Intra-operative conversion is a cause of masked mortality in off-pump coronary artery bypass: a meta-analysis

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Summary

Coronary artery bypass surgery can offer excellent results when performed with cardiopulmonary bypass (on pump) or without cardiopulmonary bypass (off pump). The debate as to which technique is superior remains unanswered. Intra-operative conversion from off- to on-pump coronary surgery is a relatively unexplored phenomenon, which cannot be assessed within randomised controlled trial design. We aimed to assess the effect of off-pump conversion on patient mortality. Medline, Embase, Cochrane and Google Scholar databases were systematically reviewed for studies published between 1980 and 2010 that compared the incidence of mortality between converted and non-converted off-pump patients. Publication bias and heterogeneity were assessed and data were extracted independently by multiple observers. We undertook a meta-analysis of these studies using random effects modelling. A total of 17 studies fulfilled our inclusion criteria, containing data for 18,870 off-pump coronary artery bypass operations spanning a decade (1998–2008), involving 920 cases of conversion. Overall, conversion increased mortality by an odds ratio of 6.18 (95% confidence interval 4.65–8.20), whereas emergency conversion further raised the odds ratio of mortality to 6.99 (95% confidence interval 5.18–9.45). The conversion from off- to on-pump cardiac surgery may significantly increase the chance of an adverse outcome, whereas emergency conversion confers a significant rise in mortality. The risk of conversion should be discussed when obtaining the patient’s informed consent and its prevention warrants serious consideration by cardiac surgeons and cardiac surgical training programmes.

Keywords: Conversion • Off-pump coronary artery bypass • Outcomes after beating heart surgery

INTRODUCTION

In 2001, in accordance with key recommendations published in the Kennedy Report (www.bristol-inquiry.org.uk), the Healthcare Commission and the Society for Cardiothoracic Surgery in Great Britain & Ireland (SCTS) began the collation and publication of mortality data for cardiac surgical units and their individual surgeons. Surgeon-specific patient survival statistics were subsequently made freely accessible on the Care Quality Commission website (http://heartsurgery.cqc.org.uk). Since then, the Sixth National Adult Cardiac Surgical Database Report in 2009 [1] published data for 400,000 patients spanning 15 years, demonstrating an impressive 21% reduction in risk-adjusted mortality in coronary artery bypass surgery (CABG) patients. These encouraging findings – coupled with the fact that no other surgical or medical specialty has adopted the policy of publishing outcomes of care (as recommended by the Kennedy Report) – highlight the central role of mortality between other quality performance indicators in cardiac surgery.

The accurate assessment of operative risk has been vital in reducing the rates of mortality in coronary surgery in addition to increased efforts for establishing the most mortality-proof techniques of revascularisation [2]. The logistic EuroSCORE (European System for Cardiac Operative Risk Evaluation) is frequently used [3] (largely replacing the older Parsonnet score) [4], although debate continues to rage regarding which conduits are ideal, whether minimal incisions offer the speediest recovery and whether or not to use cardiopulmonary bypass (CPB). This article is concerned with the latter debate – the comparison of off-pump coronary artery bypass (OPCAB) [5] and on-pump coronary artery bypass (ONCAB) – but aims to address a less-explored area within it, focussing on patients whose operations were commenced ‘off-pump’ but who required intra-operative conversion to an ‘on-pump’ strategy. Conversion may be emergency or elective, depending on the degree of urgency involved. There have been numerous randomised and non-randomised studies comparing off-pump and on-pump revascularisation, but there has been little mention of conversion or its associated patient outcomes. This may have been understandable, given that large retrospective analyses, such as that of the Society of Thoracic Surgeons (STS) national database, declare conversion rates as low as 2.2% [6]. However, these low conversion rates have recently been challenged by the Veterans Affairs Randomized On/Off Bypass (ROOBY) trial, which, regardless of
its limitations as a comparative study [7], reported conversion in almost one in eight (12.4%) OPCAB cases [8]. In similarity to the vast majority of randomised studies comparing OPCAB and ONCAB, the ROOBY trial did not report the specific outcomes of its sizeable conversion group. Although there have been institutional reports that consider the effects of intra-operative conversion from OPCAB to ONCAB surgery, there are no previous studies that systematically quantify the effects of conversion on patient mortality.

This article is a meta-analysis of studies reporting mortality in off- to on-pump conversion. Our aim was to quantify the effect of conversion on in-hospital mortality in OPCAB patients through assimilated data from the published literature and to discuss the broader implications of our findings.

METHODS

Definitions of conversion

Emergency conversion was defined as the urgent institution of CPB (with or without cardioplegia) to manage clinical instability (severe or persistent hypotension and arrhythmia), usually after commencement of coronary anastomoses. Elective conversion was defined as a semi-planned measure to prevent clinical instability, usually prior to the commencement of any coronary anastomoses. Overall conversion was considered to encompass both emergency and elective subtypes of conversion.

Search strategy

The following searching strategy was followed; we used the MeSH term ‘off-pump versus on-pump/coronary artery bypass*’ in Medline (PubMed interface) and usage of the ‘Limits’ feature to search for randomised controlled trials and meta-analyses comparing off-pump versus on-pump (first literature search). Following this, two literature searches were performed using Medline, Embase, Cochrane Library and Google Scholar databases for all studies between 1980 and 2010 reporting on ‘off-pump bypass/coronary bypass* and conversion’ or ‘beating heart/coronary bypass* and conversion’ (second and third literature search). The ‘Related Articles’ feature was used to expand our catchment of studies and reference lists from retrieved articles were reviewed to identify further studies. This meta-analysis was planned, conducted and reported in accordance with official guidelines for reporting meta-analyses of randomised and observational studies (including: www.cochrane-handbook.org) [9,10].

Eligibility criteria

The exposure of interest was intra-operative conversion from OPCAB to ONCAB and the outcome of interest was the mortality rate. Studies were included if they reported the mortality rate for converted patients (exposure group) and for non-converted patients (control group) in such a way that a comparison could be drawn. The ‘non-conversion’ reference group included both non-converted (successful) OPCAB cases and a risk-matched ONCAB group. Animal studies, non-English-language publications and studies that provided insufficient data to enable a numeric comparison of mortality between groups were excluded.

Data extraction and study quality assessment

Two reviewers (D.M. and T.A.) independently screened and reviewed all titles and abstracts identified from the search strategy and extracted the following data from the full texts of each eligible study: first author, year of publication, country of origin, study design, study period baseline patient characteristics, cardiovascular risk factors, rate of conversion (measure and range of exposure), number of non-converted cases, total number of attempted OPCAB cases, definitions of conversion used, reasons for conversion and any identified predictors of conversion. A quality score was assigned to each included study using a modified Newcastle–Ottawa scale for non-randomised cohort studies [11].

Statistical analysis

Our meta-analysis combines the odds ratio (OR) estimates for conversion mortality for each study using the random effects model, which accounts for both within- and between-study variation [12]. An OR >1, with a point estimate at the level p <0.05 and a 95% confidence interval (CI) that does not include the value 1, indicates an increased risk of mortality in converted patients compared with non-converted patients that is statistically significant. Within these statistical pre-conditions, the higher the OR value, the higher the likelihood of the adverse effect in converted patients. Aggregation of the overall rates of the outcomes of interest was performed with the Mantel-Haenszel chi-square test [13]. Yate’s correction was used for those studies that contained a zero in any cell for the number of events of interest in one of the two groups.

In the first instance, we meta-analysed conversion mortality comparing converted patients (both overall and emergency) with non-converted OPCAB patients. In the second instance, we meta-analysed mortality comparing converted patients with risk-matched ONCAB control groups, simply for the reason that seven of our included studies also offered this data in their reports.

The following quantitative and graphical methods were used to assess, explain and account for determinants of meta-analytical validity, heterogeneity and bias:

1. Statistical analysis using a random effect model.
2. Exploration of publication bias: Publication bias was assessed graphically with funnel plots to assess for asymmetry and evidence of outliers; we also performed the Egger regression asymmetry test [14] and included the Egger regression line in the funnel plots. Finally, Harbord’s modified graph was used to assess small study effects.
3. Sensitivity analysis through subgroup analysis was performed according to the statistical model used (random vs fixed), study quality, haemodynamic safety measures reported to prevent conversion, high versus low sample size (split according to median), older versus newer studies (split according to median year of publication: 2005) and elective versus emergency conversion.
Multivariate metaregression analysis was undertaken using the command ‘metareg’ in Stata and permutation test approach to calculate p-values (Monte Carlo Simulation ~20,000 permutations).

Heterogeneity assessment through the $I^2$ statistic: This represents the proportion of total variation observed between the trials attributable to differences between trials rather than sampling error (chance); the degree of heterogeneity was graded as low ($I^2 < 25\%$), moderate ($I^2 = 25–75\%$) or high ($I^2 > 75\%$).

Review Manager (RevMan) Version 5.0 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2008) and Stata/SE 10.0 for Windows (Stata Corp LP; College Station, TX, USA) were used to perform the statistical analysis.

RESULTS

Selected studies

The first, second and third literature search identified 245 articles (109, 30 and 106 articles, respectively). A total of 74 randomised and 22 non-randomised studies comparing OPCAB to ONCAB were identified, as outlined in Fig. 1. Seventeen studies were isolated using our selection criteria. The Newcastle–Ottawa quality scoring of each study is demonstrated in Table 1. The 17 selected studies [15–31] were published between 1998 and 2008 and contained data for 18,870 OPCAB cases, of which 920 were conversions to ONCAB. Of these conversions, 701 were defined as emergency, 178 were elective and, in the remaining 41, the conversion subtype was not specified. Mortality data was provided specifically for the emergency conversion subgroup in nine studies and for the elective conversion subgroup in three studies. Only two of these studies provided mortality data for both emergency and elective subgroups. One study [18] only compared converted patients to a risk-matched ONCAB group, instead of an OPCAB group. The study characteristics are illustrated in Table 2.

Meta-analysis

When compared with non-converted OPCAB, overall conversion (undifferentiated between emergency and elective) produced an OR for mortality of 6.18 (95% CI 4.65–8.20). Emergency conversion (Fig. 2) produced an OR of 6.99 for mortality (95% CI 5.18–9.45). Both these analyses were performed using a random effects model and were highly significant for overall effect (both $p < 0.00001$).

When compared with risk-matched ONCAB groups (Fig. 3), overall conversion produced a non-significant OR for mortality, whereas emergency conversion produced a significant OR of 4.48 (95% CI 2.69–12.46).

A large database analysis by Li and colleagues [32] could not be formally included in our analysis, as it was impossible to rule out an overlap of patient populations with the study by Jin and colleagues [22]. We included the latter article [22], as it had more specific and detailed information regarding conversions. We separately tested the data from each study in our meta-analysis to ensure that they did not produce significantly different results, which they did not.

Sensitivity analysis and heterogeneity

No significant difference in meta-analytic findings occurred with use of either the random-effects or fixed-effects technique in any of the overall or subgroup comparisons.

No significant statistical difference in treatment effect was observed when meta-analysis was performed comparing conversions to non-converted OPCAB with regard to the following subgroups: less than or more than two safety measures reported,
### Table 1: Newcastle-Ottawa scoring

<table>
<thead>
<tr>
<th>Study</th>
<th>Selection (4)</th>
<th>Comparability (2)</th>
<th>Outcome (3)</th>
<th>Score</th>
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<tr>
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<td>Qu.2</td>
<td>Qu.3</td>
<td>Qu.4</td>
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<tr>
<td>Anyanwu (2002)</td>
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<tr>
<td>Carrier (2003)</td>
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<td>Da Col (2008)</td>
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<td>Edgerton (2003)</td>
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<tr>
<td>Fuji (2006)</td>
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<td>*</td>
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<td>*</td>
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<tr>
<td>Hovakimyan (2008)</td>
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<td>Iaco (1999)</td>
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<td>Jin (2005)</td>
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<td>Landoni (2007)</td>
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<td>Legare (2005)</td>
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<td>Mujanovic (2003)</td>
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<td>Novick (2002)</td>
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<td>Patel (2004)</td>
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<td>Reeves (2006)</td>
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<td>Soltoski (1998)</td>
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<td>Tabata (2006)</td>
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<td>Vassiliades (2002)</td>
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</tbody>
</table>

**Qu:**
1. Representativeness of exposed cohort.
2. Selection of non-exposed cohort.
3. Ascertainment of exposure.
4. Demonstration that outcome of interest was not present at start of study.
5. Comparability of cohorts based on design/analysis (only one star if >1 significant difference between groups OR if differences simply described as 'nonsignificant').
6. Assessment of outcome.
7. Was follow-up long enough for outcomes to occur?
8. Adequacy of follow-up of cohorts.

### Table 2: Study characteristics

<table>
<thead>
<tr>
<th>Study</th>
<th>Location</th>
<th>Sex (% female)</th>
<th>Mean age</th>
<th>Total OPCAB cases</th>
<th>Conversions</th>
<th>Overall conversion rate (%)</th>
<th>Newcastle-Ottawa study quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anyanwu (2002)</td>
<td>UK</td>
<td>19.3</td>
<td>64.0</td>
<td>285</td>
<td>8</td>
<td>2.81</td>
<td>7</td>
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<tr>
<td>Carrier (2003)</td>
<td>Canada</td>
<td>32.1</td>
<td>70.0</td>
<td>32</td>
<td>5</td>
<td>15.6</td>
<td>9</td>
</tr>
<tr>
<td>Da Col (2008)</td>
<td>Italy</td>
<td>24.5</td>
<td>67.6</td>
<td>257</td>
<td>10</td>
<td>3.89</td>
<td>7</td>
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<tr>
<td>Edgerton (2003)</td>
<td>USA</td>
<td>ND</td>
<td>ND</td>
<td>1644</td>
<td>61</td>
<td>3.71</td>
<td>8</td>
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<td>Fuji (2006)</td>
<td>Japan</td>
<td>25.4</td>
<td>65.5</td>
<td>130</td>
<td>13</td>
<td>10.00</td>
<td>7</td>
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<tr>
<td>Hovakimyan (2008)</td>
<td>Armenia</td>
<td>17.6</td>
<td>66.7</td>
<td>467</td>
<td>17</td>
<td>5.64</td>
<td>7</td>
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<tr>
<td>Iaco (1999)</td>
<td>Italy</td>
<td>20.8</td>
<td>64.1</td>
<td>495</td>
<td>23</td>
<td>4.65</td>
<td>7</td>
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<tr>
<td>Jin (2005)</td>
<td>USA</td>
<td>32.2</td>
<td>65.6</td>
<td>7880</td>
<td>456</td>
<td>5.79</td>
<td>8</td>
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<tr>
<td>Landoni (2007)</td>
<td>Italy</td>
<td>14.9</td>
<td>65.0</td>
<td>450</td>
<td>37</td>
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<tr>
<td>Legare (2005)</td>
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<td>18.7</td>
<td>62.0</td>
<td>150</td>
<td>20</td>
<td>13.33</td>
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<tr>
<td>Mujanovic (2003)</td>
<td>Bosnia and</td>
<td>22.1</td>
<td>57.1</td>
<td>357</td>
<td>36</td>
<td>10.08</td>
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<td>Herzegovina</td>
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<tr>
<td>Novick (2002)</td>
<td>Canada</td>
<td>18.8</td>
<td>64.3</td>
<td>139</td>
<td>27</td>
<td>19.42</td>
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<tr>
<td>Patel (2004)</td>
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<td>27.5</td>
<td>66.3</td>
<td>1678</td>
<td>95</td>
<td>5.66</td>
<td>8</td>
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<tr>
<td>Reeves (2006)</td>
<td>UK</td>
<td>15.4</td>
<td>67.9</td>
<td>2492</td>
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<td>1.08</td>
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<td>USA</td>
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<td>66.6</td>
<td>378</td>
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<td>1420</td>
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<td>1.62</td>
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The 17 studies detailed here represent an assimilation of 18,870 off-pump coronary artery bypass (OPCAB) cases carried out worldwide, published between 1998 and 2008, which constitutes this meta-analysis.
Figure 2: Forest plot representing the meta-analysis comparing in-hospital mortality between converted patients and non-converted OPCAB control groups, with subgroup analysis for emergency and overall conversion.

Figure 3: Forest plot representing the meta-analysis comparing in-hospital mortality between converted patients and risk-matched ONCAB reference groups, with subgroup analysis for emergency and overall conversion.
less than or more than three safety measures reported, high versus low sample size (cut-off at median: 25 converted cases), quality score less than or more than 7 and publication year before or after 2005.

It was not possible to perform subgroup analysis of conversion mortality with regard to emergency or elective conversion due to an insufficient number of studies (<3) reporting usable data for elective conversions. However, as can be seen from the forest plots in Figs. 1 and 2, emergency conversion confers a higher odds of mortality than overall conversion when compared with both non-converted OPCAB and risk-matched ONCAB patients.

Data from the study by Novick and colleagues [26] had ‘zero events’ as the numerator for both conversion mortality and non-converted OPCAB mortality and therefore could not be included.

No heterogeneity was identified for the comparisons between converted and OPCAB groups (Fig. 2) and moderate degree of heterogeneity ($I^2 = 34–48\%$) was found for comparison between converted and risk-matched ONCAB groups (Fig. 3).

Multivariate metaregression including the log(OR) as dependent variable and the following parameters, such as year of publication (cut-off, 2005), study quality (cut-off, 7), sample size and number of safety measures, as independent predictors used to prevent conversion did not identify any significant effect.

**DISCUSSION**

Our meta-analysis consolidates the results of 18,870 OPCAB cases performed worldwide, reported between 1998 and 2008 and demonstrates, using assimilated data from 920 converted patients without heterogeneity, that there is a six- to sevenfold rise in the incidence of mortality as a result of conversion and, particularly, emergency conversion in OPCAB patients.

There has without doubt been progression in off-pump revascularisation in the past decade and several benefits, including reduction in postoperative stroke and atrial fibrillation, have been shown [34,35]. Mortality reduction in OPCAB is still an area of considerable debate. We aimed to elucidate the effect of conversion from OPCAB to ONCAB on mortality and our findings highlight several key issues of OPCAB that impact clinical governance, good clinical practice, training, future research and risk management, including: (1) how frequent is conversion, (2) what are its implications in the consent process and training/safety in OPCAB and (3) what are the evidence gaps in the OPCAB literature due to inadequate reporting within randomised controlled trials?

**Publication bias**

Fig. 4(a) is a scatter plot representing the treatment effects estimated from all the individual studies included in the meta-analysis of conversion versus non-converted OPCAB. The treatment effect OR is on the horizontal axis, with a proxy measure of the study size on the vertical axis (standard error (SE) [log(OR)]). This scatter plot resembles a symmetrical inverted funnel (representing the 95% CI) within the boundaries of which lie all the studies included in this meta-analysis. The concept of the ‘funnel plot’ is centred on the fact that precision in estimation of the underlying treatment effect will increase with the sample size of the component study [33]. All studies in this meta-analysis lay within the 95% CI lines and no asymmetry was detected, as also demonstrated by the Egger’s test (bias coefficient = −0.29, standard error = 0.28 and $p = 0.31$). Fig. 4(b) is a modified Harbord’s scatter plot to assess the effect of small studies by regressing $Z/sqrt(V)$ on $sqrt(V)$, where $Z$ is efficient score and $V$ is score variance. Harbord’s test did not identify any significant bias (bias coefficient = −0.30, SE = 0.64 and $p = 0.64$).

**The conversion rate**

The studies included in our analysis show an overall conversion rate of 4.9% (920/18,870). This is higher than some very large retrospective registry studies [6,36]. However, the two randomised studies included in our study demonstrated disproportionately high conversion rates of 15.6% [16] and 13.3% [24], which are the second and third highest rates, respectively, of all the studies presented in Table 1. In fact, high conversion rates are noted in several other high-profile randomised trials which have involved 100 or more OPCAB patients: 7% in the Octopus Study Group trial [37], 9.8% in the PRAGUE-4 (based in Prague, Czech Republic) [38] and, of course, 12.4% in the ROOBY trial [8]. The presence of higher conversion rates within the limited number of randomised trials reporting it compared with observational studies may be due more accurate documentation. Overall, it appears that conversion is a neglected issue in the off-versus on-pump debate and that a substantial proportion of...
patients may enter into a territory of unknown risk as a result of conversion.

Consent issues

The consent process in cardiac surgery is a surgeon–patient accord that is based on complex assessments of risk–benefit, with objective systems, such as the logistic EuroSCORE, in common use[3,39]. To put our findings into perspective, a 1 in 100 quoted risk of operative mortality rises to a risk of approximately 1 in 14 (7%) if emergency conversion occurs and about 1 in 16 (6.2%), if any conversion occurs. Although the majority of high-volume tertiary cardiac surgical centres may have sufficient safety measures and expertise in place to manage this risk, our findings highlight a significant impact upon the equity and transparency of the consent process in OPCAB. It is reasonable to assume that straightforward cases with favourable risk profiles will not require conversion. However, where patients present with risk factors predictive of several-fold increase in the risk of conversion, such as poor cardiac function[18,20,40], poor-quality coronary targets[20,40,41], prior myocardial infarction[22,40], redo or salvage revascularisation[18,22] or chronic obstructive pulmonary disease[23,30], informed consent should be obtained, accounting for the possibility of conversion. It is desirable, perhaps, for future research to be directed towards developing a system for predicting the individual patient’s risk of conversion. Although the EuroSCORE is currently being recalibrated, it may be important that a metric should be incorporated into a ‘modified’ logistic EuroSCORE for OPCAB, thereby producing an operative mortality risk score which takes into account the risk of conversion. In effect, this would be an empirical solution to the ethical challenge posed by conversion to the consent process.

Training and learning curve issues

Such a modification of the consent process is more important still in trainees and surgeons early in their OPCAB learning curves. A surgeon’s prior off-pump experience is another identified predictor of conversion[18,20]. With a prior experience of less than 25 OPCAB cases, the likelihood of conversion may be almost 4.5-fold higher than for surgeons with more than 100 cases[18]. It is essential for trainees and OPCAB-naïve surgeons to traverse this learning curve and, during this period, they should be mentored and supported in their institutions of practice by established OPCAB surgeons. This is preferable to the en masse uptake of OPCAB at a centre with established on-pump surgeons, without supervision from an ‘off-pump mentor’[28].

The teaching of OPCAB[42] must provide an approach to both prevention and management of conversion. In essence, this involves attention to best-practice concepts in OPCAB: patient selection, an understanding of cardiac-positioning devices, ideal grafting sequences and precipitants of haemodynamic instability, such as manipulation, ischaemia during anastomoses, arrhythmias and anaesthesiological factors[43]. Leadership of the multidisciplinary OPCAB team, which should include a standby perfusionist with the CPB pump primed, is an important skill.

The ROOBY trial exhibited an unusually high conversion rate (12.4%), largely as a result of the surgeons’ relative inexperience with OPCAB, whose natural tendencies perhaps lay towards conversion back to familiar on-pump territory. Furthermore, each surgeon performed, on average, less than four OPCAB cases per year as part of the trial, which would hardly enable progression through the learning curve. This highlights two issues for training: (1) in units undertaking OPCAB, the conversion rate should be a monitored quality metric that reflects both training and surgical performance and (2) training programmes should provide trainees with a large enough supervised OPCAB caseload to traverse their learning curves.

Safety issues

A paradox presents itself regarding the latter point. Health-care institutions responsible for the safety of their patients are faced with a conflict between limiting the exposure of patients to less-experienced OPCAB trainees or novices and safe-guarding the competence of its future OPCAB surgeons by providing them a high enough case turnover. Safety measures that deal with the prevention and management of conversion are key to solving this problem and should be an intrinsic part of training as well as routine surgical practice.

The adverse environment created by emergency conversion is one of haste, which may compromise the quality of the coronary

![Figure 5: Consent and risk of mortality for OPCAB patients.](https://academic.oup.com/ejcts/article-abstract/41/2/291/846826)
anastomosis. A poor anastomosis can lead to regional myocardial ischaemia or bleeding, which can manifest either immediately or later in the postoperative course as haemodynamic dysfunction or collapse, necessitating surgical re-exploration (for bleeding) and resulting in hypoperfusion injuries to the kidney, brain and gastrointestinal tract. As such, emergency conversion can be a cause or a consequence of an inadequate coronary anastomosis. The formation of blood-tight anastomoses on a beating heart and protection of the myocardium from potential ischaemia during grafting are therefore two key surgical strategies for success in coronary surgery. Although coronary shunts have been shown to reduce regional ischaemia during grafting [44,45], cardiac positioners are the only devices whose non-use has been found as predictive of conversion [27,30].

Maximising safety in OPCAB involves minimising the risk of conversion and associated mortality. Fig. 5 is a conceptual demonstration of a ‘multiplier effect’ theory. Factors that raise the risk of conversion (e.g., high-risk patient, less-experienced surgeon and non-use of cardiac positioners) are capable of existing simultaneously and thus may superimpose on each other. In the worst case scenario, this superimposed risk may actually materialise into conversion, in which case, according to our findings the patient is at six to seven times greater risk of death. It is likely, therefore, although by no means proven, that overall mortality risk is a function of both the risk of conversion and the risk of mortality to converted patients. This consideration significantly changes the usual preoperative evaluation of mortality risk.

Reporting issues

Of 74 randomised trials we found comparing OPCAB with ONCAB, there are only two included studies that have specifically provided mortality data for converted patients. It is understandable that cross-over groups may traditionally be excluded from analysis in randomised trials, but it is mandatory for their effect to be presented as part of sensitivity analysis. Equally, it is impossible to perform a study that randomises patients between ‘conversion’ and ‘non-conversion’ groups – this would both be practically troublesome and, on the basis of what we know, mean exposing patients to unacceptable risks of harm. The vast majority of randomised clinical trials have reported converted patients erroneously in the on-pump group (non-intention-to-treat analysis), whereas conversion outcomes are strictly ‘off-pump’ outcomes and the impact should fall squarely on OPCAB results. Another issue was the poor extent of differentiation between emergency and elective conversion subtypes. There is some evidence in the literature to suggest that elective conversion in fact has equivalent outcomes to non-converted cases, whereas emergency conversion produces adverse outcomes [18], but there was not enough sub categorised data available for us to perform a significant subgroup analysis.

The validity of the results of this meta-analysis will have to be viewed with respect to certain limitations of individual studies. The criteria for conversion varied amongst studies and were not always accurately reported. Although haemodynamic instability has been one of the main causes for conversion, technical shortcomings, such as quality of anastomoses, adequate stabilisation and effective use of adjuncts to off-pump surgery, may influence the risk and the associated outcome of conversion. Equally, previous off-pump experience of the operating surgeon and overall team performance may set variable thresholds for conversion that cannot be standardised amongst the studies included. Studies where off-pump surgery was not routinely performed by established, high-volume, off-pump surgeons may introduce significant bias in outcomes and operative conversion rate. Our goal however was to reflect ‘real life’ practice, where off-pump surgery is not being undertaken solely by those with subspecialty training and wide experience in this technique. The outcomes of converted cases may be further influenced by ischaemia and oxidative stress occurring during attempts for manipulation of the beating heart and by variable management at the level of cardioprotection techniques and number and quality of anastomoses performed following conversion. Finally, patient-related characteristics that may affect conversion, such as extent and severity of coronary artery disease, low ejection fraction and presence of ischaemic mitral regurgitation, could not be adequately controlled, as the majority of studies were observational with the inherent limitation of selection bias.

CONCLUSIONS

Our aim in this meta-analysis was to present the best evidence possible with regard to the effects of conversion on mortality in OPCAB. It is impossible to strengthen these findings through a large randomised trial (which is possible with many meta-analyses of mainly observational studies) because patients cannot ethically be randomised to a ‘conversion’ group in view of the unwarranted risk associated with this intervention. However, an even stronger evidence base would be possible if future large randomised trials reported the outcomes of their conversions. Nevertheless, the paucity of randomised studies in this meta-analysis remains a limitation.

Conversion has been missed and under emphasised in the cardiac surgical literature and this overall failure to address the issue of conversion has created potential uncertainty about the efficacy of OPCAB in comparison to ONCAB. We have demonstrated clearly the adverse effect of conversion on patient mortality in off-pump surgery. Further research is warranted to develop a system to predict patients at high risk of conversion, so as to incorporate this concept into the consent process and guide the early decision-making process surrounding selection of an on- or off-pump surgical strategy. For trainees and OPCAB novices, conversion is a hazard that must be managed within the natural progression of the learning curve through expert mentoring. Although conversion rates may be used as a proxy measure of OPCAB competence, it must not be a deterrent to the uptake of the off-pump technique.

In summary, this is a report about mortality in cardiac surgery and it is hoped that our findings may further contribute to the past decade’s improvements in quality and safety in cardiac surgical outcomes through due attention to the risks of conversion in OPCAB.

Conflict of interest: none declared.

REFERENCES