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Research Article

Centralisation of specialised healthcare services: a scoping review of definitions, types, and impact on outcomes

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Abstract

Background: Centralising specialised healthcare services into high-volume centres is proposed to improve patient outcomes and efficiency. Most reviews focus on relatively few conditions and a limited range of outcomes.
Objectives: To review the evidence on centralisation of a range of specialised acute services, to analyse (1) how centralisations are defined; (2) how centralisations are organised and delivered; and (3) the relationship between centralisation and several key outcomes.
Design: Scoping review, conducted in November 2020.
Setting: Specialised acute healthcare services.
Intervention: Centralisation of services into a reduced number of high-volume units.
Findings: We included 93 papers covering specialised emergency and elective acute healthcare services, published to November 2020. Definitions of centralisation commonly lacked detail, but, where available, covered centralisation's form, objectives, mechanisms and drivers. We proposed a typology of four forms of centralisation, reflecting the number and functions of specialist units (centralisation of whole pathway, centralisation of pathway components, hierarchy of specialist units, partial centralisation). For most outcomes, the majority of papers suggested a positive impact of centralisation: mortality (33/55 papers), survival (19/25), morbidity (17/27), quality of life (6/7), quality of care (22/30), length of stay (17/26), cost-effectiveness (3/3) and patient experience (3/3). Centralisation was associated with increased patient travel (9/12); 3/5 papers suggested no impact on inequalities.
Limitations: This review was conducted in November 2020 and did not include grey literature or studies that did not analyse outcomes, so more recent and further evidence – for example, on types of centralisation model and how centralisation was implemented – may exist. As this was a scoping review, we did not conduct a quality assessment, which may reduce the confidence with which we may view the presented impacts of centralisation.
Conclusions: Centralisation is commonly associated with improved care and outcomes. However, research seldom describes centralised services in sufficient detail, rarely compares different service models and tends to focus on a narrow range of outcomes. Therefore, understanding the extent and nature of centralisation's impact – and the mechanisms by which it is achieved – remains elusive. By addressing these gaps, future research may of greater use to all stakeholders with an interest in centralisation.
Future research: Should provide clearer descriptions of centralisations, compare different centralisation models and study a wider range of important outcomes, including patient experience and cost-effectiveness.
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Background

Centralising specialised healthcare services

Centralisation of specialised healthcare services has been defined as 'reorganisation of healthcare services into fewer specialised units serving a higher volume of patients and with the aim to improve patient outcomes and efficiency'.[1] Recommendations to centralise propose that concentrating specialised care into high-volume units may increase access to clinical experts, advanced diagnostics and evidence-based interventions, and it is suggested that the clinicians who work in high-volume services may gain expertise in delivering specialised care.[2–8] In turn, it is thought that these changes may be associated with better outcomes, including reduced mortality, morbidity and length of hospital stay.[7–13] Centralisation may potentially also contribute to cost savings through economies of scale,[1,3,14,15] and cost-effectiveness through improved outcomes.[1]

While the relationship between outcomes and certain features of centralisation, for example, level of volume and availability of specialists, has been explored in some contexts,[8] the effect of centralisations may be influenced by many aspects of how services are organised and delivered. First, if an insufficient proportion of patients are treated in specialist units, population-level benefits may not be realised.[11,12,16] Second, increased travel times may increase the risk of patients missing 'treatment windows' for life-saving interventions.[17] Third, centralised pathways may increase inequity, as older or socioeconomically deprived patients may be less able/willing to travel to more distant specialist units[18–20] (although some research suggests patients are willing to travel for longer if this results in better care or outcomes).[21] Fourth, some contexts (e.g. clinical specialty or geographic location) may benefit from different forms of centralisation, such as a single unit delivering the whole care pathway, or a 'hub and spoke' system where specialist units provide key components of the pathway, while 'spoke' services provide less specialised care closer to patients' homes. Fifth, the national context – for example, the extent to which healthcare governance is designed to enable system-wide co-ordination around change – may influence approaches to centralisation.[22] Sixth, there may be circumstances where centralisation does not offer significant benefits, or where benefits are outweighed by disbenefits.

Extending current knowledge of centralisation of specialised services

Many studies have examined the impact of centralising specialised health services on patient outcomes. However, existing reviews of this evidence tend to focus on a single condition[3–7,23,24] or a limited number of outcomes, for example, economic impact[3] or mortality and survival;[4,7,24] or they assess the quality of the existing evidence base.[1] To our knowledge, no review has assessed the impact of centralisation of all specialised services on a range of key outcomes. Also, specialised services may be centralised in numerous ways, and their effectiveness may vary depending on their features or context (clinical or organisational). While a recent scoping review addressing pancreatic cancer surgery described different approaches to developing centralised services,[23] to our knowledge no review has defined the forms that centralisations might take. To address these gaps, we conducted a scoping review to (1) report how centralisations of specialised health care are described; (2) develop a typology of centralised services; and (3) review the evidence on the impact of centralisation on key outcomes, including quality of care, patient mortality and morbidity, cost-effectiveness and patient experience.

Method

Design

This was a scoping review of evidence published in peer-reviewed journals. Following recommendations,[25,26] our review was conducted in five stages:

1. identifying research questions (RQs)
2. identifying relevant studies
3. selecting studies
4. charting data
5. collating, summarising and reporting results.

Throughout, we were guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) checklist,[27] and we consulted a librarian with expertise in literature reviews. We registered our protocol with International Prospective Register of Systematic Reviews (PROSPERO) in June 2021.[28] This review differs in a number of ways from the protocol (see *Appendix 3*)

Research questions

The review sought to answer the following questions:

1. How is centralisation of specialised healthcare services defined?
2. Can centralisation of specialised healthcare services be organised into a typology reflecting its scale and operational pathways?
3. What is the effect of centralising specialised care on key outcomes, including quality of care, patient mortality and morbidity, cost-effectiveness and patient experience?

Strategy

We searched four databases: MEDical Literature Analysis and Retrieval System (MEDLINE), Cumulative Index to Nursing and Allied Health Literature (CINAHL) Plus, Excerpta Medica dataBASE (EMBASE) and Web of Science. We applied an extensive search strategy using keywords and free text for each database (search terms were based on three previous reviews conducted in this context[1,3,29]), with no restrictions on date of publication (see *Appendix 1*). Results were combined into Mendeley (www.mendeley.com/; Elsevier Ltd, Amsterdam, Netherlands) reference manager, and all duplicates were removed. The reference lists of included articles were screened by two researchers (Sonila M Tomini and Cecilia Vindrola-Padros) to identify additional relevant publications. A pilot search was conducted in May 2020, and the full search in November 2020.

Article selection

Our inclusion criteria were:

- peer-reviewed research papers
- focus on centralisation of care (as defined above)
- focus on acute specialised health care (i.e. services addressing rare or complex health conditions; no limit applied to the health conditions included)
- describing empirical research on outcomes of centralisation
- published in English with any date of publication.

Our exclusion criteria were:

- comparisons of low- and high-volume centres, where the latter were not part of a centralised system[30,31]
- hypothetical studies of centralisation, such as papers discussing or modelling potential benefits of centralisation,[32,33] or stakeholder priorities for centralisation (e.g. discrete choice experiments)[21]
- empirical studies of implementing centralisation that did not include some analysis of outcomes.[34,35]

Following the rapid review methodology, two researchers (Cecilia Vindrola-Padros and Sonila M Tomini) screened the articles in the title screening phase, and two researchers (Sonila M Tomini and Cecilia Vindrola-Padros) cross-checked exclusions in the abstract and full-text screening phases. Three researchers (Sonila M Tomini, Cecilia Vindrola-Padros and Angus IG Ramsay) screened the identified papers at full-text stage. Disagreements between researchers were discussed until consensus was reached.

Data extraction and management

The selected articles were analysed in Research Electronic Data Capture (REDCap). The data extraction form (see *Report Supplementary Material 1*) was developed after initial screening of full-text articles, then piloted independently by two researchers (Sonila M Tomini and Cecilia Vindrola-Padros) using a random sample of five articles. Disagreements were discussed until consensus was reached. The data extraction form was finalised based on discussions with the wider team and covered author name, year of publication, location of study, disease/conditions studied, level/nature of centralisation, sector included, study design, aim(s) of the study, the research methods used, sample size, definition of centralisation and impact on outcomes.

Data synthesis

Data were exported from REDCap, and the main characteristics were synthesised using framework analysis.[36] The framework was guided by our RQs, but also attended to emerging themes. Overall findings were written up as a narrative description given that the study designs were heterogeneous, following the PRISMA-ScR 2020 checklist and guidance. To develop our centralisation typology, we used ideal-type analysis:[37,38] we reviewed descriptions of centralisation models (where reported) to produce a 'case reconstruction' (summary of key characteristics) for each example. We then examined similarities and differences between each reconstruction and grouped these according to 'ideal types'. We then produced short descriptions of illustrative cases, citing relevant examples and labelling cases appropriately in our detailed summary of included papers.

Patient and public involvement

This scoping review was part of a larger evaluation of centralisation and integration of specialised services, conducted by the NIHR Rapid Service Evaluation Team. The review was discussed regularly with patient and public involvement and engagement representatives in our project meetings in terms of design, progress and emerging findings.

Equalities, diversity and inclusion

This review was conducted as a part of a wider rapid evaluation of centralisation and integration of specialist services. The project team had diverse membership and included patient and public representatives. The team agreed that inequalities in access are an important consideration in centralisation, and it was therefore identified as a key focus for this review.

Results

Literature search

We included 93 full-text papers (*Figure 1*). Our initial search identified 7188 potentially relevant papers, of which 1097 duplicates were excluded. We then excluded 5862 papers through title screening and 80 papers through abstract screening. We excluded a further 62 papers through full-text review and identified 6 additional papers for inclusion (through reference lists and discussion with coauthors).

Characteristics of included studies

The 93 articles included in the review are summarised in *Table 1* (and in depth in *Appendix 2*, *Table 4*). The earliest article included was published in 1985, with papers mainly being published after 2000, with rate of publication increasing from 2010 onwards (*Figure 2*). Twenty-nine papers reported centralisations in the UK or UK nations, 23 papers in the USA, 16 in the Netherlands, 7 in Canada and the remainder in nations across Europe, Asia and Australasia. For most papers (n = 55), the analysis was at regional (i.e. subnational) level, for example, implementing a single centralised cancer surgery service to cover an area,[109,82] or centralising stroke services into regional 'hub and spoke' systems.[11,12,15,16,39,40] Thirty-eight papers analysed centralisation at national level, either reporting outcomes of a nationally implemented programme (e.g. major trauma networks in the English NHS)[41] or assessing national trends towards centralisation (e.g. changes in volume and number of cancer surgery units across a nation).[62] It was sometimes unclear whether a region-level analysis was of a purely regional centralisation or, instead, a region-level implementation of a wider or national centralisation programme. Most papers focused on centralisation of cancer services (n = 53) and elective surgery (n = 59). Some centralisations were analysed in several papers (e.g. major trauma[10,41,42–44] and stroke services[11,12,15,16,39,45,46,120] in England). However, these papers tended to report

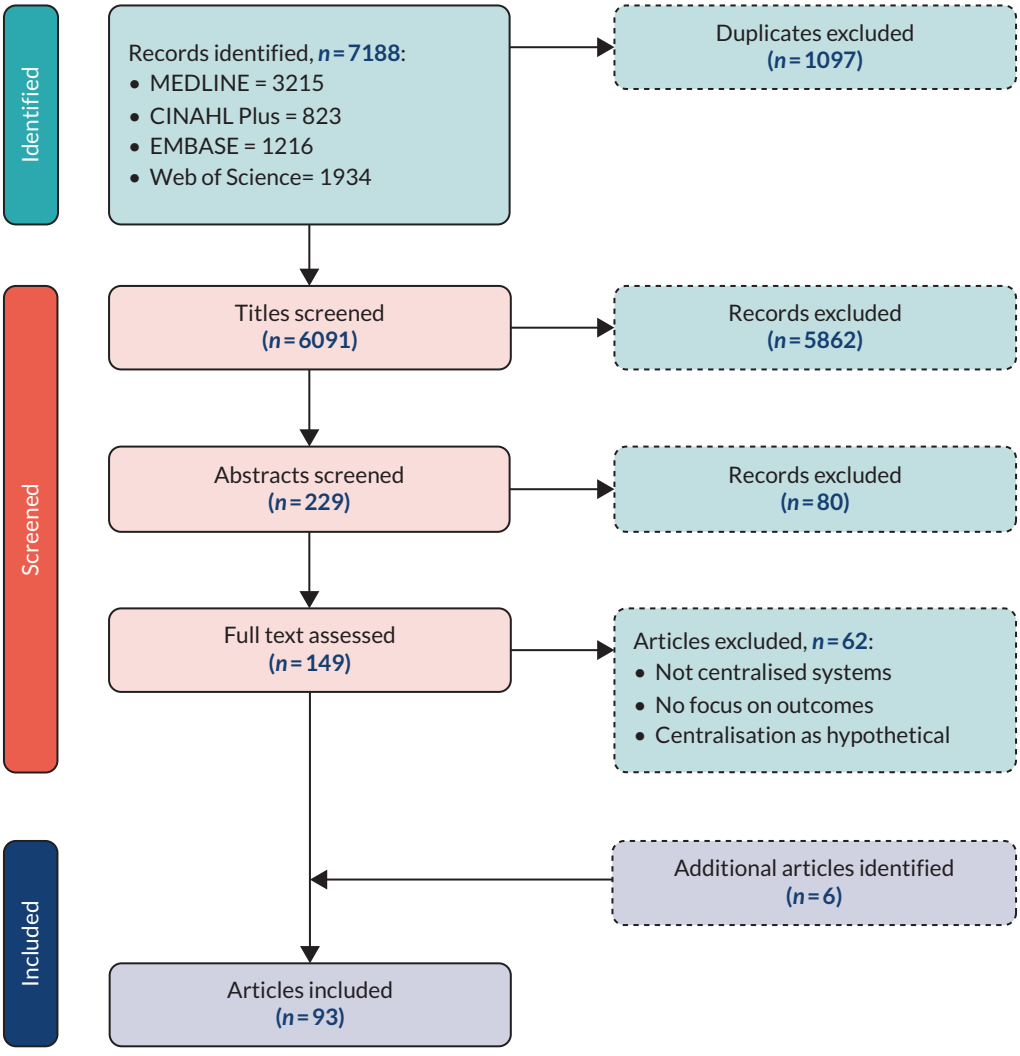

FIGURE 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

TABLE 1 Summary of included studies

Characteristics	Papers (*n*)	Study reference
Where centralisation was implemented		
UK or UK nations	29	9–12,15,16,39–41,42–44,45–61
USA	23	17,18,20,62,63–81
The Netherlands	16	14,82,83–96
Canada	7	2,19,97–101
Denmark	4	102–105
Spain	3	106–108
Sweden	3	109,110,111
Finland	2	112,113
Norway	2	114,115
Australia	1	116
France	1	117
Ireland	1	118
Taiwan (Province of China)	1	119
Total	93	
Scale of centralisation analysed		
National	38	9,14,17,18,41–43,62,50,53–55,63–66,70–73,76,77,80,83–85,90,91,93,95,98,103,104,110,111,113,114,119
Regional	55	2,10–12,15,16,19,20,39,40,82,109,44,45–49,51,52,56–61,67–69,74,75,78,79,81,86–89,92,94,96,97,99–102, 105–108,112,115–118
Total	93	
Conditions addressed by centralisation		
Cancer	53	17–20,109,82,62,48–50,54,55,57–59,61,63–66,69,71–73,76–80,83–86,88–98,104–108,114,115,117,118
Stroke	13	2,11,12,14–16,39,40,45,46,87,102,119
Paediatric/neonatal	9	47,52,74,75,100,110–113
Major trauma	8	10,41,42–44,67,68,116
Vascular	5	51,56,60,81,103
Cleft lip/palate	2	9,53
Bariatric	1	70
Cardiac	1	99
Hip replacement	1	101
Total	93	
Procedures addressed by centralisation		
Elective surgery	59	9,17,19,109,82,62,47–51,53–59,61,63–66,69–71,73,74,76–80,83–86,88–91,93,94,96–98,101,104–108,111–115,117,118
Emergency medicine	14	2,11,12,14–16,39,40,45,46,52,87,102,119
Emergency surgery	12	10,41,42–44,60,67,68,81,103,110,116
Elective surgery and medicine	3	18,92,95

continued

TABLE 1 Summary of included studies (*continued*)

Characteristics	Papers (*n*)	Study reference
Elective and emergency surgery	3	72,75,99
Elective medicine	1	20
Emergency medicine and surgery	1	100
Total	93	
Description of centralisation/centralised model		
Described in detail, for example, service functions, transfer protocols	35	9,11,12,15,16,20,39–41,42,44,45–47,50–54,56,60,67,68,81,87,89,91,94–96,112–115,119
Limited detail, for example, number/focus of services	29	2,10,14,19,109,82,48,49,57–59,61,83,86,88,90,97,99–105,107,111,116–118
No detail, beyond drive for high volume	29	17,18,62,43,55,63–66,69–80,84,85,92,93,98,106,108,110
Total	93	
Time points analysed		
Before and after	42	10–12,15,16,19,39,41,42,44,45,47–49,51,56–58,60,61,63,67,68,85,88,89,92,93,96,97,99,102,104,106,107,111–113,115,116,119
Multiple time points	29	2,9,17,109,82,62,43,52,59,66,69–73,75–80,84,86,90,91,95,98,103,108
Post centralisation	13	20,40,46,50,54,74,87,94,100,101,105,114,118
Cross-sectional	9	14,18,55,64,65,81,83,110,117
Total	93	
Factors considered in analyses		
Centralised vs. non-centralised	9	11,12,14,16,39,46,87,102,114
Volume levels	22	2,18,62,47,55,64–66,71–73,75–77,79,80,84,90,93,98,108,110
Specialist vs. non-specialist	13	43,45,50,54,81,83,91,92,95,97,110,115,117
Different models of centralisation	5	11,12,16,39,40

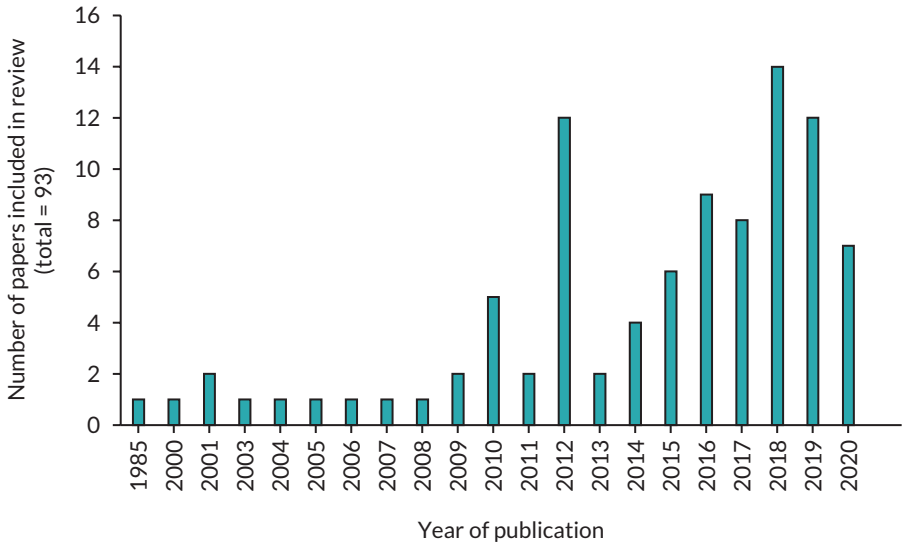

FIGURE 2 Papers included in review by year of publication.

different aspects of centralisation (e.g. analysing different impacts, different settings or different scales of change), and therefore, when including all papers in this review, we believe we do not 'double-count' the same effect; where we identified overlap, we included papers only for their uniquely reported effects [e.g. we do not include the cost-effectiveness analyses of stroke service centralisation[15,39] in our summaries of impact on mortality, length of stay (LOS) or quality of care, as the analyses overlap with other papers addressing these impacts[12,16]]. The impact of centralisation was analysed over time in several ways. Overwhelmingly, papers reported quantitative analyses (n = 92), while two papers reported qualitative analysis of patient perceptions. Some papers compared outcomes before and after change (n = 42), while others analysed outcomes at multiple time points (n = 29, several of which were used to assess general trends towards centralisation, rather than specific change programmes). Other papers did not assess changes in outcome over time (n = 9) or analysed the post-centralisation period only (n = 13). Only a proportion of papers incorporated associated factors into their analyses, for example, assessing the impact of centralised and non-centralised controls (n = 9), different volume levels (n = 22), different models of centralisation (n = 5) and the difference made by attending specialist or non-specialist units (n = 13).

Defining centralisation

When describing centralisation, papers commonly referred to a process of reorganising services into a smaller number of high-volume units,[43,55,121] and sometimes the changes required to enable this. Centralisation was discussed in relation to other overlapping concepts of organisational change, such as 'reconfiguration',[9,55,59] 'regionalisation'[42,89] and 'major system change'.[12,16,40] Definitions often cited benefits of centralisation, for example, improved quality of care,[83] patient outcomes[55,64,84] and service efficiency;[122] or, more commonly, a combination of these.[12,42,102] They discussed mechanisms by which improvements might be achieved, for example, increased service volume,[43,56,97] standardised referral pathways,[49,54,60] improved access to specialised care[109,57,73] and evidence-based diagnostics, therapies or technology.[16,67,119] Finally, definitions were framed in terms of interconnected drivers, including research evidence on centralisation benefits (as above), recommendations on good practice[82,55,61] and national/regional policy.[12,19,41] Depending on the setting for changes, different drivers tended to dominate: for example, while studies in the UK,[55,58,61] elsewhere in Europe[90,93,104] and Canada[19,98] cited national policy or recommendations as influential, several papers analysing centralisation in the USA noted an absence of national policy drivers.[63,71,76,77]

Developing a typology of centralisations

Many papers did not describe centralisations studied in detail (see *Table 1*): 29 papers referred only to drives to centralise or create high-volume units; another 22 provided some detail, for example, the number of units pre and post centralisation, or certain functions of specialist units; 42 papers offered greater detail, for example, different functions of units (e.g. of specialist and non-specialist units), referral/transfer protocols and resources available to specialist units (e.g. the clinical staff and technology required for a specialist unit to be defined as such).

Based on information provided in the 42 papers offering detail on how centralised services were organised and delivered, we identified four types of centralised model (*Table 2*). For each, centralisation involved organising specialised care around designated units, with variations in which aspects of specialised care was located in these specialist units. The first category was 'full centralisation', where specialist units deliver most or all of the care pathway.[20,53,89] Second, we found 'centralisation of specialist components', where specialist units deliver specialist procedures, with other pathway components delivered more locally by non-specialist units (e.g. 'hub and spoke' systems).[12,41,67] Third, we found hierarchies of specialist units, where specialist units deliver complex procedures, but some specialist units deliver additional functions (e.g. offering specific expertise or extended hours).[12,16,114] Fourth, we found examples of 'partial centralisation', for example, where the pathway is offered by both specialist and local units, but specialist units offer alternative, more advanced care options.[94,95] While each category was observed in a range of clinical settings/procedures, pathway-level centralisation was most commonly seen in surgical settings, while hierarchies were most commonly found in emergency medicine (in particular, stroke and major trauma).

Impact of centralisation on key outcomes

The following subsections summarise the impact of centralising specialised services on clinical outcomes (mortality, survival, morbidity), service outcomes (care delivery, length of hospital stay, costs and cost-effectiveness), patient access and experience (patient journeys, inequality of access, patient experience) and volume (a key objective of centralisation) (*Table 3*). The included papers analysed the impact of centralisation from different perspectives, including analysing all patients in a studied region; patients treated within specialist centres; patients treated in non-specialist centres; and approaches to provide similar benefits to centralisation. Throughout, we highlight such cases as they provide important insights on less-attended-to aspects of centralisation.

TABLE 2 Typology of centralisation models

Model	Description and examples
Centralisation of whole pathway into specialist unit/s[41,47,48,57,60,81,87,100,101,112,113]	*Specialist unit/s deliver most/all of the care pathway* Examples include instances where specialist units provide care and aftercare for all patients in a region, for example, for pancreatic cancer surgery,[89] cleft palate surgery and psychological follow-up[53] and haemato-poietic cell transplantation[20]
Centralisation of components of pathway into specialist units[2,9,11,12,15,16,20,39,40,82,44,45,46,50–52,54,56,89,91,115,116]	*Specialist unit/s all deliver complex procedures; other components of pathway delivered more locally* A key example is 'hub and spoke' models, where patients go to specialist hub for key procedures (e.g. robotic surgery, clot busting/removal) and then receive ongoing care at 'spoke' services closer to home, for example, complex surgery,[9,50,54,115] vascular surgery[51] or acute stroke care,[11,12,16,40,45] and major trauma[10,41,42,67,68]
Hierarchy of specialist units[10–12,16,39,40,42,67,68,114,119]	*Specialist units deliver complex procedures, but some specialist units deliver additional functions* For example, centralised systems with multiple specialist units, of which one acts as system leader or offers specific expertise on procedures,[114] or where only certain specialist units operate 24/7, while others only operate in-hours.[12,16] Note: this model overlaps with other forms of centralisation, that is, a hierarchy of specialist units may be observed in centralisations that centralise either all or part of the pathway, where there is differentiation in functions of these specialist units
Partial centralisation[94–96]	*Whole care pathway is offered by both specialist and non-specialist units, but specialist units offer alternative, more advanced options* For example, specialist units offer less-invasive approaches or robotic surgery, or specialist units advise local services on key procedures[94,95]

TABLE 3 Effects associated with centralising specialised services

Outcome	Patterns of effect reported
Mortality (*n* = 55)	Positive: 33[11,17,19,43,49,52,55,57,58,68,71–73,75,76,78–81,84,86,88,89,93,96–98,104,106,111,115,116,119] Negative: 2[45,100] Mixed: 7[2,12,15,18,77,108,114] None: 13[10,20,42,46,60,61,65,67,74,85,99,102,103]
Survival (*n* = 25)	Positive: 19[15,109,41,48,57,59,61,66,85,86,88,91,94,96,105,112,113,115,117] Mixed: 4[17,54,89,95] None: 2[83,92]
Morbidity (*n* = 27)	Positive: 17[109,39,47,55,64,72,73,88–91,93,106,110,112,113,115] Mixed: 3[74,77,97] None: 8[9,49,58,60,61,96,104,114]
Quality of life/independence (*n* = 7)	Positive: 6[10,14,42,46,68,116] None: 1[87]
Quality of care (*n* = 30)	Positive: 22[9,11,19,109,82,41,42–44,46,65,66,81,88,93,104,107,111,115,117–119] Negative: 2[17,45] Mixed: 5[16,50,87,95,102] None: 1[51]
LOS (*n* = 26)	Positive: 17[9,11,12,49,52,55,61,72,73,93,94,96–99,102,118] Negative: 2[56,75] Mixed: 3[41,46,67] None: 4[10,42,60,115]
Costs (*n* = 4)	Positive: 2[14,15] Mixed: 2[39,75]
Cost-effectiveness (*n* = 3)	Positive: 3[14,15,39]
Patient travel (*n* = 12)	Negative: 9[17,19,20,63,69,70,78,79,100,123] Mixed: 3[18,74,101]
Inequality of access (*n* = 5)	Negative: 1[78] Mixed: 1[62] None: 3[69,70,101]

TABLE 3 Effects associated with centralising specialised services (*continued*)

Outcome	Patterns of effect reported
Patient experience and satisfaction (*n* = 3)	Positive: 3[40,53,61]
Volume (*n* = 47)	Positive: 45[9–11,16,18,41,42,62,44,47,48,52,55,57,61,64,66,67,69–72,75,76,78–80,83–86,88,90–93,97–99,106–108,113,118] Negative: 1[56] Mixed: 1[77]

Note
In each case, 'positive' effects refer to what may be inferred to be 'good' outcomes, or improvement following centralisation (e.g. reduced mortality, improved survival, reduced costs); 'negative' effects refer to poor outcomes or deterioration.

Mortality

Fifty-five papers reported the effect of centralisation on mortality. Of these, 33 reported a reduction in mortality associated with centralisation, commonly attributing benefits of centralisation to increased likelihood of patients being treated in high-volume centres that met recommended care standards.[55] Seven papers reported mixed effects, for example, where different service models were associated with differing effects on mortality,[12,39] or where the benefits of centralisation plateaued at a certain level of service volume, beyond which no advantage of centralisation could be demonstrated.[2] Thirteen studies reported no significant effect: one paper analysed the 6 months directly post centralisation, suggesting no negative effect on outcomes even when not making allowances for 'bedding-in' time of the new system.[60] Two papers reported an association between centralisation and increased mortality.[45,100] However, these papers focused on particular subgroups of patients who did not experience the optimal version of these systems, that is, stroke patients who were not treated in a specialist unit,[45] and paediatric intensive care unit (PICU) patients who were not admitted directly to a specialist unit.[100]

Survival

Twenty-five papers analysed survival. Of these, 19 reported increases associated with centralisation. Two papers reported no change in survival.[83,92] Four papers reported mixed effects, combining significant increases in survival with some non-significant effects.[17,54,89,95] We found no papers where centralisation was associated with a significant reduction in survival.

Morbidity

Twenty-seven papers reported effects on morbidity (which included complications, unplanned re-admissions and residual disease). Sixteen papers reported reductions in morbidity following centralisation, for example, significantly fewer patients with incomplete cytoreduction following cancer surgery.[91] Eight papers reported no effect on morbidity, while three papers reported mixed effects, combining reductions in morbidity with some non-significant effects.[74,77,97] Again, we found no papers that reported increased morbidity following centralisation.

Quality of life/independence

Seven papers described quality of life (QoL)/patient independence. Of these, six suggested patients' QoL was better following centralisation,[10,14,42,46,68,116] – for instance, reporting significant improvements in trauma patient recovery at discharge from hospital[10,42] – while one paper reported no effect.[87]

Quality of care

Improving aspects of quality of care (e.g. increasing timely access to advanced diagnostics, specialist assessment and evidence-based interventions) may be seen as key to achieving many of the other improvements discussed in this review (e.g. improved clinical outcomes and patient experience). Quality of care was addressed in 30 papers, covering a range of context-specific measures. Twenty-two papers found centralisation to be associated with improvements in quality, including timely access to relevant diagnostics and tests,[11,42,43] specialist clinicians (e.g. physicians, nurses and allied health professionals),[11,42,43] and recommended interventions and therapies (e.g. thrombolysis in relation to ischaemic stroke,[11] tranexamic acid in relation to major trauma,[43] surgery, removal of cancer cells[90] and of lymph nodes for cancers).[104,107] These results were commonly attributed to increases in service volume, and associated improvements in access to specialists, resources and processes. Five papers reported a mixed effect of centralisation,[16,50,87,95,102] illustrating that different approaches to centralisation may have different effects: for example, analysis of centralising acute stroke services in London and Greater Manchester demonstrated that models where only a selection of stroke patients are eligible for treatment in a specialist centre are not more likely to deliver evidence-based clinical interventions.[16] One paper found no significant effect.[51] Two papers

reported a reduction in quality of care associated with centralisation:[17,45] again, these analyses focused on subsets of patients who were systemically disadvantaged by centralisation (i.e. stroke patients not treated in a specialist unit,[45] and pancreatic cancer patients who had further to travel for surgery).[17]

Length of hospital stay

Length of hospital stay is an important indicator of service efficiency, potentially influencing the cost per hospitalised patient; it may also reflect quality of care in terms of how quickly patients recover. Of the 26 papers addressing length of hospital stay, 17 reported significant decreases, for example, high-volume specialist units were frequently associated with significantly lower LOS than low-volume units, and significant reductions following region-wide centralisation.[11,12,93] Three papers reported mixed effects, combining significant reductions with non-significant effects;[41,46,67] for example, centralising trauma services resulted in significant reductions in length of intensive care unit (ICU) stay, but no change in overall LOS.[41,67] Four papers reported no effect.[10,42,60,115] Two papers reported an increase in LOS:[56,75] one focused only on a subset of patients who were treated in a non-specialist centre,[56] while the other reported general trends in paediatric heart surgery (PHS), finding increases in the proportion of patients treated in high- and medium-volume services, and that these patients had significantly higher length of hospital stay than patients treated in low-volume services, but significantly lower risk-adjusted mortality and costs.[75]

Costs and cost-effectiveness

Four papers reported the impact of centralisation on costs and/or cost-effectiveness. One paper focused on costs alone, reporting that overall costs of PHS increased as the proportion of patients treated in high-volume hospitals grew over time; at the same time, risk-adjusted costs of high-volume services were found to be significantly lower than those of low-volume services.[75] Three papers described effects on cost and cost-effectiveness:[14,15,39] each reported that centralisations were cost-effective, with two reporting reduced costs and improved outcomes,[14,15] and another reporting a mixed effect, where one centralisation was associated with increased costs, but achieved cost-effectiveness through its impact on patient mortality; whereas another achieved cost-effectiveness through its reduction of costs.[39]

Patient travel

Twelve papers reported impact of centralisation on travel distance. Nine of these indicated an increase in travel distance following centralisation, with two papers associating this with increased mortality,[18,100] and two associating it with reduced quality;[17,18] while three papers reported reduced mortality regardless of increased travel distances.[17,19,78] One paper reported that increased distance to specialist centre was associated with reduced adverse events (AEs) for neonatal heart surgery,[74] while another found no relationship between distance to specialist centre and hip replacement rate.[101]

Inequality of access

Five papers analysed how centralisation affects patients who may be disadvantaged due to personal characteristics (e.g. location, race or socioeconomic status). Three papers reported no significant effect on inequalities in access:[69,70,101] for instance, centralisation of endometrial bariatric surgery services saw increases in the proportion of racial minority patients treated in specialist units;[70] while centralisation of endometrial services in New York resulted in increased travel distance for all racial groups (with increases most pronounced for white patients).[69] However, one paper reported mixed effects (with some characteristics affected by centralisation),[62] and another reported increases in inequality of access.[78] While both papers reported general trends towards increased likelihood of being treated in high-volume cancer surgery units, one paper reported that patients still treated in low-volume units were based in more rural areas with higher levels of poverty,[78] while both papers reported that such patients were likelier to be black and on Medicare/Medicaid or uninsured.[62,78]

Patient experience and satisfaction

Three papers reported impact of centralisation on patient experience and satisfaction. Two papers presented qualitative evidence of positive experiences of services: one reported long-term service users' views on how cleft lip and palate services had improved post centralisation (e.g. increased involvement in decision-making and access to psychological support and peer support);[53] the other found that stroke patients reported positive experiences of centralised stroke services in terms of aspects of care that evidence suggest matter most to stroke patients.[40] Finally, patient questionnaire data suggested high satisfaction with centralised upper gastrointestinal cancer surgery services, with patients reporting a median satisfaction score of 9.6 out of 10, post centralisation.[61]

Volume

A common goal of centralisation was to increase patient volume – whether at clinician, team or hospital level – and was reported in 47 papers. In 45 papers, centralisation was associated with increased volume, which in some

cases was used as shorthand for improved quality of care. One paper reported mixed effects on volume achieved in services treating different types of cancer.[77] One paper reported reduced volume, though this related to a service that did not become a specialist centre.[56]

Discussion

Overview

This scoping review analysed a substantial, diverse body of research on centralising specialised healthcare services. We found that definitions of centralisation covered their form (concentrating some or all aspects of a care pathway into a reduced number of high-volume units); their objectives (e.g. to improve care, outcomes and efficiency); their mechanisms (e.g. increasing volume, and improving access to evidence-based care); and their drivers (e.g. research evidence, guidance and policy). Based on limited descriptions of centralised service models, we developed a proposed typology of centralisation: this summarised ways in which services might be organised to enable delivery of high-volume specialised care across a region. By extension, this typology may be of value to researchers and other stakeholders when thinking about centralisations in future. Finally, our review found that centralisation of specialised services has been analysed in relation to numerous patient and service outcomes, and in the overwhelming majority of cases, centralisation has been associated with improvement.

Relating our findings to evidence

Our findings on centralisation definitions and typology complement previous work to codify centralisation approaches[8,23] and current work to define core outcomes for centralisation research.[124] The limited descriptions of centralisation in certain contexts, for example, the USA, may reflect established structural barriers to system-wide changes.[22] Our analysis of centralisation's effect on outcomes contributes to (and extends) a wider debate across previous reviews. Our findings support previous conclusions that centralisation is associated with reduced mortality and increased survival,[5–7,13,24,96] reduced LOS[13,96,125,126] and improvements in quality of care.[96] We found the relationship between centralisation and morbidity is mixed, although a majority of papers suggested reductions; this reflects previous reviews, which report some reductions in morbidity and complications.[5,96] We found very few papers that addressed centralisation's effect on QoL, cost, cost-effectiveness and patient experience. In each case, available evidence suggested overall benefits of centralisation (e.g. positive patient experience, cost-effective services).

Gaps in the evidence

This review offered insights on how centralisation has been analysed and reported to date. First, most papers offered limited detail on centralisations (e.g. context, functions, staffing, referral pathways, hours active). Second, very few papers compared different centralisation models: most papers treated centralisation as a binary (centralised vs. not), and many used unit volume level as a proxy for centralisation (as noted by Bhattarai *et al.*[1]). Therefore, it was not possible to explore whether certain models of care, for example, those falling within different typology categories, were associated with different outcomes. However, our previous research suggests that centralised models vary considerably, with potential implications for care and outcomes. Third, we found very little evidence on the impact of centralisation on some important (and interrelated) outcomes, including QoL, patient experience and cost-effectiveness. In part, this resulted from a lack of routine data on key measures, but also highlighted the need for qualitative and mixed-methods research to examine these issues.

Strengths and limitations

To our knowledge, this was the first attempt to review evidence for centralisations implemented across all specialised services. We reviewed 93 papers covering numerous clinical and geographic settings. We have made several contributions: first, establishing how authors define centralisation; second, proposing a typology to help categorise centralisations; third, describing the effect of centralisation on key outcomes and identifying important gaps in knowledge.

Our review had several limitations. First, our search terms may not have been sufficiently inclusive to identify all relevant papers, for example, we did not find any studies focusing on the outcomes of centralising acute mental health services. However, by drawing on our team's knowledge of the field, we believe we managed to include a substantial body of relevant research. Second, our search was conducted in November 2020, and it is likely that further relevant literature has been published since then. Third, we did not include grey literature and papers not written in English, so we may have missed further relevant work. Fourth, we did not focus on studies of implementation (see *Appendix 3*): while this made the analysis manageable, it is likely that we missed out on richer data in relation to service models implemented (a weakness in the analyses included in this review). Finally, while we reflected on the strengths and weaknesses of the existing body of evidence, as this was a scoping review we did not conduct a formal quality assessment of the papers we included; this in turn may reduce the confidence with

which we may view the presented effects of centralisation on outcomes.

Conclusions and recommendations

Our review analysed a diverse literature: it has extended understanding of how centralisation of specialised services is defined and proposed a typology that helps describe centralised services. Our review found that centralisation is broadly associated with improved care and outcomes. However, we identified important gaps in the evidence, including (1) limited descriptions of centralisations, (2) few comparisons between different centralisation models and (3) few analyses of key outcomes, including patient experience and cost-effectiveness. Addressing these gaps may increase the relevance of future research to researchers, clinicians, service and system leaders and the wider public who are interested in centralisation.

Additional information

CRediT contribution statement

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Patient and Public Involvement Advisory Group

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Data-sharing statement

As this was a scoping review of published literature, all relevant data are available from the manuscript and appendices. Further information can be obtained from the corresponding author.

Ethics statement

The study was reviewed by the East Midlands – Nottingham 1 Research Ethics Committee and received ethical approval from

the Health Research Authority and Health and Care Research Wales on 25 January 2023 (REC reference: 22/EM/0277).

Information governance statement

University College London (the study sponsor) is committed to handling all personal information in line with the UK Data Protection Act (2018) and the General Data Protection Regulation (EU GDPR) 2016/679. Under the Data Protection legislation, University of Cambridge is the Data Processor; University College London is the Data Controller; and the University of Cambridge processes personal data in accordance with University College London's instructions. You can find out more about how we handle personal data, including how to exercise your individual rights and the contact details for University College London's Data Protection Officer here: www.ucl.ac.uk/data-protection/data-protection-0.

Disclosure of interests

Full disclosure of interests: Completed ICMJE forms for all authors, including all related interests, are available in the toolkit on the NIHR Journals Library report publication page at https://doi.org/10.3310/REMD6648.

Primary conflicts of interest: Angus IG Ramsay was an associate member of the NIHR HS&DR Commissioned Board (2014–5) and associate member of the NIHR HS&DR Board (2015–8) and is a trustee of the charity Health Services Research UK (March 2019–present).

Naomi J Fulop is an NIHR senior investigator and was a member of the NIHR HS&DR Programme Funding Committee (2013–8), HS&DR Evidence Synthesis Sub Board (2016); UKRI and NIHR College of Experts Research Funding (2020). She was a trustee of Health Services Research UK (March 2019 to November 2022). She was the University College London-nominated non-executive director for Whittington Health NHS Trust (2018–24) and is non-executive director on the board of COVID-19 Bereaved Families for Justice.

Stephen Morris was formerly a member of the National Institute for Health and Care Research (NIHR) Health and Social Care Delivery Research (HS&DR) Programme Funding Committee (2014–6), the NIHR HS&DR Evidence Synthesis Sub Board (2016), the NIHR Unmet Need Sub Board (2019), the NIHR Health Technology Assessment (HTA) Clinical Evaluation and Trials Board (2007–9), the NIHR HTA Commissioning Board (2009–13), the NIHR Public Health Research (PHR) Research Funding Board (2011–7), and the NIHR Programme Grants for Applied Research expert subpanel (2015–9). He was also a member of council and trustee of Murray Edwards College, University of Cambridge (2022–4).

All other authors declare no competing interests.

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List of abbreviations

AE	adverse event
CINAHL	Cumulative Index to Nursing and Allied Health Literature
EMBASE	Excerpta Medica dataBASE
ICU	intensive care unit
MEDLINE	MEDical Literature Analysis and Retrieval System
NSD	no significant difference
PHS	paediatric heart surgery
PICU	paediatric intensive care unit
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews
PROSPERO	International Prospective Register of Systematic Reviews
QoL	quality of life
REDCap	Research Electronic Data Capture
RQ	research question

List of supplementary material

Report Supplementary Material 1
Sample data extraction form

Supplementary material can be found on the NIHR Journals Library report page (https://doi.org/10.3310/REMD6648).

Supplementary material has been provided by the authors to support the report and any files provided at submission will have been seen by peer reviewers, but not extensively reviewed. Any supplementary material provided at a later stage in the process may not have been peer reviewed.

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Appendix 1 Search strategy

Searches

This will be a phased search strategy that will be expanded and refined as relevant literature is found and reviewed (with new terms being added during each phase). The reference lists of included articles will be screened to identify additional relevant publications.

Phase 1

The scoping review will first aim to provide a rapid mapping of the literature on centralisation of specialist health services (i.e. reorganisation of specialised healthcare services that is characterised by fewer specialised units serving a higher volume of patients), including the main domains/dimensions of centralisation, the settings where it is applied and the advantages and disadvantages of different models of centralisation in different settings. Specific questions that the scoping review will address are

the following: what does 'centralising specialist healthcare services' mean? What are the elements of centralising specialist services? How do the different models of centralisation work in different settings?

Phase 2

The second phase will conduct a review of published literature using multiple databases: MEDLINE, CINAHL Plus, EMBASE, Web of Science. Results will be combined into EndNote [Clarivate Analytics (formerly Thomson Reuters), Philadelphia, PA, USA] and duplicates removed. The reference lists of included articles will be screened to identify additional relevant publications. We will also hand-search other relevant databases, such as institutions reports, and will send the list of the grouped papers to the relevant disease experts.

Search terms (informed by Iverson *et al.* 2019; Ke *et al.* 2012; Bhattarai *et al.* 2016).

((centralisation[All Fields] OR regionalization[All Fields] OR reconfiguration[All Fields] OR reconfigured[All Fields] OR "concentration"[All Fields] OR volume[All Fields]) AND ("specialised services"[All Fields] OR "specialised care"[All Fields] OR "specialised"[All Fields] OR "specialized"[All Fields] OR "tertiary care" OR "tertiary services" AND ("humans"[MeSH Terms]))

Appendix 2

NIHR Journals Library www.journalslibrary.nihr.ac.uk

DOI: 10.3310/REMD6648

TABLE 4 Summary of papers included in review

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Afshar *et al.*[55]	2018	England	Bladder cancer/radical cystectomies	National	Insufficient detail, beyond drive for high volume	No detail on model, beyond creating high-volume centres; centralisation inferred from reductions in number of services and surgeons providing surgery (while total number of cystectomies increased)	Quantitative Cross-sectional Volume levels	Volume: that is, improving outcomes guidance (IOG) compliant (performing 50 or more surgeries per year) vs. IOG non-compliant Comparison was between IOG compliant vs. non-compliant, that is, high vs. low volume	Mortality LOS Reintervention	A key impact was an increase in proportion of surgeries that were performed in IOG-compliant centres. a reduced proportion of surgeries that were not IOG compliant – IOG compliance associated with: • Significant reduction in mortality at 30 days and 1 year • Significant reduction in LOS • Significant reduction in reintervention
Almström *et al.*[110]	2019	Sweden	Paediatric appendectomy	National	Insufficient detail, beyond drive for high volume	No detail on model – comparison between specialised paediatric surgical centres (which cover almost all acute paediatric care)	Quantitative Cross-sectional Volume levels Specialist vs. non-specialist	Specialist paediatric centres vs. non specialist centres; high volume vs. low volume	Post-op morbidity (complications)	Treatment in specialist paediatric centres associated with lower risk of complications, reoperation and re-admission However, non-specialist hospitals with high volume also saw reduced post-op complications
Anderson[63]	2017	USA	Radical cystectomy	National	Insufficient detail, beyond drive for high volume	No detail on model – just general trend towards centralisation	Quantitative Before and after	Comparison between 2001–6 and 2007–11, covering bladder cancer patients on Medicare	Travel distance (straight-line, not actual journey)	50% increase in median distance from patient home to centre for treatment (10.4–16 miles) ($p < 0.01$) Patients traveling < 15 miles reduced from 58% to 48% Significant increase in proportion of patients who had to travel outside local area/hospital referral region (HRR) for surgery
Arora *et al.*[64]	2020	USA	Bladder cancer, cystectomy	National	Insufficient detail, beyond drive for high volume	No clear statement of model	Quantitative Cross-sectional Volume levels	Hospital volume for surgery	Morbidity (complications)	Increased hospital volume was associated with reduced morbidity and surgical complications This effect plateaued at 50–55 cases per year for any complications ($p = 0.024$) and 45–50 cases/year for major complications ($p = 0.007$)
Barrie *et al.*[43]	2018	England; Wales	Hepatic (liver) trauma	National	Insufficient detail, beyond drive for high volume	Drive for increased access to onsite hepatopancreatico-biliary [HPB unit (specialist unit for liver and other conditions)]	Quantitative Multiple time points Specialist vs. non-specialist	10 years' data divided into 5 × 2-year cohorts – key comparison pre vs. post 2010	Access to specialist Access to diagnostics survival	Overall pattern of improvements over time, in terms of early consultant input, diagnostics (CT scan), delivery of tranexamic acid and 30-day mortality Being treated in a centre with an onsite HPB (HPB unit, i.e. specialist unit for liver and other conditions) increased likelihood of survival [odds ratio 3.5, 95% confidence intervals (CIs) 2.7 to 4.5] Suggested this effect is due to improved access to specialist care, suggesting potential benefits of centralisation

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Becker *et al.*[65]	2014	USA	Nephrectomy; non-metastatic renal cell carcinoma	National	Insufficient detail, beyond drive for high volume	Encouragement to regionalise services so that patients treated in high-volume centres for nephrectomy	Quantitative Cross-sectional Volume levels	Treatment in high- vs. low-volume hospitals	Complications (intra and post operation) Blood transfusions Prolonged LOS In-hospital mortality	Patients undergoing radical or partial nephrectomy in high-volume hospitals had better care and outcomes than those treated in low-volume hospitals, in terms of lower rates of • Complications • Blood transfusions • Excessive LOS (5 days or over) Mortality: no significant effect on in-hospital mortality
Beggs *et al.*[56]	2012	England	Vascular surgical services	Regional	Detail – model described	**Centralisation of components** Regionalised vascular surgery centres. Hub and spoke model, featuring regional centres with 10–12 vascular specialists Services supported by a £12,000 tariff, following the patient's treatment by hub and spoke services	Quantitative Before and after	Analysis focused on ***unintended consequences*** – that is, vascular surgery in a district general hospital (outskirts of London, UK), following centralisation to a regional centre	Focus on patient characteristics, caseload and financial income	Centralisation had the following consequences in this hospital (i.e. a non-specialist centre): • Patients had longer hospital stay • Patients tended to have more comorbidities (among those repatriated from specialist unit) • Significant reduction in surgical activity • Significant decrease in financial income
Bendzsak *et al.*[97]	2017	Canada	Lung cancer surgery	Regional	Insufficient detail – centralisation described in numbers	Regionalisation across Ontario – 14 designated specialist hospitals; implemented in 2007	Quantitative Before and after Specialist vs. non-specialist	Data from 1 January 2004 to 31 December 2012 Pre-post centralisation (in 2004, 37 hospitals; from 2008 centralised to 14 hospitals) Analysis at regional level	Mortality operative Mortality (30 days) Complications Re-admissions within 30 days	By 2012, 91.6% of operations performed in designated hospitals (71.1% pre regionalisation) Patients in designated hospitals had greater comorbidity Overall impacts on outcomes (i.e. at regional level, including all patients receiving surgery), post centralisation: • Mortality reduced (however, this was explained by pre-existing trend in reducing mortality) • Complications reduced • Length of hospital stay reduced • No change in reoperations, re-admissions, or return to ED Several advantages in designated hospitals over non-designated were present both pre and post centralisation (mortality, complications, reoperations, LOS)

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TABLE 4 Summary of papers included in review (*continued*)

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Boddy *et al.*[57]	2012	England	Oesophagogastric (OG) resectional	Regional	Detail – model described	**Centralisation of pathway** Centralised service: pre centralisation, four hospitals delivered resections independently, post centralisation in 2006, all resections performed at one site (Gloucestershire Royal)	Quantitative Before and after	Single centre analysis 10 years pre centralisation, 5 years post centralisation Focus on resections for OG cancer – conducted in Gloucestershire Royal (i.e. not looking at surgery performed in other pre-centralisation hospitals)	Case rate Survival rates 30-day mortality	Increased number of resections performed at Gloucestershire hospital (pre: 23.4 cancer resections per year; post 44 cancer resections per year) Median survival improved significantly, with a step-wise reduction (above and beyond established prior trends) following centralisation in 2006 Combined OG 30-day mortality reduced significantly (10.3–3.6%) Combined OG 90-day mortality reduced (15–9%), but not significant Disaggregating into gastric and oesophageal resections did not achieve significance due to low numbers
Branagan and Davies[58]	2004	England	Oesophageal cancer	Regional	Insufficient detail – centralisation described in numbers	Services centralised from four to one site	Quantitative Before and after	Comparison of pre centralisation (four sites, 1999–2000) vs. post centralisation (one site, May 2002–April 2003)	Surgical complications In-hospital mortality Pathology reporting	Complications – no significant difference In-hospital mortality – significantly lower, post centralisation Pathology reporting – significantly lower incomplete reports
Chan *et al.*[61]	2013	Wales	Upper gastrointestinal cancer	Regional	Insufficient detail – centralisation described in numbers	Centralisation from four separate sites providing surgery independently to one surgical site, implemented in August 2010	Quantitative Before and after	Analysis pre vs. post centralisation (NB data only from specialist centre in post phase)	Operative morbidity Operative + 30-day mortality Length of hospital stay Survival Caseload Patient satisfaction (only post centralisation)	Morbidity – 50% reduction in serious morbidity (non-significant) Mortality – no significant difference Length of hospital stay- significant reduction (3 days) Survival – 1 year survival increased 20% Caseload – median number of operations per surgeon increased from 4 to 23 Patient satisfaction was high, post centralisation: median satisfaction score 9.6 (on scale of 1–10)
Crawford *et al.*[59]	2012	England	Gynaecological cancer	regional	Insufficient detail – centralisation described in numbers	East of England Centralisation from six hospitals to one (i.e. referrals now from five other hospitals), implemented in 2000	Quantitative Multiple time points	Analysis of data for all sites from 1996 to 2003 Data analysed year on year and pre post (i.e. 3 years before, 3 years after centralisation)	Patient survival	Survival was steady, pre centralisation; Significant improvement in year of implementation, then ongoing improvements in the years following centralisation Pre-post comparison showed a significant improvement in survival following centralisation [hazard ratio (HR) of 0.71 (HR = 95% CI 0.64 to 0.79)]

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Dahm-Kähler *et al.*[109]	2016	Sweden	Ovarian and fallopian tube cancers	Regional	Insufficient detail – centralisation described in numbers	Western Sweden region January 2011, surgery for all ovarian and fallopian tube cancers centralised onto a single site, at the region's university hospital	Quantitative Multiple time points	Analysis of surgery conducted over the period 2008–13 (follow-up data to 2015)	Residual disease following primary surgery (primary debulking) Time from primary surgery to chemotherapy 3 year post-surgical survival	Post centralisation: significantly greater reduction in residual disease (37% before compared to 49% after centralisation; $p < 0.03$) Significantly shorter time between surgery and chemotherapy [36 days (median) before compared to 24 days after centralisation ($p < 0.01$)] Significantly greater 3-year survival [4% before compared to 65% after centralisation with a reduced excess mortality rate ratio (EMRR) (0.58, 95% CI 0.42 to 0.79)]
de Ruiter *et al.*[83]	2020	The Netherlands	Lung cancer surgery	National	Insufficient detail – centralisation described in numbers	Centralisation resulted in a reduction of hospitals providing in-house lung surgery from 79 in 2005 to 43 in 2015	Quantitative Cross-sectional Specialist vs. non-specialist	All patients diagnosed with lung cancer and receiving curative radiotherapy or surgery, covering 1 January 2012–31 December 2016 – analysis compared patients treated in hospitals with in-house surgery vs. hospitals without	Survival following curative radiotherapy or surgery	Hospitals providing surgery reduced over time (50 in 2012, 43 in 2016) Patients less likely to undergo surgery if diagnosed in a hospital without an in-house lung service No significant difference in post-treatment survival between services with/without an in-house service
de Wilde *et al.*[84]	2012	The Netherlands	Pancreatic-oduodenectomy (surgery to address malignancy of the pancreatic head or periampullary region)	National	Insufficient detail, beyond drive for high volume	Centralisation flowed from a national requirement implemented in 2006 to have a minimum of 10 operations per year	Quantitative Multiple time points Volume levels	Data analysed from 2004 to 2009. Comparison across services conducting different levels of surgical volume	In-hospital mortality	Proportion of patients treated in a service treating over 10 patients per year increased from 53 to 91% In-hospital mortality rates after surgery decreased from 9.8 to 5.1% ($p < 0.01$) Significantly lower mortality rates in high-volume services (i.e. treating 20 + per year) than in medium-volume services (i.e. treating 11–19 per year) ($p < 0.01$)
Derbel *et al.*[117]	2017	France	Sarcoma	Regional	Insufficient detail – features of unit provided	Rhone Alps region – little/no detail on nature of centralisation. Expert centres defined in terms of volume and presence of multidisciplinary team (MDT)	Quantitative Cross-sectional Specialist vs. non-specialist	All new cases of Sarcoma March 2005–March 2007	Adherence to clinical guidelines Progression-free survival Overall survival	Adherence to clinical guidelines: significantly higher in expert centres than non-expert centres Progression-free survival: higher in expert centres Overall survival: higher in expert centres, especially where surgical guidelines adhered to

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Eggink *et al.*[82]	2017	The Netherlands	Ovarian cancer	Regional	Detail – model described	**Centralisation of components** Managed Clinical Network, covering 10 hospitals, including a single specialist hospital in Groningen	Quantitative Multiple time points	Post-centralisation analysis – January 2013–December 2014 Comparison between patients directly referred by primary care to the specialist centre (n = 40) vs. indirectly referred patients (n = 330)	Referral interval – time from first consultation with primary care to first consultation with specialist Diagnostic interval – time from first consultation with specialist to diagnosis Treatment interval (NB identified as key measure) – time from first consultation with specialist to primary treatment	Referral interval – no change between 2013 and 2014 Diagnostic interval – proportion receiving diagnosis within 21 days increased significantly from 60.5% in 2013 to 67.6% in 2014. Median diagnostic interval reduced between 2013 (19 days) and 2014 (18 days) Treatment interval – proportion receiving treatment within 42 days increased from 63.5% in 2013 to 72.2% in 2014. Median treatment interval reduced between 2013 (34 days) and 2014 (29 days) Patients referred directly to the specialist centre were more likely to receive diagnosis and treatment within recommended timings. However, only a small proportion of patients were referred directly
Finley *et al.*[98]	2010	Canada	Pulmonary lobectomy Thoracic surgery	National	Insufficient detail, beyond drive for high volume	National drive to centralise, implemented to differing degrees across Canada, and in different ways (e.g. British Columbia and Ontario provided additional funding and resources)	Quantitative Multiple time points Volume levels	Year-on-year analysis of hospital volumes for pulmonary lobectomy, and associated in-hospital mortality and length of hospital stay	In-hospital mortality Length of hospital stay	Number of centres reduced from 77 in 1999 to 69 in 2007 Proportion of procedures conducted in high-volume centres (60 + cases per year) increased from ≈50% (1999–2005) to 65% in 2007 Proportion treated in low-volume centres (10 and under per year) reduced over time from ≈8% to ≈4% Unadjusted analysis: high-volume centres associated with lower mortality than low-volume centres (1.8% vs. 4.8%) Risk-adjusted analysis: Mortality: 15% relative risk reduction for every additional 20 cases performed LOS: 5% relative risk reduction for every additional 20 cases performed Data suggested centralisation had resulted in 26 lives saved and 3900 patient days in hospital avoided in 2007

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Fitzsimons *et al.*[9]	2012	UK	Cleft lip or palate	National	Detail – model described	**Centralisation of components** National drive to centralised services into nine 'hub and spoke' services nationally (1–2 units per region), each performing 100–120 new cases per year, and surgeons performing 40–50 new cases per year Implementation happened over several years (first region in 2001, fourth by 2004, sixth by 2005 and ninth by 2007)	Quantitative Multiple time points	Analysis of patients born between 1 April 1997 and 31 December 2008, with follow-up data to 31 December 2009 (i.e. 12-month follow-up at least)	Timing of repair Length of hospital stay Emergency re-admission	Reduction in hospitals performing primary surgery: 49 in 1997, 13 in 2007. In 2007, 12/13 sites performed over 40 cases, 6/13 performed over 60 and 2 performed ≈100 Surgeon volume increased: • Number of surgeons performing surgery fell (≈100 in 1997; 24 in 2007) • Surgeons performed more operations: ◦ in 1997–8, > 20% operated on just 1 patient, while only 1surgeon operated on over 40 patients ◦ in 2007–8, 67% of surgeons operated on 20–39 patients per year, while 24% operated on 40 + patients per year • Increase in proportion of patients receiving timely surgery ◦ from 47% to 75% for lip ◦ from 69% to 86% for palate ◦ late repairs (after 2 years) reduced from 14% to 4% • Length of hospital stay reduced significantly ◦ from 3.8 to 3.0 days for primary lip repairs ◦ from 3.8 to 3.3 days for primary palate repairs ◦ from 4.6 to 2.6 days for combined repairs ($p < 0.01$) • No significant change in emergency re-admission over time

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Freriks *et al.*[14]	2020	The Netherlands	Stroke	National	Insufficient detail – centralisation described in numbers	Northern Netherlands had neighbouring centralised stroke/thrombolysis service (four hospitals around a tertiary hospital in Groningen) and non-centralised stroke/thrombolysis service (nine hospitals)	Quantitative Cross-sectional Centralised vs. non-centralised	Comparison of centralised vs. decentralised stroke systems, drawing on patient-level hospital data covering 6 months of activity in 2010	QoL – admission (short National Institutes of Health Stroke Scale (NIHSS)) vs. long term (modified rankin scale (mRS) at 3 months) Service costs – pre-, intra- and post-hospital care. Included staffing, transport and therapies	• Disability/independence: decentralised system associated with significantly higher disability and dependence at 3 months (while no difference in dependence on admission) • Costs: while pre-hospital costs higher in centralised, overall costs (including pre, intra and post hospital) were significantly lower in centralised systems than decentralised system • Final analysis suggested centralisation had a causal influence on savings [$1581 (£1194.05)] and a QoL gain of 1.4%
Friebel *et al.*[45]	2018	UK	Stroke	Regional	Detail – model described	**Centralisation of components** London centralised stroke services into 8 Hyper Acute Stroke Units (HASUs) in 2010	Quantitative Before and after Specialist vs. non-specialist	Difference in differences comparison of care and outcomes for stroke patients treated in HASUs and non-HASUs, with national regional control Comparison covered April 2006–April 2014	Care delivery (scans, thrombolysis) Mortality (at 7 and 30 days) LOS Discharge to usual place 30-day re-admissions Aspiration pneumonia rate	Approximately 15% of stroke patients in London were treated in non-HASUs These patients were less likely to receive evidence-based care and had poorer mortality outcomes than stroke patients treated in HASU NB quite limited, as not conducted on patient-level data
Gabbe *et al.*[116]	2012	Australia	Major trauma	Regional	Detail – model described	**Centralisation of components** Victoria, Australia created a regionalised major trauma system in 2000. While there are 138 hospitals, there is 1 paediatric and 2 adult major trauma level 1 centres. The system is served by a single ambulance (road and air) service	Quantitative Before and after	Analysis over period October 2006–June 2009	Key outcome: level of function at 12 months post injury	• Mortality: decreased from 11.9% in 2006–7 to 9.9% in 2008–9 • Function at 12 months: risk-adjusted functional outcomes improved over time, despite reduced mortality • Likelihood of good functional outcome lower for patients who were not treated in one of the major trauma centres (MTCs)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Gooiker *et al.*[85]	2014	The Netherlands	Pancreatic surgery	National	Insufficient detail – centralisation described in numbers	Netherlands commenced centralisation of pancreatic surgery in 2005	Quantitative Before and after	Comparison of care and outcomes of pancreatic surgery across the Netherlands, comparing performance 2000–4 vs. 2005–9	Survival rates Resection rates	1. The resection rate increased from 10.7% in 2000–4 to 15.3% in 2005–9 ($p < 0.001$) 2. high hospital volume remained associated with better overall survival after resection [hazard ratio (HR) 0.70, 95% CI 0.58 to 0.84; $p < 0.001$] 3. Post-operative mortality was lower in high-volume hospitals than in medium- and low-volume hospitals, but the difference was not statistically significant
Gooiker *et al.*[86]	2011	The Netherlands	Pancreatic surgery	Regional	Detail – model described	**Centralisation of pathway** In 2006, the Western Netherlands agreed to centralise pancreatic surgery into 2 high-volume centres	Quantitative Multiple time points	Comparison across three time periods: 1996–2000 (pre) 2001–5 (post introduction of standards) 2006–8 (post centralisation)	Mortality (30-day) Survival (90-day, 1 year, 2 years)	Activity/volume. Following centralisation, mean annual hospital volume increased from ≈2 to 23, and proportion of patients undergoing surgery increased from 14.3% to 18.4% Mortality fell (from 8% to 0% and 2% in latter periods) – could not test significance due to low numbers Risk-adjusted analyses suggested survival significantly better, post centralisation (HR 0.50, CI 0.34 to 0.73)
Hall *et al.*[2]	2015	Canada	Stroke	Regional	Detail – model described	**Centralisation of components** Ontario stroke system – notes existence of regional stroke centres and district stroke centres, but does not go into great depth about the model	Quantitative Multiple time points Volume levels	Comparison of hospitals treating high/medium/low volume of ischaemic stroke patients (over the period 2005/06–2011/12)	Risk adjusted mortality rate (at 7 and 30 days)	Attenuated effect of volume: • low-volume services had significantly higher risk-adjusted mortality than high-volume services, with 7-day mortality 47% higher and 30-day mortality 37% higher • No significant difference between high- and medium-volume services on risk-adjusted mortality. Authors suggest that this may be because medium-volume services are more likely to have been designated stroke centres, thus have similar protocols to high volume service (again, likely to be specialist services)

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Hardwicke *et al.*[47]	2007	UK	Hypospadias repair service	Regional/ local	Detail – model described	**Centralisation of pathway** Surgeon-level centralisation Pre 2000: hypospadias repair (i.e. correcting mis-development of urethral opening) conducted by multiple surgeons across (and beyond) local area. From 2000, single surgeon conducted all instances in region, using a more standardised approach	Quantitative Before and after Volume levels	Comparison of audit results (1995–9 vs. 2000–4)	Occurrence of major complications (fistulae, urethral stricture)	Similar volume (67 pre change, 70, post change), but now all performed within one service – that is, one unit of higher volume than previous units Complications reduced, post centralisation: 1. fistulae occurrence reducing from 35.8% to 6.7% 2. urethral stricture rates reduced from 4.4% to 0%.
Hastrup *et al.*[102]	2018	Denmark	Stroke	Regional	Insufficient detail – centralisation described in numbers	Central Denmark Region (CDR) centralised stroke care from 6 to 2 acute stroke units.	Quantitative Before and after Centralised vs. non-centralised	Before and after, difference in differences design. Comparison between centralised area and rest of Denmark (not centralised), pre centralisation (May 2011–April 2012) and post (May 2013–April 2014)	Care delivery Thrombolysis rate Length of hospital stay Re-admissions (30-day) Mortality (30-day, 1 year)	Centralisation associated with the following effects over time, relative to rest of Denmark: Care: improved in line with rest of Denmark Thrombolysis: non-significant increase LOS: significant reduction in acute stay [a median of 5–2 days with a LOS ratio of 0.53 (95% CI 0.38 to 0.75), data adjusted] Re-admissions: non-significant increase Mortality: no significant change in CDR or rest of Denmark
Hemmelgarn *et al.*[99]	2001	Canada	Coronary revascularisation	Regional	Insufficient detail – centralisation described in numbers	Reduction from two centres to one, implemented April 1996 – part of a wider regional restructure, involving closure of several hospitals	Quantitative Before and after	Before and after comparison (21 months pre, 24 months post) for patients undergoing coronary artery bypass grafting (CABG) and percutaneous transluminal coronary angioplasty (PTCA)	Volume/ discharges per month Level of comorbidity Length of hospital stay In-hospital mortality	Volume/discharges: significant increase for CABG (from 50.8 to 63.7, $p < 0.001$) and PTCA (from 111.4 to 129.1, $p < 0.001$) Comorbidity: index score increased for CABG (1.3–1.5, $p < 0.001$) and PTCA (1.0–1.1, $p < 0.05$) LOS: significantly lower for CABG (by 1.3 days) and PTCA (by 1.0 days) Mortality: after risk-adjustment, no significant reduction in either group

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Hindenburg *et al.*[103]	2019	Denmark	Abdominal aortic aneurysm	National	Insufficient detail – centralisation described in numbers	In 2008, services providing surgery for ruptured abdominal aortic aneurysm (rAAA) were centralised, reducing from 10 to 6 services	Quantitative Multiple time points	Analysis of post-centralisation trends (i.e. 2009–15) within one specialist hospital – Rigshospitalet in Copehagen, focusing only on patients with rAAA and who lived long enough to receive care	Patient mortality (30 days, 90 days, 1 year) Secondary surgery Complications, for example, intestinal ischaemia	Mortality: no clear pattern of reduction over post-centralisation period Other outcomes not analysed over time, that is, purely single descriptive figure for post-implementation period
Hukkinen *et al.*[112]	2018	Finland	Biliary atresia (BA), portoenterostomy	Regional	Detail – model described	**Centralisation of pathway** In 2005, services treating bilateral atresia in Finland were centralised from five hospitals to one, with a single team led by one surgeon delivering all treatments, and approaches to treatment and follow-up standardised	Quantitative Before and after	Single centre, before and after comparison covering all cases of bilateral atresia treated in Helsinki tertiary hospital from 1987 to 2016 (analysis covered a total of 61 patients over this period – 25 pre centralisation, 36 post centralisation)	Clearance of jaundice Liver survival Overall survival	Following centralisation… Clearance of jaundice increased (42% vs. 80%, $p < 0.01$) 5-year native liver survival increased (38–70%, $p < 0.05$) 5-year overall survival increased (68–94%, $p < 0.01$)
Hunter *et al.*[39]	2018	UK	Stroke	Regional	Detail – model described	**Centralisation of components/hierarchy** Centralisation implemented in London and Greater Manchester (GM) in 2010, creating hub and spoke systems around HASUs London: 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment GM: 3 HASUs, one admitting 24/7, two admitting 7 a.m.–7 p.m., Monday–Friday. Only patients reaching hospital within 4 hours eligible for HASU treatment	Quantitative Before and after Centralised vs. non-centralised control	Differences in costs and outcomes [calculated as quality-adjusted live years (QALYs)], before and after centralisation in London and GM, against a national control	Mortality LOS Cost-effectiveness	Mortality: relative reduction in deaths in London compared to the rest of England of 0.9% or 9 deaths per 1000 patients. No equivalent reduction in deaths in GM at 90 days LOS: both areas had a reduction in LOS relative to the rest of England, 2 days less in GM and 0.6 days less in London Cost-effectiveness: both GM and London were cost-effective, but GM more likely to be cost-effective at lower levels of willingness to pay (WTP) for a QALY, while London more likely at higher WTP GM likely to achieve cost-effectiveness through reduced costs (e.g. related to LOS reduction), whereas London tended to cost more than elsewhere, but achieve cost-effectiveness through reduced mortality

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Hunter *et al.*[15]	2013	UK	Stroke	National	Detail – model described	**Centralisation of components** Centralisation implemented in London in 2010, creating hub and spoke system around HASUs London: 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment	Quantitative Before and after	Single region before and after comparison Pre-centralisation data covered July 2007–June 2008; post centralisation covered July 2010–June 2011 90-day and 10-year models, adjusting for national trends	Stroke patient survival Stroke patient mortality Stroke clinical interventions Cost of services Cost-effectiveness (cost per QALY gained) at 90 days and 10 years	Survival: increased significantly [87.2% 'before' (95% CI 86.7% to 87.7%) and 88.7% 'after' (95% CI 88.6% to 88.8%)] Mortality: reduced significantly by 12% (95% CI 8% to 16%) Interventions: increase in thrombolysis (5–12%) Cost: significantly lower – cost saving of £5.2M per year at 90 days (95% CI £4.9M to £5.5M; £811 per patient) Cost-effectiveness: at 10 years, model dominant – reduced costs, with 4193 QALYs gained (0.65 per patient)
Idrees *et al.*[66]	2019	USA	Resected cholangiocarcinoma	National	Insufficient detail, beyond drive for high volume	National drive to achieve regionalisation of care (though NB not mandated); cites use of high volume as a criterion for becoming a centre of excellence; no models specified	Quantitative Multiple time points Volume levels	Analysis covering 2004–15 (split into 2004–7, 2008–10 and 2011–5), focusing on degree of centralisation and its association with compliance with guidelines and patient outcomes	Degree of centralisation (i.e. proportion of surgeries conducted in high-volume centres, disaggregated into five groups from low to high volume) Compliance with National Comprehensive Cancer Network guidelines Survival (overall and at 1, 3, 5 years) Access to care (age, ethnic minority status, socioeconomic status)	Proportion of surgeries conducted in high-volume centres (20 + patients per year) increased over time (25–44%) and proportion in low-volume centres (< 5 patients per year) reduced (30–15%) Median survival improved over the study period (2004–7), 2.9 years; 2011–5, 3.7 years ($p < 0.005$) Both treatment at high-volume hospital (HR 0.92, 95% CI 0.88 to 0.97; $p < 0.001$) and compliance with guidelines (HR 0.87, 95% CI 0.83 to 0.91; $p < 0.001$) were independently associated with improved survival Access to care: no significant effect of age, ethnicity, or socioeconomic status on being treated in high-volume centre

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
James *et al.*[44]	2006	UK	Emergency oral and maxillofacial surgery	Regional	Detail – model described	**Centralisation of components** Before, emergency services in oral and maxillofacial surgery (OMFS) delivered by six hospitals; post centralisation in 2001, there was a single hub (located at University Hospital Birmingham and Birmingham Children's Hospital), with five spoke hospitals Hub service offered two dedicated operating lists per week; and at all other times emergency lists were available Daily 'trauma-only' ward rounds made by dedicated specialist registrar, on duty to address only emergency cases All adult patients seen at spoke units who required a maxillofacial opinion were sent to Selly Oak Hospital and all children to the Children's Hospital	Quantitative Before and after	Single site analysis, focusing on the hub service Comparison of adult emergency workload in the 6 months pre centralisation and the 6 months post centralisation	Time from admission to operation Time of day of operation Grade of surgeon conducting operation Grade of anaesthetist	Number of emergency operations increased by 61% from 135 to 220 Time to surgery: before centralisation, 94% operated on within 24 hours; after centralisation, 84% within 24 hours Time of surgery: before, 84% operated on in-hours (09.00–17.00, Monday–Friday); after, 74% operated on in-hours Proportion treated on emergency list: before, 45% of emergencies treated on elective lists; after, 100% treated on emergency lists (i.e. major reduction of cancellation of non-emergency surgeries) Grade of surgeon: before, 83% registrar; after, 84% specialist registrar Grade of anaesthetist: before, 67% specialist anaesthetist; after, 91% specialist anaesthetist Note: discussion reports that patients referred from spokes were seen ≈1 hour than those who attended the hub directly, which was interpreted as not greatly affecting access to emergency surgery
Jensen *et al.*[104]	2010	Denmark	Gastric cancer	National	Insufficient detail – centralisation described in numbers	Pre-centralisation, gastric cancer surgery provided by 37 units. 1996 and 2001 saw recommendations to centralise so that all gastric surgery to be delivered in 5 units, based in university hospitals across Denmark	Quantitative Before and after	Comparison of pre centralisation (1999–2003) with post centralisation (2003–8)	Quality of care: proportion of patients having at least 15 lymph nodes removed Post-operative morbidity (anastomotic leakage) Hospital mortality (post-operative death within 30 days)	Lymph nodes removed: proportion of patients increased significantly (before, 19%, after, 76%) Morbidity: reduced, but not significantly [before 6.1% (95% CI 4.3 to 8.6), after 5% (CI 3.2 to 7.7)] Hospital mortality: reduced significantly [before 8.2% (CI 6.0 to 10.4), after 2.4% (CI 1.2 to 4.4)] ($p < 0.05$) Note: fidelity to centralisation. Post-centralisation analysis focused only on the 5 specialist units. However, analysis reported that four–6sixpatients reported as treated outside these 5 units annually 2003–6, but none from 2007

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Jindal *et al.*[17]	2017	USA	Pancreatectomy	National	Insufficient detail, beyond drive for high volume	No description of model of centralisation	Quantitative Multiple time points	Analysis of data for pancreatectomy over the period 2004–13, focusing on changes in travel distance from home to cancer surgery unit, and associations with outcomes, adjusting for patient characteristics	Travel distance between centre of zip-code area and address of cancer surgery unit Delayed surgery (i.e. more than 30 days after diagnosis) 30-day mortality Patient survival	Travel distance: increased significantly [16.5–18.7 miles (*p*-value for trend < 0.001)] Delayed surgery: increased travel distance associated with increased likelihood of delayed surgery. Relative to first quartile, odds ratio (OR) for second quartile 1.05 (95% CI 0.99 to 1.26); third quartile OR 1.16 (95% CI 1.09 to 1.25); fourth quartile OR 1.36 (95% CI 1.26 to 1.46) Mortality: increased travel distance associated with reduced mortality. Relative to first quartile, second quartile OR 0.85 (95% CI 0.73 to 0.98); third quartile OR 0.76 (95% CI 0.65 to 089); fourth quartile OR 0.62 (95% CI 0.51 to 0.75). Following adjustment for hospital volume, only association between travel distance and 30-day mortality remained, and only when comparing first and fourth quartile of travel distance (OR 0.82, 95% CI 0.67 to 1.00) Survival: patients travelling furthest (fourth quartile) had 6% lower hazard of death than first quartile (HR 1.07, 95% CI 1.03 to 1.10). No significant effects associated with travel distance once adjusting for hospital volume Interpretation – people travelling further may be more likely to be going to a high-volume unit
Kalaiselvan *et al.*[48]	2019	UK	Retroperitoneal tumours Retroperitoneal sarcomas (RPS)	Regional	Detail – model described	**Centralisation of pathway** Treatment of RPS was centralised across NW Coastal region of England in May 2011. This brought together services in the Merseyside, Cheshire and Lancashire, and Cumbria networks. This resulted in a single specialist MDT based in Liverpool providing this treatment for the whole region (population 3.9m)	Quantitative Before and after	Analysis of all RPS excisions from 1 January 2004 to 30 November 2017 Comparison between before centralisation (2004–April 2011) and after (May 2011–30 November 2017)	Number of patients Number of resections Survival	Large increase in activity (though still low numbers, given rare condition): Number of patients: before 13 (2.5/year); after 59 (13/year) Resections: before, 2.5/year; after, 13/year Survival: 5-year survival within region increased from 48% to 60% over the study period (p = 0.575; non-significant) Overall survival was significantly higher in studied region than in national registry figures in the post-centralisation period [60% vs. 40%; OR 2.262 (1.226 to 3.911), p < 0.01]

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Kawaguchi *et al.*[100]	2020	Canada	Intensive care for children	Regional	Detail – model described	**Centralisation of pathway** Centralised system around a PICU launched 1996. Shift in patient transportation system from 2008	Quantitative Post centralisation Admission route	Comparison between patients transferred to PICU following assessment in a remote 'referral hospital' (paediatric critical care transported) and patients who presented directly at the specialist centre (i.e. emergency department linked to the PICU) (paediatric emergency department)	Mortality 72 hours after initial contact with paediatric critical care (NB defined differently for studied groups: arrival of transport team for transported patients; admission to PICU for direct presentation patients)	Transported patients had significantly higher 72 hours mortality than patients presenting directly to specialist centre (OR 2.18, 95% CI 1.07 to 4.45, $p < 0.05$) Noted potential influence of greater distances covered in Canadian context than in previous research (e.g. in UK, which suggested equivalent mortality for patients who travelled and patients who presented directly)
Kelly *et al.*[68]	2015	USA	Traumatic brain injury	Regional	Detail – model described	**Hierarchy of specialist units** Regionalised trauma system covering Northern Ohio (USA) Covers two large hospital systems and features one level 1 trauma centre (including trauma-specific ICU), four level 2 centres, non-trauma hospitals and local emergency medical services (NB two level 2 centres closed during study period) Level 1 centre co-ordinates system and transfers; triage protocols include criteria for transfer to level 1 and level 2 centres	Quantitative Before and after	Comparison of pre vs. post centralisation, with data covering patients with severe traumatic brain injury (sTBI) from 2008 to 2012, with centralisation taking place in 2010	Post-discharge mortality Post-acute destination Functional independence	30-day mortality reduced significantly: before 21%, after 16% ($p < 0.01$) 6-month mortality reduced significantly: before 24%, after 20% ($p < 0.01$) Discharges to TBI rehab unit increased from 9% to 14%; no changes in discharges home or to non-TBI nursing units Functional independence gains for patients discharged to TBI rehab units did not change significantly, suggesting that reduced mortality did not result in associated increases in disability

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TABLE 4 Summary of papers included in review (*continued*)

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Kelly *et al.*[67]	2019	USA	Trauma care; traumatic spine injury	Regional	Detail – model described	**Hierarchy of specialist units** Regionalised trauma system covering Northern Ohio (USA) See Kelly *et al.* 2015[68]	Quantitative Before and after	Comparison of pre vs. post centralisation, with data covering patients with traumatic spinal injury (TSI) and patients with traumatic spinal cord injury (TSCI) from 2008 to 2012, with centralisation taking place in 2010	LOS (overall) LOS (in ICU) Likelihood of undergoing surgery Discharge location Hospital mortality	TSI patients LOS: no significant change overall, but significant reduction in ICU LOS (OR −1.68, 95% CI −2.98 to 0.39, $R^2 = 0.74$) Surgery: significant increase in spinal surgery overall (before 11%, after 13%, $p < 0.05$) and increase in proportion undergoing surgery within 24 hours (before 55%, after 65%, $p < 0.05$) Discharge location: no significant change Mortality: no significant change TSCI patients LOS: no significant change overall, but significant reduction in ICU LOS (OR −2.42, 95% CI −3.99 to 0.85, $R^2 = 0.72$) Surgery: significant increase in spinal surgery overall increased (before 15%, after 21%, $p < 0.05$) and non-significant trend of increase in proportion undergoing surgery within 24 hours (before 57%, after 66%, $p > 0.05$) Discharge location: no significant change Mortality: no significant change
Khera *et al.*[20]	2016	USA	Haematological malignancies/ haematopoietic cell transplantation	Regional	Detail – model described	**Centralisation of components** Centralised system covering the Seattle area Patients travel to centre to receive cell transplants They then stay within 30 minutes of centre for the first 80–100 days post transplant. Patients then return home, with a 1-year check at a long-term follow-up clinic	Quantitative Post centralisation Cross-sectional	Post-centralisation analysis, focusing on influence of home residence (distance from specialist centre and rural/urban status) on outcomes	Overall mortality Non-relapse mortality (NRM) Relapse	Overall mortality: no significant influence of location (distance from centre or degree of rurality) on overall mortality Non-relapse mortality: no significant influence of location (distance from centre or degree of rurality) on NRM Relapse: no significant influence of location (distance from centre or degree of rurality) on likelihood of relapse That is no clear effect of inequality of outcome based on distance in centralised system

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Knisely *et al.*[69]	2020	USA	Endometrial cancer	Regional	Insufficient detail, beyond drive for high volume	Trends to reduce number of units providing care for endometrial cancer and hysterectomy	Quantitative Multiple time points	Changes over time in New York State, from 2000 to 2014	Number of hospitals and surgeons providing hysterectomy Travel distance to receive care	Number of hospitals providing hysterectomy reduced across NY state, but variably by district [e.g. reduction of 16.7% in Syracuse (from 12 to 10 hospitals), and reduction of 76.5% in Rochester (from 17 to 4 hospitals)] Number of surgeons providing hysterectomy also reduced, and again variably by district [e.g. reduction of 45.2% in Buffalo (84 surgeons in 2000 to 46 surgeons in 2014), and reduction of 77.8% in Albany (72 surgeons in 2000 to 16 surgeons in 2014)] Travel distance increased in all districts, especially in rural areas All racial categories saw increases in travel distance (though most pronounced among white category)
Kostalas *et al.*[49]	2018	UK	Pancreatic surgery	Regional	Insufficient detail – features of unit provided	National drivers for centralisation of cancer surgery. Local case of developing a tertiary surgical centre, from 2010 have full consultant team supported by MDT	Quantitative Before and after	Single-unit comparison, comparing unit pre centralisation and period while developing (1998–2009) vs. after establishment as tertiary unit (2010–14)	Intraoperative data (surgery length, blood-loss, transfusions, portal vein resection) Morbidity: Return to theatre LOS Early discharge (pre 10 days post-op) 30-day mortality	Intraoperative data: significantly longer surgery, no other significant changes Morbidity: no significant change Return to theatre: no significant change LOS: significant reduction in median LOS from 14 to 12 days ($p < 0.01$) Early discharge (pre 10 days post-op): significant increase in proportion discharged early (from 13% to 35%, $p < 0.01$) 30-day mortality: significant reduction from 3% to 0.5% ($p < 0.05$)
Kuo *et al.*[70]	2015	USA	Bariatric surgery	National	Insufficient detail, beyond drive for high volume	Medicare/Medicaid restricted bariatric procedures to centres of excellence, designated based on achieving quality standards	Quantitative Multiple time points	Analysis of two regions – New York and Florida over the period 2008–11	Number of surgeries – overall and performed at centre of excellence (COE) Access – travel distance and patient characteristics	Number of overall surgeries reduced from 13,073 in 2008 to 11,228 in 2011 Number/percentage of procedures performed at COEs increased from 7912 (60.5%) in 2008 to 8203 (73.1%) in 2011 ($p < 0.01$) Proportion of patients from racial or ethnic minorities treated in specialist centres increased over time

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Lahr *et al.*[87]	2012	The Netherlands	Stroke	Regional	Detail – model described	**Centralisation of pathway** Centralised system around one specialist centre in Groningen (which offers 24/7 access to neurology specialists and imaging) and three other hospitals Comparison area, also in northern Netherlands, has nine hospitals each providing stroke care (each with 24/7 access to neurologists and imaging) to its local catchment area	Quantitative Post centralisation Centralised vs. non-centralised	Cross-sectional comparison between centralised and non-centralised systems, covering period February–July 2010	Proportion receiving thrombolysis (TpA) Proportion of patients arriving in time for TpA Timings (onset to door, door to needle, onset to needle) Proportion treated out of hours Intracerebral haemorrhage Functional outcome at 90 days	Proportion receiving TpA: significantly higher in centralised 21.9% vs. 14.1% (OR 1.72, 95% CI 1.22 to 2.43); adjusting for patient characteristics, OR 2.03 (95% CI 1.39 to 2.96) Arriving in time for TpA: centralised significantly higher (124 of 283 vs. 227 of 801; $p < 0.01$) Timings: Onset to door: centralised 84 minutes, non-centralised 72 minutes [$p > 0.05$, no significant difference (NSD)]) Door to needle: centralised 35 minutes, non-centralised 47 minutes ($p < 0.01$) Onset to needle: centralised 124 minutes, non-centralised 120 minutes ($p > 0.05$, NSD) Proportion treated out of hours: 40% in both models Intracerebral haemorrhage: no significant difference Favourable functional outcome at 90 days: non-significant difference between centralised [41 of 62 [66%)] and non-centralised [59 of 113 [52%)]
Lampela *et al.*[113]	2012	Finland	BA care	National	Detail – model described	**Centralisation of pathway** In 2005, units providing BA treatment were centralised from 5 to 1 unit serving the whole population. The specialist unit included a limited number of consultants and dedicated MDT	Quantitative Before and after	Analysis over the period 1987–2010, with centralisation taking place in 2005	Annual caseload per centre Clearance of jaundice Survival with native liver Transplant-free at 4 years Survival of patient	Annual caseload per centre: increased, from before= 0(0–3), to after= 4(3–5) ($p < 0.01$) Clearance of jaundice: increased from before (all centres 27%, Helsinki 36%) to after (Helsinki 75%) ($p < 0.01$) Survival with native liver: before 23% after 70% ($p < 0.01$) Transplant-free at 4 years: before 25% after 75% ($p < 0.01$) Survival of patient > 1 year: before 75%, after 100% ($p < 0.05$) Survival of patient > 2 years: before 64%, after 92% ($p > 0.05$, NSD)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Learn and Bach[71]	2010	USA	Pancreatectomy, oesophagectomy, gastrectomy or major lung resection (oncological surgery)	National	Insufficient detail, beyond drive for high volume	Centralisation recommended but not mandated	Quantitative Multiple time points Volume levels	Comparison over time (1997–9, 2000–3, 2004–6) Comparison between conditions that received differing levels public policy attention Focus on Pancreatectomy and oesophagectomy (both subject of high public policy attention) and Gastrectomy and major lung resection (treated as 'controls', as having had less public policy attention)	Degree of concentration of services Inpatient mortality	Proportion of procedures carried out in high-volume services increased significantly for all four conditions (all trends $p < 0.01$) Pancreatectomy: 1997, 31%; 2006, 47% Oesophagectomy: 1997, 25%; 2006, 52% Gastrectomy: 1997, 32%; 2006, 36% major lung resection: 1997, 33%; 2006, 45% Mortality: Mortality significantly reduced over time for all conditions Mortality significantly lower in high-volume services for all conditions However, the bulk of improvements in outcomes were seen within volume categories (i.e. improvements were occurring within volume categories and not purely located around greater concentration in high-volume centres)
Leighton *et al.*[60]	2019	England	Vascular surgery	Regional	Detail – model described	**Centralisation of pathway** Before: vascular surgery provided by three NHS hospital organisations in Bristol and Bath area of South West England After: from 13 October 2014, all vascular care for the area was transferred to a single centre in North Bristol area. Dedicated MDT, including vascular specialists and 24/7 interventional radiology. They cover a cover dedicated 32 bed ward. System supported by policy to bypass other hospitals in the area	Quantitative Before and after	Pre-post comparison, focusing on immediate impact of changes Before: 1 March 2012–31 December 2012 After: 13 October 2014–31 March 2015	30-day mortality 30-day morbidity LOS hospital LOS intensive care	Mortality: no significant difference Morbidity: no significant difference LOS hospital: before 8 days, after 6 days (no significant difference) LOS intensive care: no significant difference Noted that this demonstrates no negative immediate effects of centralisation, that is, after period commenced on the day of centralisation with no 'bedding in' time

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Lemmens *et al.*[88]	2011	The Netherlands	Pancreatic surgery	Regional	Insufficient detail – centralisation described in numbers	Before 2000, eight hospitals performed pancreatic surgery in south Netherlands (low volume, e.g. 4 per year). Poor outcomes prompted drive to centralise from 2005	Quantitative Before and after	Comparison before (1995–2000) vs. after (2005–8)	Degree of centralisation Resection rates In-hospital Mortality Post-operative complications 2-year post-surgical survival	Centralisation: • 2005, six hospitals performing resections (five resections per hospital per year) • 2006–7, five hospitals (six resections per hospital per year) • 2008, 3 hospitals (16 resections per hospital per year) Resection rates increased: before, 19%, after, 30% ($p < 0.01$) Mortality (for patients undergoing resection) reduced: before, 24%; after, 3.6% ($p < 0.01$) (NB 2008 mortality rate was zero) Complications (for patients undergoing resection) reduced: before, 72%, after, 36.9% ($p < 0.01$) Survival (for patients undergoing resection) increased: before, 38.1%; after, 49.4% ($p < 0.01$) Survival (for all pancreatic patients) increased: before, 10.3%; after, 16% ($p < 0.01$) Survival (for non-resected patients): no significant difference
Lundström *et al.*[111]	2000	Sweden	PHS	National	Insufficient detail – centralisation described in numbers	Reduction in number of units performing PHS from 4 to 2 Selection of two-centre model was to (a) encourage competition, and (b) provide resilience (e.g. against infection outbreaks)	Quantitative Before and after	Before (1988–91) vs. after (1995–7)	30-day mortality	After centralisation, 93% of PHS was performed in the two specialist centres 30-day mortality reduced significantly: Open-heart surgery (overall): before, 9.5%; after, 1.9% ($p < 0.01$) Open-heart surgery (Grade II): before, 11%; after, 0.3% ($p < 0.01$) Open-heart surgery (Grade III): before, 17.9%; after, 4.4% ($p < 0.01$) After, far fewer patients referred to palliative care, instead undergoing corrective surgery After, new techniques (Norwood surgery, Fontan surgery) were being used far more in both centres

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Macleod *et al.*[18]	2018	USA	Testicular cancer	National	Insufficient detail, beyond drive for high volume	Model not described – broad trends to centralisation inferred	Quantitative Cross-sectional Volume levels	Regionalisation defined in terms of travel distance (up to 50 miles vs. 50 + miles) and volume (< 4, 4–9, and > 9 cases per year)	Odds of large primary tumour Incidence of presentation at stage III Delays in orchiectomy Overall mortality	Mixed message around regionalisation: higher distances associated with poorer outcomes, but higher volume associated with better volumes Odds of large primary tumour: • Travel distance: higher distance increased likelihood, adjusted OR 1.10 (1.01 to 1.22) • Volume: higher volume reduced likelihood, adjusted OR 0.92 (0.86 to 0.98) Incidence of presentation at stage III • Travel distance: higher distance increased likelihood, adjusted OR 1.29 (1.14 to 1.45) • Volume: no significant effect Delays in orchiectomy • Travel distance: no significant effect • Volume: no significant effect Overall mortality • Travel distance: higher distance increased likelihood, adjusted HR 1.36 (1.11 to 1.65) • Volume: higher volume reduced likelihood, adjusted HR 0.78 (0.67 to 0.90)
Manchon-Walsh *et al.*[106]	2016	Spain	Rectal cancer surgery	Regional	Insufficient detail, beyond drive for high volume	Evidence that low-volume providers were having poorer outcomes let to increasingly firm recommendations to centralise into high-volume units. This culminated in formal regulation in 2012. No detail on formal models of care	Quantitative Before and after	Before (2005, 2007) After (2011–2)	Relapse (Locoregional recurrence at 2 years) Mortality	Number of hospitals offering rectal surgery reduced from 51 to 32 Proportion of patients receiving surgery in centres performing > 11 surgeries per year increased from 84% to 90.4% Centres with annual caseload of > 40 increased from 37.5% to 52.8% Relapse: before, 4.5/100 person years; after, 3.06/100 person years ($p < 0.01$). Adjusted HR 0.65 (0.49 to 0.86; $p < 001$) Mortality reduced significantly 3 months: after, adjusted HR 0.48 (0.34 to 0.69), $p < 0.01$ 12 months: after, adjusted HR 0.62 (0.50 to 0.78); $p < 0.01$ 24 months: after, adjusted HR 0.65 (0.55 to 0.77); $p < 0.01$

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TABLE 4 Summary of papers included in review (*continued*)

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Melnychuk *et al.*[46]	2019	UK	Stroke	Regional	Detail – model described	**Centralisation of components** Centralised hyper acute stroke system in London 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment	Quantitative Post centralisation Centralised vs. non-centralised	Comparison between London system and national control (broadly non-centralised or less centralised), focusing on changes in care delivery and outcomes at different times of day and week	16 quality indicators 3-day mortality, post admission Disability at end of inpatient spell (modified Rankin scale) Length of hospital stay	Quality less affected by time of day/week in London than elsewhere: • brain scanning, stroke nursing care and thrombolysis: no effect in London, significant variation elsewhere • assessment by stroke consultant, physiotherapists, speech and language therapists, and occupational therapists: variations in London and elsewhere 3-day mortality: no variation in London or elsewhere Disability: no variation in London, significant variation elsewhere LOS: significant variations in London (pooling data suggested higher LOS for patients admitted at weekends); elsewhere, significant variation, indicating higher LOS for patients admitted at night

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Metcalfe *et al.*[42]	2016	UK	Major trauma care, injury	National	Detail – model described	**Hierarchy of specialist units** Regional trauma networks launched across NHS in England from April 2012. Networks include MTCs, supported by local trauma units (which offer initial stabilisation or definitive management depending on nature of injuries) 10 are adult only, 4 are children only, and 12 receive both adults and children Manchester and Liverpool MTCs operate across multiple hospital sites Transfer: patients suffering major trauma who meet pre-hospital triage criteria are transported directly to an MTC, providing that the journey time does not exceed 45 minutes MTC characteristics: all MTCs are expected to provide an all-hours consultant-led trauma team, immediate access to major trauma CT scanning and a dedicated operating theatre for trauma	Quantitative Before and after	Pre-post comparison of care and outcomes in all major trauma networks For each network, comparison was of 270 days before vs. 270 days after local launch of the regional network	LOS hospital LOS intensive care In-hospital mortality Quality of recovery at discharge (Glasgow Outcome Scale) Quality of care	Proportion of patients arriving at hospital by air ambulance increased from 7.2% to 9.7% ($p < 0.01$) Significant reduction in proportion of patients having secondary transfer to MTC (before, 31.3%; after, 25.9%, $p < 0.01$) LOS hospital: no significant difference LOS intensive care: no significant difference In-hospital mortality: no significant difference Quality of recovery at discharge: before, 52.4%, after, 64.5% ($p < 0.01$) Quality of care: all indicators showed improvement • Treatment by consultant: before, 30.4%, after, 54.3% ($p < 0.01$) • Time to CT scan for patients with head injury: before, 49.2 minutes; after, 31.2 minutes ($p < 0.01$) [Implementation: 17 hospitals (65%) became MTCs within a week either side of 1 April 2012, 14 MTCs (54%) became fully operational on a single day, and 12 (46%) used a phasing period]

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Metcalfe *et al.*[10]	2014	UK	Major trauma	Regional	Detail – model described	**Hierarchy of specialist units** Region of West Midlands of England served by a network featuring four MTCs (one of which includes a paediatric MTC)	Quantitative Before and after	Before and after comparison, covering 200 days before and after launch of the MT network	LOS hospital LOS intensive care Quality of recovery at discharge (Glasgow Outcome Scale) Mortality	Volume increased significantly, from 442 (mean 2.2/day) to 1326 (mean 6.6/day) Proportion requiring surgery did not change significantly, but absolute number of operations increased by 253%, from 349 (1.7/day) to 1231 (6.2/day) Patients overall: • LOS hospital: no significant difference • LOS intensive care: no significant difference • Good recovery at discharge increased from 55.5% to 62.3% ($p < 0.01$) • Mortality: no significant difference Patients with injury severity of 15 or over: • No significant effects
Moran *et al.*[41]	2018	England	Major trauma	National	Detail – model described	**Centralisation of pathway** Review of outcomes in 2007 prompted development of regional trauma networks. London system implemented in 2010, national implementation from April 2012 27 designated MTCs: 11 for adults and children, 10 adult-only, 5 children-only and 1 collaborative between several hospitals Care incentivised through a 'best practice tariff', which provides additional payment per patient for additional care provided through MTCs	Quantitative Before and after	Analysis covered all services submitting data on major trauma [via Trauma Audit and Research Network (TARN) system] Primary analysis was on 35 services that submitted data consistently throughout the study period. Analysis repeated on all data submitted Analysis covered period April 2008–March 2017, comparing year on year. Interrupted time-series analysis conducted around period of introduction of MT networks (April 2012–April 2013) Given large sample size, analysis prioritised differences that were both statistically and clinically significant (because statistical significance easily achieved)	Transfer to MTC Care delivery LOS (hospital, intensive care) Survival (to discharge/30 days)	Transfer to MTC increased significantly: • MTC as initial destination: before 53%; after 72% ($p < 0.01$) • MTC as final destination: before 73%; after 82% ($p < 0.01$) Care delivery – significant improvements • Consultant attends as team lead: before, 29%; after, 63% ($p < 0.01$) • Use of tranexamic acid: before, near zero (though 2011–2 23%); after, ~90% ($p < 0.01$) • CT scanning increased: before 50%; after, 72% ($p < 0.01$) LOS (hospital, intensive care): mixed effect • Intensive care: before, 4 days; after, 3 days ($p < 0.01$) • Acute care: no significant difference Survival (to discharge/30-day) increased • Risk adjusted survival increased, 2008–9 vs. 2016–7 [OR 1.19 (95% CI 1.03 to 1.36; $p < 0.05$)] • Interrupted time series: before, no significant change between quarters; after, significant improvements between quarters (+ 0.08% additional survivors per quarter, $p < 0.05$) Similar patterns of results for 'consistent submitters' and full data set.

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Morris *et al.*[11]	2019	UK	Stroke	Regional	Detail – model described	**Centralisation of components/hierarchy** Centralisation implemented in London and GM in 2010, creating hub and spoke systems around HASUs London: 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment GM – further centralised: 3 HASUs, one admitting 24/7, two admitting 7 a.m.–11 p.m., 7 days a week. Patients reaching hospital within 24 hours eligible for HASU treatment	Quantitative Before and after Centralised vs. non-centralised control Different models of centralisation	Outcomes – GM: controlled before and after analysis with difference in differences design, comparing before change (2008–10) with after full centralisation (2015–6), relative to a national control Outcomes – London: tested for any significant variations in outcomes since centralisation implemented Clinical interventions – GM and London: analysed likelihood of delivery of clinical interventions year on year from April 2013 to March 2016. For GM, focus was significant change post 2015, for London, focus was sustainability of care delivery over time	Mortality at 90 days LOS Quality of care	Treated in HASU: • GM: 86% of patients treated in HASU • London: ≈95% of patients treated in a HASU Mortality at 90 days: • GM: for patients treated in HASU, there was a significant reduction in mortality of 1.8% (−3.4 to −0.2), suggesting 69 additional deaths avoided per year • London: no significant variation in mortality at 90 days over time since centralisation LOS • GM: significant reduction of 1.5 (−2.5 to −0.4) days over and above reductions in rest of England ($p < 0.01$), suggesting 6750 fewer patient bed-days per year • London: significant reduction since centralisation ($p < 0.01$) Quality of care • GM: significant improvements in care delivery, post 2015, becoming significantly higher than rest of England • London: care delivery broadly sustained, significantly higher than rest of England

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Morris *et al.*[12]	2014	UK	Stroke	Regional	Detail – model described	**Centralisation of components/hierarchy** Centralisation implemented in London and GM in 2010, creating hub and spoke systems around HASUs London: 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment GM: 3 HASUs, one admitting 24/7, two admitting 7 a.m.–7 p.m., Monday–Friday. Only patients reaching hospital within 4 hours eligible for HASU treatment	Quantitative Before and after Centralised vs. non-centralised control Different models of centralisation	Controlled before and after analysis with difference in differences design, comparing before change (2008–10) with after full centralisation (2010–2), relative to a national control	Mortality (90 days) Length of hospital stay	Mortality • GM: there was a reduction in stroke patient mortality, but it was not significantly different from reductions in the rest of England • London: 90-day mortality reduced significantly, −1.1% (95% CI −2.1 to −0.1; relative reduction 5%), indicating 168 fewer deaths Length of hospital stay • GM: significant reduction of 2 days (95% CI −2.8 to −1.2; 9%) • London: significant reduction of 1.4 days in London (−2.3 to −0.5; 7%) Reductions in mortality and length of hospital stay were largely seen among patients with ischaemic stroke.
Nica *et al.*[19]	2021	Canada	Endometrial cancers	Regional	Insufficient detail – centralisation described in numbers	Cancer Care Ontario published guidance for gynaecological oncology services in June 2013, recommending that higher risk (Grade 2 and above) patients should receive surgery from a gynaecological oncologist and MDT in a designated Gynaecological Oncology (GO) Centre	Quantitative Before and after	Comparison of before (1 June 2003–31 December 2013) and after (1 January 2014–31 March 2017)	Specialist care Post-surgical mortality Surgical staging Minimally invasive surgery	Specialist care: proportion of patients treated by a GO increased: before, 69.1%; after, 84.7% ($p < 0.01$) Post-surgical mortality: risk adjusted all-cause mortality reduced significantly after regionalisation (HR 0.85, $p < 0.05$) Surgical staging: increased significantly: before, 50%; after, 63% ($p < 0.01$) Minimally invasive surgery: increased significantly: before, 24.2%; after, 47.9% ($p < 0.01$) Travel distance: travel to receive treatment from a GO (vs. another clinician) increased significantly – before 54 km for GO, 20 km for other; after 67 km for GO, 21 km for other. Overall, travel for surgery increased significantly: before, 43 km; after, 60 km ($p < 0.01$)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Nienhuijs *et al.*[89]	2010	The Netherlands	Pancreatic and periampullary cancer	Regional	Detail – model described	**Centralisation of components** Originally, surgery delivered across eight hospitals (≈4 cases per year). Centralisation driven by poor outcomes Single team developed from three collaborating surgical departments Initial pre-operative work-up performed by referring hospital. All surgical procedures performed in single centre in one hospital (Catharina Hospital Eindhoven) by at least two surgeons from the dedicated team; and post-operative care also performed at centre	Quantitative Before and after	Before (January 1995–April 2000) and after (July 2005–July 2009)	Morbidity (complications, reoperations) Mortality (in-hospital) Survival	Morbidity • Intraoperative complications: before 9.8%; after, 3.9% ($p > 0.05$, NSD) • Post-operative complications: reduced significantly – before 71.9%; after, 34.2% ($p < 0.01$) • Reoperations: reduced significantly – before 37.8%, after 18.4% ($p < 0.01$) In-hospital mortality: reduced significantly – before 24.4%; after, 2.6% ($p < 0.01$) Survival: • 3-month: increased significantly – before 75%; after, 97% ($p < 0.01$) • 12-month: increased significantly – before 55%; after, 76% ($p < 0.05$) • 24 month: before, 37%; after, 52% ($p > 0.05$, NSD)
Nuño *et al.*[72]	2012	USA	Brain tumour	National	Insufficient detail, beyond drive for high volume	Trend to centralisation 1988–2000, with more rapid increase in volumes in high caseload centres than low-caseload centres	Quantitative Multiple time points Volume levels	Comparison of high vs.. low-caseload centres, analysing changes in volume and outcomes for patients discharged 2001–7	Volume In-hospital mortality LOS hospital Adverse discharges	Volume: cases decreased by 15.7% at lowest quintile hospitals (1–16 cases per year); cases increased by 136.9% in highest quintile hospitals (139 + cases per year) In-hospital mortality lower in high-volume centres: • lowest quintile 2.8%, highest quintile 1.1% ($p < 0.01$) • Risk-adjusted analysis suggested patients treated in lower volume hospitals had increased risk of death (OR 1.8, CI 1.2 to 2.7; $p < 0.01$) LOS hospital: lowest quintile 8.0 days, highest quintile 6.4 days ($p < 0.01$) Adverse discharges: lowest quintile, 41.8%; highest quintile, 24.9% ($p < 0.01$)

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Nymo *et al.*[114]	2020	Norway	Pancreatic surgery	National	Detail – model described	**Hierarchy of specialist units** Five HPB centres across the four regional health authorities (RHAs) – three RHAs host one HPB centre, the fourth RHA has two collaborating HPB centres. All centres have access to advanced radiology, vascular experts and intensive care wards with specialist MDT support. One centre (in Oslo) offers a second opinion on complex pancreatic surgery/resections These centres have differing catchment areas, which has implications for surgical volumes in these centres	Quantitative Post centralisation Centralised vs. non-centralised	Comparison of one high-volume centre vs. four low-/edium-volume centres operating within the centralised system Data covered 2015–6 for all patients undergoing pancreatoduodenectomy (Whipple procedure – surgery to remove tumours from head of pancreas)	Mortality (90-day) Post-operative complications Mortality among people with complications	Mortality: medium-/low-volume services associated with lower mortality – OR 0.24 (95% CI 0.07 to 0.82), $p < 0.05$ Complications: no effect of volume – OR 1.28 (95% CI 0.82 to 1.98); $p > 0.05$, NSD Mortality following complications: no effect of volume – OR 0.49 (95% CI 0.26 to 1.63), $p > 0.05$, NSD
O'Mahoney *et al.*[73]	2016	USA	Pancreatic surgery	National	Insufficient detail, beyond drive for high volume	General drive for high-volume, quality improvement initiatives, and associated improvements in outcome Analysis reported general increases in patients being treated in higher volume services – for example, increased proportion being treated in high- and very-high-volume services.	Quantitative Multiple time points Volume levels	Analysis of pancreatic surgery in New York, California and Florida states, over three periods: 2002–5, 2006–8, and 2009–11 Comparison of different levels of volume for pancreatoduodenectomy – low (< 11 p.a.), medium (11–25 p.a.), high (26–60 p.a.), and very high (61 +)	Mortality LOS Morbidity (perioperative complications) 30-day re-admissions	Mortality: • risk-adjusted analysis suggested that medium-, high-, and very-high-volume services tended to have significantly lower mortality than low-volume services • However, no significant differences in mortality between medium-, high-, and very-high-volume services LOS: prolonged LOS (i.e. over 14 days) significantly lower in high-volume services ($p < 0.01$) Complications: generally, perioperative gastrointestinal, respiratory, infectious and bleeding complications decreased significantly with increased volume ($p < 0.01$) – only exception being infectious complications in Florida Re-admissions: no significant difference between volume levels

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Onete *et al.*[90]	2015	The Netherlands	Pancreatic surgery	National	Insufficient detail – centralisation described in numbers	Nationwide guideline recommended that high-risk surgeries such as pancreatoduodenectomy (PD) should only be treated in centres conducting a minimum volume of 20 surgeries per year Progress of centralisation: total number of hospitals conducting pancreatic surgery reduced (39–23), while the number of high-volume centres (i.e. 20 + cases per year) increased from 3 to 9.	Quantitative Multiple time points Volume levels	Analysis of impact of centralisation on aspects of care delivery over the period 2005–9, covering a total of 1736 pathology reports	R0 resections (i.e. absence of cancer cells in pancreas or circumferential margin) Quality of pathology reports	Resection rate: • R0 resection rate: increased significantly – 2004, 6.3%; 2009, 10.5% ($p < 0.01$) PD frequency: increased significantly - 2004, 258 surgeries; 2009, 394 surgeries ($p < 0.01$) Pathology reports: low-volume centres significantly more likely to exclude data, for example, on staging of tumour – low volume 25%, high volume 15% ($p < 0.01$)
Parry *et al.*[50]	2019	UK	Prostate cancer surgery	National	Detail – model described	**Centralisation of components** Longstanding centralisation of prostate cancer surgical services Nationally, 48 specialist MDTs co-ordinate access to specialist services. MDTs made up of regional referral network of hospitals Networks use hub and spoke design, with specialist centre acting as the hub, providing specialist care and co-ordinating the system. Spoke services generally non-specialist and refer in to the hub, but in some cases provide some specialist care	Quantitative Post centralisation Specialist vs. non-specialist	Analysis of 24 months of data (April 2014–March 2016), assessing impact of centralisation on decisions to use radical surgery or radiotherapy Comparison in terms of whether patients treated in a specialist unit and the treatments available in hospitals	Delivery of radical treatments: whether men with high-risk or locally advanced prostate cancer received any radical treatment (external beam radiotherapy (EBRT), brachytherapy, radical prostatectomy, or a combination) within 1 year of diagnosis Use of radical surgery: whether surgery was the chosen form of radical treatment Provision of HDRBT: whether high dose-rate brachytherapy (HDR-BT) provided for men who undergo radiotherapy	Delivery of radical treatments: patients diagnosed in hubs, 67.7%, diagnosed in spokes 64.8% [adjusted risk ratio (ARR) 0.99, 95% CI 0.91 to 1.08, NSD] Use of radical surgery: radical prostatectomy more likely if patients diagnosed in a hospital that could deliver specialist surgery onsite – onsite surgery, 32.0%; no onsite surgery, 24.7% (ARR 1.24, 95% CI 1.10 to 1.40) Provision of HDRBT: HDRBT more likely to be provided if diagnosed at a hospital with regional access to HDRBT – with access, 7.7%; without access, 1.2% (ARR 6.16, 95% CI 2.94 to 12.92) Note: nationally, there was substantial variation in likelihood of high-risk prostate patients undergoing radical treatment: overall, 66%, lower level 43.4%, upper level 84.9%

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Partridge *et al.*[51]	2017	UK	Carotid endarterectomy, transient ischaemic attack	Regional	Detail – model described	**Centralisation of components** Centralisation of vascular surgical services in Bath, Bristol, and Weston area of Western England was implemented in October 2014 Hub and spoke model, with one site providing all arterial surgery and where the team of specialist vascular surgeons are based. Two sites act as spokes, providing diagnosis, day-case interventional radiology, and consultant outpatient appointments	Quantitative Before and after	Pre-post analysis of delivery of carotid endarterectomy, focusing on performance within the hub and spoke services individually and overall as a system Also compared across different payer organisation areas Two years of data covered October 2013–October 2015 (total of 261 carotid endarterectomy procedures)	Symptom onset to surgery (broken into time to referral, first scan, surgical review, and referral to surgery) Timing of surgery follow-up	Symptom onset to surgery: • no significant difference between pre-centralisation timings (either individual sites or overall) and post-centralisation network timings • 65% of patients underwent surgery within national guideline timing of 14 days • Payer area analysis suggested (non-significant) trends towards reduced variations in services • However, one payer area saw an increase in time from symptom to surgery (from 13 to 21 days), meaning that area no longer met national guidelines Surgery to follow-up appointment: no significant change – before, 50 days [interquartile range (IQR) 27; 42–69]; after, 56 days (IQR 19; 48–67)
Pearson *et al.*[52]	2001	UK	Intensive care for children	Regional	Detail – model described	**Centralisation of components** National policy recommended centralisation of paediatric intensive care into 'lead units' Some progress made on this in the late 1990 second in Birmingham. Key changes included: increased size of PICU (from six to eight beds) and opening of a second PICU to the north of the city	Quantitative Multiple time points	Comparison between 1991 and 1999, focusing on changes in paediatric activity and outcomes	Proportion of patients treated in PICU Child mortality Intensive care LOS	Proportion of children treated in PICU increased substantially: • 1991, 1.3 per 1000 population; 1999, 2.3 per 1000 population • In 1999, 29% more children received intensive care in PICU • Only nine patients from Birmingham treated in outer region PICU Child mortality: reduced significantly – by 0.34 deaths per 1000 children (95% CI 0.16 to 0.51; $p < 0.01$) – resulting in 75 fewer child deaths Intensive care LOS: reduced significantly - 1991, 103 hours; 1999, 75 hours, a reduction of 29.5 hours (95% CI 4.78 to 54.2; $p < 0.05$)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Perry *et al.*[40]	2018	UK	Stroke	Regional	Detail – model described	**Centralisation of components/hierarchy** Centralisation implemented in London and GM in 2010, creating hub and spoke systems around HASUs London: 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment GM: 3 HASUs, one admitting 24/7, two admitting 7 a.m.–7 p.m., Monday–Friday Only patients reaching hospital within 4 hours eligible for HASU treatment	Qualitative Post centralisation Different models of centralisation	Qualitative analysis of patient experience of centralised services, based on interviews with 36 patients and 17 partners or carers Analysis drew on (1) literature review of factors influencing stroke patient experience and (2) key stages of the centralised systems.	(1) Issues identified in the literature as associated with stroke patient experience • Initial contact with services • Ambulance transfer • Explanation and information • Person-centred approaches • Availability of therapy (2) Characteristics of centralised systems • Initial transfer • Reception at hospital • In-hospital care • Repatriation to local unit • Discharge home	Initial transfer • Patients and carers impressed with ambulance services • Some concerns about bypassing local hospital, but this was addressed by clear explanations from ambulance clinicians Reception at hospital • Patients and carers impressed with reception and organisation of stroke team at the front door – clearly prepared In-hospital care • Patients and carers felt they knew who was treating them and were confident in their expertise • Patents and carers reported that they felt involved in decisions about their care • Some patients noted that it was challenging for family members to visit from long distances Repatriation to local unit • Patients reported some delays in repatriation to a local unit, which was frustrating, but did not have too negative an effect • Generally care was felt to continue smoothly following transfer to a local acute rehabilitation unit Discharge home • Discharge home/to the community was sometimes not communicated clearly, and patients reported issues when patients were discharged into areas that were more remote from the specialist centre, as local community services were less aware of discharge processes from the centralised system

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Pinto *et al.*[74]	2012	USA	Neonatal congenital heart surgery	Regional	Insufficient detail, beyond drive for high volume	General drivers for centralisation/high volume. No description of model	Quantitative Post centralisation	Single centre analysis, focusing on relationship between travel distance to hospital and outcomes Data cover period January 2005–June 2006	Mortality AEs (unplanned re-admissions and unplanned cardiac reinterventions)	Mortality: no significant relationship between travel time and mortality – patients < 90 minutes away, 6.2%; patients 90–300 minutes away, 14.5%; patients 300 + minutes away 2.9% ($p > 0.05$, NSD) AEs: some evidence to suggest increased distance associated with fewer AEs – patients 90–300 minutes away from centre significantly less likely than other groups to have AEs
Prades *et al.*[107]	2016	Spain	Rectal cancer surgery	Regional	Insufficient detail – centralisation described in numbers	General drives for centralisation; hospitals conducting rectal surgery reduced from 51 to 32	Quantitative Before and after	Mixed method analysis – only quantitative focusing on outcomes Quantitative analysis of quality in care comparing before (2005–7) and after (2011–2) centralisation – based on national clinical audit data for patients undergoing rectal cancer surgery Qualitative analysis of organisational factors	Proportion of emergency surgeries Quality of mesorectal excision Number of lymph nodes examined	Degree of centralisation: • hospitals conducting rectal surgery reduced from 51 to 32 • proportion of patients treated in a high-volume centre increased from 37.5% to 52.8% • number of low-volume services reduced from 25 to 6 Emergency surgery: reduced significantly – 2005–7, 5.6%; 2011–2, 3.6% Quality of mesorectal excision improved significantly, with complete excision increasing – 2005–7, 63.9%; 2011–2, 78.6% ($p < 0.01$) Lymph nodes examined: patients with 12 + nodes examined increased significantly – 2005–7, 56.8%; 2011–2, 66.5% ($p < 0.01$)
Ramsay *et al.*[16]	2015	UK	Stroke	Regional	Detail – model described	**Centralisation of components/hierarchy** Centralisation implemented in London and GM in 2010, creating hub and spoke systems around HASUs London: 8 HASUs, all admitting 24/7; all patients eligible for HASU treatment GM: 3 HASUs, one admitting 24/7, two admitting 7 a.m.–7 p.m., Monday–Friday. Only patients reaching hospital within 4 hours eligible for HASU treatment	Quantitative Before and after Centralised vs. non-centralised control Different models of centralisation	Comparison of likelihood of receiving stroke clinical interventions before (2008) and after centralisation (2010–2) in London and GM, relative to a national comparator made up of non-centralised services that had high audit participation	Proportion of patients treated in HASU Stroke clinical interventions (including brain scan, admission to stroke unit, assessment by specialists)	London: • significantly more likely to deliver all clinical interventions than national Comparator • 93% of patients treated in HASU GM: • GM patients only significantly more likely to undergo timely brain scan than patients in national comparator. All other measures either NSD or national comparator more likely • GM patients treated in HASU significantly more likely to receive interventions than national control on all but one intervention • However, only 39% of stroke patients treated in HASU; 34% of patients who were eligible for HASU were not treated in one

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Roos and Lyttle[101]	1985	Canada	Hip replacement	Regional	Detail – model described	**Centralisation of pathway** Two specialist centres delivering total hip replacement, both based in urban centres (Winnipeg and Brandon). Half the population of Manitoba province is based outside these two centres	Quantitative Post centralisation	Comparison of total hip replacement rates for people within the urban centres hosting specialist centres, and people living more remotely	Access to care: total hip replacement rate by provincial region	Access to care: following adjustment for age and sex, there was no pattern to suggest a relationship between distance from centre and total hip replacement rate
Sakai-Bizmark *et al.*[75]	2019	USA	PHS	Regional	Insufficient detail, beyond drive for high volume	General trends to regionalisation. No descriptions of models	Quantitative Multiple time points Volume levels	Comparison over time (2000–12), focusing on trends in centralisation (proportion of patients treated in high-/medium-/low-volume services) and outcomes	Mortality LOS Cost	Volume: • significant increase in patients treated in high-volume services – 2000, 60.5%; 2012, 71.2% ($p < 0.01$) • significant decrease in patients treated in medium-volume services – 2000, 30.9%; 2012, 21.0% ($p < 0.01$) • no significant change in patients treated in low-volume services – 2000, 8.6%; 2012, 7.8% ($p > 0.05$, NSD) Mortality: • Trends suggest mortality reduced significantly over time • High-volume services had significantly lower risk-adjusted mortality than low-volume services (OR 0.59, $p < 0.01$); no significant difference between medium- and low-volume services LOS • Trends suggest LOS increased significantly over time • High- and medium-volume services had significantly higher LOS than low-volume hospitals [high-volume relative risk 1.18; 95% CI 1.15 to 1.21; $p < 0.01$; medium-volume RR 1.05; 95% CI 1.03 to 1.07; $p < 0.01$] Cost • Trends suggest cost increased significantly over time • High-volume services had significantly lower risk-adjusted cost than low-volume services (OR 0.91, $p < 0.01$); no significant difference between medium- and low-volume services

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Schlottmann *et al.*[76]	2018	USA	Oesophageal cancer surgery	National	Insufficient detail, beyond drive for high volume	In absence of national guidance or recommendations, 'spontaneous' centralisation has taken place, though with little uniformity	Quantitative Multiple time points Volume levels	Analysis of oesophagectomy conducted across the USA over the period 2000–14. Comparison between volume levels categorised as low (< 5 procedures p.a.), medium (5–20 p.a.) and high (> 20 p.a.)	In-patient mortality	Volume: pattern of treatment changed significantly ($p < 0.01$) • high-volume centres increased – 2000, 29.2%, 2011, 68.5% • medium-volume centres decreased – 2000, 45.9%, 2011, 21.9% • low-volume centres decreased – 2000, 24.9%, 2011, 9.6% In-patient mortality: • reduced significantly – 2000, 10%; 2011, 3.5% ($p < 0.01$) • reductions significantly greater in low household income patients (2000, 31.0%; 2011, 2.3%) than in higher income groups (2000, 9.1%; 2011, 3.6%), $p < 0.05$ • variations in mortality between white and non-white groups, and public/private health insurance – but these differences did not change significantly over time – that is reductions were seen in all groups

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Sheetz *et al.*[77]	2019	USA	High-risk cancer	National	Insufficient detail, beyond drive for high volume	Again notes absence of national recommendations for centralisation in the USA, but also opportunity offered by trends in hospital mergers	Quantitative Multiple time points Volume levels	Comparison over time (2005–14), focusing on five high-risk surgery for the following cancers: Pancreatic; Oesophageal; Colon; Lung; Rectal Focus on degree of centralisation, healthcare use, and short-term clinical outcomes	30-day post-operative complications 30-day mortality 30-day re-admission	Degree of centralisation over time varied by condition/process: • Colectomy 25.2% (range 6.6–100%); pancreatectomy 71.2% (8.3–100%) • Proportion of systems achieving Leapfrog volume thresholds also varied: pancreatectomy (25.8%), oesophagectomy (15.5%), proctectomy (47.1%), lung resection (49.9%) and colectomy (90.4%) 30-day post-operative complications – mixed pattern • Higher volume associated with significant reductions in complications for pancreatectomy, oesophagectomy and lung resection • No effect for colectomy or proctectomy 30-day mortality – mixed pattern, in line with complications • Higher volume associated with significant reductions in mortality for pancreatectomy, oesophagectomy and lung resection • No effect for colectomy or proctectomy 30-day re-admission – mixed pattern • Higher volume associated with increased re-admissions for oesophagectomy

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Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Soegard Andersen *et al.*[105]	2005	Denmark	Ovarian carcinoma cancer	Regional	Insufficient detail – centralisation described in numbers	Centralisation of pathway Northern Jutland centralised surgery for ovarian cancer into a single centre in 1999	Quantitative Post centralisation Cross-sectional	Analysis of post-centralisation data for all patients undergoing surgery for ovarian cancer in North Jutland	Post-operative death Survival relative to cancer stage	Survival: • Overall, survival at 2 years was 64.6%; 3 years, 54.4%; and 4 years, 49.2% • For stage IIIC and IV disease, survival at 1 year was 79.5%; 2 years, 56.5%; 3 years, 45.3%; and 4 years, 34.1% • Median survival was 46 months Relative to previously published results for the country, authors suggest centralisation associated with an increase in median survival for all stages of approximately 15 months
Stephens *et al.*[118]	2019	Ireland	Rectal cancer surgery	Regional	Insufficient detail – centralisation described in numbers	Rectal cancer surgery centralised from 49 hospitals into 8 specialist centres across Ireland To help manage the anticipated increase in workload, one of these centres introduced day of surgery admission (DOSA) first as a pilot in 2011, then formally from 2012	Quantitative Multiple time points Post centralisation	Analysis focusing on impact of DOSA in one specialist centre in the years 2011, 2012 and 2016	Overall surgical activity Proportion of DOSAs Length of hospital stay	Overall surgical activity: elective rectal cancer resection increased – 2011 (44 patients), 2012 (67 patients), 2016 (68 patients) Proportion of DOSAs: 2010 (none), 2011 (15.9%), 2012 (92.5%), 2016 (98.5%) – significant difference between 2011 and 2016 ($p < 0.01$) Length of hospital stay: • Mean LOS: 2011 (16.4 days), 2012 (13.4 days), 2016 (12.4 days) • While caseload increased 54% from 2011 to 2016, only 122 more bed-days used in 2016 (vs. 2011) – with an estimated saving of 272 bed-days in 2016

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Stitzenberg *et al.*[78]	2009	USA	Cancer surgery (surgery for colorectal, oesophageal and pancreatic cancer)	Regional	Insufficient detail, beyond drive for high volume	General trends towards centralisation. No description of models	Quantitative Multiple time points	Analysis of proportion of patients treated in services with different volumes, focusing on surgery for colon, rectal, oesophageal, and pancreatic cancers Compared distribution of cases over the period 1996–2006. Focus on three neighbouring US states: New York, New Jersey, Pennsylvania	Degree of centralisation Mortality: in-hospital mortality Access – travel distance to hospital: straight-line distance from home to hospital for surgery	Centralisation increased over time – most pronounced in oesophageal and pancreatic cancers: • Proportion treated in high-/very-high-volume hospitals increased substantially over time for oesophageal and pancreatic cancers. Slight increase in colon, and no change in rectal cancer surgery • Centralisation reflected in number of high-/very-high-volume hospitals increasing over time and number of procedures performed at high-/very-high-volume hospitals increasing over time • Significant reduction in patients being treated in low-volume services over time for cancers of oesophagus, pancreas, and colon (again, NSD for rectum) Mortality: in-hospital mortality reduced significantly over time for colon, oesophageal and pancreatic cancers. No significant change for rectal, but this was low (< 2%) throughout Travel distance increased with centralisation, extending some inequalities: • Travel distance increased over time: oesophagus 72%, pancreas 40%, colon 17%, and rectum 28% (in each case, $p < 0.01$) – increases in distance tended to reflect extent of centralisation • Patients travelled further to receive treatment in high-volume centres • Rural patients travelled significantly further than urban patients for all cancers. Additional distance travelled by rural patients (vs. urban patients) increased significantly over time for colon, rectal and pancreatic cancers • For each cancer, over 10% of patients treated in a low-volume centre could have accessed a high-volume centre by travelling the same or less distance • For each cancer, over 50% of patients treated in a low-volume centre could have reached a high-volume centre by travelling < 10 additional miles

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DOI: 10.3310/REMD6648

TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Stitzenberg *et al.*[62]	2010	USA	Oesophageal and pancreatic	National	Insufficient detail, beyond drive for high volume	National recommendations to centralise complex cancer surgery into high-volume services. No description of models	Quantitative Multiple time points Volume levels	Analysis of proportion of patients treated in services with different volumes, focusing on surgery for colon, rectal, oesophageal, and pancreatic cancers Comparison over the period 1999–2007. Focus on national dataset.	Degree of centralisation In-hospital mortality Access: likelihood of being treated in low-volume centres, based on sociodemographic factors, insurance status, and admission type	Centralisation increased over time – more pronounced for oesophageal and pancreatic cancers: • While number of units providing surgery reduced, the proportion of high-volume units increased over time • The number of procedures performed at low-volume units reduced over time • The most pronounced shifts were for oesophagus and pancreas surgery In-hospital mortality reduced over time for all diseases (in each case, $p < 0.01$). High-volume units had a highly significant effect on oesophageal and pancreatic cancers Access: • rural patients no more likely to be treated in a low-volume unit than urban patients • people admitted through emergency departments significantly more likely to be treated in a low-volume centre • black patients more likely than white patients to be treated in low-volume centres for oesophageal, pancreatic, and rectal cancers • private payers least likely to be treated in low-volume centre, uninsured much more likely to be treated in low-volume centre
Stitzenberg *et al.*[79]	2012	USA	Prostatectomy	Regional	Insufficient detail, beyond drive for high volume	National recommendations to centralise complex cancer surgery into high-volume services alongside approval then adoption of robotic surgery from 2001. No description of models	Quantitative Multiple time points Volume levels	Analysis of proportion of radical prostatectomies performed in services with different volumes Compared distribution of cases over the period 2000–9. Focus on three neighbouring US states: New York, New Jersey, Pennsylvania	Degree of centralisation Number of radical prostatectomies performed over time Travel distance	Degree of centralisation/activity: • Number of prostatectomies increased over time: 2000, 8115; 2009, 10,241. These increases resulted wholly from increased activity in high-volume units • Number of hospitals providing prostatectomy reduced over time: 2000, 390; 2009, 244 (37% reduction) • Proportion of prostatectomies performed in low volume • Odds of surgery at a high-volume unit increased significantly (odds ratio, 6.04; 95% confidence interval) Travel distance increased 54% over time (seen as in line with degree of centralisation). Proportion of patients travelling 15 + miles increased significantly: 2000, 24%; 2009, 40% ($p < 0.01$)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Stock *et al.*[53]	2018	UK	Cleft lip and palate services	National	Insufficient detail – centralisation described in numbers	Following national recommendations, services to treat cleft palate were centralised from 57 to 11 units/ networks Alongside this there was a recommendation to integrate psychologists into all cleft palate teams	Qualitative Before and after	Qualitative analysis of interviews (n = 8) and focus group (n = 1; eight participants) Participants were adults, reflecting on changes on services since they received cleft palate surgery as children – and had therefore experienced services both pre and post centralisation	Patient experience of cleft palate services in terms of four themes: • involvement in treatment decisions • integration of psychological support • opportunities to engage in peer support • improved standards of care	• involvement in treatment decisions: strong view that pre-centralisation services did not engage well with children who were to undergo surgery, which had traumatic implications; post-centralisation services much more focused on involving patients • integration of psychological support: patients described having had little emotional support and having to deal with psychological implications of cleft palate alone as they went through school; contrasted with post-centralisation services and the benefits in terms of their opportunities to talk about experiences around this condition • opportunities to engage in peer support: patients described having been left entirely alone, with no connections with others with shared experiences; post-centralisation services now seen as much better at offering networks and connections to patients • improved standards of care: pre centralisation, patients described a lack of specialist care; post centralisation, patients described increased confidence in quality of services, due to the presence of plastic surgeons and a specialist MDT – a key outcome included feeling more confident in starting a family – greater trust that any future children with cleft palate would get high-quality care

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Tebé *et al.*[108]	2017	Spain	Cancer surgery (oesophagus, pancreas, liver, stomach, rectum)	Regional	Insufficient detail, beyond drive for high volume	The Catalan health service went through a process of restructuring services for specialist cancer surgery	Quantitative Multiple time points Volume levels	Comparison of low-volume (up to 5 p.a.) medium-volume (6–10 p.a.), and high-volume (10 + p.a.) services Analysis covered the period 2005–12, during which there was a drive to centralise services, splitting the period into 2005–8 and 2009–12 Previously-published findings for the period 1996–2000 were used as a reference point	Centralisation (inferred from volume proportions) In-hospital mortality	Centralisation • Substantial reduction in number of hospitals providing surgery • Significant increase in proportion of patients treated in high-volume centres for pancreas, liver, stomach, rectum cancers ($p < 0.01$); NSD in oesophagus cancer Mortality – mixed effects • Significant reduction for oesophagus ($p < 0.01$) and pancreas ($p < 0.01$). Non-significant reductions for liver and stomach cancers. No change for rectum cancers • Non-significant Inverse relationship between volume and mortality for all cancers

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Timmermans *et al.*[91]	2018	The Netherlands	Epithelial ovarian cancer	National	Detail – model described	**Centralisation of components** Drive for treatment by specialist surgeons, in order to minimise post-surgical residual disease Multistage centralisation process: 1. Gynaecologists in smaller units consulted colleagues in larger units 2. National consensus that surgery only to take place in units conducting 20 + cytoreductive surgeries per year 3. Increased focus on regional multidisciplinary tumour boards However, initial diagnosis still takes place in local hospitals: this may influence decision on whether patient will undergo surgery	Quantitative Multiple time points Specialist vs. non-specialist	Analysis of all patients diagnosed with epithelial ovarian cancer over the period 2000–15 (disaggregated into three groups: 2000–5, 2006–11, 2012–5)	Degree of centralisation Volume of residual disease: proportion with incomplete cytoreduction (i.e. 1 cm + residual tumour) Likelihood of undergoing surgery – in terms of: • Disease stage • Hospital of diagnosis Survival	Degree of centralisation: • Number of hospitals performing surgery: reduced – 2006–11, 77; 2012–5, 39 • Mean number of surgeries per hospital: increased significantly – 2006–11, 9 (IQR 3–12); 2012–5, 17 (IQR 5–20) • Proportion referred to specialist hospital for surgery: increased significantly – 2006–11, 35%; 2012–5, 71% ($p < 0.01$) • Proportion of centres providing 20 + procedures p.a.: increased significantly – 2006–11, 8%; 2012–5, 26% (and 69% in 2015 alone) Proportion incomplete cytoreduction: decreased significantly–2006–11, 23%; 2012–5, 13% ($p < 0.01$) Likelihood of undergoing surgery: • Patients with high-grade tumours (i.e. further spread of cancer) less likely to undergo surgery • Hospital of diagnosis:◦ overall, hospital of diagnosis resulted in significant variation in patients in 2000–5 ($p < 0.01$) and 2006–11 ($p < 0.01$) ◦ However, this effect disappeared in the 2012–5 period, with no variation in likelihood of undergoing surgery associated with hospital of diagnosis Survival: • Risk-adjusted survival (stratified by surgical treatment) improved over time: 2000–5 [HR 1.17 (1.11 to 1.23)]; 2006–11 (reference); 2012–5 [HR 0.9 (0.84–0.96)]

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Tingulstad *et al.*[115]	2003	Norway	Ovarian cancer	Regional	Detail – model described	**Centralisation of components** Cancer surgery services centralised in mid-1990 second There is a single regional specialist surgical centre, with three specialist gynaecological oncologists conducting all surgeries There are seven non-specialist hospitals across the region, which feature general gynaecologists, and which refer patients to the specialist centre for primary surgery	Quantitative Before and after Specialist vs. non-specialist	Analysis of a single health region in Norway (Region IV) Comparison between pre- and post-centralisation periods Post-centralisation group was made up of patients referred by non-specialist centres to the specialist centre from 1995 to 1997; pre-centralisation control was made up of patients who were (a) matched for stage and age with each post-centralisation patient and (b) treated in the referral hospitals in the pre-centralisation period 1992–5	Provision of standard minimum surgical procedure: total abdominal hysterectomy, bilateral salpingo-oophorectomy, and omentectomy Volume of residual disease reduced to < 1 cm Post-operative mortality Length of hospital stay Post-surgical survival	Provision of standard minimum surgical procedure: significantly improved, post centralisation – control, 54%; post centralisation, 100% ($p < 0.01$) Volume of residual disease: significantly improved, post centralisation – control, 24%; post centralisation, 48% ($p < 0.05$) Operative mortality: control, deaths deaths; post centralisation, zero (despite more extensive surgery performed post centralisation) Length of hospital stay: no significant difference Post-surgical survival: improved, post centralisation • No significant difference for early-stage disease Advanced disease (III/IV): ◦ 5-year survival significantly lower for control patients (4%) than patients referred to specialist centre (26%) ($p < 0.01$) ◦ median survival significantly lower for control patients (12 months) than patients referred to specialist centre (21 months) ($p < 0.01$)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Tung *et al.*[119]	2016	Taiwan (Province of China)	Stroke	National	Detail – model described	**Hierarchy of specialist units** Stroke care was centralised across Taiwan (Province of China) from July 2009. This was part of a wider centralisation of five time-sensitive emergency conditions. Main objective of centralisation was to increase access to thrombolysis Stroke services classified as Comprehensive or Primary Stroke Centres – these are designated, certified, and audited nationally (recertification happens every 4 years). Service performance is publicly reported Ambulance services have protocols that permit them to bypass hospitals in order to take stroke patients to the nearest stroke unit In recognition that a proportion of patients will not arrive via ambulance (e.g. by foot, private transport), system recognises need for strong emergency department triage processes There is a single national insurer, so insurance status unlikely to influence access/system performance	Quantitative Before and after	Interrupted time series analysis, focusing on blocks of time before and after centralisation in 2009, over the period January 2004–September 2012	Thrombolysis rate Number of stroke care processes 30-day mortality	Thrombolysis rate: increased significantly – before 0.9%; after 3.1% ($p < 0.01$); Interrupted time series showed ongoing increase over time (0.3% in January 2004; 2.1% in January 2009), which accelerated following centralisation (to 4.6% in January 2012) Number of stroke care processes: increased significantly – before 1.7; after 1.9 ($p < 0.01$); Interrupted time series showed ongoing increase over time (1.61% in January 2004; 1.74% in January 2009), acceleration after centralisation (to 1.90% in January 2012) 30-day mortality: before centralisation, no month-to month change in mortality; after, there was an immediate drop in monthly mortality of 0.442% ($p < 0.01$), then an ongoing trend of reduction of 0.021% per month ($p < 0.05$). It is estimated that, over the 39 months following centralisation 828 deaths had been avoided Mediator analysis suggested that the reductions in mortality were accounted for by changes in care delivery

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Vallance *et al.*[54]	2017	UK	Liver resection	National	Detail – model described	**Centralisation of components** Following recommendations in 2001, hepatobiliary services were centralised into hub and spoke arrangements. Specialist hubs present in 27 sites across 142 NHS hospital organisations Referral: if colorectal MDT thinks patient is potentially resectable, patient should be referred to a specialist hepatobiliary team	Quantitative Post centralisation Specialist vs. non-specialist	Analysis of patients diagnosed with primary bowel cancer (over the period April 2010–March 2014) and who underwent major colorectal resection Comparison between specialist centres (hubs) and non-specialist centres (spokes) in terms of care delivery and outcomes	Care delivery: liver resection Survival	Care delivery: patients diagnosed in hubs significantly more likely to undergo resection – hubs, 50.4%; spokes, 40.7% (risk-adjusted odds ratio 1.52, 95% CI 1.20 to 1.91) Survival: • higher in hubs – hubs, 30.6 months; spokes, 25.3 months. Adjusting for patient and tumour characteristics, this was a significant difference (OR 0.83, 95% CI 0.75 to 0.91) • no significant difference in survival when focusing only on patients who had liver resection ($p > 0.05$, NSD) or patients who did not undergo liver resection ($p > 0.05$, NSD). This suggests that the effect on survival may be explained in terms of higher resection rate in hubs
van den Einden.[92]	2012	The Netherlands	Vulvar malignancies	Regional	Insufficient detail, beyond drive for high volume	Centralisation of services for vulvar squamous cell carcinoma (Vulvar SCC – an extremely rare cancer) recommended nationally from 2000	Quantitative Before and after Specialist vs. non-specialist	Analysis focused on all patients with vulvar malignancy from 1989 to 2008 in the Eastern region of the Netherlands Comparison was between patients treated 1989–99 with 2000–8	Survival: relative survival rates (RSR) at 1, 5 and 10 years	Degree of centralisation: • Proportion of vulvar SCC patients treated in a specialist centre overall increased – before, 53%; after, 85% ($p < 0.01$) • Proportion of vulvar SCC patients requiring groin surgery who were treated in a specialist centre increased – before, 62%; after, 93% ($p < 0.01$) Survival • RSR overall: increased, but not significantly [5-year RSR before 67.5% (95% CI 58.7 to 75.7); after 72.3% (62.8 to 80.7)] • RSR for specialist centres: no significant difference between before and after at 1, 5, and 10 years • Noted that introduction of SLND (inguinofemoral lymphadenectomy – new form of groin surgery) may have improved the accuracy of staging, post centralisation, thus potentially influencing the risk adjustment for survival analysis

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
van Putten *et al.*[93]	2018	The Netherlands	Gastric cancer surgery	National	Insufficient detail, beyond drive for high volume	National recommendation in 2012 that gastric cancer surgery should only be performed in centres performing 10 + gastrectomies p.a.; in 2013, this recommendation extended to 20 + p.a.	Quantitative Before and after Volume levels	Analysis focused on national data over the period 2009–15, comparing before (2009–11) with after (2013–5) centralisation	Care delivery: proportion undergoing gastrectomy Length of hospital stay Post-operative residual disease Post-operative mortality (30-day, 60-day, and 90-day) Survival: of gastric patients undergoing gastrectomy; and of all gastric cancer patients overall	Degree of centralisation – significant changes in volume treating gastrectomy ($p < 0.01$): • gastrectomy in low-volume hospitals reduced: before, 50.1%; after, 9.2% • gastrectomy in high-volume hospitals increased: before, 13.0%; after, 54.3% Care delivery: proportion undergoing gastrectomy increased – before, 37.6%; after, 39.6% ($p < 0.05$) LOS: median reduced significantly – before, 10 days (IQR 8–15); after, 9 days (IQR 7–13) ($p < 0.01$) Post-operative residual disease reduced: • proportion of patients tumour-free before, 76.8%; after, 80.6% ($p < 0.01$) Post-operative mortality reduced significantly • 30-day: before, 6.5%; after, 4.1% ($p < 0.01$) • 60-day: before, 8.7%; after, 5.8% ($p < 0.01$) • 90-day: before, 10.6%; after, 7.2% ($p < 0.01$) Survival increased significantly • 2-year survival, post gastrectomy: before, 55.4%; after, 58.5% ($p < 0.05$) • after adjustment for patient and tumour characteristics, reduction still significant (HR 0.88, 95% CI 0.79 to 0.97) • adding adjustment for volume removed the effect, suggesting volume contributed to the centralisation effect • similar patterns observed for all patients, including those who did not undergo surgery, for example 2-year survival: before, 27.1%; after, 29.6% ($p < 0.01$)

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
van Vliet *et al.*[94]	2015	The Netherlands	Epithelial ovarian cancer	Regional	Detail – model described	**Partial centralisation** Non-centralised/partial concentration Uncertainty about full centralisation of services. Almost all 105 service provide care to epithelial ovarian cancer (EOC) patients The model is characterised as 'partial concentration of cancer care' The studied service is a regional teaching hospital, which has had a gynaecological oncologist since 1998. The service discusses all gynaecological malignancies with the GO specialists at UMC Utrecht	Quantitative Post centralisation	Analysis focused on the studied service over the period 1999–2011, in terms of care delivery and outcomes No formal comparator and little in the way of analysis of change over time (aside from length of hospital stay) Main comparisons with levels identified in the literature	Survival – overall, disease-free Length of hospital stay	Survival: • Overall survival: 52% at 5 years; median 63 months • Disease-free survival: 47% at 5 years; median 45 months • Seen as comparable to published literature on specialist centres LOS: reduced over time significantly: • Early-stage disease: 1999–2003, 10.4 days; 2007–11, 8.0 days • Advanced-stage disease: 1999–2003, 16.3 days; 2007–11, 9.0 days • Reported as in line with elsewhere in the Netherlands Argued that partial centralisation – that is, a peripheral hospital with GO onsite and collaboration with specialist centre – can achieve equivalent effects to specialist centres

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Vernooij *et al.*[95]	2008	The Netherlands	Ovarian cancer	National	Detail – model described	**Partial centralisation** Non-centralised: minority of patients treated in specialised centres; variable involvement of specialist MDTs; surgery commonly performed by semi-specialised gynaecologists NB see van Vliet *et al.*[96] for case where specialist gynaecological oncologist is based in peripheral service	Quantitative Multiple time points Specialist vs. non-specialist	National data over the period 1996–2003 Analysis comparing association between hospital type (level of specialisation) and outcomes	Survival – overall	Survival increased with degree of specialisation: • 5-year disease-free survival: general, 38.0% (95% CI 36.0 to 39.9); semi-specialised, 39.4% (95% CI 37.5 to 41.4); specialised, 40.3% (95% CI 37.4 to 43.1) • Earlier stage cancers saw significant improvements in survival associated with greater specialisation – up to stage IIIA (for younger patients) • for example, patients aged 50–75 with stage I–IIA: compared with general hospitals, more specialised services had lower risk of dying of ovarian cancer: semi-specialised HR 0.70 (95% CI 0.53 to 0.93); specialised HR 0.58 (95% CI 0.38 to 0.87) • Later stage cancers had no clear advantage of specialisation Treatment by a specialist gynaecological oncologist associated with better outcomes Concluded insufficient collaboration with specialist services meant non-centralised system not sufficient to provide care to Dutch ovarian cancer patients
Waingankar *et al.*[80]	2019	USA	Radical cystectomy	National	Insufficient detail, beyond drive for high volume	National drivers, for example, value-based payment models No model described	Quantitative Multiple time points Volume levels	Analysis of all hospitals performing at least one radical cystectomy over the period 2004–13 Comparison over 2-year intervals between low-volume (5 or fewer p.a.) and high-volume (30 + p.a.) services	Mortality (30-day and 90-day)	Degree of centralisation increased significantly over time: • Proportion of RCs performed in low volume: 2004, 28.7%; 2013, 17.0% ($p < 0.01$) • Proportion of RCs performed in high volume: 2004, 15.6%; 2013, 33.3% ($p < 0.01$) Mortality • 30-day risk-adjusted mortality significantly higher in low-volume services than high (HR 1.66, 95% CI 1.53 to 1.80) • 90-day risk-adjusted mortality significantly higher in low-volume services than high (HR 1.37, 95% CI 1.30 to 1.44) • Risk-adjusted (30- and 90-day) mortality in high- and low-volume hospitals reduced over time but not significantly

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TABLE 4 Summary of papers included in review (*continued*)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Warner *et al.*[81]	2016	USA	Endovascular aneurysm repair (EVAR) for rAAA	Regional	Detail – model described	**Centralisation of pathway** Centralised system across 12 hospitals in Eastern upstate New York: patients with rAAA are transferred to specialist tertiary centre for EVAR Specialist centre is a level 1 trauma centre with 24/7 operating room A group of 19 certified vascular surgeons ('The Vascular Group') are the only surgeons with vascular privileges, conduct all operations, and make decisions on patient transfer A multidisciplinary group developed a protocol for assessing all suspected ruptures, including notifying vascular team, referring for CTA scan, and transfer to suitably equipped and staffed operating room Discussion refers to 'scoop and run' approach – to ensure patients are taken to a service with appropriate capacity and capability. Emphasises the importance of the whole team and environment – not the surgeon, but the other professionals, 24/7 operating theatre, and comprehensive post-operative care. Also the value of having a single contact number that the wider system knows and uses	Quantitative Cross-sectional Specialist vs. non-specialist	Analysis of all rAAA patients presenting to the 12 local hospitals (including the specialist centre) over the period 2002–15 Comparison between (1) patients presenting directly to community hospital, (2) patients transferred from community hospital to specialist centre and (3) patients presenting directly at the specialist centre	Type of repair: open vs. EVAR Mortality (30-day perioperative)	Type of repair: • Much less likely to have EVAR in Community hospital (6%) than in specialist centre (62% for both direct and transfer admissions) Mortality lower in specialist centre, regardless of admission process: • overall higher in community hospitals (46%) than in in specialist centre (27% for both direct and transfer admissions) • EVAR had significantly lower mortality than open repair, whether admission was direct (EVAR 20%, open 37%, $p < 0.01$) or transfer (EVAR 20.7%, open 36.1%, $p < 0.01$)

Reference	Year	Location	Care setting	Level	Level of detail	Description of model	Analysis	Comparison	Outcomes	Key findings
Wouters *et al.*[96]	2009	The Netherlands	Oesophageal surgery	Regional	Detail – model described	**Partial centralisation** Regional review of care and outcomes conducted in 1997, covering 11 hospitals affiliated to Comprehensive Cancer Centre West (CCCW) Based on this local surgeons agreed to refer oesophageal cancer patients for surgery at centres with better outcomes – referral process on a voluntary basis: no formal requirement to do so	Quantitative Before and after	Analysis covered patients registered pre centralisation (1990–4; 1995–9) and post centralisation (2000–4, registered prospectively) Comparison of CCCW as a region with a nearby referral centre outside CCCW	Post-operative residual disease Complications Reinterventions Length of hospital stay In-hospital mortality Survival	Post-operative residual disease: no significant change Complications: no significant change Reinterventions: no significant change Length of hospital stay: reduced significantly – 1990–4, 20 days (range 9–92); 2000–4, 17 days (8–273) ($p < 0.01$) In-hospital mortality: reduced significantly – 1990–4, 14.3%; 2000–4, 4.7% ($p < 0.01$) Risk-adjusted survival: • significantly lower risk of dying, post centralisation (2000–4, HR 0.61, 95% CI 0.44 to 0.86)

Note
Conversion rate $1 = £0.75525 on 17 April 2025.
Bold signifies the form of centralisation implemented as summarised in *Table 2*.

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Appendix 3 Key changes from protocol

Section/item	Original	Change/explanation
Title	Title refers to phased systematic review of the literature	From an early stage, it was agreed that this was to be a scoping review. The current title of this article reflects our design appropriately
RQs	Lists six questions, related to: 1. Features of centralisation 2. Definitions of centralisation 3. Benefits, problems and outcomes of centralisation 4. How is specialised health care centralised in different services/settings? 5. What theoretical frameworks are used? 6. What are the levels of a taxonomy of centralisation?	From an early stage, it was agreed that due to volume of peer-reviewed published studies, the focus of the review would be only on studies where outcomes of centralisation were discussed As a result, while we described models of centralisation through our typology, we did not focus on processes of implementation (RQ4) and associated theoretical frameworks to understand implementation (RQ5) Our analysis still addresses features and definitions of centralisation, how services have been centralised and the impact on outcomes
Scope	Focus on implementation and outcomes	As discussed above, the authors made the decision to focus on outcomes of centralisation, reflecting
Database	PsycInfo® (American Psychological Association, Washington, DC, USA) identified as a database for the search	PsycInfo dropped as database on advice from University Librarian
Grey literature	Proposal to study grey literature as well as peer-reviewed articles	Following our search, it became clear that there was substantial peer-reviewed literature on the outcomes of centralisation Therefore, we decided to focus on this rather than include grey literature
Quality assessment	Proposal to use mixed methods appraisal tool	In line with other scoping reviews, the authors agreed that quality assessment would not be necessary for this scoping review. We set out some potential limitations that result from this in our discussion