The relation between volume and outcome of coronary interventions: a systematic review and meta-analysis

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Aims

Although various studies reported better outcomes in centres performing a high volume of procedures of coronary artery bypass grafting (CABG) or percutaneous coronary interventions (PCIs), it is unclear how strong this relation is and whether it pertains to today’s practice.

Methods and results

Medline, Embase, and conference reports were searched for studies reporting the effect of high volume of CABG or PCI on in-hospital mortality, adjusted for differences in case-mix. Of 140 potentially relevant papers, 15 were included, 2 of which reported data on both CABG and PCI. Meta-analysis of 10 studies on PCI, comprising 1,322,342 patients in 1,746 hospitals, indicated an odds ratio (OR) of in-hospital mortality for patients treated in a high-volume hospital of 0.87 (95% confidence interval (CI) 0.83–0.91) compared to those treated in a low-volume hospital. The 7 CABG studies taken together, comprising 1,470,990 patients in 2,040 hospitals, also revealed a significant effect of high volume (OR 0.85; CI 0.79–0.92). A differential effect for specific cut-off points could not be identified. Meta-regression did not show notable changes in the effect size over the years.

Conclusions

Patients undergoing CABG or PCI in a high-volume hospital exhibit lower in-hospital mortality than those treated at low-volume hospitals. Our meta-analysis does not support the view that this relation has attenuated over time.

Keywords

Hospital volume • Coronary artery bypass grafting • Percutaneous coronary interventions • In-hospital mortality • Meta-analysis

Introduction

Since the first publication of Luft et al.1 on the effect of high volume on coronary artery bypass grafting (CABG) in 1979, numerous studies reported on the association between the volume of procedures and the outcome of CABG or percutaneous coronary intervention (PCI). Usually, the effect of treatment in a high-volume centre on a short-term adverse outcome such as in-hospital mortality is examined. The idea behind these studies is that performing a procedure more frequently results in better outcomes (practice makes perfect). An alternative explanation would be that centres providing the best results attract more patients than other centres (selective referral).2 Most of these studies indeed reported better outcomes for high-volume centres. As a consequence, these results have been embraced by initiatives such as the Leapfrog Group to promote CABG and PCI in high-volume centres.3 However, the literature concerning the volume–outcome relationship for PCI has not been reviewed. Yet, there is some evidence that the disparity in outcomes of PCI between high- and low-volume hospitals has narrowed over time.4 Reviews on the volume–outcome relationship for CABG exist, but do not include articles published after 2002.5,6 Moreover, a meta-analysis has, to our knowledge, never been performed for CABG or PCI. Therefore, we reviewed the literature up to 2008 and performed a meta-analysis to provide a more precise estimate of the relation between volume and procedure-related mortality after CABG and PCI, with a special interest in the more recent literature.
Methods

Search strategy and selection criteria
An experienced librarian searched the databases Medline and Embase from inception to September 2008, using WINSPIRS software (Silver-platter Information, Inc., Norwood, MA, USA), for articles that report on the relation between centre volume and the outcome of CABG or PCI. MeSH terms and ‘free text’ were used to search for articles addressing the question of interest (professional competence, case-load, expertise, volume, etc.) combined with search terms defining CABG and PCI (angioplasty–transluminal–percutaneous–coronary; coronary–artery–bypass) and search terms defining relevant outcomes (outcome-assessment, audit-delivery of, mortality, morbidity, delivery-of-healthcare, etc.).

In addition, the annual conference reports (1998–2008) of the following annual conferences were searched for additional studies: American College of Cardiology (www.acc.org), American Heart Association (www.aha.org), European Society of Cardiology (www.escardio.org), Transcatheter Cardiovascular Therapeutics (www.tctmd.com), Euro Percutaneous Coronary Revascularisation (www.europcr.com), Society of Thoracic Surgeons (www.sts.org), European Association of Cardio-Thoracic Surgery (www.eacts.org), and the American Association of Thoracic Surgery (www.aats.org).

We checked the reference lists of included articles for additional articles.

Search strategy and selection criteria

Inclusion criteria

Hospital volume is an independent variable in the study
A cut-off point is used to distinguish high-volume from low-volume hospitals
The relation of volume to a relevant short-term outcome of PCI or CABG is investigated
Outcome is in-hospital mortality
The study contains a representative sample of patients treated at that centre
The results are adjusted for differences in case-mix at baseline in a multivariate model, at least for age and sex
The results are presented as odds ratios (or relative risks or similar) of high-volume vs. low-volume hospitals

Exclusion criteria

Multiple publications based on the same database; in that case, only the most recent or most informative article is included
The study does not contain primary data
Results reported off-pump CABG
CABG studies reporting on combined surgery (CABG and valve surgery)

Data extraction and quality assessments

Two of the authors (P.N.P. and M.K.) extracted the data independently and assessed the quality of the selected papers, using a standard extraction form. The results of data extraction and quality assessment were compared. Disagreements between the two reviewers were mainly caused by unclear reporting in the included articles or by oversight of one of the reviewers and were resolved by discussion. If authors reported separate effect estimates for subsequent periods, these were entered individually in the analysis. If insufficient information was available in the article, authors were contacted for additional information.

Data synthesis

Odds ratios of the mortality risk for treatment in a high-volume centre relative to treatment in a low-volume centre were extracted. Adjusted ORs (adjusted for case-mix) and the lower and upper limit of its 95% confidence interval were used in the analysis. If available, the relative mortality risk of the category with yearly volumes ≥600 (or close to 600) to that of the next lower category was calculated (e.g. mortality rate ≥600 vs. mortality rate 400–600 or <600). This cut-off point was chosen because in some earlier reports it was found that increasing the volume of procedures above 600 did not have an additional beneficial effect. If other relative measures were used, these were used as ORs, provided that the rare disease assumption was not violated. If only adjusted rates were available, rate ratios thereof and its confidence interval were calculated.

Summary estimates were calculated with corresponding forest plots using Comprehensive Meta-analysis version 2 (Biostat, Engwood Cliffs, NJ, USA). The Q-statistic and I² were calculated to assess the amount of between-study heterogeneity. A random-effects model was assumed to obtain summary estimates. If substantial between-study heterogeneity was observed, mixed-effects subgroup analyses and meta-regression were undertaken to identify the source of heterogeneity. The impact of studies of inferior quality was examined in sensitivity analyses using mixed-effects analysis. Sensitivity analyses were planned for the data source (clinical, if prospectively collected data were primarily used for clinical purposes; administrative, if data were collected for administrative purposes), the degree of completeness of case-mix adjustment (complete, if adjusted for age, sex, severity of disease, and co-morbidity; incomplete, for any other combination), and definition of procedural mortality, and the presence of an explicit statement that CABG combined with valve surgery was excluded. Publication bias was examined constructing funnel plots of standard error by log OR and was tested using the Egger regression test. All reported P-values are two-sided.
Results

Our literature search initially revealed 1624 articles. After screening the title and abstract, 140 articles were of potential interest. Application of the selection criteria led to the inclusion of 10 articles on PCI and 7 on CABG (two articles provided results for PCI as well as CABG). Important reasons for exclusion were: the absence of a confidence interval for the relative measure reported, multiple papers based on the same database, absence of primary data, or absence of data describing the volume outcome relation (Figure 1).

Of the 18 first authors contacted to supply additional information, 5 responded and 3 supplied information that resulted in the inclusion of the study. These results were included in the analyses labelled as ‘unpublished results’.

Percutaneous coronary interventions

Ten studies comprising 1322342 patients in 1746 hospitals were included in the analysis. Except two Japanese studies, all studies took place in the USA, whereas the period under study ranged from 1995 to 2003 (Table 2a). The two Japanese studies and one American study reported high in-hospital mortality rates of 7.4, 10.1, and 6.4%, respectively. Three studies used administrative data for case-mix adjustment and the remainder used higher-quality clinical data. All included studies used in-hospital mortality as the outcome.

Meta-analysis revealed an overall OR of in-hospital mortality for patients treated in a high-volume hospital compared with those treated in a low-volume hospital of 0.87 (CI 0.83–0.91) (Figure 2). The $I^2$ value of 38% (Q-statistic: $P = 0.088$) indicated moderate heterogeneity. Omitting Kimmel et al. (the only study suggesting an adverse effect of high volume) from the analyses reduced the heterogeneity ($I^2 = 20\%$; $P = 0.26$), but barely changed the overall OR (0.86; CI 0.82–0.90). Heterogeneity was also limited when restricting the analysis to the (two) administrative studies using a cut-off point of 400 ($I^2 = 34\%$; $P = 0.2$), but did not change the effect estimate (OR 0.86; CI 0.82–0.90). The overall OR was not sensitive to the source of data used for case-mix correction ($P = 0.74$), nor for completeness of case-mix correction ($P = 0.18$).

Figure 1 Flowchart of literature review.
### Table 2  Characteristics of included studies

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Country</th>
<th>Period of study</th>
<th>Data source</th>
<th>Patients</th>
<th>Hospitals</th>
<th>Data source</th>
<th>Case-mix adjustment</th>
<th>Cut-off point</th>
<th>Average mortality rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) PCI volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allareddy et al.</td>
<td>2007</td>
<td>USA</td>
<td>2000–2003</td>
<td>Nation-wide inpatient sample</td>
<td>573 072</td>
<td>744</td>
<td>Administrative</td>
<td>Not severity</td>
<td>400</td>
<td>0.8%</td>
</tr>
<tr>
<td>Hannan et al.</td>
<td>1997</td>
<td>USA</td>
<td>1991–1994</td>
<td>NY state-wide PCI reporting system</td>
<td>62 670</td>
<td>31</td>
<td>Clinical</td>
<td>Complete</td>
<td>600</td>
<td>0.9%</td>
</tr>
<tr>
<td>Hannan et al.</td>
<td>2005</td>
<td>USA</td>
<td>1998–2000</td>
<td>NY state-wide PCI reporting system</td>
<td>107 713</td>
<td>34</td>
<td>Clinical</td>
<td>Complete</td>
<td>600</td>
<td>0.8%</td>
</tr>
<tr>
<td>Ho</td>
<td>2000</td>
<td>USA</td>
<td>1984–1996</td>
<td>California OSHPD</td>
<td>353 488</td>
<td>129</td>
<td>Administrative</td>
<td>Complete</td>
<td>400</td>
<td>1.5%</td>
</tr>
<tr>
<td>Kimmel et al.</td>
<td>2002</td>
<td>USA</td>
<td>1994–1995</td>
<td>Pennsylvania HCCC</td>
<td>25 222</td>
<td>43</td>
<td>Clinical</td>
<td>Not co-morbidity</td>
<td>600</td>
<td>34%</td>
</tr>
<tr>
<td>Tsuchihashi et al.</td>
<td>2004</td>
<td>Japan</td>
<td>1997</td>
<td>Nation-wide registry</td>
<td>2491</td>
<td>129</td>
<td>Clinical</td>
<td>Complete</td>
<td>56</td>
<td>7.4%</td>
</tr>
<tr>
<td>Vakili et al.</td>
<td>2001</td>
<td>USA</td>
<td>1995</td>
<td>NY coronary angioplasty reporting system</td>
<td>1342</td>
<td>32</td>
<td>Clinical</td>
<td>Complete</td>
<td>57</td>
<td>5%</td>
</tr>
<tr>
<td>Canto et al.</td>
<td>2000</td>
<td>USA</td>
<td>1994–1998</td>
<td>National (sample) registry of MI</td>
<td>36 535</td>
<td>450</td>
<td>Clinical</td>
<td>Complete</td>
<td>33</td>
<td>6.4%</td>
</tr>
<tr>
<td>Carey et al.</td>
<td>2005</td>
<td>USA</td>
<td>1999–2001</td>
<td>California OSHPD</td>
<td>153 755</td>
<td>138</td>
<td>Administrative</td>
<td>Not co-morbidity</td>
<td>600</td>
<td>1.4%</td>
</tr>
<tr>
<td>Shirashi et al.</td>
<td>2008</td>
<td>Japan</td>
<td>2000–2005</td>
<td>Multi-centre study</td>
<td>6054</td>
<td>16</td>
<td>Clinical</td>
<td>Complete</td>
<td>5th quintile</td>
<td>10.1%</td>
</tr>
<tr>
<td>(b) CABG volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allareddy et al.</td>
<td>2007</td>
<td>USA</td>
<td>2000–2003</td>
<td>Nation-wide inpatient sample</td>
<td>261 551</td>
<td>587</td>
<td>Administrative</td>
<td>Not severity</td>
<td>450</td>
<td>2.4%</td>
</tr>
<tr>
<td>Birkmeyer et al.</td>
<td>2002</td>
<td>USA</td>
<td>1994–1999</td>
<td>Medicare</td>
<td>901 667</td>
<td>1068</td>
<td>Administrative</td>
<td>Not severity</td>
<td>550</td>
<td>5.46%</td>
</tr>
<tr>
<td>Carey et al.</td>
<td>2005</td>
<td>USA</td>
<td>1999–2001</td>
<td>California OSHPD</td>
<td>82 353</td>
<td>121</td>
<td>Administrative</td>
<td>Complete</td>
<td>300</td>
<td>2.9%</td>
</tr>
<tr>
<td>Christian et al.</td>
<td>2003</td>
<td>USA</td>
<td>2000</td>
<td>UHC Clinical Database</td>
<td>69 827</td>
<td>99</td>
<td>Clinical</td>
<td>Complete</td>
<td>500</td>
<td>3.9%</td>
</tr>
<tr>
<td>Nallamothu et al.</td>
<td>2001</td>
<td>USA</td>
<td>1997</td>
<td>Solucient Explore Database</td>
<td>13 644</td>
<td>56</td>
<td>Clinical</td>
<td>Complete</td>
<td>200</td>
<td>2.5%</td>
</tr>
<tr>
<td>Marcin et al.</td>
<td>2008</td>
<td>USA</td>
<td>1998–2004</td>
<td>California CABG mortality reporting program</td>
<td>137 224</td>
<td>75</td>
<td>Clinical</td>
<td>Complete</td>
<td>450</td>
<td>3.0%</td>
</tr>
<tr>
<td>Wu et al.</td>
<td>2005</td>
<td>Taiwan</td>
<td>2000–2001</td>
<td>National Health Insurance Program</td>
<td>4724</td>
<td>34</td>
<td>Administrative</td>
<td>Not severity</td>
<td>218</td>
<td>3.5%</td>
</tr>
</tbody>
</table>

HCCCC, Healthcare Cost Containment Council Database; OSHPD, Office of State-wide Health Planning and Development; UHS, University Health System Consortium; STS, Society of Thoracic Surgeons.

*aCase-mix adjustment is considered complete if adjusted for age, sex, severity of disease, and co-morbidity.*
Table 3. Results of sensitivity and subgroup analyses

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Variable</th>
<th>Subgroup</th>
<th>Odds ratio (CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCI</td>
<td>Source of case-mix data</td>
<td>Administrative</td>
<td>0.87 (0.83–0.91)</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>Source of case-mix data</td>
<td>Clinical</td>
<td>0.84 (0.70–1.01)</td>
<td></td>
</tr>
<tr>
<td>PCI</td>
<td>Completeness of case-mix data</td>
<td>Complete</td>
<td>0.86 (0.82–0.90)</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Completeness of case-mix data</td>
<td>Not co-morbidity</td>
<td>1.04 (0.82–1.32)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Completeness of case-mix data</td>
<td>Not severity</td>
<td>0.81 (0.73–0.90)</td>
<td></td>
</tr>
<tr>
<td>PCI</td>
<td>Cut-off point high-volume very low</td>
<td>Cut-off point &lt; 60</td>
<td>0.86 (0.76–0.96)</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>Cut-off point &gt; 60</td>
<td>0.87 (0.82–0.91)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABG</td>
<td>Source of case-mix data</td>
<td>Administrative</td>
<td>0.90 (0.82–0.99)</td>
<td>0.091</td>
</tr>
<tr>
<td></td>
<td>Source of case-mix data</td>
<td>Clinical</td>
<td>0.78 (0.68–0.89)</td>
<td></td>
</tr>
<tr>
<td>CABG</td>
<td>Completeness of case-mix data</td>
<td>Complete</td>
<td>0.78 (0.68–0.89)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Completeness of case-mix data</td>
<td>Not co-morbidity</td>
<td>0.92 (0.83–1.03)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Completeness of case-mix data</td>
<td>Not severity</td>
<td>0.91 (0.79–1.04)</td>
<td></td>
</tr>
<tr>
<td>CABG</td>
<td>Reporting of valve surgery</td>
<td>Valve surgery explicitly excluded</td>
<td>0.72 (0.51–1.03)</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Reporting of valve surgery</td>
<td>Exclusion of valve surgery unclear</td>
<td>0.88 (0.81–0.96)</td>
<td></td>
</tr>
<tr>
<td>CABG</td>
<td>Outcome definition</td>
<td>30 day + in-hospital mortality</td>
<td>0.84 (0.79–0.90)</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>In-hospital mortality</td>
<td>0.85 (0.77–0.94)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Relation between volume and outcome of coronary interventions

(Table 3). Omitting the three studies with high mortality rates,10–12 or studies providing unpublished results,12,14 from the analysis neither changed the OR. Meta-regression revealed no interaction with the cut-off point used to distinguish high vs. low volume ($P = 0.11$). Nor did a sensitivity analysis of the three studies using a very low cut-off point (Canto et al.,12 Vakili et al.,15 and Tsuchihashi et al.10) reveal a differential effect. Meta-regression failed to show a relationship between the proportion of patients undergoing PCI for an acute lesion and the strength of the relationship with volume ($P = 0.7$). However, studies containing a higher proportion of patients treated with stents reported a stronger relationship between volume and outcome ($P = 0.03$) (Figure 3). Furthermore, more recent studies seemed to report a slightly smaller effect size than earlier studies ($P = 0.055$) (Figure 4). The funnel plot of standard error by log OR was not suggestive for publication bias ($P = 0.79$).

Coronary artery bypass grafting

The seven included studies comprised 1 470 990 patients in 2040 hospitals, except one Taiwanese study,16 all originating from the...
USA, using data from 1997 to 2003. Four studies used administrative data for case-mix adjustment and six used clinical data (Table 2b). Meta-analysis indicated a reduction in mortality at higher volume centres (OR 0.85; CI 0.79–0.92) (Figure 5). However, moderate heterogeneity was observed ($I^2 = 47\%$; Q-statistic: $P = 0.03$). Excluding Wu et al.$^{16}$ (the only study suggesting an adverse effect of high volume) from the analysis did not change the effect size, but reduced the heterogeneity ($I^2 = 33\%$; $P = 0.13$). The results were not sensitive to the planned sensitivity analyses (Table 3). Nor did excluding Birkmeyer et al.$^{17}$ (the only study comparing the highest volume category with the lowest) change the results. Meta-regression revealed no interaction with the cut-off point used ($P = 0.63$). There was no significant trend in the effect size over time, although more recent studies seemed to report a slightly smaller effect size than earlier studies ($P = 0.13$) (Figure 6). The funnel plot of standard error by log OR was somewhat suspicious of publication bias, but did not show an excess of small positive studies ($P = 0.054$) (Figure 7).

### Discussion

Most studies investigating the influence of the yearly volume of coronary interventions reported a negative association between volume and the occurrence of short-term adverse events. However, a reliable estimate of the effect size is lacking. Moreover, it is unclear whether this association pertains to today’s practice. Our meta-analysis showed a significant relation between high volume and outcome of PCI. Moreover, we found no evidence that the strength of this relation has attenuated over time, although the results of our meta-regression analyses showed a slight attenuation of the effect size that was close to significant. Interestingly, studies containing a large proportion of patients treated with stents reported a stronger relationship. A possible explanation could be that in the period that stents were introduced, operators had to perform a sufficient number of procedures to reach results of sufficient quality. Ho$^4$ reported a slight attenuation of the volume–outcome relation for PCI, but his finding pertained to the period between 1984 and 1996. Two systematic reviews suggested that the size of the reduction in mortality after CABG associated with treatment in a high-volume centre attenuated between 1972 and 1989,$^{3,6}$ but reports of more recent trends in the volume–outcome relationship are not available. We found a significant reduction in in-hospital mortality associated with CABG performed in a high-volume centre, but no evidence for attenuation of this effect since 1990.

### Methodological limitations

Several issues have to be discussed that might affect the validity of our results.

A first concern is the amount of heterogeneity observed between studies. Although we restricted our analysis to studies with rather similar characteristics, considerable variation was observed in the selection of hospitals (nation-wide, state-wide, hospitals participating in a voluntary registry), definitions for which the volume–outcome relation was reported (cut-off point between $>33$ and $>600$, etc.), methods to adjust for differences in case-mix (administrative vs. clinical data, correction for some or all of the following components: age, sex, severity, co-morbidity), reported crude mortality rates (0.8–10.1% for PCI; 2.4–5.4% for CABG). This clinical heterogeneity indeed translated in moderate-to-high statistical heterogeneity. However, when we restricted the analyses to more similar studies, the statistical heterogeneity also decreased. We deliberately chose not to exclude studies with high mortality rates or deviant definitions of high volume, etc. Instead, by showing the main results including or all of the following components: age, sex, severity, co-morbidity), reported crude mortality rates (0.8–10.1% for PCI; 2.4–5.4% for CABG). This clinical heterogeneity indeed translated in moderate-to-high statistical heterogeneity. However, when we restricted the analyses to more similar studies, the statistical heterogeneity also decreased. We deliberately chose not to exclude studies with high mortality rates or deviant definitions of high volume, etc. Instead, by showing the main results including all studies followed by more restrictive analyses, we provided insights in the consequences of strict vs. more liberal inclusion criteria. However, the fact that studies reporting results of off-pump CABG were excluded might limit the generalizability of our results. However, if any effect, we consider it more likely that exclusion of patients treated with off-pump CABG has inflated rather than overestimated our effect estimate.

The fact that we did quite a few subgroup and meta-regression analyses might be criticized, given the small number of studies in the analyses. However, we interpreted the results of these analyses with caution. Moreover, investigation of the specific clinical factors that were consistent across studies might be a promising direction for future research.

### Figure 3

Results of meta-regression of the percentage of percutaneous coronary intervention patients treated with stents by effect size (the more negative log odds ratio, the stronger the effect size).

### Figure 4

Results of meta-regression of mean study year of patients treated with percutaneous coronary interventions by effect size (the more negative log odds ratio, the stronger the effect size).
differences between studies is generally preferred rather than to rely on a statistical test for heterogeneity.\(^7\)

Another point of critique might be that we included unpublished results, obtained from authors of published papers, because the methods used to obtain these results are not scrutinized to a similar extent as published results. However, excluding unpublished results in sensitivity analyses did not change our results. Publication bias might play a role. However, neither inspection of funnel plots of standard error by log OR nor Egger regression test provided evidence for publication bias. Moreover, we suspect that a study reporting the lack of a volume–outcome relationship would also be an interesting result worthwhile to publish, making publication bias less likely to occur as in reviews of randomized controlled trials reporting the effect of interventions.

**Implications**

In-hospital mortality was significantly lower when CABG or PCI were performed in a high-volume centre when compared with low-volume centres. Whether this finding supports the concentration of all coronary interventions in high-volume centres has to be judged in light of several issues.

First of all, all included studies were observational studies. Although randomization between treatments in a high-volume centre vs. a low-volume centre seems to encounter practical problems, a causal relation between the volume of patients and the
outcome of treatment cannot be concluded from these observational studies. Moreover, it seems more likely that specific processes of care are responsible for the better outcomes in high-volume centres. For example, the differential use of proven effective medical treatment explained up to one-third of the survival benefit of elderly patients with myocardial infarction attributed to high-volume hospitals.

It is not possible to define a specific minimum procedure below which the outcome of coronary interventions would be worse than for patients meeting this minimum requirement. Various cut-off points were used in the included studies. Moreover, inspection of the forest plots of the main analyses, nor meta-regression by cut-off point, did reveal a differential effect.

Most included studies originated in the USA. The number of studies from outside the USA was too small (two for PCI and one for CABG) to explore the similarity of the effect across countries. Moreover, all three studies originated from Asian countries. It is, therefore, unclear whether our results can be generalized to other countries outside the USA, such as in Europe or Canada. Nonetheless, the occurrence of repeat percutaneous transluminal coronary angioplasty, CABG, or death after PCI at 7 days was higher for high-volume hospitals in Canada between 1991 and 1993 (OR 0.79; CI 0.65–0.96). Significantly lower mortality rates after emergency (P = 0.03), but not after planned PCI (P = 0.99), were observed in hospitals performing >400 PCIs in France between 2001 and 2002. Although, we cannot quantify the similarity between these studies and the overall results in our analyses, it is likely that a relation between volume and outcome after coronary interventions exists in countries outside the USA.

In conclusion, patients undergoing CABG or PCI in a high-volume hospital exhibit lower in-hospital mortality than those treated at low-volume hospitals. Our meta-analysis does not support the view that this relation has attenuated over time.

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Conflict of interest: F.Z. and T.E. work for the Thorax Centre of the UMC, which is responsible for 2050 PCI and 700–750 CABGs per year. As employees of the UMC, their income is not related to the number of procedures. The same applies to M.K., who is in training for cardiothoracic surgery.

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