Systematic review

A systematic review of the impact of volume of surgery and specialization on patient outcome

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Background and methods: **Volume of surgery and specialization may affect patient outcome. Articles examining the effects of one or more of three variables (hospital volume of surgery, surgeon volume and specialization) on outcome (measured by length of hospital stay, mortality and complication rate) were analysed. Reviews, opinion articles and observational studies were excluded. The methodological quality of each study was assessed, a correlation between the variables analysed and the outcome accepted if it was significant.**

Results: **The search identified 55 391 articles published between 1957 and 2002; 1075 were relevant to the study, of which 163 (9 904 850 patients) fulfilled the entry criteria. These 163 examined 42 different surgical procedures, spanning 13 surgical specialities. None were randomized and 40 investigated more than one variable. Hospital volume was reported in 127 studies; high-volume hospitals had significantly better outcomes in 74·2 per cent of studies, but this effect was limited in prospective studies (40 per cent). Surgeon volume was reported in 58 studies; high-volume surgeons had significantly better outcomes in 74 per cent of studies. Specialization was reported in 22 studies; specialist surgeons had significantly better outcomes than general surgeons in 91 per cent of studies. The benefit of high surgeon volume and specialization varied in magnitude between specialities.**

Conclusion: **High surgeon volume and specialization are associated with improved patient outcome, while high hospital volume is of limited benefit.**

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Introduction

For nearly a century, the most contentious issue in surgery has been plagued by rhetoric and opinion rather than evidence-based clinical practice. This issue is specialization.

The main benefit suggested for specialization[1] has been that performing higher volumes of selective procedures would enhance surgical proficiency and in turn improve patient outcome. As early as 1957, Lee and colleagues[2] identified differences in mortality rates between hospitals of different experiences. The relationship between volume of surgery and clinical outcome itself was first examined in 1973 when Adams and colleagues[3] demonstrated that for one procedure low-volume centres had higher complication rates. Conversely it has been claimed that increased specialization would reduce general care locally[4], adversely affect emergency cover for individual specialities[5] and possibly restrict surgical training[1], particularly if a high proportion of trainees' time was spent in a single subspeciality. The debate requires irrefutable evidence on the effect of specialization and subsequent increased case-volume on patient outcomes. It is unlikely that randomized controlled trials will ever take place for this purpose. Therefore macrostatistics, in spite of its inherent limitations, offers considerable ethical and practical advantages in studying this particular relationship between volume of surgery and outcome[6,7].

To date there has been no comprehensive review of the evidence examining the effects of volume of surgery and specialization on patient outcome across all surgical disciplines. What follows is a systematic review of the literature using a defined search strategy to present the available evidence.

Methods

Search strategy

A literature search on Medline identified articles cited up to and including 31 August 2002. Three factors relating

Table 1 Search criteria and history

Keywords	No. of cited articles	No. of relevant articles
Volume of surgery	22 914	193
Hospital volume	6844	234
Surgeon volume	633	46
Physician volume	1352	48
Clinician volume	315	25
Surgeon workload	100	21
Physician workload	909	19
Clinician workload	42	2
Volume outcome	9553	239
Factors affecting outcome in surgery	611	15
Operative experience and outcome	1892	40
Surgical experience and outcome	5164	90
Specialisation or specialization	4834	79
Subspecialisation or subspecialization	228	24
Total	55 391	1075

to surgical service with a possible influence on clinical outcome were used: cumulative volume of surgery of the hospital, volume of surgery of individual surgeons and surgeon specialization. Keywords were entered in both English and American English (*Table 1*). The search strategy was intentionally very sensitive, retrieving more articles than were required to ensure that no articles were missed.

Abstracts of 55 391 citations were retrieved, either from electronic sources (Medline, Ovid, Web of Science) or from the British Library or University College London Libraries. For each keyword applied, duplicate articles cited in more than one of these database sources were initially excluded. Following this, again for each keyword category, articles that did not address the issue of volume of surgery/specialization and its relationship with outcome were further omitted, leaving 1075 relevant papers. These 1075 abstracts were scrutinized again, and 632 duplicate articles that were cited under more than one of the 14 keyword search categories (Table 1), were excluded. A number of exclusion criteria were applied to the remaining 443: articles not available in English (43 articles), articles on laparoscopic surgery (34), articles on ophthalmic surgery (five) and on gynaecology and obstetric surgery (16), review articles (36), editorials, letters and opinion articles (90), articles for which the full publication was unobtainable from any of the sources listed above (26), non-comparative studies reporting only single-centre or single-surgeon experiences (17) and articles in which patient outcome was not measured by a clinical variable such as treatment cost (13). Exclusion of these left 163 original articles for critical review (*Fig. 1*).

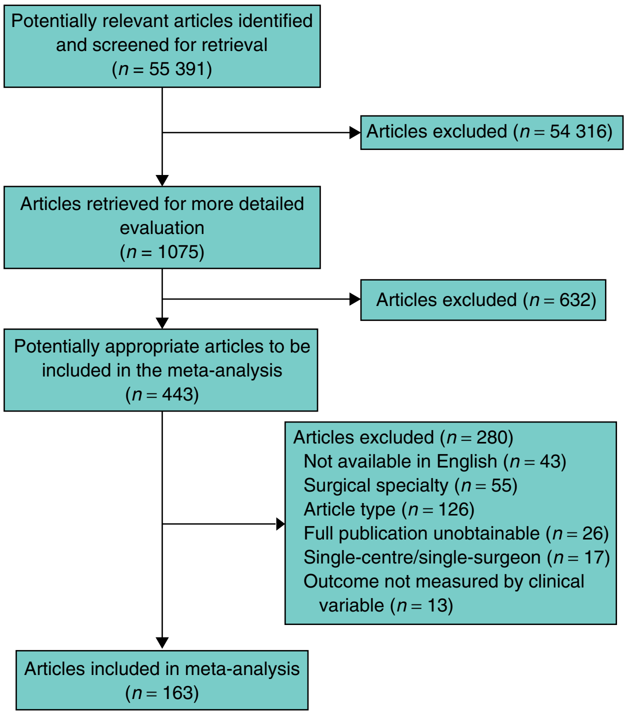

Fig. 1 Summary of the literature search and exclusion process

Quality assessment

The first two authors independently reviewed these 165 articles again in full, classifying the papers according to surgical speciality as well as to the three variables to be analysed. Quality assessment of each paper was made in terms of study design (prospective or retrospective, randomization status, longitudinal or cross-sectional), outcome measures, potential biases and whether it identified and controlled for case-mix differences (differences in patient demographics, co-morbidities and severity of illness between groups that might have biased results). Outcome measures were categorized into mortality rates, complication rates and length of hospital stay. A positive correlation between the variable studied and outcome was accepted only if it was significant ($P < 0{\cdot}050$) within each study.

Statistical analysis

The systematic review found that the literature was heterogeneous, with studies examining different procedures spanning different surgical specialties. Generalization of volume–outcome relationships for one procedure to another in another specialty would be fundamentally flawed. Furthermore, the definitions used to define high and low volume were heterogeneous among some studies examining the same procedure. Because of this heterogeneity, a weighted meta-analysis of the data was not feasible and would have been unreliable. The results of the review are therefore reported in descriptive terms.

Results

The 163 articles that met the inclusion criteria collectively examined 42 different surgical procedures spanning 13 surgical specialities and incorporating a total of 9 904 850 patients. There were no randomized studies; 19 (11·7 per cent) were prospective and 144 (88·3 per cent) were retrospective; ten (6·1 per cent) were longitudinal and 153 (93·9 per cent) were cross-sectional. Forty studies examined more than one of the three variables. As for outcome measures, 142 studies used mortality rates, 66 used complication rates and 34 used length of hospital stay; 78 studies examined more than one outcome measure.

Volume of surgery

Of 153 studies studying volume–outcome relationship, 127 compared outcomes of hospitals of different volumes (total 9 535 354 patients), 58 examined surgeon volume (total 978 985 patients) and 32 examined both variables.

Hospital volume

High-volume hospitals had significantly better overall outcome in 94 (74·0 per cent) of the 127 studies (*Fig. 2*). This was consistent for all outcome measures, demonstrated by lower mortality rate in 76 per cent, shorter hospital stay in 79 per cent and fewer complications in 62 per cent of the studies. No study identified a significant association between high hospital volume and poorer outcomes. The effect of hospital volume varied between specialities (*Table 2*). High volume was beneficial in 17 (85 per cent) of 20 studies in hepatobiliary and pancreatic surgery, 28 (76 per cent) of 37 studies in cardiothoracic surgery, 21 (72 per cent) of 29 studies in surgical oncology, 18 (72 per cent) of 25 studies in vascular

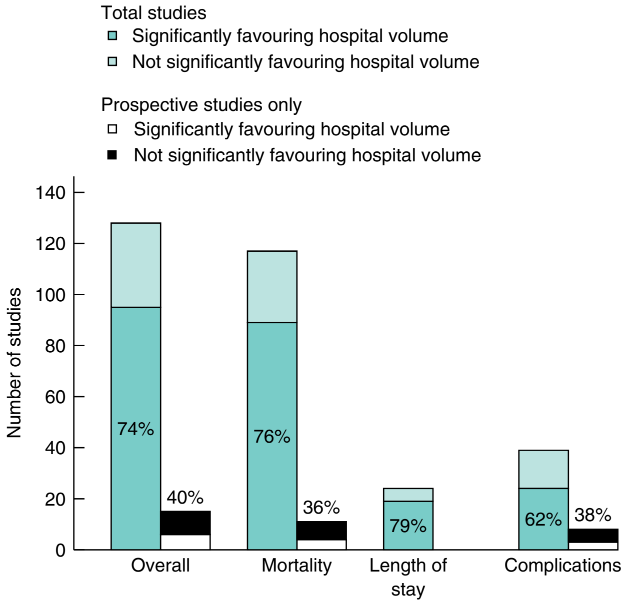

Fig. 2 Histogram illustrating the effect of hospital volume on overall outcome, mortality, length of hospital stay and complication rate

Table 2 Effect of hospital volume on outcome

			Prospective studies		Retrospective studies	
Speciality	References	Total	Total	Case-mix adjusted	Total	Case-mix adjusted
Cardiothoracic	8–43	36 (28)	2 (0)	2 (0)	34 (28)	17 (15)
Surgical oncology	44–72	29 (21)	6 (1)	4 (1)	23 (20)	15 (13)
Vascular	24, 40, 41, 43, 72–93	25 (18)	1 (0)	1 (0)	24 (18)	11 (10)
Hepatobiliary/pancreatic	40, 41, 43, 59, 93–110	20 (17)	2 (1)	1 (0)	18 (16)	9 (9)
Orthopaedics and trauma	15, 41, 43, 109–125	21 (13)	5 (2)	2 (1)	16 (11)	10 (7)
Urology	41, 43, 94, 126, 127	5 (5)	0	0	5 (5)	5 (5)
Gastrointestinal surgery	40, 41, 43, 128	4 (3)	1 (0)	1 (0)	3 (3)	2 (2)
Neurosurgery	43, 121, 129	3 (3)	0	0	3 (3)	1 (1)
Transplant surgery	130–132	3 (3)	1 (1)	1 (1)	2 (2)	0
Endocrine surgery	133, 134	2 (1)	1 (1)	1 (1)	1 (0)	1 (0)
ENT surgery	43	1 (1)	0	0	1 (1)	1 (1)
Total*		127 (94)	15 (6)	9 (4)	112 (88)	56 (46)

Values in parentheses are the number of studies that demonstrated significantly better outcomes from high volume hospitals ($P < 0{\cdot}050$). *Some studies examined the influence of hospital volume in more than one speciality. ENT, ear, nose and throat.

surgery and 13 (62 per cent) of 21 studies in orthopaedic surgery.

The influence of hospital volume, however, was distinctly different between retrospective and prospective studies (*Fig. 2; Table 2*). High volume was beneficial in 88 (78·6 per cent) of 112 retrospective studies but in only six (40 per cent) of 15 prospective studies. The diminished benefit of high volume in the prospective studies was consistent; mortality was lower in only 36 per cent and there were fewer complications in only 38 per cent of the studies. No prospective study examined length of hospital stay.

The potential effect of case-mix differences on these results was also examined; 65 of the 127 studies were adjusted for case-mix differences. Of these, 50 (77 per cent) described a significant benefit from high hospital volume. However, as with the overall data, this benefit appeared principally in the retrospective data. High hospital volume was beneficial in four (44 per cent) of nine prospective studies that were adjusted for case-mix differences compared with 46 (82 per cent) of 56 retrospective studies. Case-mix differences, therefore, did not appear to influence these results in either prospective or retrospective studies. Within the prospective group, high-volume hospitals had significantly better outcomes in four (44 per cent) of nine studies adjusted for case-mix differences compared with two (40 per cent) of five studies not adjusted for case-mix differences. Similarly, in the retrospective group, 46 (82 per cent) of 56 studies that were adjusted for case-mix differences benefited from high

Table 3 Hospital volume thresholds: recommended annual volume of operations per hospital

Procedure	Reference	High volume	Low volume	Significant difference
Lung cancer	44	20–100	< 9	Yes†
Oesophageal cancer	51	> 6	< 6	Yes
Oesophageal cancer	62	30	1–5	Yes
Colorectal cancer	63	> 18	< 11	Yes
Colorectal cancer	56	> 33	< 23	Yes
Colorectal cancer	45	40	20	Yes†
Colorectal cancer	49	70	< 40	Yes
Oncology‡	54	> 11	1–5	Yes†
Pancreaticoduodenectomy	88	> 21	< 21	Yes
Pancreaticoduodenectomy	101	25	5	Yes
Pancreaticoduodenectomy	93	> 50	1	Yes†
Pancreaticoduodenectomy	102	5·5 (4·2, 8·1)*	0·5 (– 0·2, 2·0)*	Yes
Liver resection	100	> 15	< 7	Yes
Liver transplant	130	> 20	< 20	Yes
Coronary interventions	135	209	68	Yes
Angioplasty	31	> 33	5–11	Yes
Angioplasty	10	> 57	1–56	No†
Angioplasty	22	> 75	< 75	Yes
Angioplasty	12	200	100	No
Angioplasty	30	200–400	100	Yes
Angioplasty	14	400	200	Yes
Angioplasty	13	600	200	Yes
Carotid endarterectomy	76	100	33–44	No
AAA repair/carotid endarterectomy	79	50	20	Yes
AAA repair	87	> 10		Yes
AAA repair	136	> 10		Yes
AAA repair	73	> 30		Yes†
CABG	8		< 200	Yes†
CABG	19	66	6	No
CABG	27	600	100	Yes
CABG	26	> 100		Yes
Paediatric cardiac surgery	9	> 100		Yes†
Cardiac surgery	18	> 120	80	Yes
Trauma	110	200	140	Yes†
Trauma	109	251	150	No†
Trauma	117	> 650		Yes†

*Values are median (95 per cent confidence intervals). †Studies adjusted for case-mix differences. ‡Study considered cancer of pancreas, lung, oesophagus, liver and colon. AAA, abdominal aortic aneurysm; CABG, coronary artery bypass grafting.

volume compared with 42 (75 per cent) of 56 studies not so adjusted.

Table 3 gives the cut-off values, or the annual volume performed of a given procedure, defining 'high volume' for hospitals in which high volume was associated with significantly better outcomes. This demonstrates that the definition of high- and low-volume hospitals varied for different procedures, and in some instances between studies examining the same procedure. Indeed, for some procedures, the thresholds for high and low volume overlapped between studies, so that the number of procedures considered high in one study was considered low in another study.

Restricting the analysis of cut-off values defining high-volume hospitals to studies that adjusted for case-mix differences revealed that a positive relationship between high hospital volume and better outcome was demonstrable only for a limited number of procedures. For each of these procedures, the annual volumes recommended to achieve significantly better outcomes are outlined in *Table 4*: 20 lung cancer operations[44], 40 colorectal cancer operations[45], 50 pancreaticoduodenectomies[93], 30 abdominal aortic aneurysms[73], 200 coronary artery bypass grafts[8], 100 paediatric cardiac surgical procedures[9] and 200–250 trauma procedures[109,110].

In summary, although the initial impression is that the literature overwhelmingly substantiates a benefit from high hospital volume, analysis of the quality of the data suggests that this conclusion is unsafe. The apparent benefit from high hospital volume comes predominantly from retrospective studies. Factors responsible for the discrepancy between the findings of the prospective and retrospective data, the apparent resistance of the results to being affected by case-mix differences and potential biases are explored later.

Table 4 Annual thresholds for operations associated with a positive volume–outcome relationship (case-mix adjusted studies only)

Procedure	Reference	Thresholds defining high volume (operations per year)
Hospital volume		
Lung cancer	44	20
Colorectal cancer	45, 56	33–40
Pancreaticoduodenectomy	93	50
AAA repair	73	30
CABG	8	200
Paediatric cardiac surgery	9	100
Trauma	109, 110	200–250
Surgeon volume		
Colorectal cancer	46,137	13–21
Lobectomy	46	50
Gastrectomy	46	6
Angioplasty	10	11
Paediatric cardiac surgery	9	75

AAA, abdominal aortic aneurysm; CABG, coronary artery bypass grafting.

Surgeon volume

High-volume had significantly better overall outcomes in 43 (74 per cent) of the 58 relevant studies (*Fig. 3*). This effect was measured by lower mortality rate in 71 per cent, shorter hospital stay in 78 per cent and fewer complications in 81 per cent. No study identified a significant association between high surgeon volume and poorer outcomes. Unlike high hospital volume, high surgeon volume benefited outcome consistently in both prospective and retrospective studies (seven (88 per cent) of eight studies and 36 (72 per cent) of 50 studies respectively). In prospective studies, high-volume surgeons had significantly lower mortality rates (in four of four studies) and fewer complications (in five of six studies). No study examined length of hospital stay.

The effect of surgeon volume varied between specialities, high volume being beneficial in 12 (75 per cent) of 16 studies in cardiothoracic surgery, 11 (73 per cent) of 15 in vascular surgery, nine (69 per cent) of 13 in surgical oncology and five (56 per cent) of nine studies in orthopaedic surgery (*Table 5*). No reliable conclusion could be made for individual specialities from the limited number of prospective studies available.

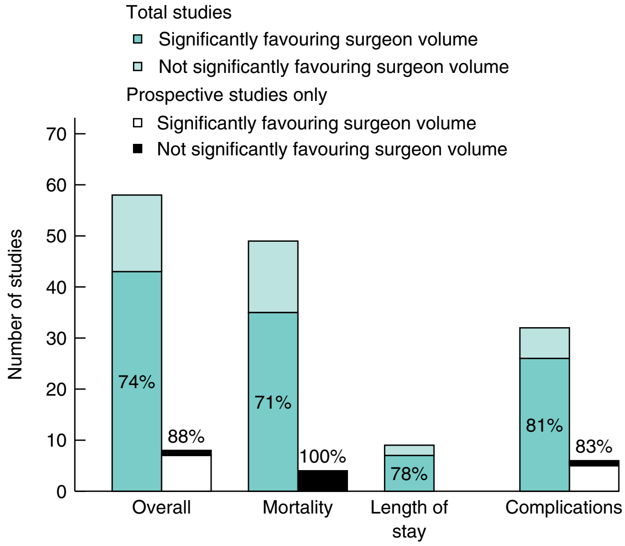

Fig. 3 Histogram illustrating the effect of surgeon volume on overall outcome, mortality, length of hospital stay and complication rate

Table 5 Effect of surgeon volume on outcome

			Prospective studies		Retrospective studies	
Speciality	References	Total	Total	Case-mix adjusted	Total	Case-mix adjusted
Cardiothoracic	9–11, 25, 32–34, 37, 135, 138–144	16 (12)	0	0	16 (12)	9 (7)
Vascular	72, 74, 78, 80, 82–84, 86, 91, 136, 145–149	15 (11)	1 (1)	0	14 (10)	4 (2)
Surgical oncology	46, 47, 49, 50, 66, 68, 70, 72, 137, 150–153	13 (9*)	6 (6)	4 (4*)	7 (3)	5 (2)
Orthopaedics and trauma	111, 112, 116, 119, 125, 154–157	9 (5†)	2 (1)	0	7 (4†)	1 (1)
Hepatobiliary/pancreatic	94, 95, 158, 159	4 (4)	0	0	4 (4)	1 (1)
Urology	94	1 (1)	0	0	1 (1)	1 (1)
Endocrine surgery	133	1 (1)	0	0	1 (1)	1 (1)
Plastic surgery	160	1 (1)	0	0	1 (1)	0
Total‡		58 (43)	8 (7)	4 (4)	50 (36)	19 (14)

Values in parentheses are the number of studies that demonstrated significantly better outcomes from high volume surgeons ($P < 0{\cdot}050$). *Includes reference 66; high volume surgeons had significantly less locoregional recurrence of cancer, but no difference for mortality. †Includes reference 125; high volume surgeons had significantly better outcome for blunt trauma but not for penetrating trauma. ‡Some studies examined the influence of surgeon volume in more than one speciality.

Table 6 Surgeon volume thresholds: recommended annual volume of operations per surgeon

Procedure	Reference	High volume	Low volume	Significant difference
Oncology				
Colorectal cancer	46	13	1	Yes*
Colorectal cancer	49	> 10	< 5	Yes
Colorectal cancer	56	> 33	< 23	Yes
Colorectal cancer	137		< 21	Yes*
Gastrectomy	46	> 6	< 1	Yes*
Lobectomy	46	50	1·5	Yes*
Oesophageal cancer	50	> 12	< 4	No*
Oesophageal cancer	152	> 6	< 6	Yes
Orthopaedics				
Total hip replacement	116	32	10	No*
Arthroplasty	155		< 10	Yes
Vascular				
Angioplasty	10	> 11	1–10	Yes*
Angioplasty	139	> 30	< 30	Yes
Angioplasty	141	> 50		Yes
Carotid endarterectomy	82		< 10	Yes
Carotid endarterectomy	145	> 3	1–2	Yes
Carotid endarterectomy	148	10	1	Yes
Carotid endarterectomy	83	175	75	Yes
CABG	140	150	50	Yes
Paediatric cardiac surgery	9	> 75	< 75	Yes*
Hepatobiliary				
Pancreaticoduodenectomy	159	4	1–3	Yes
Pancreaticoduodenectomy	95	41	9	Yes
Ear, nose and throat				
Palatoplasty	160	> 16		Yes

*Studies adjusted for case-mix differences. CABG, carotid artery bypass grafting.

The results for neither the prospective nor the retrospective sample of studies were significantly affected by adjustment for case-mix differences. Among prospective studies, a benefit of high surgeon volume was noted in four of four studies adjusted for case-mix differences and three of four studies not so adjusted. Among retrospective studies, a benefit of high surgeon volume was noted in 14 (74 per cent) of 19 studies adjusted for case-mix differences and 22 (71 per cent) of 31 studies not so adjusted. As with hospital volume, the definitions of high and low surgeon volume varied between different operations and, in some instances, between studies examining the same operation (*Table 6*).

Restricting the analysis to studies that adjusted for case-mix differences, a significant benefit from high surgeon volume was demonstrated for colectomy[46], lobectomy[46], gastrectomy[46], colorectal cancer surgery[137], angioplasty[10] and paediatric cardiac surgery[9]. For each of these, the annual volumes recommended to achieve significantly better outcomes are outlined in *Table 4*: 13 colectomies[46], 50 lobectomies[46], six gastrectomies[46], 21 operations for colorectal cancer[137], 11 angioplasties[10] and 75 paediatric cardiac surgical procedures[9].

Given that the results of hospital volume may at least in part be a reflection of the effect of surgeon volume, it was important to examine the independent contribution of each to outcome. Of the 32 studies that examined both hospital and surgeon volume variables, 13 performed regression analysis to identify the relative contributions of hospital and surgeon volume. Of the 13 studies, 11 (85 per cent) demonstrated a significant benefit from high-volume surgeons after adjusting for hospital volume variations[9,11,46–48,68,74,94,111,112,133], and six (46 per cent) demonstrated a significant benefit from high-volume hospitals after controlling for surgeon volume variations[9,11,46,74,95,111]. These results are therefore consistent with the conclusions from the prospective data discussed above examining the effect of either hospital or surgeon volume.

Specialization

A total of 22 studies in 144 421 patients examined the influence of specialization on outcome (*Table 7*; *Fig. 4*). Specialist surgeons had significantly better overall outcome than general surgeons performing the same procedure in 20 of 22 studies (91 per cent), lower mortality rate in 11 of 12 studies (92 per cent), shorter hospital stay in five of five studies (100 per cent) and fewer complication rates in 14 of 17 studies (82 per cent). No study demonstrated a significant outcome benefit from non-specialization.

The effect of specialization was evident in both prospective and retrospective studies, being beneficial in all three prospective and in 17 of 19 retrospective studies. Case-mix differences did not influence these results: a positive relationship between specialization and significantly improved outcome was reported in all ten studies adjusted for case-mix and seven of nine studies not adjusted for case-mix differences. Surgical oncology

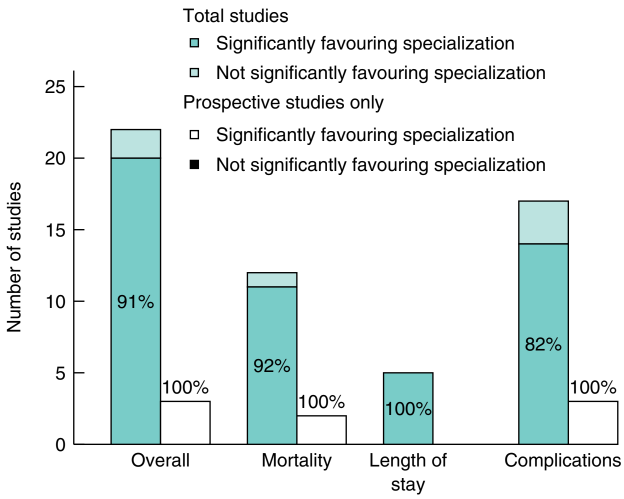

Fig. 4 Histogram illustrating the effect of specialization on outcome, as measured by overall outcome, mortality, length of hospital stay and complication rate for specialist surgeons compared with general surgeons

Table 7 Effect of specialization on outcome

			Prospective studies		Retrospective studies	
Speciality	References	Total	Total	Case-mix adjusted	Total	Case-mix adjusted
Surgical oncology	48, 58, 63, 69, 72, 137, 161, 162	8 (7)	3 (3)	3 (3)	5 (4)	3 (3)
Vascular	72, 78, 90, 145, 148, 163, 164	7 (7)	0	0	7 (7)	2 (2)
Hepatobiliary/pancreatic	94, 165	2 (2)	0	0	2 (2)	1 (1)
Endocrine surgery	166, 167	2 (2)	0	0	2 (2)	0
Gastrointestinal surgery	168	1 (1)	0	0	1 (1)	1 (1)
Orthopaedics and trauma	169	1 (1*)	0	0	1 (1*)	1 (1*)
Urology	94	1 (0)	0	0	1 (1)	1 (1)
Neurosurgery	170	1 (0)	0	0	1 (0)	0
Total†		22 (20)	3 (3)	3 (3)	19 (17)	7 (7)

Values in parentheses are the number of studies that demonstrated significantly better outcomes from specialist surgeons ($P < 0{\cdot}050$). No studies demonstrated a significant benefit of non-specialization. *Specialization reduced length of hospital stay, but not mortality or complication rate. †Some studies examined the influence of specialization in more than one speciality.

and vascular surgery were most frequently examined, with specialization being beneficial in seven of eight studies in surgical oncology and all seven in vascular surgery. The numbers of studies in the remaining specialities were too sporadic to draw reliable conclusions.

Regression analysis was performed in four of the 22 studies to isolate the independent contributions of volume of surgery and specialization. In three of these, high volume of surgery was found to be independently beneficial to outcome[94,137,145], but even after adjusting for discrepancies in volume between specialist and general surgeons, the benefit from specialization was still apparent. The fourth study by Swisher and colleagues[48] demonstrated that, for oesophagectomies for cancer, high surgeon volume was the most influential factor leading to better outcome, with no benefit from cancer specialization after controlling for volume.

Discussion

This systematic review suggests that high surgeon volume and specialization benefit patient outcome. The benefit of high hospital volume is less clear and varies between procedures. Where high hospital volume has been shown to be beneficial, the data come predominantly from retrospective studies. The interpretation of these associations, however, is complex and worthy of further consideration.

Defining high volume

Analysis of the crude data found a positive relationship between high volume and better outcome for both hospital and surgeon. However, the definition of high volume was very heterogeneous and in most cases chosen arbitrarily by the authors of the individual articles. For instance, volumes reported to be high in one study, such as 200 angioplasties per year[12], were often considered to be low in another[13,14].

Such heterogeneity precludes any macrostatistical analysis. It does, however, offer an alternative explanation for studies where no significant difference was apparent in outcomes between high- and low-volume hospitals or surgeons. In such studies, thresholds defining high and low volume may both be either too low (so no demonstrable differences between the two volumes), or have exceeded a plateau beyond which further increases in volume will not significantly improve outcome. Three studies examining the effect of hospital volume on outcomes following angioplasty demonstrate this. Maynard and colleagues[12] found no benefit from high hospital volume, defined as 200 angioplasties per year. However, this arbitrary figure of 200 was categorized as low volume in other studies[13,14], where a significant benefit was found for hospitals performing more than 400 angioplasties per year compared with those performing fewer than 200 per year.

One way of identifying whether the lack of a benefit from high hospital volume in most studies is a real effect would be to use not two arbitrarily selected volumes but graded volumes (such as 0–20, 21–40, 41–60 and so on). This should identify a true cut-off and allow a proper definition of 'high' for procedures that appear to benefit from high hospital volume. This review found that high and low volumes were defined arbitrarily for most of the 42 procedures considered. From such studies, one can only conclude the presence or absence of a volume–outcome relationship. With respect to identifying cut-off values that define high volume, the data are limited to only a few procedures (*Table 4*).

Among these limited number of studies from which thresholds of high and low volume could be ascertained reasonably reliably, it is clear that the definition of high volume also varies between procedures (*Table 4*). This heterogeneity in volume thresholds may reflect a differential degree of technical difficulty. It is also inevitably influenced by the incidence of a particular pathology; for instance, fewer pancreaticoduodenectomies are performed than hernia repairs. Thresholds defining 'high volume' cannot be generalized to all procedures; each operation must be considered individually.

Volume–outcome relationship

The evidence from this review suggests that the volume of surgery of the individual surgeon has more bearing on patient outcome than the cumulative volume of the hospital. For hospital volume, there is a discrepancy between the results of prospective and retrospective studies, with a positive relationship between high-volume hospitals and improved outcome reported in 75 per cent of retrospective studies but in only 40 per cent of prospective studies. This disparity may reflect the inherent limitations of retrospective data collection. One such limitation, as Hughes and co-workers[171] illustrated, is that hospitals that transfer patients after primary surgery back to a referring (often smaller and lower volume) hospital may have better outcomes because patients who develop complications or die are more likely to do so in the referring institution. Length of hospital stay will also appear shorter than in hospitals that retain their own patients after primary surgery until discharge home.

This interhospital transfer is common and may bias outcomes in favour of certain hospitals, typically high-volume referral centres. Retrospective studies that usually provide only data collected during the patients' stay in the operative hospital are unlikely to unmask these inaccuracies. The smaller but more reliable sample of prospective studies demonstrated that when this and other potential inaccuracies are minimized, the benefit from high hospital volume is limited; high surgeon volume was still beneficial.

A second confounding variable is the volume of the individual surgeon. High hospital volume may accrue from a large group of low-volume surgeons in one hospital, while a hospital volume may be low if a single surgeon performs all of a given procedure. So, without controlling for individual surgeon volume, interpreting the relationship between high hospital volume and outcome is complicated.

Hospital and surgeon volumes were both examined in 13 studies. High surgeon volume was beneficial in 85 per cent and high hospital volume in 46 per cent of these studies, after controlling for surgeon volume. These findings suggest that the cumulative volume of surgery in a hospital has a positive effect on outcome that is independent of the contribution of individual surgeon volume. However, as independent variables, the volume of an individual surgeon has a greater influence on outcome. It is probable that the high volume of an individual surgeon is a greater determinant of outcome than a high-volume hospital employing low-volume surgeons.

Various factors may explain the positive volume–outcome relationship, including the 'practice makes perfect' effect, the 'selective referral' effect and potential biases of studies. The 'practice makes perfect' theory postulates that surgeons performing a particular procedure on a regular basis become more proficient in that procedure, which is reflected in better patient outcome[172,173]. The 'selective referral' theory postulates that excellent units that have qualities specific to the surgeon or hospital (hospital-specific fixed effects) independent of the volume of surgery develop a reputation for good outcome and receive more referrals[173]. The selective referral theory therefore suggests that better outcome is the *cause rather than the effect* of high volume. Isolating the contribution of the 'practice makes perfect' effect from hospital-specific fixed effects to the overall outcome is difficult[15,172,173]. One solution would be to conduct longitudinal studies to examine whether outcome was affected by changes in volume within the same centre, thereby controlling for interhospital variations in quality. If outcome differences between high- and low-volume groups were exclusively due to the effect of volume, the outcomes of low-volume groups would become similar to those of high-volume groups as the volume of surgery increased. Conversely, if outcome was resistant to changes in volume over time, then it could be concluded that the better outcome was a result, at least in part, of hospital-specific fixed effects, supporting the selective referral hypothesis.

Four of the 154 volume–outcome studies performed longitudinal analysis[15,16,113,126], the rest being solely cross-sectional within a given time. Cross-sectional analysis in these four studies found a positive volume–outcome relationship for hernia repair[15], coronary artery bypass grafting[15], coronary angioplasty[16], hip fracture surgery[113] and prostatectomy[126]. However, subsequent longitudinal study demonstrated that, when the volumes of the two groups were comparable, outcome differences persisted for hernia repair, narrowed for coronary angioplasty and prostatectomy, and disappeared for coronary artery bypass and hip fracture surgery. These four studies highlight the need to consider volume-independent factors, such as hospital-specific qualities, when considering the volume–outcome relationship and in the wider issue of specialization.

Influence of case-mix differences

Differences in case-mix between high- and low-volume groups may bias outcomes. For instance, there is some evidence that patients with higher preoperative risk factors, elderly patients and patients with advanced disease are treated more often in primary hospitals[174] and by low-volume surgeons[175]. This is particularly true for emergency surgery services, when patients are more likely to be admitted to their local hospital. Such case-mix differences may favour outcomes of high-volume groups, independent of the effect of volume of surgery. Conversely, a referral pattern of complex patients from low-volume to high-volume centres may favour outcomes of low-volume groups. Differences in the choice of treatment, where low-volume centres tended to opt for more conservative procedures than high-volume centres, have been identified for elective[114] and emergency[174] orthopaedic procedures. Since lower-risk procedures are likely to be associated with lower morbidity and mortality, such discrepancies are likely to bias in favour of low-volume groups. The present review found no difference between the results of studies adjusted and those not adjusted for case-mix differences. However, the poor design of most studies made it impossible to conclude whether outcome was genuinely unaffected by case-mix differences or whether there were opposing biases such as those highlighted above.

Sources of bias

Case-mix differences are one source of bias. Another is the outcome measure. In the present review, 99 studies (60 per cent) used length of hospital stay or mortality rates or both as the only measures of outcome. The potential inaccuracies of these two measures have already been noted, particularly if they reflect only what happened in the hospital where the operation was performed. Furthermore, mortality is not sensitive enough for low-risk procedures (for example hernia repair or cholecystectomy) for which quality factors are more likely to influence morbidity than mortality. Mortality might also be inappropriate for high-risk procedures. For instance, if a patient lived following an orthopaedic procedure but lost mobility, the operation would be considered unsuccessful, yet this would register as a good outcome on the basis of mortality. Measuring outcomes without quality factors may, therefore, be misleading.

The influence of specialization

The differences in outcomes between specialist and general surgeons may be explained in several ways, including the effect of high volume, systematic differences in choice of treatment and the contribution of other healthcare professionals. Specialist surgeons are more likely to perform higher volumes of select procedures. Systematic differences in treatment choice have already been described between high- and low-volume surgeons. Similarly, comparison of colorectal specialists and general surgeons has demonstrated considerable variations in the management of elective[168,176] and emergency[177] colorectal surgery. Likewise, Golledge and colleagues[161] demonstrated that improved outcomes in breast cancer surgery, as measured by longer disease-free survival and lower recurrence rates, are partly attributable to specialists' increased axillary node clearance and more appropriate use of systemic medical therapy. Finally, the contribution of other healthcare professionals needs to be borne in mind. For instance, the survival of patients with cancer treated at oncology centres appears to be better than those treated at general surgical units of similar volume[46,49]. While this may be attributable exclusively to the specialist surgeon, the contribution of other multidisciplinary team members such as oncologists or nurse specialists, which may be less available in general surgical units, has not been examined and, indeed, may be impossible to isolate.

The four studies that examined the independent contributions of specialization and volume of surgery demonstrated that when volume discrepancies between specialist and general surgeons were controlled for, the benefit from specialization was still apparent. These findings suggest that the benefit of specialization cannot be explained simply by 'practice makes perfect'. It is more likely to be a cumulative benefit of high volume, more effective choice of treatment modalities and factors unrelated to the surgeon, such as contribution of other healthcare professionals.

In conclusion, high surgeon volume and specialization are independently associated with improved patient outcome. Although the cumulative volume of surgery of the hospital has a beneficial effect on outcome, independent of the effect of surgeon volume, this is true for fewer procedures. While this review has identified a substantial body of literature on volume of surgery and specialization, given the inherent inaccuracies of the retrospective data described, only 12 per cent of those data (prospective studies) can be considered reliable. Furthermore, case-mix differences, uncontrolled for in half the studies, and other confounding variables such as hospital-specific qualities, when not adjusted for, substantially reduce the reliability of the data. A consequence of this is that recommendation of thresholds defining high volume has occurred for only a few operations. This review supports specialization in surgery, with emphasis on the experience of the individual surgeon rather than simply high-volume centralized institutions. However, the weak data highlight a need for further prospective, population-based, risk-adjusted studies that control for potential confounding variables. These should examine quality measures of outcome within defined specialities, particularly if health policy changes dictate radical specialization. The clinical implications of such policy changes are too great to be left to anecdote.

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