe and effective, and no significant difference was observed between them. However, a meta-analysis including 12 studies detected a lower rate of death and adverse effects after OPCAB compared with conventional CABG. Generally speaking, OPCAB is considered as lower incidence of neurological complications (including stroke, cognitive decline, etc.), in addition to a comparable less mortality and morbidity, particularly in high-risk groups and elderly patients.

HCR combines minimally invasive CABG and PCI, offering a relatively atraumatic therapy for multivessel CAD. HCR utilizes a left internal mammary artery (LIMA) graft to the left anterior...
descending (LAD) coronary artery with drug-eluting stents (DES) to non-LAD target coronary arteries. Several studies have proved the excellent postoperative survival (higher than 99%) and LIMA patency rates (higher than 95%) of HCR, suggesting HCR should be considered as an alternative approach for patients with multivessel CAD. A study in France confirmed the feasibility and safety of HCR and also detected that HCR compared favorably to those with traditional CABG alone. In addition, both of simultaneous and staged HCR were indicated to be efficient and feasible with favorable outcomes at more than 12-month follow-up. However, a 1-year clinical follow-up study angiographically showed a high rate of repeat revascularization after HCR. In addition, a transient reduction in the antiplatelet effect of aspirin and clopidogrel was observed after HCR despite limited surgical trauma and off-pump technique. Neither baseline platelet aggregation nor postoperatively increased platelet turnover and acute-phase response could explain it. Therefore, further research is badly needed.

Currently, several comparative studies about the clinical outcomes of OPCAB and HCR are available. Nonetheless, the optimal surgical strategy remains disputable. In the present analysis, we sought to compare the short-term and mid-term clinical outcomes of HCR versus OPCAB for the treatment of multivessel or left main CAD with a pooled data.

Methods

Search strategy and selection criteria

We searched four electronic bibliographic databases including PubMed, EMBASE, Web of Science and Cochrane by using following keywords with different combinations: “coronary artery disease”, “multivessel coronary artery disease”, “left main coronary artery disease”, “no-touch coronary artery bypass”, “off-pump coronary artery bypass”, “hybrid coronary revascularization”, “minimally invasive coronary artery bypass” and “percutaneous coronary intervention”. The searches were limited to human studies and English-language literatures only. The last search date was March 1, 2017.

Inclusion criteria were: (1) RCTs, cohort studies or case-control trials (CCT) comparing the outcomes of HCR and OPCAB; (2) at least 15 participants in each group; (3) available to get complete data. In addition, exclusion criteria were: (1) duplicated papers that fail to provide supplementary information; (2) unfinished studies or unavailable data; (3) studies with obvious defects in design or data statistics. Two researchers selected literatures and any disagreements were resolved through consensus.

Data extraction and quality assessment

For articles approved in the primary selection, two reviewers assessed the quality of studies and extract data independently. The CONSORT statement and STROBE statement were used to measure the quality of RCTs and observational studies, respectively. Low-quality studies should be excluded and any disagreements were resolved by consensus or judged by the senior author.

Statistical analysis

We performed the analyses using RevMan 5.3 software (Cochrane Collaboration, Copenhagen, Denmark). Relative risk (RR) with 95% confidence interval (CI) was calculated for dichotomous variables and standardized mean difference (SMD) with 95% CI was calculated for continuous variables. Forest plots were presented graphically for all clinical outcomes. Statistical heterogeneity between studies was calculated using chi-squared test and the I-squared measure on a scale of 0-100% (less than 50% represented a low heterogeneity, 50%-75% indicated a moderate inconsistency and higher than 75% meant a large degree of heterogeneity). Fix-effect model was used in analysis with heterogeneity < 50% while random-effect model was conducted with heterogeneity ≥ 50%. In addition, publication bias of short-term (in-hospital or 30-day) MACCE rate was also assessed using funnel plot. Two-sided p value < 0.05 was considered statistically significant.

Results

Literature selection and characteristics of studies

The process of literature selection for potentially eligible studies and exclusion reasons is illustrated using a flow diagram in Figure 1. Initially, 1045 published articles were identified (455 from PubMed, 469 from EMBASE, 106 from Web of Science and 15 from Cochrane). Overall, 52 unduplicated English articles related to HCR and OPCAB were selected from these citations. Finally, nine observational studies with 6121 patients were included in the present analysis.

The basic characteristics of these studies are presented in Table 1. Among 6121 patients, 5418 (88.5%) subjects got OPCAB while 290 (4.7%) patients received staged HCR and 398 (6.7%) patients received simultaneous HCR. For those who underwent HCR, minimal invasive techniques such as endoscopic atrumatic coronary artery bypass (endo-ACAB), mini-sternotomy and mini-thoracotomy were utilized. Most of them received DES and a combination of aspirin and clopidogrel was applied as a preventive antiplatelet therapy. Short-term (in-hospital or 30-day) and mid-term clinical outcomes are shown in Table 2.

Short-term outcomes

As illustrated in Table 3, there was no significant difference in short-term MACCE rate (relative risk (RR): 0.55, 95% confidence interval (CI): 0.30–1.03, p = 0.06; p...
Literatures were searched in Pubmed, EMBASE, Web of Science and Cochrane databases.

Articles identified from databases above: 1045

Articles included in the meta-analysis: 9

Duplicated papers: 399
Non-English: 124
Irrelevant papers: 470

Case report: 2
Review or meta-analysis: 14
Letter or comment: 5
Conference abstract: 1
Others did not meet the inclusion criteria: 21

Figure 1 – Flow diagram shows the process of literature selection.

for heterogeneity = 0.85, I² = 0%) or mortality (RR: 0.51, 95% CI: 0.17–1.48, p = 0.22; p for heterogeneity = 0.99, I² = 0%) or stroke (RR: 0.93, 95% CI: 0.28–3.05, p = 0.90; p for heterogeneity = 1.00, I² = 0%) between the two groups. HCR required less ventilator time (standardized mean difference (SMD): -0.36, 95% CI: -0.55– -0.16, p < 0.001), ICU stay (SMD: -0.35, 95% CI: -0.58– -0.13, p < 0.01), hospital stay (SMD: -0.29, 95% CI: -0.50– -0.07, p < 0.05) and blood transfusion rate (relative risk (RR): 0.57, 95% CI: 0.49–0.67, p < 0.001), but needed more operation time (SMD: 1.29, 95% CI: 0.54–2.05, p < 0.001) and hospitalization costs (SMD: 1.06, 95% CI: 0.45–1.66, p < 0.001).

Subgroup analysis

Table 3 also showed the subgroup analysis, which was performed by dividing the studies into staged-HCR group and simultaneous-HCR group. No statistical difference was observed in short-term MACCE rate or mortality in the two subgroups (p value in both subgroups > 0.05).

Mid-term outcomes

The studies that contained mid-term outcomes were included in the analysis. As shown in Figure 2, the HCR group had lower MACCE rate (RR: 0.49, 95% CI: 0.26–0.92, p < 0.05, P for heterogeneity = 0.26, I² = 25%) but had higher rate in TVR (RR: 2.20, 95% CI: 1.32–3.67, p < 0.01, P for heterogeneity = 0.46, I² = 0%) in mid-term follow. No significant difference in mid-term mortality was detected between the two groups (RR: 0.47, 95% CI: 0.17–1.32, p < 0.01, P for heterogeneity = 0.34, I² = 7%).

Heterogeneity

In the current analysis, no obvious heterogeneity was found between studies in either short-term or mid-term MACCE rate and mortality (p for heterogeneity > 0.05, I² < 50%). And subgroup analysis showed no heterogeneity (p for heterogeneity = 0.95, I² = 0%).

Publication bias

The funnel graph of short-term MACCE rate was established in Figure 3, and there was no evident publication bias among all included studies by visual examination.

Discussion

The present meta-analysis shows that HCR, compared with OPCAB, seems not to significantly improve short-term mortality and morbidity of postoperative complications for patients with CAD. These results are similar to previous research. Hu first systematically compared the short-term clinical outcomes after HCR versus OPCAB for the treatment of multivessel or left main CAD, and most of the results were consistent with the current analysis. However, some differences between the two analyses should be also mentioned. We excluded one study due to small sample size (less than 15 patients), outdated...
Table 1 – Characteristics of the included studies

| Reference | Year | Setting | Mean age (years) | Follow-up | Number of patients | Primary endpoint | Antiplatelet strategy | Stents | Baseline LVEF (%) | Post-procedure LVEF (%) |
|-----------|------|---------|------------------|-----------|--------------------|-----------------|--------------------|--------|------------------|---------------------|
| Kon       | 2008 | In-hospital | 61.0 ± 10.0 | 1 year | 15                | MACCE           | Strategy           | DES    | 47.0 ± 14.0      | 61.0 ± 10.0          |
| Vassiliades| 2009 | In-hospital | 64.7 ± 13.7 | 1 year | 91                | MACCE           | Strategy           | DES    | 51.5 ± 9.4       | 64.7 ± 13.7          |
| Hu        | 2010 | In-hospital | 61.8 ± 10.2 | Mean 18 months | 104               | MACCE           | Strategy           | DES    | 62.4 ± 6.9       | 61.8 ± 10.2          |
| Halkos    | 2011 | Median 3.2 years | 64.3 ± 12.8 | 147               | 64.3 ± 12.8      | MACCE           | Strategy           | DES    | 54.6 ± 8.7       | 64.3 ± 12.8          |
| Halkos    | 2011 | Median 3.2 years | 63.9 ± 10.5 | 27               | 63.9 ± 10.5      | MACCE           | Strategy           | DES    | 56.6 ± 7.7       | 63.9 ± 10.5          |
| Bachinsky | 2012 | In-hospital and 30-day MACCE | 63.2 ± 10.5 | 25               | 63.2 ± 10.5      | MACCE           | Strategy           | DES    | 55.3 ± 10.4       | 63.2 ± 10.5          |
| Zhou      | 2013 | In-hospital | 62.0 ± 10.1 | 30 days | 141               | MACCE           | Strategy           | DES    | 61.8 ± 6.9       | 62.0 ± 10.1          |
| Harskamp  | 2014 | In-hospital | 65.0 ± 6.5 | 1 year | 33                | In-hospital | Strategy           | DES    | 55.0 ± 7.5       | 65.0 ± 6.5          |
| Song      | 2016 | In-hospital | 62.8 ± 8.4 | 27               | 62.8 ± 8.4       | In-hospital | Strategy           | DES    | 60.1 ± 9.3       | 62.8 ± 8.4          |
Table 2 – Short-term and mid-term clinical outcomes of the included studies

| References | Time of outcomes | Number of patients | HCR | OPCAB |
|------------|-----------------|--------------------|-----|-------|
|            | MACCE | Death | Stroke | MI | TVR | MACCE | Death | Stroke | MI | TVR |
| Kon18      | Short-term | 15 | 0 | 0 | 0 | 0 | 30 | 7 | 0 | 1 | 6 | 0 |
| Vassiliades19 | Short-term | 91 | 1 | 0 | 1 | 0 | 0 | 4175 | 126 | 74 | 47 | 20 | 12 |
| Hu20       | Short-term | 104 | 0 | 0 | 0 | 0 | 104 | 0 | 0 | 0 | 0 | 0 |
| Halkos21   | Short-term | 147 | 3 | 1 | 1 | 1 | 0 | 588 | 12 | 5 | 4 | 3 | 0 |
| Halkos22   | Mid-term | 147 | -- | -- | -- | -- | 13 | 588 | -- | -- | -- | -- | 18 |
| Bachinsky23 | Short-term | 27 | 0 | 0 | 0 | 0 | 81 | 4 | 3 | 0 | 2 | 0 |
| Zhou24     | Short-term | 147 | 3 | 1 | 1 | 1 | 0 | 588 | 12 | 5 | 4 | 3 | 0 |
| Harskamp25 | Mid-term | 33 | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 18 |
| Song26     | Mid-term | 120 | 8 | 3 | 0 | 0 | 5 | 237 | 19 | 6 | 8 | 2 | 6 |

HCR: hybrid coronary revascularization, OPCAB: Off-pump coronary artery bypass grafting, MACCE: major adverse cardiac and cerebrovascular event, MI: myocardial infarction, TVR: target vessel revascularization.

Table 3 – Summary of results for short-term clinical outcomes of HCR versus OPCAB

| Outcomes                  | Number of studies | Total numbers of patients | SMD or RR | 95% CI             | p value |
|---------------------------|-------------------|---------------------------|-----------|--------------------|---------|
| Short-term MACCE rate     | 8                 | 5761                      | 0.55      | [0.30, 1.03]       | 0.06    |
| Staged HCR                | 4                 | 5161                      | 0.58      | [0.23, 1.47]       | 0.25    |
| Simultaneous HCR          | 4                 | 600                       | 0.54      | [0.23, 1.23]       | 0.14    |
| Short-term mortality      | 8                 | 5761                      | 0.51      | [0.17, 1.48]       | 0.22    |
| Staged HCR                | 4                 | 5161                      | 0.46      | [0.12, 1.73]       | 0.25    |
| Simultaneous HCR          | 4                 | 600                       | 0.66      | [0.11, 3.88]       | 0.64    |
| Short-term stroke         | 8                 | 5761                      | 0.93      | [0.28, 3.05]       | 0.90    |
| Operation time            | 3                 | 542                       | 1.29      | [0.54, 2.05]       | < 0.001 |
| Ventilator time           | 6                 | 1981                      | -0.36     | [-0.55, -0.16]     | < 0.001 |
| ICU stay                  | 7                 | 1913                      | -0.35     | [-0.58, -0.13]     | 0.002   |
| Hospital stay             | 7                 | 1538                      | -0.29     | [-0.50, -0.07]     | 0.01    |
| Blood transfusion rate    | 6                 | 1361                      | 0.57      | [0.49, 0.67]       | < 0.001 |
| AF rate                   | 7                 | 1933                      | 1.08      | [0.83, 1.40]       | 0.56    |
| Hospitalization costs     | 3                 | 305                       | 1.06      | [0.45, 1.66]       | < 0.001 |

HCR: hybrid coronary revascularization, OPCAB: Off-pump coronary artery bypass grafting, MACCE: major adverse cardiac and cerebrovascular event, MI: myocardial infarction, AF: atrial fibrillation, SMD: standardized mean difference, RR: relative risk, CI: confidence interval.

To our knowledge, this is the first meta-analysis comparing the mid-term clinical outcomes between HCR and OPCAB so far. Our data shows that HCR has a lower mid-term MACCE rate while OPCAB shows a better result in mid-term TVR. Moreover, no significant difference in mid-term mortality was detected between the two groups. Patients undergoing the hybrid procedure have relatively better mid-term clinical outcomes probably owing to reduced myocardial manipulation.
A. Mid-term MACCE rate

| Study or Subgroup | Weight | Risk Ratio M-H, Fixed, 95% Cl | Risk Ratio M-H, Fixed, 95% Cl |
|-------------------|--------|-------------------------------|-------------------------------|
| Harskamp 2014     | 7.1%   | 0.48 [0.05, 5.09]              |                               |
| Hu 2010           | 31.6%  | 0.11 [0.01, 0.86]              |                               |
| Kon 2008          | 16.4%  | 0.29 [0.04, 2.11]              |                               |
| Song 2016         | 44.9%  | 0.83 [0.38, 1.84]              |                               |
| **Total (95 CI)** | 100.0% | **0.49 [0.26, 0.92]**         |                               |

Heterogeneity: $\chi^2 = 3.99$, df = 3 ($p = 0.26$); $I^2 = 25$

Test for overall effect: $Z = 2.21$ ($p = 0.03$)

B. Mid-term mortality

| Study or Subgroup | Weight   | Risk Ratio M-H, Fixed, 95% Cl | Risk Ratio M-H, Fixed, 95% Cl |
|-------------------|----------|-------------------------------|-------------------------------|
| Harskamp 2014     | 6.8%     | 0.97 [0.06, 14.85]            |                               |
| Hu 2010           | Not estimable |                               |                               |
| Kon 2008          | Not estimable |                               |                               |
| Song 2016         | 27.1%    | 0.99 [0.25, 3.88]             |                               |
| Vassiliades 2009  | 66.0%    | 0.20 [0.03, 1.41]             |                               |
| **Total (95 CI)** | 100.0%   | **0.47 [0.17, 1.32]**        |                               |

Heterogeneity: $\chi^2 = 4.62$, df = 2 ($p = 0.34$); $I^2 = 7$

Test for overall effect: $Z = 1.44$ ($p = 0.15$)

C. Mid-term TVR

| Study or Subgroup | Weight   | Risk Ratio M-H, Fixed, 95% Cl | Risk Ratio M-H, Fixed, 95% Cl |
|-------------------|----------|-------------------------------|-------------------------------|
| Halkos(a) 2011    | 2.1%     | 5.81 [0.25, 134.73]           |                               |
| Halkos(b) 2011    | 18.6%    | 0.33 [0.04, 3.15]             |                               |
| Harskamp 2014     | 44.7%    | 2.89 [1.45, 5.76]             |                               |
| Hu 2010           | 3.1%     | 6.00 [0.57, 63.58]            |                               |
| Kon 2008          | 6.3%     | 1.94 [0.18, 20.35]            |                               |
| Song 2016         | 25.1%    | 1.65 [0.51, 5.28]             |                               |
| **Total (95 CI)** | 100.0%   | **2.20 [1.32, 3.67]**        |                               |

Heterogeneity: $\chi^2 = 4.62$, df = 5 ($p = 0.46$); $I^2 = 0$

Test for overall effect: $Z = 3.02$ ($p = 0.003$)

Figure 2 – Meta-analysis shows the relative risk (RR) of mid-term MACCE rate, mortality and TVR. MACCE: major adverse cardiac and cerebrovascular event, TVR: target vessel revascularization, CI: confidence interval, HCR: hybrid coronary revascularization; OPCAB: off-pump coronary artery bypass grafting.

and activation of coagulation. It has been widely recognized that the dislodgement or rupture of atherosclerotic plaques during surgical aortic manipulation results in a major cause of stroke. Since the aorta is more or less affected in the surgical procedure, it is still unclear whether OPCAB can decrease postoperative stroke rate compared with on-pump CABG. In contrast, grafting in HCR only involves LAD artery while other coronary arteries are treated by PCI. As a result, low rate of neurological complications becomes one of the main advantages of HCR. Although, in the present analysis we detect no significant difference of stroke rate between OPCAB and HCR in a short-term follow-up, which seems to be contradictory to some previous analyses.

However, Song et al. reported that more patients in OPCAB group suffer from stroke than HCR group in a 30-month follow-up, which indicates that the differences may be well recognized in a long-term follow-up. In recent years, technical advances in OPCAB utilize a no-touch technique to avoid aortic manipulation during grafting. A retrospective study showed that the OPCAB with no-touch technique could improve prognosis by minimizing the neurological complications and the morbidity. Emmert et al. also reported that the aortic...
no-touch OPCAB provided superior neurological outcomes than on-pump CABG and no-touch technique should be properly applied. Halbersma et al. 32 investigated the four-year clinical outcomes after OPCAB with no-touch technique and concluded that it was a safe and efficient choice for patients with multivessel or left main CAD. Compelling data have indicated that the combination of OPCAB and clampless strategies can reduce stroke risk. However, the major shortcoming of no-touch OPCAB is its greater technical requirement so that it is not applicable for every surgical team or every patient. 33 Nevertheless, further investigations should be still carried out to compare no-touch OPCAB and HCR.

In the current analysis, neither staged HCR nor simultaneous HCR makes a difference to the short-term outcomes, which is consistent with former studies. 27 Commonly, there are three strategies for HCR: (1) performing LIMA-LAD grafting first and then followed by PCI, the interval varies from several hours to a few weeks; (2) vice versa; (3) combined LIMA-LAD grafting and PCI at the same time in a hybrid operative unit. The optimal sequence of LIMA-LAD grafting and PCI has been debated but still remains unclear. In fact, most centers choose their own surgical procedures mainly based on preferences of physicians, considerations of patients, economic issues and available resources. Although several studies have indicated that both simultaneous and staged HCR contribute to excellent results, most centers prefer to adopt the latter one with LIMA-LAD grafting performed first. 14 The CABG-first approach is recommended by the American College of Cardiology Foundation/American Heart Association 35 and it has some obvious advantages. It can reduce the overlapping from two different teams so that they can perform in their most familiar way and avoid to interacting with each other in operation room. Then antiplatelet and antithrombotic strategies can be well managed and adjusted according to physicians from different teams. 36 However, the disadvantages include that patients have to undergo at least two surgeries and need more time to recover. Moreover, hemorrhagic tendency and overload of kidneys also deserve significant attention. Currently, no study has compared the clinical outcomes of staged HCR and simultaneous HCR directly, so further research should be placed on it.

In the present analysis, we also confirm that HCR apparently decreases the ventilator time, ICU stay, hospital stay and blood transfusion rate comparing to OPCAB. Although these items may not directly influence the main outcomes, they are also important criteria to judge a surgical procedure. Several reasons may account for these advantages of HCR. With the development of surgical procedures, endoscopic technique and mini incision are widely utilized in HCR to help patients ease suffering and recover sooner. 17 And retractor-stabilizer, such as robot, provides access that LIMA-LAD grafting can be performed with accuracy and precision with minimally invasive thoracotomy or sternotomy. 38 Practically, with the assistance of a surgical robot, it offers an excellent visual field and reduces operation time. However, some drawbacks of HCR also deserve our attention. Our study detects that the hybrid procedure required longer operation time and incurred much higher in-hospital costs than OPCAB. In Bachinsky’s study, 23 despite lower postoperative costs, the HCR group still needs more overall hospital costs owning to its higher procedural costs. Consequently, pros and cons of HCR should be weighed and considered carefully before operation.
Some limitations of the present analysis should be also emphasized. Firstly, all included studies belong to observational studies and no single RCT has been conducted so far. Secondly, some included studies contain relatively small samples (fewer than 50 patients) and remain imbalance of patient number between groups so that deviation of results may inevitably exist. Thirdly, long-term patency is more convincing than short-term and mid-term outcomes, but very limited references were published with long-term follow-up so far. Finally, some uncontrolled factors may interfere with the current analysis. Variables like gender ratio and LVEF at baseline have not been adjusted. And diverse surgery procedures, stents (DES or bare stent) as well as antiplatelet strategies may disturb the accuracy of results too.

Conclusions

HCR shows similar results with OPCAB in short-term clinical outcomes. HCR decreases the ventilator time, ICU stay, hospital stay, blood transfusion rate and increases the operation time and hospitalization costs. Although repeated vessel revascularization is greater with HCR, it has a lower mid-term MACCE rate and could provide a safe and reproducible alternative for patients with multivessel CAD.

References

1. Enkner JC, Enkner IC. Coronary artery surgery: now and in the next decade. HSR Proc Intensive Care and Cardiovasc Anesth. 2012;4(4):217-23. PMID: 23439278.
2. Arom KV, Flavin TF, Emery RW, Kshettry VR, Petersen RJ, Janey PA. Is low ejection fraction safe for off-pump coronary artery bypass operation? Ann Thorac Surg. 2000;70(3):1021-5. doi: http://dx.doi.org/10.1016/S0003-4975(00)01761-6.
3. Gao C, Yang M, Wu Y, Wang G, Xiao C, Liu H, et al. Hybrid coronary revascularization by endoscopic robotic coronary artery bypass grafting on beating heart and stent placement. Ann Thorac Surg. 2009;87(3):737-41. doi: 10.1016/j.athoracsur.2008.12.017.
4. Lamy A, Devereaux PJ, Prabhakaran D, Taggart DP, Hu S, Straka Z, et al; CORONARY Investigators. Five-year outcomes after off-pump or on-pump coronary artery bypass grafting. N Engl J Med. 2016;375(24):2359-68. doi: 10.1056/NEJMoa1601564.
5. Riess FC, Heller S, Cramer E, Awwad N, Amin W, Hansen L, et al. On-pump versus off-pump complete arterial revascularization using bilateral internal mammary arteries and the t-graft technique: clinical and angiographic results for 3,445 patients in 13 years of follow-up. Cardiology. 2016;136(3):170-9. doi: 10.1159/000448428.
6. Sepehrpour AH, Chaudhry UA, Suliman A, Kidher E, Sayani N, Ashrafian H, et al. How revascularization on the beating heart with cardiopulmonary bypass compares to off-pump? A meta-analysis of observational studies. Interact Cardiovasc Thorac Surg. 2016;22(1):63-71. doi: 10.1093/icvts/ivw291.
7. Valley MP, Potger K, McMillan D, Hemilä JM, Brady PW, Breeton RJ, et al. Anaortic techniques reduce neurological morbidity after off-pump coronary artery bypass surgery. Heart Lung Circ. 2008;17(4):299-304. doi: 10.1016/j.hlc.2007.11.138.
8. Lemma GM, Consolini E, Centofanti P, Centofanti P, Fondazione C, Salica A, et al. On-pump versus off-pump coronary artery bypass surgery in high-risk patients: operative results of a prospective randomized trial (on-off study). J Thorac Cardiovasc Surg. 2012;143(3):625-31. doi: 10.1016/j.jtcvs.2011.11.011.
9. Falk V. Stay off-pump and do not touch the aorta! Eur Heart J. 2010;31(3):278-80. doi: 10.1093/eurheartj/ehp527.
10. Bonatti JO, Zimrin D, Lehr EJ, Vesely M, Kon ZN, Wehman B, et al. Hybrid coronary revascularization using robotic totally endoscopic surgery: perioperative outcomes and 5-year results. Ann Thorac Surg. 2012;94(6):1920-6. doi: 10.1016/j.athoracsur.2012.05.041.
11. Delhaye C, Sudre A, Lemesle G, Vannson L, Koussa M, Fayad G, et al. Hybrid revascularization, comprising coronary artery bypass graft with exclusive arterial conduits followed by early drug-eluting stent implantation, in multivessel coronary artery disease. Arch Cardiovasc Dis. 2010;103(10):502-11. doi: 10.1016/j.acvd.2010.09.003.
12. Adams C, Burns DJ, Chu MW, Jones PM, Shridar K, Teefy P, et al. Single-stage hybrid coronary revascularization with long-term follow-up. Eur J Cardiothorac Surg. 2014;45(3):438-43. doi: 10.1093/ejcts/ezt390.
13. Versaci F, Reimers B, Del Giudice C, Schofer J, Giacomini A, Saccà S, et al. Simultaneous hybrid revascularization by carotid stenting and coronary artery bypass grafting: the SHARP study. JACC Cardiovasc Interv. 2009;2(5):393-401. doi: 10.1016/j.jcin.2009.02.010.
14. Modrau IS, Holm NR, Maeng M, Bøtker HE, Christiansen EH, Kristensen SD, et al. One-year clinical and angiographic results of hybrid coronary revascularization. J Thorac Cardiovasc Surg. 2015;150(5):1181-6. doi: 10.1016/j.jtcvs.2015.08.072.
15. Modrau IS, Wurtz M, Kristensen SD, Hvas AM. Reduced effect of aspirin and clopidogrel following hybrid coronary revascularization. Clin Appl Thromb Hemost. 2015;21(7):603-11. doi: 10.1177/1076029615573304.
16. Schulz KF, Altman DG, Moher D; CONSORT Group. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. PLoS Med. 2010;7(3):e1000251. doi: 10.1371/journal.pmed.1000251.
17. Vandenbroucke JP, Von Elm E, Altman DG, Egger M, Gøtzsche PC, Mulrow CD, et al; STROBE Initiative. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. PLoS Med. 2007;4(10):e297. doi: 10.1371/journal.pmed.0040297.

Author contributions

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18. Kon ZN, Brown EN, Tran R, Joshi A, Reicher B, Grant MC, et al. Simultaneous hybrid coronary revascularization reduces postoperative morbidity compared with results from conventional off-pump coronary artery bypass. J Thorac Cardiovasc Surg. 2008;135(2):367-75. doi: 10.1016/j.jtcvs.2007.09.025.

19. Vassiliades TA, Kilgo PD, Douglas JS, Babalarios VC, Block PC, Samady H, et al. Clinical outcomes after hybrid coronary revascularization versus off pump coronary artery bypass. Innovations (Phila). 2009;4(6):299-306. doi: 10.1097/MIN.0b013e3181b6f96.

20. Hu S, Li Q, Gao P, Xiong H, Zheng Z, Li L, et al. Simultaneous hybrid revascularization versus off-pump coronary artery bypass for multivessel coronary artery disease. Ann Thorac Surg. 2011;91(2):432-8. doi: 10.1016/j.athoracsur.2010.10.020.

21. Halkos ME, Vassiliades TA, Douglas JS, Morris DC, Rab ST, Liberman HA, et al. Hybrid coronary revascularization versus off-pump coronary artery bypass grafting for the treatment of multivessel coronary artery disease. Ann Thorac Surg. 2011;92(5):1695-701. doi: 10.1016/j.athoracsur.2011.05.090.

22. Halkos ME, Rab ST, Vassiliades TA, Morris DC, Douglas JS, Kilgo PD, et al. Hybrid coronary revascularization versus off-pump coronary artery bypass graft for the treatment of left main coronary stenosis. Ann Thorac Surg. 2011;92(6):2155-60. doi: 10.1016/j.athoracsur.2011.08.012.

23. Bachinsky WB, Abdelsalam M, Boga C, Klijanek L, Mumtaz M, McCarty C. Comparative study of same sitting hybrid coronary artery revascularization versus off-pump coronary artery bypass in multivessel coronary artery disease. J Interv Cardiol. 2012;25(5):460-8. doi: 10.1111/j.1540-8183.2012.00752.x.

24. Zhou S, Fang Z, Xiong H, Hu S, Xu B, Chen L, Wang W. Effect of one-stop hybrid coronary revascularization on postoperative renal function and bleeding; a comparison study with off-pump coronary artery bypass grafting surgery. J Thorac Cardiovasc Surg. 2014;147(5):1511-6.e1. doi: 10.1016/j.jtcvs.2013.05.026.

25. Hankamp RE, Abdelsalam M, Lopes RD, Boga C, Hirji S, Krishnan M, et al. Cardiac troponin release following hybrid coronary revascularization versus off-pump coronary artery bypass surgery. Interact Cardiovasc Thorac Surg. 2014;19(6):1008-12. doi: 10.1093/icvts/nuz297.

26. Song Z, Shen L, Zheng Z, Xu B, Xiong H, Li L, et al. One-stop hybrid coronary revascularization versus off-pump coronary artery bypass in patients with diabetes mellitus. J Thorac Cardiovasc Surg. 2016;151(6):1695-701.e1. doi: 10.1016/j.jtcvs.2016.01.049.

27. Hu FB, Cui LQ. Short-term clinical outcomes after hybrid coronary revascularization versus off-pump coronary artery bypass for the treatment of multivessel or left main coronary artery disease: a meta-analysis. Coron Artery Dis. 2015;26(6):526-34. doi: 10.1097/MCA.0000000000000265.

28. Reicher B, Poston RS, Mehra MR, Joshi A, Odonkor P, Kon Z, et al. Simultaneous ‘hybrid’ percutaneous coronary intervention and minimally invasive surgical bypass grafting: feasibility, safety, and clinical outcomes. Am Heart J. 2008;155(4):661-7. doi: 10.1016/j.ahj.2007.12.032.

29. Lev-Ran O, Braunstein R, Sharon R, Kramer A, Paz Y, Mohr R, Uretzky G. No-touch aorta off-pump coronary surgery: the effect on stroke. J Thorac Cardiovasc Surg. 2005;129(2):307-13. doi: 10.1016/j.jtcvs.2004.06.013.

30. Arigoni SC, Meccozzi G, Grandjean JC, Hillege HL, Kappetein AP, Mariani MA. Off-pump no-touch technique: 3-year results compared with the SYNTAX trial. Interact Cardiovasc Thorac Surg. 2015;20(5):601-4. doi: 10.1093/icvts/ivw012.

31. Emmert MV, Seilert B, Wilhelm M, Grünenfelder J, Falk V, Salzberg SP. Aortic no-touch technique makes the difference in off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2011;142(6):1499-506. doi: 10.1016/j.jtcvs.2011.04.031. Erratum in: J Thorac Cardiovasc Surg. 2012;143(4):995.

32. Halbersma WA, Arrigoni SC, Meccozzi G, Grandjean JC, Kappetein AP, van der Palen J, et al. Four-year outcome of OPCAB no-touch with total arterial Y-graft: making the best treatment a daily practice. Ann Thorac Surg. 2009;88(3):796-801. doi: 10.1016/j.athoracsur.2009.04.104.

33. Yanagawa B, Neadurad R, Puskas JD. The future of off-pump coronary artery bypass grafting: a North American perspective. J Thorac Dis. 2016;8(Suppl 10):S812-8. doi: 10.21037/jtd.2016.10.07.

34. Zhang L, Cui Z, Song Z, Yang H, Fu Y, Gong Y, et al. Minimally invasive direct coronary artery bypass for left anterior descending artery revascularization - a North American perspective. J Thorac Dis. 2016;8(Suppl 10):S812-8. doi: 10.21037/jtd.2016.10.07.

35. Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, et al; American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery: executive summary: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. J Thorac Cardiovasc Surg. 2011;143(1):4-34. doi: 10.1016/j.jtcvs.2011.10.015. Erratum in: J Thorac Cardiovasc Surg. 2012;143(5):1235.

36. Halkos ME, Walker PF, Vassiliades TA, Douglas JS, Deviredly C, Guyton RA, et al. Clinical and angiographic results after hybrid coronary revascularization. Ann Thorac Surg. 2014;98(3):796-801. doi: 10.1016/j.athoracsur.2013.08.041.

37. Aubin H, Alkhyari P, Lichtenberg A, Albert A. Additional right-sided upper “Half-Mini-Thoracotomy” for aortocoronary bypass grafting during minimally invasive multivessel revascularization. J Cardiothorac Vasc Anesth. 2015;29(4):1235-41. doi: 10.1053/j.jvca.2014.11.012.

38. Ejiofor JI, Leacche M, Byrne JG. Robotic CABG and hybrid approaches: the current landscape. Prog Cardiovasc Dis. 2015;58(3):356-64. doi: 10.1016/j.pcad.2015.08.012.
