Review

# Provider volume and outcomes for oncological procedures

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**Background:** **Oncological procedures may have better outcomes if performed by high-volume providers.**
**Methods:** **A review of the English language literature incorporating searches of the Medline, Embase and Cochrane collaboration databases was performed. Studies were included if they involved a patient cohort from 1984 onwards, were community or population based, and assessed health outcome as a dependent variable and volume as an independent variable. The studies were also scored quantifiably to assess generalizability with respect to any observed volume–outcome relationship and analysed according to organ system; numbers needed to treat were estimated where possible.**
**Results:** **Sixty-eight relevant studies were identified and a total of 41 were included, of which 13 were based on clinical data. All showed either an inverse relationship, of variable magnitude, between provider volume and mortality, or no volume–outcome effect. All but two clinical reports revealed a statistically significant positive relationship between volume and outcome; none demonstrated the opposite.**
**Conclusion:** **High-volume providers have a significantly better outcome for complex cancer surgery, specifically for pancreatectomy, oesophagectomy, gastrectomy and rectal resection.**

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## Introduction

A relationship between high provider volume (both hospital and surgeon) and better outcome for complex surgical procedures has long been postulated. Since the groundbreaking work of Luft *et al.*[1] almost 25 years ago, the medical literature has abounded with studies appearing to support this hypothesis. There is an international trend towards regionalization of cancer services. Volume–outcome studies appear to support such a strategy, with a number demonstrating a significant volume–outcome relationship for the treatment of cancer[5–47]. However, there is substantial variation in results between studies, which is further confounded by heterogeneous study design, size, currency and scientific rigour. The aim of the present study is to synthesize the available volume–outcome data relating specifically to surgery for cancer in a structured systematic review and thereby determine whether high provider volume is associated with improved outcome for oncological procedures. In addition, the relative contributions to this relationship of hospital volume and surgeon volume ae examined.

## Methods

Multiple electronic searches of the Medline database (from 1984 to 2004) were performed for reports published in the English language literature with the keywords (alone or in combination): volume, outcome, mortality, cancer and regionalization. The search strategy incorporated MESH terms, and results were evaluated for sensitivity and specificity. In an attempt to reduce 'hand-picked' selection bias, the explicit study inclusion criteria used by Dudley *et al.*[2] and the Institute of Medicine[3] were employed to identify appropriate studies. These inclusion criteria were: patient cohort treated from 1984 onwards, community- or population-based sample (case series excluded), data referring solely to operations for malignant disease, health outcome(s) assessed as dependent variables, volume as an independent variable and study quality score greater than 4. Multiple studies from the same database were excluded (only the most recent and complete were used), as were single-institute studies because of the poor generalizability of the data. Reports in which the health outcome was a composite of death and complications, as determined by administrative databases, were also excluded owing to the poor reliability of such databases in identifying complications. The Cochrane Collaboration database was searched for systematic reviews and the bibliography of any included articles was also reviewed. Where papers examined more than one procedure, the data for each procedure were analysed separately. Included studies were scored using the quality scoring system produced by Halm *et al.*[3] to quantifiably assess data generalizability with respect to the nature and magnitude of any volume–outcome relationship (*Table 1*)[3]. Three reviewers (S.D.K., J.C.C. and M.J.O.) examined each article for inclusion and independently assigned quality scores. Inter-reviewer discrepancies were resolved by majority vote. The number needed to treat, that is the number of patients who must be treated to prevent one adverse outcome, was estimated from pooling available absolute risk differences for each procedure where available[4].

## Results

Volume–outcome literature is heterogeneous. In total 68 studies were identified and 41 fulfilled the inclusion criteria. Thirteen studies involved assessment of medical therapies, whereas five involved samples that were not community or population based and six did not evaluate volume as an independent variable; these papers were excluded. Seven reports described more than one procedure. Eighteen studies were based on clinical and 24 on administrative data. The variable platforms used precluded formal meta-analysis.

### Pancreatic resection

Eleven studies investigated pancreatic resection for malignant disease (*Table 2*)[5–15]. The study scores varied widely from 5 to 10 (median 7). The unit of analysis was the hospital in eight studies, with three assessing both hospital and surgeon volumes. Definitions of low-volume hospitals varied markedly from one case per year to fewer than 22 cases per year. No study examined the appropriateness of patient selection, and none based risk adjustment on clinical variables or investigated clinical processes. Inpatient and 30-day mortality were the primary outcomes assessed. Simunovic *et al.*[6] examined length of hospital stay whereas Glasgow *et al.*[7] recorded bleeding and infection rates.

All reports demonstrated a statistically significant inverse relationship between hospital volume and mortality. Of the three studies that described hospital and surgeon volume, two[10] found that surgeon volume was an independent predictor of outcome and another[8] that hospital volume was significant regardless of surgeon volume. These papers, while heterogeneous in design, demonstrate a strong provider–outcome relationship. The magnitude of this volume effect is large; the number needed to treat for a high-volume provider to prevent one death is ten to 15 patients.

**Table 1** Scoring system for rating the quality of research on volume and outcome[3]

| Characteristic | Score |
|---|---|
| Representativeness of sample | |
| Not representative | 0 |
| Representative | 1 |
| No. of hospitals or surgeons | |
| $<20$ hospitals and/or $<50$ surgeons | 0 |
| $\geqslant 20$ hospitals and/or $\geqslant 50$ surgeons | 1 |
| Total sample size (patients) | |
| $<1000$ | 0 |
| $\geqslant 1000$ | 1 |
| No. of adverse events | |
| $\leqslant 20$ | 0 |
| 21–100 | 1 |
| $>100$ | 2 |
| Unit of analysis | |
| Hospital or surgeon | 0 |
| Both separately | 1 |
| Both together | 2 |
| Both + | 3 |
| Appropriateness of patient selection | |
| Not measured | 0 |
| Measured separately | 1 |
| Measured and analysed separately | 2 |
| Volume | |
| Two categories | 0 |
| Multiple categories | 1 |
| Risk adjustment | |
| None | 0 |
| Administrative only | 1 |
| Clinical data | 2 |
| Clinical + C $>$ 0·75 and H/L test* | 3 |
| Clinical processes of care | |
| Not measured | 0 |
| 1 | 1 |
| $\geqslant 2$ | 2 |
| Outcomes | |
| Death only | 0 |
| Death + other | 1 |

*Logistical regression model demonstrating good calibration by the Hosmer–Lemeshow (H/L) test and good discrimination (by a C-statistic of 0·75 or greater).

### Oesophagectomy

Ten studies investigating surgical volume for oesophageal cancer and outcome were included (*Table 3*). Quality scores varied from 6 to 10 (median 7). Four studies examined oesophageal cancers exclusively[16–18,20]. The hospital was the sole unit of analysis in seven studies, with only two assessing both hospital and surgeon volume. All studies

**Table 2** Studies of pancreatic resection

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Unit of analysis | Primary outcome | Risk adjustment data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1984–1991 | 1972 | NS | 184 | H, S both | Hospital mortality | Admin. | vLVH: < 10<br>LVH: 10–50<br>MVH: 51–80<br>HVH: > 81<br>LVS: < 9<br>HVS: > 41 | RAMR 21·8 *versus* 12·3 *versus* 4·0% for VLVH *versus* LVH *versus* HVH<br>RAMR 15·5 *versus* 4·7% for LVS *versus* HVS | 8 |
| 6 | 1994–1995 | 842 | NS | 68 | H | Hospital mortality: mortality at 64 days | Admin. | LVH: < 22<br>MVH: 22–42<br>HVH: > 42 | Mortality 5·1 and 4·5% for LVH and MVH *versus* HVH | 6 |
| 7 | 1990–1994 | 1705 | NS | 298 | H | Hospital mortality, bleeding, infection | Admin. | LVH: 1–5<br>HVH: > 50 | RAMR 14 *versus* 3·5% for LVH *versus* HVH | 8 |
| 10 | 1998–1999 | 3060 | 1624 | NS | H, S, both | Operative mortality; death before discharge or 30-day mortality | Admin. | LVH: < 3<br>MVH: 3–13<br>HVH: < 13<br>LVS: < 2·0<br>MVH: 2–4<br>HVH: > 4 | OR = 3·61 for LVS *versus* HVS. Surgeon volume accounted for 55% of observed effect of hospital volume | 10 |
| 8 | 1990–1995 | 1236 | 373 | 48 | H, S, both | Hospital mortality | Admin. | LVS: < 2·0<br>MVS: 2·0–4·0<br>HVS: > 4·0<br>LVH: < 3·0<br>MVH: 3·0–13·0<br>HVH: > 13·0 | RR 19·3% for LVH *versus* HVH<br>HVH better regardless of surgeon volume | 9 |
| 9 | 1994–1999 | 1840 | NS | 1053 | H | Operative mortality; death before discharge or 30-day mortality | Admin. | LVH: < 11 | Difference in RAMR 12% (vLVH *versus* vHVH) | 8 |
| 11 | 1994–1999 | 686 | NS | 49 | H | 30-day mortality | Admin. | Quantiles: 2·2 for lowest quartile *versus* 24·8 for highest quartile | RAMR 2·2 for lowest quartile *versus* 1·0 for highest quartile. No significant relationship | 6 |
| 12 | 1994–1998 | 1,126 | NS | 257 | H | Hospital mortality | Admin. | LVH: < 5<br>HVH: > 25 | Lower RR (20 *versus* 3%) for HVH | 6 |
| 13 | 1988–1995 | 24 926 | NS | 938 | H | Hospital mortality | Admin. | LVH: < 10 | RAMR 1·5 for LVH | 8 |
| 14 | 1995–1997 | 3414 | NS | 483 | H | Hospital mortality | Admin. | LVH: < 3<br>MVH: 3–13<br>HVH: > 13 | Mortality 13·1 *versus* 2·5% for LVH *versus* HVH | 8 |
| 15 | 1991–1994 | 579 | NS | 117 | H | Hospital mortality | Admin. | LVH: 1–5<br>HVH: > 25 | Mortality 14·3 *versus* 2·2% (RR 6·87) for LVH *versus* HVH | 5 |

H, hospital; S, surgeon; (v)LVH, (very) low-volume hospital; MVH, medium-volume hospital; (v)HVH, (very) high-volume hospital; LVS, low-volume surgeon; HVS, high-volume surgeon; Admin. administrative; RAMR, risk-adjusted mortality rate; OR, odds ratio; RR, relative risk: NS, not specified.

**Table 3** Studies of oesophageal cancer (including cardia)

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1998–1999 | 1640 | 997 | NS | Operative mortality; death before discharge or 30-day mortality | H, S, both | Admin. | LVH: < 13<br>LVS: < 2<br>MVS: 2–6<br>HVS: > 6 | OR for operative death 2·30 (LVS *versus* HVS) Surgeon volume accounted for 46% of observed effect of hospital volume | 10 |
| 9 | 1994–1999 | 6337 | NS | 1405 | Hospital + 30-day mortality | H | Admin. | Continuous variable with quintiles:<br>vLVH: < 2<br>LVH: 2–4<br>MVH: 5–7<br>HVH: 8–19<br>vHVH: > 19 | Absolute RAMR decrease of > 10% for vHVH *versus* vLVH (20·3 *versus* 8·4%) | 10 |
| 11 | 1994–1999 | 613 | NS | 49 | 30-day mortality | H | Admin. | Quantiles | RAMR 1·9 *versus* 1·0 for LVH *versus* HVH | 6 |
| 14 | 1995–1997 | 5282 | NS | 603 | Hospital mortality | H | Admin. | LVH: < 3<br>MVH: 3–13<br>HVH: > 13 | Operative mortality 15·0 *versus* 6·5% for LVH *versus* HVH | 8 |
| 16 | 1984–1999 | 1136 | NS | 52 | Hospital mortality, LOS and cost | H | Admin. | LVH: < 3<br>MVH: 3–13<br>HVH: > 13 | Operative mortality 16 *versus* 2·7% for LVH *versus* HVH Decreased LOS and cost for HVH | 7 |
| 17 | 1995–1999 | 3025 | NS | > 200 | Operative mortality and LOS | H | Admin. | LVH: < 3<br>MVH: 3–5<br>HVH: > 6–16<br>vHVH: > 16 | Operative mortality 13·0 *versus* 3·7% for LVH *versus* HVH | 8 |
| 18 | 1995 | 1125 | 64 | NS | 30-day mortality; 5-year survival | S | Clinical | Infrequent operator: < 4<br>Intermediate: 4–11<br>Frequent: > 12 | No significant relationship | 9 |
| 19 | 1996–1997 | 1512 | 731 | 23 | Hospital mortality | H, S, both | Clinical | LVH: 7–32<br>MVH: 35–53<br>HVH: 60–83<br>LVS: 1–6<br>MVS: 7–14<br>HVS: 157–48 | Operative mortality decreased by 41% for each 10-patient increase in operator volume. OR 0·6. No relationship with hospital volume | 10 |
| 20 | 1990–1994 | 1561 | NS | 273 | Hospital mortality | H | Admin. | LVH: < 5<br>HVH: > 30 | Mortality 16 *versus* 4·8% for annual case load < 30 *versus* > 30 | 8 |
| 22 | 1984–1993 | 503 | NS | 190 | Hospital + 30-day mortality | H | Clinical | LVH: < 5<br>HVH: 11 | Mortality 17·3 *versus* 3·4% for LVH *versus* HVH | 6 |

H, hospital; S, surgeon; v(LVH), (very) low-volume hospital; MVH, medium-volume hospital; h(HVH), high-volume hospital; LVS, low-volume surgeon; MVS, medium-volume surgeon, HVS, high-volume surgeon; Admin., administrative; LOS, length of stay, OR, odds ratio; RAMR, risk-adjusted mortality rate; NS, not specified.

performed risk adjustment. Administrative data were used in seven studies. The definition of a low-volume provider differed greatly with hospitals performing less than two, five or 13 cases per year being classified as low volume. High-volume institutes were variably defined as those performing more than six or 83 operations per year. Thirty-day or inpatient mortality was the predominant outcome. No study examined processes of care or co-morbidities and study designs were heterogenous. All studies except one found a statistically significant difference in mortality with respect to outcome. The magnitude of this difference was notable. Birkmeyer *et al.*[10] demonstrated a greater than 10 per cent absolute reduction in risk-adjusted mortality rate (RAMR) from 20·8 per cent for low-volume hospital to 8·4 per cent for high-volume facilities, whereas Finlayson *et al.*[14] found an 8·5 per cent reduction in the same variable for high-volume hospitals. So the number of oesphagectomies that a high-volume provider needs to prevent one death appears to be as low as seven to nine.

## Surgery for gastric cancer

Five included studies investigated gastrectomy and volume–outcome correlations (*Table 4*). Quality scores ranged from 4 to 10 (median 7). Only Bachmann *et al.*[19] exclusively examined gastric cancer resection. The unit of analysis was the hospital itself in three studies[10,14,21], and two studies assessed both hospital and surgeon impact[19,23]. All studies performed risk adjustment, four employing only administrative data, with one group using clinical variables[19]. Definitions of volume status varied. The primary outcome assessed was inpatient mortality. No study examined survival data or relevant co-morbidities, and none reviewed sample representiveness. Three papers described a statistically significant inverse relationship between provider volume and mortality[10,19,23]. Hannan *et al.*[23] showed a significant mortality reduction for both higher-volume hospitals (7·1 per cent) and surgeons (6·0 per cent) with respect to mortality after gastrectomy. This was mirrored by the findings of Birkmeyer *et al.*[10] (1·1 per cent reduction in RAMR) and Bachmann *et al.*[19]

**Table 4** Studies of surgery for gastric cancer

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | MVH: 6–12 definition volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 1995–1997 | 16 081 | NS | 911 | Hospital mortality | H | Admin. | LVH: < 5<br>MVH: 6–12<br>HVH: > 13 | RAMR 8·7 *versus* 6·9% for LVH *versus* HVH ($P < 0.07$) | 8 |
| 23 | 1994–1997 | 3711 | 1114 | 207 | Hospital mortality | H, S, both | Admin. | LVS: < 1–2<br>HVS: > 12<br>LVH: < 15<br>HVH: > 63 | RAMR decreased by 7·1% for HVH *versus* LVH RAMR decreased by 6·0% for HVS *versus* LVS ($P < 0.001$) | 10 |
| 9 | 1994–1999 | 31 944 | NS | 3423 | Hospital + 30-day mortality | H | Admin. | vLVH: < 5<br>LVH: 5–8<br>MVH: 9–13<br>HVH: 14–21<br>vHVH: > 21 | Absolute decrease in RAMR of 1·1% for vHVH *versus* vLVH ($P < 0.001$) | 10 |
| 19 | 1996–1997 | 731 | NS | 23 | Hospital mortality | H, S, both | Clinical | LVH: 9–26<br>MVH: 31–40<br>HVH: 44–67 | Operative mortality decreased by 40% for each 10-patient increase in operator volume. OR 0·6 ($P = 0.047$) | 10 |
| 21 | 1987–1997 | 1978 | NS | 22 | Hospital mortality | H | Admin | LVH: < 7<br>MVH: 7–10<br>HVH: > 10 | No significant relationship | 4 |

H, hospital; S, surgeon; (v)LVH, very low-volume hospital; MVH, medium-volume hospital; (v)HVH, very high-volume hospital; LVS, low-volume surgeon; HVS, high-volume surgeon; Admin., administrative; RAMR, risk-adjusted mortality rate, OR, odds ratio; NS, not specified.

(operative mortality decreased by 40 per cent for each ten-patient increase in operator volume). Finlayson *et al.*[14] demonstrated a 2·2 per cent reduction in RAMR for high-volume hospitals, but this was not statistically significant.

The studies of provider volume and outcome in gastric cancer surgery demonstrate a significant inverse relationship. Although Hannan *et al.*[23] found that the mortality benefit with high-volume providers was preserved for both hospital and surgeon volume after adjustment, the relative contribution of hospital and surgeon volume remains uncertain[23]. The magnitude of the volume effect on mortality is variable, with a mortality reduction typically in the region of 1–6 per cent. Owing to low patient throughput, a high-volume provider needs to treat 20–100 patients to prevent one death.

## Surgery for lung cancer

Ten studies examining volume and outcomes of surgery for lung cancer were identified, with two solely assessing oncological procedures (*Table 5*)[25,26]. Quality scores ranged from 6 to 10 (median score 7). The majority of studies used the hospital as the unit of analysis and inpatient or 30-day mortality as the primary outcome variable. Hannan *et al.*[23] and Birkmeyer *et al.*[10] assessed both hospital and surgeons, whereas one study detailed postoperative complication rates and 5-year survival rates[25]. Two studies used clinical data for risk adjustment[22,25].

Four studies demonstrated an inverse relationship between hospital volume and outcome of variable magnitude (reduction in RAMR ranging from 1·65 to 5·4 per cent), which was maintained when Birkmeyer *et al.*[10] analysed pneumonectomy and lobectomy separately. Bach *et al.*[25] also reported a statistically significant lower 30-day and postoperative complication rate for lung cancer resections performed in high-volume units. With respect to lobectomy, Hannan *et al.*[23] found that the observed volume–mortality benefit with high-volume surgeons disappeared after adjustment for hospital volume, confirming the findings of Birkmeyer *et al.*[10] who estimated that surgeon volume accounted for only 24 per cent of improved volume-related outcome.

The weight of evidence supports a volume–outcome relationship for lung cancer resections, although this is not as marked as it is for other malignancies. The estimated number of patients that a high-volume unit would need to treat to prevent one death associated with low volume is between 20 and 50[10,25].

## Breast cancer

Four studies were identified relating to breast cancer surgery volume and outcome (*Table 6*)[27–30]. Quality scores were high, ranging from 7 to 11 (median 9). Patient numbers were generally large. The unit of analysis was the hospital in two studies and the surgeon in two. The primary outcome assessed was 5- year survival. The definition of a low-volume provider varied. Surgeons performing fewer than ten and 30 operations per year were classified as low volume by Roohan *et al.*[27] and Sainsbury *et al.*[28] respectively. Hospitals with fewer than ten breast procedures per year were deemed low volume by both Roohan *et al.*[27] and Stefoski *et al.*[30]. The risk assessment in all studies[27,30] used clinical data including cancer stage, adjuvant therapies received, patient co-morbidities and operation.

Three studies found a significant inverse relationship between provider volume and outcome for breast cancer procedures[27,28,30]. Roohan *et al.*[27] had the largest study population and found a significantly increased risk of death of 19 per cent for moderate- *versus* high-volume hospitals, 30 per cent for low- *versus* high-volume hospitals and 60 per cent for very low- *versus* high-volume hospitals[27]. The authors speculate that, as operative and inpatient mortality is very low, the observed volume–outcome relationship may result from better adjuvant therapy provided at large-volume centres. Sainsbury *et al.*[28] found a significantly lower risk of death for patients of high-volume surgeons (over 29 operations per year) compared with patients of low-volume surgeons (fewer than ten operations per year), which was preserved after volume adjustment[28]. Stefoski *et al.*[30] demonstrated decreased mortality for patients of very high-volume surgeons (over 49 procedures per year) compared with those treated by low-volume operators (fewer than ten procedures per year)[30]. The single study that failed to show a significant volume–outcome correlation was the smallest of those included, with only 2409 patients and nine hospitals[29]. No study evaluated the relative contribution of surgeon or hospital volume to the improved survival figures for patients with breast cancer treated in high-volume units.

## Colorectal cancer resection

The 16 studies of colorectal cancer resection had quality scores ranging from 5 to 11 (*Table 7*)[9,14,22,31–43]. They were heterogeneous in design, definitions used, variables assessed and results. Twelve studies examined colorectal cancers exclusively, with Schrag *et al.*[33] investigating rectal cancer only. The remaining four had detailed subset analysis. All studies involved resections for malignant disease only. The unit of analysis was hospital volume only in nine reports, surgeon volume in one, and both hospital and surgeon volume in six.

The definition of low volume ranged from one to fewer than 12 procedures for low-volume surgeons and from one to fewer than 84 operations per year for low-volume hospitals. All studies performed risk adjustment; ten used

**Table 5** Studies of surgery for lung cancer

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 1995–1997 | 27 890 | NS | 674 | Hospital mortality | H | Admin. | LVH: 14<br>MVH: 14–37<br>HVH: 37 | RAMR 10·6% *versus* 8·5 for LVH *versus* HVH ($P < 0.07$) | 8 |
| 11 | 1994–1999 | 5156 | NS | 54 | 30-day mortality | H | Admin. | Quantiles | No significant relationship | 6 |
| 23 | 1994–1997 | 3711 | 373 | 178 | Hospital mortality | H, S, both | Admin. | LVS: < 23<br>LVH: < 38 | RAMR decreased by 1·65% for HVH *versus* LVH ($P < 0.005$)<br>No relationship for surgeon | 10 |
| 24 | 1991–1995 | 1583 | 147 | NS | Hospital mortality | S | Admin. | LVS: < 10 | No significant relationship | 6 |
| 9 | 1994–1999 | 75 563 (pulmonary resection) | NS | 2763 | Hospital + 30-day mortality | H | Admin. | vLVH: < 9<br>LVH: 9–17<br>MVH: 18–27<br>HVH: 28–46<br>vHVH: > 46 | Absolute RAMR reduction of 5·4% for vHVH *versus* vLVH ($P < 0.001$) | 10 |
| 9 | 1994–1999 | 10 410 (pneumo-nectomy) | NS | 1817 | Hospital + 30-day mortality | H | Admin. | Continuous variable<br>vLVH: < 9<br>LVH: 9–17<br>MVH: 18–27<br>HVH: 28–46<br>vHVH: > 46 | Absolute RAMR reduction of 1·7% for vHVH *versus* vLVH ($P < 0.001$) | 10 |
| 10 | 1998–1999 | 24 092 | 4178 | NS | Operative mortality; death before discharge or 30-day mortality | H, S, both | Admin. | LVS: < 7<br>MVS: 7–17·0<br>HVS: > 17<br>LVH: < 17<br>MVH: 17–35·0<br>HVH: > 35 | OR 1·24 for LVS *versus* HVS. Surgeon volume accounted for 24% of observed effect of hospital volume | 10 |
| 25 | 1985–1996 | 2118 | NS | 76 | Hospital + 30-day mortality; complications; 5-year survival | H | Clinical | vLVH: < 8<br>LVH: 9–14<br>MVH: 15–19<br>HVH: 20–66<br>vHVH: > 66 | 5-year survival 44 *versus* 33% for HVH *versus* LVH<br>Post operative complication rate 20 *versus* 44%<br>30-day mortality 3 *versus* 6% | 10 |
| 22 | 1984–1993 | 1375 | NS | 313 | Hospital + 30-day mortality | H | Clinical | LVH: < 6 | No significant relationship | 6 |
| 26 | 1983–1986 | 12 439 | NS | 389 | Hospital + 30-day mortality | H | Admin. | LVH: < 9 | OR 0·6 for HVH *versus* LVH | 8 |

H, hospital; S, surgeon; (v)LVH, low-volume hospital; MVH, medium-volume hospital, v(HVH), high-volume hospital; LVS, low-volume surgeon; HVS, high-volume surgeon; Admin., administrative; RAMR, risk-adjusted mortality rate; OR, odds ratio; NS, not specified.

**Table 6** Studies of surgery for breast cancer

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 1984–1989 | 47 890 | NS | 266 | 5 year survival | H | Clinical | LVH: < 10<br>HVH: > 149 | OR 1·6 for HVH *versus* LVH | 10 |
| 28 | 1979–1988 | 12 861 | 180 | NS | 5 year survival | S | Clinical | LVS: < 10<br>MVH: 10–29<br>LVH: 30–49<br>vHVH: ≥ 50 | Adjusted RR: < 10 patients, 1·0; 10–29 patients, 0·97; 30–49 patients, 0·85; ≥ 50 patients, 0·86 | 11 |
| 29 | 1980–1995 | 2409 | NS | 9 | 5 year survival | H | Clinical | LVH < 25 | No significant relationship | 7 |
| 30 | 1989–1994 | 11 329 | 176 | NS | 5 year survival | S | Clinical | LVS: < 10<br>MVS: 10–29<br>HVS: 30–49<br>vHVS: > 49 | 5-year survival 68 *versus* 60% for vHVS *versus* LVS<br>RR 1·15 and 1·10 for LVS and MVS *versus* HVS | 11 |

H, hospital; S, surgeon; LVH, low-volume hospital; HVH, high-volume hospital; LVS, low-volume surgeon, MVS, medium-volume surgeon; v(HVS), (very) high-volume surgeon; OR, odds ratio; RR, relative risk; NS, not specified.

clinical data and eight incorporated this in risk assessment. Schrag *et al.*[33] analysed abdominoperineal resection rates and overall survival, whereas *Ko et al.*[32] incorporated data on emergency and elective procedures. The outcomes used were primarily inpatient or 30-day mortality, and nine studies also assessed 5-year survival data[10,15,23,31–34,35,40]. No study measured pertinent complications such as infection or anastomotic leak.

Most authors found a significant relationship between provider volume and outcome. Of the fifteen that assessed hospital volume (either alone or in conjunction with surgeon volume) and outcome, ten noted a significant inverse relationship. The reduction in RAMR ranged from 1·1 to 1·9. Two studies showed a volume–outcome relationship that disappeared when surgeon volume was controlled[22,33]. Simunovic *et al.*[40] and Meyerhardt *et al.*[41] demonstrated no significant relationship between hospital volume and outcome.

Of the seven studies that measured surgeon volume (either alone or in conjunction with hospital volume), three found a significant volume–outcome relationship with a reduction in risk-adjusted mortality of between 0·5 and 0·64[23,33,35]. However, when Hannan *et al.*[23] controlled for hospital volume, surgeon volume had no effect on outcome. Of the three studies that failed to show a significant correlation, the investigation by Parry *et al.*[36] involved only 927 patients, one of the smallest study populations of any of the included reports. McArdle *et al.*[34], although failing to demonstrate a significant volume–outcome relationship, did show an increase in 5-year cancer-specific survival after curative resection for patients treated by specialist colorectal surgeons (72·7 *versus* 63·8 per cent). Schrag *et al.*[33] demonstrated a surgeon-specific improvement in 2-year mortality rate for high-volume surgeons performing rectal cancer procedures after adjustment for hospital volume. There was no inpatient or 30-day survival benefit and there was no survival benefit for high-volume hospitals after adjusting for surgeon volume. However, Hannan *et al.*[23] showed that the surgeon volume-related outcome benefit for oncological colectomy disappeared when risk adjustment was controlled for hospital volume.

The studies of provider volume and outcome in surgery for colorectal cancer demonstrate a significant inverse relationship. The relative contribution of hospital and surgeon to this volume-associated outcome remains to be elucidated. Furthermore, the magnitude of the volume effect on mortality is variable and small, typically in the region of 1–2 per cent. This translates into a number needed to treat of 50–100 patients.

## Operations for miscellaneous cancers

Three studies examined provider volume and outcome with respect to cystectomy (*Table 8*). Birkmeyer *et al.*[10] found a significant inverse relationship between provider

**Table 7** Studies of colorectal resection

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 31 | 1991–1996 | 24 166 | 2682 | 579 | Hospital mortality; 2-year survival and stoma rates | H, S, both | Admin. | vLVH: 1–61<br>LVH: 62–116<br>MVH: 117–167<br>HVH: 169–383<br>vLVS: 1–9<br>LVS: 10–16<br>MVS: 17–27<br>HVS: > 28–85 | RR mortality 1·15 for vLVH *versus* 1·10 for LVH *versus* HVH: ($P < 0·001$)<br>RR mortality 1·06 for LVS *versus* HVS ($P = 0·10$) | 9 |
| 11 | 1994–1999 | 18 898 | NS | 134 | 30-day mortality | H | Admin. | Quantiles | No significant relationship | 6 |
| 32 | 1996 | 22 408 (colon) | NS | 600 | Hospital mortality | H | Clinical | None | Probability of in-hospital mortality 12 in 1000 for baseline *versus* 11 in 1000 and 10 in 1000 for HVS and HVH respectively | 5 |
| 23 | 1994–1997 | 22 128 | 2052 | 229 | Hospital mortality | H, S, both | Admin. | LVS: < 12<br>HVS: > 34<br>LVH: < 84<br>HVH: > 253 | RAMR decreased by 1·9% for HVH *versus* LVH<br>No surgeon effect when hospital volume controlled | 10 |
| 9 | 1994–1999 | 304 285 | 4587 | NS | Hospital + 30-day mortality | H | Admin. | Continuous variable but quintiles | Absolute RAMR reduction of 1·1% for vHVH *versus* vLVH | 10 |
| 33 | 1992–1996 | 2815 | 1141 | 420 | 30-day, 2-year mortality; overall survival; APR | H, S, both | Clinical | Continuous variable but quantiles with top quantile as referral category | RAMR at 2 years 0·86 *versus* 1·36 for HVS *versus* LVS. No relationship with hospital volume once surgeon volume controlled | 11 |
| 34 | 1991–1994 | 3200 | 94 | 11 | 5-year survival | S | Admin. | LVS:< 30<br>MVH: 30–60<br>HVH: < 60 in study period | No significant relationship on adjustment for volume | 9 |
| 35 | 1992–1996 | 9739 | 812 | 50 | Hospital mortality | H, S, both | Admin. | LVS: < 6<br>LVH: < 40 | OR 0·64 for HVS *versus* LVS<br>OR 0·78 for HVH *versus* LVH<br>MVS at HVH/MVH equivalent to HVS; HVS better at any hospital | 10 |
| 36 | 1993 (6 months) | 927 | 123 | 39 | 30-day mortality; 3-year survival | H, S, both | Clinical | LVS: < 7 in 6 months<br>LVH: < 30 in 6 months | No significant relationship | 9 |

(*continued overleaf*)

**Table 7** (Continued)

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| 37 | 1991–2000 | 22 633 | NS | 172 | 5-year survival | H | Clinical | LVH: < 25<br>HVH: > 25 | Decrease in RAMR of 7% for colonic and 11% for rectal cancer in HVH *versus* LVH | 10 |
| 38 | 1991–1996 | 27 986 | 611 | NS | 30-day mortality; 5-year survival | H | Clinical | vLVH: < 58<br>LVH: 58–112<br>MVH: 113–165<br>HVH: > 166 | 30-day mortality 3·5 *versus* 5·5% for HVH *versus* vLVH | 9 |
| 39 | 1990–1994 | 3127 | NS | NS | 2-year survival | H,S, both | Clinical | vLVH: < 33<br>LVH: 33–46<br>MVH: 47–54<br>HVH: > 54 | No significant relationship | 9 |
| 40 | 1990 | 418 | 124 | NS | 30-day mortality | H | Clinical | LVH: < 11<br>MVH: 12–17<br>HVH: > 18 | No significant relationship | 6 |
| 41 | 1990–1992 | 1330 | NS | 646 | Rates of sphincter-preserving operations, overall survival and cancer recurrence | H | Clinical | LVH: < 8·3<br>MVH: 8·4–16·7<br>HVH: > 16·8 | No significant effect on rectal cancer recurrence or survival when patients completed standard adjuvant therapy | 8 |
| 42 | 1994–1997 | 7257 | NS | 367 | Colostomy rates: 30-day and 2-year mortality | H | Clinical | Quartiles<br>LVH: < 7<br>MVH: 7–13<br>HVH: 14–20<br>vHVH: > 20 | Higher colostomy rates (OR 1·37), 30-day (OR 2·64) and 2-year mortality (HR 1·28) in LVH | |
| 43 | 1988–1992 | 3161 | NS | 1078 | 5-year survival | H | Clinical | LVH: < 46<br>MVH: 47–84<br>HVH: > 85 | 5-year survival 63·8 *versus* 67·3% in LVH *versus* LVH (HR 1·16).<br>No difference in recurrence | 9 |

H, hospital; S, surgeon; (v)LVH, (very) low-volume hospital; MVH, medium-volume hospital; (v)HVH, (very) high-volume hospital; (v)LVS, very low-volume surgeon; MVS, medium-volume surgeon; HVS, high-volume surgeon; Admin. administrative; APR, abdominoperineal resection; RR, relative risk; RAMR, risk-adjusted mortality rate; OR, odds ratio; HR, hazard ratio; NS, not specified.

volume and outcome, with an absolute reduction in RAMR of 1·83 per cent for high-volume hospitals compared with low-volume institutes. In a separate Medicare-based nationwide study, the same group estimated that surgeon volume accounted for 39 per cent of the observed volume–outcome relationship[10]. Both studies used administrative data for risk adjustment and had high quality scores. However Finlayson *et al.*[14] failed to show any significant volume–outcome correlation for radical cystectomy for malignancy. This was also a nationwide study that used administrative data to conduct risk adjustment.

Similarly, there is conflicting evidence regarding a volume–outcome correlation for nephrectomy. Birkmeyer *et al.*[9] showed a 0·5 per cent reduction in RAMR for high-volume hospitals whereas Finlayson *et al.*[14] found no significant relationship. Given the paucity of studies, contrasting findings and small magnitude of the correlation described in the positive studies, it is difficult to support the idea of a

**Table 8** Studies of surgery for miscelloneous cancers

| Reference | Interval | No. of patients | No. of surgeons | No. of hospitals | Primary outcome | Unit of analysis | Data source | Definition of volume (per year) | Volume–outcome results | Study quality score[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| Cystectomy | | | | | | | | | | |
| 14 | 1995–1997 | 4937 | NS | 590 | Hospital mortality | H | Admin. | LVH: < 4<br>MVH: 5–8<br>HVH: ?> 8 | No significant relationship | 8 |
| 9 | 1994–1999 | 22 354 | NS | 2422 | Hospital + 30-day mortality | H | Admin. | vLVH: < 2<br>LVH: 2–3<br>MVH: 4–5<br>HVH: 6–11<br>vHVH: > 11 | Absolute RAMR reduction of 2·9% for vHVH *versus* vLVH ($P < 0.001$) | 10 |
| 10 | 1998–1999 | 6340 | 2918 | NS | Operative mortality; death before discharge or 30-day mortality | H, S, both | Admin. | LVS: < 2<br>MVS: 2–3·5<br>HVS: > 3·5<br>LVH: < 4·0<br>MVH: 4·0–10·0<br>HVH: > 10 | OR 1·83 for LVS *versus* HVS. Surgeon volume accounted for 39% of observed effect of hospital volume | 10 |
| Nephrectomy | | | | | | | | | | |
| 9 | 1994–1999 | 61 430 | NS | 3292 | Hospital + 30-day mortality | H | Admin. | vLVH: < 7<br>LVH: 7–12<br>MVH: 13–19<br>HVH: 20–31<br>vHVH: > 31 | Absolute RAMR reduction of 0·5% for vHVH *versus* vLVH ($P < 0.001$) | 10 |
| 14 | 1995–1997 | 23,278 | NS | 820 | Hospital mortality | H | Admin. | LVH: 12<br>MVH: 13–33<br>HVH: > 33 | No significant relationship | 8 |
| Radical prostatectomy | | | | | | | | | | |
| 44 | 1989–1995 | 66 693 | NS | 550+ | Hospital + 30-day mortality; cost; LOS | H | Admin. | LVH: < 25<br>MVH: 25–54<br>HVH: > 54 | LVH 78% more likely to have a death (OR 1·78 for LVH *versus* HVH). Increased LOS (7·3 *versus* 6·1 days) for LVH ($P < 0.001$) | 8 |
| Hepatic resection | | | | | | | | | | |
| 45 | 1990–1994 | 507 | NS | 138 | Hospital + 30-day mortality | H | Admin. | LVH: < 2<br>HVH: > 16 | RAMR 22·7 *versus* 9·4% for LVH *versus* HVH | 6 |
| 22 | 1984–1993 | 801 | NS | 250+ | Hospital + 30-day mortality | H | Clinical. | LVH: 1–5<br>HVH: > 11 | Unadjusted 30-day mortality: 5·4 *versus* 1·7% | 8 |
| 17 | 1996–1997 | 2097 | NS | 221 | Hospital + 30-day mortality | H | Admin. | LVH: < 10<br>HVH: > 10 | 40% lower risk of death for HVH (OR 0·6) | 8 |
| Intracranial tumours | | | | | | | | | | |
| 46 | 1996–1997 | 7547 | 379 | 637 | Hospital mortality | H, S | Admin. | Quartiles | Lower adjusted mortality for HVH (OR 0·58; $P = 0.038$) and HVS (OR 0·42; $P = 0.012$) | 9 |

H, hospital; S, surgeon; (v)LVH, (very) low-volume hospital; MVH, medium-volume hospital; (v)HVH, (very) high-volume hospital; LVS, low-volume surgeon; MVS, medium-volume surgeon; HVH, high-volume surgeon; Admin., administrative; LOS, length of stay; RAMR, risk-adjusted mortality rate; OR, odds ratio; NS, not specified.

volume–outcome relationship for either of these procedures.

The single eligible study assessing hospital volume and outcome for radical prostatectomy found a decreased mortality rate for high-volume providers[44]. Although overall mortality was 0·25 per cent, low-volume hospitals were 78 per cent more likely to have a death than high-volume providers. Length of stay and cost were also higher. This was a large nationwide study involving over 66 000 patients and multiple outcome variables.

Three included studies describing liver resection found lower adjusted and unadjusted mortality rates in high-volume units[21,45,46]. Studies involved primary or secondary liver malignancies. Two were national studies[17,22] and Begg *et al.*[17] used clinical data for risk adjustment. The hospital was the unit of analysis and inpatient mortality the primary outcome assessed. Dimick *et al.*[17] described a 40 per cent decrease in adjusted mortality, Begg *et al.*[22] a 3·7 per cent decrease in absolute mortality and Glasgow *et al.*[45] a 13·3 per cent reduction in RAMR for high-volume hospitals, suggesting a significant volume–outcome relationship for hepatic resections.

Cowan *et al.*[46] found a lower adjusted mortality rate associated with operations for intracranial tumour for high-volume hospitals and surgeons, with an odds ratio of 0·58 for high-volume hospitals and 0·42 for high-volume surgeons after multiple logistic regression analysis.

## Discussion

All studies showed either an inverse relationship, of variable magnitude, between provider volume and mortality, or no volume–outcome effect. The majority of clinical studies, except two that scored low for quality, revealed a statistically significant correlation between volume and outcome; no study demonstrated the opposite relationship. This suggests that outcome for most cancer procedures is intrinsically linked to provider volume. Although other factors undoubtedly have a bearing, provider volume is the only acutely mutable variable. The magnitude of this relationship varies from procedure to procedure and the limitations of the studies examined here permit only speculation about the mechanisms underlying this phenomenon.

Present findings support volume-based referral initiatives. Centralization of most, if not all, oncological procedures now seems appropriate. Certainly, given the low numbers needed to treat to achieve a reduction in mortality, pancreatectomy, oephagectomy, gastrectomy and oncological rectal resections should be performed by high-volume providers. In the USA the Leapfrog group already has minimal volume-based criteria for a number of operations, including pancreatectomy and oesphagectomy. There are also sufficient grounds to suggest that surgeon-based volume parameters may justifiably be added to such criteria.

The question of whether the hospital or the doctor is a stronger influence is difficult to answer. Given the large sample-size requirements encompassing many surgeons and hospitals, and the difficulty in obtaining surgeon-specific volume estimates, few studies have simultaneously assessed the effect of surgeon volume and hospital volume. Only six studies analysed both variables simultaneously, often with conflicting results. It seems that the impacts of surgeon and hospital volumes differ from procedure to procedure, with surgeon volume more important in technically demanding operations such as pancreatectomy, oesphagectomy, gastrectomy and rectal cancer procedures (compared with colonic resections). In contrast, patients having lung resection rarely die because of technical complications; rather they die from cardiac events and pneumonia. Hospital-based services such as intensive care, physiotherapy and pain management, are often vital and so it is not surprising that hospital volume has a major role in the outcome of operations requiring such services.

The underlying mechanism of this relationship remains elusive. In complex procedures the surgeon's ability and experience may be enhanced with familiarity, i.e. there is a direct causal relationship. Furthermore, 'inverse causality' may result from better outcomes leading to increased referrals. Whatever the mechanism, better outcomes would be achieved by referral to high-volume units. The issue is further clouded by clustering of good or bad outcomes within a particular provider. It is important to determine whether low-volume providers generally achieve worse outcomes or whether a few high-volume providers with exceptionally good outcomes make low-volume providers look bad. A high volume–better outcome relationship found among many high-volume providers supports a regionalization policy, but if only a few providers exhibit this relationship, strategies to identify the features of their practice that make them successful seem more rational.

A note of caution is advisable before advocating policy changes based solely on currently available evidence. Many studies have assessed a single measure of provider volume, namely either hospital or surgeon volume, and there is no consensus definition of low- or high-provider volume. Most have used restrictive databases (such as Medicare which is confined to patients aged 65 years of age or older) which make assessment of cancer stage, adjuvant treatment and time to intervention impossible. Subgroup analysis in large studies was frequently based on relatively small numbers of patients[9], and assignment of unique provider identification numbers and data entries are subject to coding errors. In addition, most of the included studies involved risk assessment based on administrative data. Some experts have suggested that risk analysis based on clinical data is less likely to reveal a significant association between volume and outcome. The present review, however, has disproved this as most studies using clinical variables for risk adjustment demonstrated a positive correlation between volume and outcome. Despite all of the above caveats, it appears that high-volume providers are associated with a significantly better outcome, at least after complex surgery for cancer. These findings support the centralization of oncology services.

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