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Associations of hospital volume and hospital competition with short-term, middle-term and long-term patient outcomes after breast cancer surgery: a retrospective population-based study

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ABSTRACT

Objectives For oncological care, there is a clear tendency towards centralisation and collaboration aimed at improving patient outcomes. However, in market-based healthcare systems, this trend is related to the potential trade-off between hospital volume and hospital competition. We analyse the association between hospital volume, competition from neighbouring hospitals and outcomes for patients who underwent surgery for invasive breast cancer (IBC).

Outcome measures Surgical margins, 90 days re-excision, overall survival.

Design, setting, participants In this population-based study, we use data from the Netherlands Cancer Registry. Our study sample consists of 136 958 patients who underwent surgery for IBC between 2004 and 2014 in the Netherlands.

Results Our findings show that treatment types as well as patient and tumour characteristics explain most of the variation in all outcomes. After adjusting for confounding variables and intrahospital correlation in multivariate logistic regressions, hospital volume and competition from neighbouring hospitals did not show significant associations with surgical margins and re-excision rates. For patients who underwent surgery in hospitals annually performing 250 surgeries or more, multilevel Cox proportional hazard models show that survival was somewhat higher (HR 0.94). Survival in hospitals with four or more (potential) competitors within 30 km was slightly higher (HR 0.97). However, this effect did not hold after changing this proxy for hospital competition.

Conclusions Based on the selection of patient outcomes, hospital volume and regional competition appear to play only a limited role in the explanation of variation in IBC outcomes across Dutch hospitals. Further research into hospital variation for high-volume tumours like the one studied here is recommended to (i) use consistently measured quality indicators that better reflect multidisciplinary clinical practice and patient and provider decision-making, (ii) include more sophisticated measures for hospital competition and (iii) assess the entire process of care within the hospital, as well as care provided by other providers in cancer networks.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The population-based sampling, nationwide inclusion of all hospitals and patients and long follow-up resulted in a large retrospective dataset.
⇒ The use of short-term, mid-term and long-term patient outcomes can be regarded as a major strength of this study.
⇒ We use multilevel models to correct for unobserved differences across hospitals and years.
⇒ Due to the retrospective character of this study, there is some inconsistency with contemporary practice, such as the current collaboration and division of tasks in networks, as well as developments of quality indicators.
⇒ Retrospective data on re-excision rates, surgical margins and the influence of comorbidity was not fully available for the entire study cohort or period.

BACKGROUND

In the past decades, oncological healthcare provision for breast cancer, currently being the most common form of cancer within women, has undergone major changes and advances.[1 2] As the complexity and multidisciplinary character of oncological care continually increases, the organisation of high-quality care provision in health systems is an ever-growing challenge. The introduction of clinical (transmural) pathways, national audits like the NABON breast cancer audit (NBCA), centralisation of low-volume oncological surgeries, the establishment of hospital networks and the introduction of competition can be regarded as policy measures aimed at maintaining and improving the quality of care in order to obtain the best outcomes for patients.[3–6] Yet, the optimum design and organisation of oncological care is still debated and subject to research for

frequently occurring cancer types, such as breast cancer, which are often not centralised.[7 8] Among others, two factors—one on the hospital level and one on the health system level—are central to this debate: hospital volume and hospital competition.

Hospital volume

On the hospital level, the volume-outcome relationship for surgical procedures has been subject for research since the late 1970s. Literature has demonstrated the presence of the volume-outcome relationship for many interventions, especially those of high complexity.[9–12] This has resulted in increased centralisation for procedures. More recently, interest is shifting over to procedures for frequently occurring tumours, such as breast cancer surgery. Literature mainly reveals a positive relationship between surgical volume and patient outcomes, predominantly when using survival as an outcome measure.[13–17] Generally, the existence of the volume-outcome relationship can be attributed to a combination of different explanations such as learning by doing, work in multidisciplinary teams, enhanced recovery plans and technical and IT support.[6 14] Total hospital volume is commonly used as indicator in this literature since it best reflects the multidisciplinary and comprehensive nature of contemporary provision of breast cancer, compared with individual surgeon volume.[16] Since 2012, in the Netherlands the minimum volume threshold for hospital-level breast cancer surgical volume is set at 50.[18] The European quality assurance scheme, published in 2020, uses a higher number, namely 50 per surgeon and 150 per hospital.[19 20]

Hospital competition

On the health system level, recent literature focuses on the effect of competition between proximate hospitals. In countries with market-based hospital systems, including the Netherlands, competition between hospitals has been introduced as a tool to improve efficiency and quality.[21–23] That is, it is expected that the presence of competitors might incentivise hospitals to increase quality relative to other hospitals in order to attract more patients (either directly by exercising hospital choice or indirectly through referrals by general practitioners and/or selectively purchasing of care by health insurers) (box 1).

Box 1 Hospital competition and quality

The relationship between hospital competition and quality depends on the structural characteristics of the health system and the public availability of quality information. If competition on both price and quality is possible, as is the case for breast cancer surgery in the Netherlands since prices are freely negotiable, it follows from economic theory that hospitals place most emphasis on either price or quality, dependent of the responsiveness of demand by patients or healthcare purchasers and the availability, transparency and comparability of quality or price information.[52] An extensive overview of the literature for both the volume-outcome relationship and the effects of hospital competition on quality can be found in the online supplemental file 1.

However, in contrast to hospital systems with regulated prices, the effect of competition on quality in hospital markets with freely negotiable prices is less investigated, especially in cancer care.[24–26] Studies considering the relationship found evidence that increased hospital competition was associated with improved quality outcomes for a limited number of interventions, such as coronary artery bypass grafting in the acute setting.[27–29] As the current tendency towards centralisation of procedures aimed at increasing volume will further reduce the number of hospitals offering this care, it is important to acknowledge that surgical consolidation potentially lowers incentives for quality competition among hospitals.[30]

Study aim

An adequate analysis of hospital variation in patient outcomes should thus address the joint impact of both surgical volume on the hospital level and hospital competition on the health system level. In our study, this interaction is analysed for three different patient outcomes: surgical margins, re-excision rates and overall survival. Our study focuses on surgery for IBC in the Netherlands. The reason for this focus is threefold. First, IBC surgery in the Netherlands has not undergone the same degree of centralisation compared with low-volume tumours. Hospital variation in relation to volume and competition is therefore still present. Second, in contrast to low-volume tumours, literature demonstrates contradicting and country-specific volume effects with regard to IBC surgical procedures.[15] Moreover, in previously performed studies on the volume-outcome relationship, correction for unobserved differences across hospitals has not been performed.[31] Therefore, we here use a multilevel approach. Third, over the past years, quality indicators in national and international breast cancer guidelines have been repeatedly subject to change[19 32 33] We aim to contribute to knowledge on the use of patient outcomes in both clinical and policy decision-making. The outcome parameters surgical margins and re-excision rate are known to be associated with psychological stress, increased disease burden and potentially worse cosmetic outcomes.[34 35] Survival was included in our study as it has the benefit of the long follow-up assessment of potential hospital variation and suitability for international comparison in clinical and applied research.

METHODS

Data source

The Netherlands Cancer Registry (NCR), hosted by the Netherlands Comprehensive Cancer Organisation (IKNL), is used as our primary data source. This population-based registry covers the Dutch population and all Dutch hospitals. It is based on a notification of all newly diagnosed malignancies by the national automated pathological archive (PALGA). Additional

notification sources are the national registry of hospital discharges and radiotherapy institutions. Specially trained data managers of the NCR routinely extract information on patient characteristics, diagnosis, tumour characteristics and treatment directly from the medical records. Comorbidity was available only for hospitals in the southern part of the Netherlands. Each patient's vital status was retrieved from the Dutch Municipality Register (GBA). Follow-up was completed until February 2020. Our dataset was combined with information on the location of all Dutch hospitals and outpatient facilities defined by zip codes enabling us to calculate travel time and competition measures. This data were retrieved from the National Institute for Public Health and the Environment (RIVM).

Patient selection criteria

In our study, 136 958 patients with breast cancer were included who underwent a first surgery (breast conserving or mastectomy) for a primary invasive breast cancer tumour in the Netherlands between 1 January 2004 and 31 December 2014 in any Dutch hospital. Patients with Ductal carcinoma in situ or metastasis at diagnosis were excluded. The same applies if the name of the hospital where the surgery was performed was missing (n=37, <1%). For patients with multiple surgeries on the same day (n=1337, <1%), only the first surgery was included.

Patient and public involvement

Patient perspectives are important for the Netherlands Comprehensive Cancer Organisation to reduce the impact of cancer and are therefore involved in the evaluation for the application for the use of data by means of a Patient Advisory Board. We used data on an aggregated level. Patients were thus not directly involved in the data collection phase, nor in defining the research question or the outcome measures, nor were patients asked to advise on interpretation or writing up of results. However, the patient's perspective was incorporated in the definition of these quality indicators by scientific associations, such as the NBCA. The results of this study will be broadly disseminated through patient organisations, patient communities and scientific associations, both digitally and in-person.

Measures

Patient outcomes

Survival was calculated as follow-up from the date of diagnosis to date of the event. As the actionability of volume-outcome research is limited in daily clinical practice due to the complexity of the relationship with survival and uncontrolled confounding factors, surgical margins and 90 days re-excision were therefore also included as short-term and middle-term outcomes. Based on the definition of the Dutch Healthcare Inspectorate, surgical margins were defined as margins free when the pathologist found no cancer cells at the edge of the tissue and focally positive when cancer cells are found (available for 2011–2014, only calculated for patients who underwent a lumpectomy). For re-excision, it was assessed whether a patient underwent a second surgery within 90 days after the first surgery irrespectively of the reason (available for 2009–2014).

Hospital volume

Hospital volume has been defined as the total number of annual IBC surgeries following the guidelines of the European Society of Breast Cancer Specialists (EUSOMA), operationalised as the rolling average over 3 years. Hence, as expressed in the following formula it refers to the annual mean based on the year of surgery (T_0) and the two preceding years (T_{-1} and T_{-2}): $\frac{Volume_{T0}+Volume_{T-1}+Volume_{T-2}}{3}$. For 2004, only the year T_0 was used. For 2005, the average was taken over the years T_0 and T_{-1}. Hospitals that merged in the study period were included separately up to the year of merging. Postmerger, the volumes of the merged hospitals' locations were aggregated. Following this approach, 15 hospital mergers were processed. Based on the latest population-based study, hospital surgical volume was categorised in six groups (ie, <75 surgeries, 75–99 surgeries, 100–149 surgeries, 50–199 surgeries, 200–249 surgeries and 250 or more surgeries).[17] The 200–250 category was added to account for the overall increase in hospital volumes in the Netherlands during our study period.

Hospital competition

Hospital competition has been operationalised through the number of proximate hospitals within a fixed radius. This so-called *fascia count* is a simple but commonly used proxy for the level of hospital competition.[29 36] We assessed the number of hospitals within a fixed isodistance. This is a more accurate measure compared with a simple circular radius since it takes into account differences in road networks (and thus differences in travel time). Isodistance was calculated based on a dataset containing travel times between all combinations of Dutch zip codes. From previous studies, it followed that patients' average willingness to travel for hospital care in the Netherlands equals about 20 min by car which can be translated into 30 km.[37 38] Therefore, in this study, regional hospital markets were operationalised by the 30 km isodistance. Both 20 km and 40 km isodistance were included as sensitivity checks. For hospitals with multiple locations, we identified the number of unique competitors on the organisational level instead of the location level. Because financial operation and contract negotiations with health insurers take place on the organisational level, hospital locations that are part of the same organisation are not expected to compete with each other. Hospital locations that are part of the same (merged) organisation are thus not counted as unique hospitals. Hence, mergers did not necessarily influence the travel

Table 1 Patient characteristics and overall survival of the first invasive breast cancer surgery

	Baseline		5-year overall survival (n=136 958)			10-year overall survival (n=52 513)		
	N	%	%	95% CI L	95% CI U	%	95% CI L	95% CI U
Sex*†								
Female	136 099	99.4	87.7	87.5%	87.9%	74.5	74.2%	74.8%
Male	859	0.6	76.7	73.7%	79.4%	55.1	51.3%	58.8%
Age at diagnosis (years)*†								
15–29	712	0.5	89.9	87.5%	91.9%	83.8	80.6%	86.5%
30–44	15 500	11.3	91.5	91.1%	92.0%	84.7	84.1%	85.3%
45–59	51 292	37.5	92.9	92.7%	93.1%	85.3	85.0%	85.6%
60–74	50 989	37.2	89.4	89.2%	89.7%	75.3	74.8%	75.7%
75+	18 465	13.5	64.6	63.9%	65.3%	32.2	31.4%	32.9%
Socioeconomic status*†								
Low	39 084	28.5	86.1	85.8%	86.4%	71.2	70.7%	71.7%
Middle	54 533	39.8	87.6	87.3%	87.8%	74.5	74.1%	74.9%
High	43 341	31.7	89.1	88.8%	89.4%	77.1	76.6%	77.5%
Year of surgery*†								
2004	10 409	7.6	84.3	83.6%	85.0%	69.7	68.8%	70.5%
2005	11 340	8.3	85.9	85.3%	86.5%	71.7	70.9%	72.5%
2006	11 676	8.5	86.3	85.7%	86.9%	73.0	72.2%	73.8%
2007	12 235	8.9	86.7	86.1%	87.3%	73.4	72.6%	74.2%
2008	12 200	8.9	86.9	86.3%	87.5%	73.9	73.1%	74.7%
2009	12 712	9.3	87.9	87.3%	88.4%	74.5	73.8%	75.3%
2010	12 585	9.2	88.2	87.6%	88.7%	75.8	75.0%	76.5%
2011	13 175	9.6	89.0	88.4%	89.5%			
2012	13 355	9.8	89.1	88.6%	89.6%			
2013	13 576	9.9	89.1	88.6%	89.6%			
2014	13 568	9.9	89.5	88.9%	90.0%			
Morphology*†								
Invasive ductal	103 537	75.6	87.8	87.6%	88.0%	75.0	74.7%	75.3%
Invasive lobular	15 018	11.0	87.2	86.7%	87.7%	70.8	70.0%	71.6%
Other	18 403	13.4	87.3	86.8%	87.8%	73.8	73.1%	74.5%
Surgical procedure*†								
Lumpectomy	81 714	59.7	92.3	92.1%	92.5%	81.8	81.5%	82.1%
Mastectomy	55 033	40.2	80.7	80.3%	81.0%	63.5	63.0%	63.9%
Other	211	0.2	89.5	84.5%	93.0%	80.5	74.2%	85.4%
TNM stage*†								
1	65 333	47.7	93.0	92.8%	93.2%	81.9	81.6%	82.2%
2	53 495	39.1	86.4	86.1%	86.7%	72.3	71.9%	72.7%
3	17 899	13.1	72.0	71.3%	72.6%	53.8	53.0%	54.6%
Unknown	230	0.2	87.4	82.4%	91.1%	75.7	69.1%	81.1%
Grade*†								
I	29 971	21.9	92.6	92.3%	92.9%	80.8	80.3%	81.3%
II	56 832	41.6	89.4	89.2%	89.7%	75.2	74.8%	75.6%
III or undifferentiated	37 811	27.6	81.8	81.4%	82.1%	68.9	68.4%	69.4%
Unknown	12 344	9.0	85.1	84.5%	85.8%	71.9	71.0%	72.8%

Continued

Table 1 Continued

	Baseline		5-year overall survival (n=136 958)			10-year overall survival (n=52 513)		
	N	%	%	95% CI L	95% CI U	%	95% CI L	95% CI U
ER/PR*†								
–/–	21 428	16.6	77.6	77.0%	78.1%	67.6	66.9%	68.2%
–/+	1026	0.8	82.7	80.2%	84.9%	72.8	69.9%	75.5%
+/–	20 993	16.2	86.0	85.5%	86.5%	70.3	69.6%	71.0%
+/+	85 958	66.4	90.7	90.5%	90.9%	77.3	77.0%	77.6%
Radiotherapy*†								
No	45 997	33.6	82.6	82.3%	83.0%	66.3	65.8%	66.7%
Yes	90 961	66.4	90.2	90.0%	90.4%	78.6	78.3%	78.9%
Chemotherapy*†								
No	90 193	65.9	85.7	85.5%	86.0%	70.1	69.8%	70.4%
Yes	46 765	34.2	91.3	91.0%	91.6%	82.5	82.2%	82.9%
Hormone therapy*†								
No	66 198	48.3	86.6	86.4%	86.9%	75.1	74.8%	75.5%
Yes	70 760	51.7	88.6	88.3%	88.8%	73.6	73.2%	74.0%
Neoadjuvant chemotherapy*†								
No	127 141	92.8	88.0	87.9%	88.2%	74.7	74.4&	74.9%
Yes	9817	7.17	82.5	81.7%	83.2%	70.8	69.7%	71.8%
Hospital type*†								
General	68 217	49.7	87.4	87.2%	87.7%	74.2	73.8%	74.6%
Tertiary/University	68 992	50.3	87.8	87.6%	88.1%	74.6	74.2%	74.9%
Annual hospital volume*† (rolling three-year average)								
<75	10 099	7.4	85.8	85.1%	86.4%	72.0	71.1%	73.0%
75–99	17 309	12.7	86.9	86.4%	87.4%	73.2	72.5%	73.9%
100–149	37 997	27.8	87.2	86.9%	87.6%	74.0	73.6%	74.5%
150–199	27 329	20.0	87.9	87.5%	88.3%	74.5	73.9%	75.0%
200–249	25 775	18.8	88.1	87.7%	88.4%	74.8	74.2%	75.4%
250 or more	18 322	13.4	89.2	88.7%	89.6%	77.5	76.7%	78.2%
Number of hospitals in the proximity of hospital *i* within 30 km radius								
3 or less (no or weak competition)	68 197	50.0	87.4	87.2%	87.7%	74.1	73.7%	74.4%
4 or more (strong competition)	68 306	50.0	87.9	87.6%	88.1%	74.7	74.4%	75.1%

*P<0.05, uncorrected significant differences in 5-year survival rates based on CIs.
†P<0.05, uncorrected significant differences in 10-year survival rates based on CIs.
ER, oestrogen; L, Lower bound; PR, progesterone; TNM, tumour, node, metastases; U, Upper bound.

time for patients on the organisational level, since hospital locations were most often not closed postmerger.

Control variables

Control variables were categorised into four groups: (i) patient characteristics, (ii) tumour characteristics, (iii) treatment characteristics and (iv) hospital characteristics. In all multivariate analyses, we corrected for age at diagnosis, socioeconomic status, tumour morphology (invasive ductal, invasive lobular, other), tumour, node, metastases (TNM) stage (sixth edition), tumour grade, surgical procedure (mastectomy/lumpectomy), hospital type (general hospital and tertiary/university hospital) and year of surgery. Patients' socioeconomic status was based on the scores for their postal codes at time of diagnosis and grouped using guidelines from Statistics Netherlands. Survival analyses were also corrected for the use of neoadjuvant chemotherapy, hormone receptor status based on oestrogen (ER) and progesterone (PR) receptors. Additionally, for 25% of the patient population comorbidity status was available and was included as a control variable.

Table 2 Hospital-level characteristics for start (2004), middle (2009) and end (2014) of the study period

	2004		2009		2014	
	N	%	N	%	N	%
Annual hospital volume (absolute)						
<75	26	27.1	16	17.6	9	11.0
75–99	25	26.0	15	16.5	7	8.5
100–149	29	30.2	29	31.9	28	34.2
150–199	8	8.3	12	13.2	16	19.5
200–249	7	7.3	12	13.2	8	9.8
250 or more	1	1.0	7	7.7	14	17.1
Number of hospitals in the proximity of hospital *i* within 30 km radius						
3 or less	48	50.0	46	51.1	42	51.2
4 or more	48	50.0	44	48.9	40	48.8
Hospital type						
General	61	63.5	55	60.4	48	58.5
Tertiary/University	35	36.5	36	39.6	34	41.5
	Median	**IQR**	**Median**	**IQR**	**Median**	**IQR**
Annual hospital volume (absolute)	118	84–173	170	117–230	191	234–272
Number of hospitals in the proximity of hospital *i* within 30 km radius	4	2–10	3	2–11	3	2–8

Statistical analyses

Baseline statistics on the individual patient level included proportions, SD and uncorrected 5-years and 10-year survival rates with 95% CIs to test uncorrected significant differences. Baseline statistics on the hospital level included the distribution of hospitals across volume groups, the number of proximate hospitals and hospital type. We performed multivariate logistic regressions using 90 days re-excision and surgical margins as outcome variables. Surgical margins were only calculated for patients who underwent a lumpectomy. SEs were clustered on the hospital organisational level to account for intrahospital correlation (ie, patients treated in the same centre). Multilevel Cox survival regression models with hospital and year of surgery random effects were used to examine the association between hospital volume, the number of proximate hospitals and covariates with patient survival. These analyses were executed for the entire cohort and, as an additional analysis for the subcohort with available comorbidity status. The reference category for annual hospital volume was set at 100–149 surgeries, as this category included most hospitals and the highest number of treated patients. Sensitivity checks were conducted to test the robustness of our findings. These checks included among others (i) the alternative categorisations of the number of proximate hospitals and alternative fixed isodistances for calculating the number of proximate hospitals (20 and 40 km), (ii) the use of continuous variables for hospital volume and number of proximate hospitals instead of categorised variables and (iii) the use of continuous variables for hospital volume and number of proximate hospitals, scaled by the IQR (75th percentile minus 25th percentile). Potential violation of the proportional hazard assumption was tested by the inclusion of time-varying covariates and graphing of Schoenfeld residuals. No clear violations were found. All analyses were performed in STATA V.16.1.

RESULTS

Patient characteristics

Patient-level descriptive statistics are presented in table 1. Median age at diagnosis was 60 years. Of all patients, 48% had stage 1 breast cancer and 39% had stage 2 breast cancer, 60% underwent a lumpectomy and 40% a mastectomy. Of all patients with breast cancer, 76% were diagnosed with an invasive ductal type. Furthermore, 18% of patients received surgery in hospitals annually performing 100 or less surgeries and 28% of the patients received surgery in hospitals with on average 100–149 surgeries per year. The proportion of patients who underwent surgery in a hospital with zero to three proximate hospitals (indicating weak competition) was equal to the proportion of patients who had surgery in a hospital with four or more proximate hospitals (indicating stronger competition).

Uncorrected survival

Higher rates of uncorrected 5-year and 10-year survival were reported with the increase of annual hospital volume. No clear differences were observed for the hospital proximity measure. When assessing control variables, the largest significant differences in overall survival were found for age and TNM stage. Briefly, uncorrected for other factors female patients, younger patients and patients who underwent a lumpectomy showed a

Table 3 Multivariate logistic regression with surgical margins status (2011–2014, n=31 593) and 90 days re-excision (2009–2014, n=77 965) as dependent variables

	Surgical margins (0=margins free, 1=focally positive)		90 days re-excision rate (0=no re-excision, 1=re-excision)	
	OR	95% CI	OR	95% CI
Annual hospital volume (rolling three-year average)				
<75	0.815	0.607 to 1.094	1.060	0.818 to 1.374
75–99	0.874	0.740 to 1.033	1.026	0.870 to 1.211
100–149	1		1	
150–199	0.847	0.656 to 1.094	0.864	0.688 to 1.086
200–249	0.869	0.674 to 1.119	0.857	0.708 to 1.038
250 or more	0.847	0.626 to 1.146	0.807	0.601 to 1.083
Number of other hospitals in the proximity of hospital *i* in 30 km radius				
0–3	1		1	
4 or more	0.945	0.806 to 1.110	0.875	0.755 to 1.013
Age at diagnosis (years)				
15–29	1		1	
30–44	1.943	0.923 to 4.089	0.927	0.545 to 1.579
45–59	1.920	0.886 to 4.161	0.764	0.453 to 1.286
60–74	1.768	0.804 to 3.891	0.605	0.361 to 1.013
75+	1.907	0.868 to 4.192	0.547*	0.319 to 0.937
Socioeconomic status				
Low	1		1	
Middle	0.947	0.838 to 1.069	0.992	0.901 to 1.091
High	0.989	0.858 to 1.141	1.081	0.965 to 1.211
Surgical procedure				
Lumpectomy	N/A		1	
Mastectomy	N/A		0.033**	0.0236 to 0.0447
Morphology				
Ductal	1		1	
Lobular	2.941**	2.637 to 3.281	2.161**	1.959 to 2.383
Other	1.405**	1.248 to 1.582	1.579**	1.452 to 1.717
TNM stage				
1	1		1	
2	2.216**	2.019 to 2.433	1.552**	1.441 to 1.672
3	5.016**	4.245 to 5.927	2.837**	2.454 to 3.279
Tumour grade				
I	1		1	
II	1.173**	1.061 to 1.297	1.318**	1.205 to 1.442
III or undifferentiated	0.928	0.838 to 1.027	1.159*	1.030 to 1.303
Unknown	1.108	0.923 to 1.331	1.361**	1.128 to 1.642
Hospital type				
General	1		1	
Tertiary/University	1.131	0.919 to 1.392	1.163	0.985 to 1.374

Also corrected for year of surgery.
Adjusted explained variance: surgical margins: 6%, 90 days re-excision: 14%.
Surgical margins were only calculated for patients who underwent a lumpectomy. Therefore, the variable 'surgical procedure' has been excluded from this analysis.
*P<0.05, **p<0.01.
TNM, tumour, node, metastases.

Table 4 Multilevel Cox survival regression model with hospital and year of surgery random effects (hospital volume and hospital competition as categorised variables and continuous scaled variables for IQR (95% CIs; n=127 886)

	Model A: survival model with categorised variables for hospital volume and competition		Model B: survival model with continuous IQR scaled variables for hospital volume and competition	
	HR	95% CI	HR	95% CI
Annual hospital volume (rolling three-year average)				
<75	1.016	0.970 to 1.064		
75–99	0.991	0.953 to 1.032		
100–149	1			
150–199	0.958*	0.922 to 0.994		
200–249	0.976	0.938 to 1.016		
250 or more	0.941*	0.897 to 0.987		
Continuous (scaled for IQR)	–		0.968**	0.948 to 0.989
Number of other hospitals in the proximity of hospital *i* in 30 km radius				
0–3	1			
4 or more	0.973*	0.949 to 0.999		
Continuous (scaled for IQR)			0.972*	0.950 to 0.994
Age at diagnosis (years)				
15–29	1		1	
30–44	1.105	0.907 to 1.349	1.104	0.905 to 1.347
45–59	1.300*	1.065 to 1.577	1.229	1.063 to 1.574
60–74	2.731**	2.245 to 3.321	2.725**	2.241 to 3.315
75+	8.858**	7.282 to 10.774	8.838**	7.266 to 10.750
Socioeconomic status				
Low	1		1	
Middle	0.924	0.901 to 0.949	0.924**	0.900 to 0.948
High	0.869	0.845 to 0.895	0.869**	0.844 to 0.894
Surgical procedure				
Lumpectomy	1		1	
Mastectomy	1.411**	1.377 to 1.445	1.411**	1.377 to 1.445
Morphology				
Ductal	1		1	
Lobular	1.000	0.967 to 1.035	1.000	0.9665 to 1.035
Other	0.942**	0.913 to 0.973	0.943**	0.913 to 0.974
TNM stage				
1	1			
2	1.277**	1.243 to 1.311	1.276**	1.243 to 1.310
3	2.400**	2.322 to 2.480	2.398**	2.321 to 2.479
Tumour grade				
I	1			
II	1.092**	1.058 to 1.128	1.093**	1.060 to 1.129
III or undifferentiated	1.332**	1.285 to 1.381	1.334**	1.287 to 1.383
Unknown	1.118**	1.062 to 1.177	1.118**	1.063 to 1.177
Hospital type				
General	1		1	
Tertiary/University	1.044**	1.014 to 1.074	1.046**	1.018 to 1.076
Neoadjuvant chemotherapy				
No	1		1	
Yes	1.319**	1.253 to 1.389	1.321**	1.255 to 1.391

Continued

Table 4 Continued

	Model A: survival model with categorised variables for hospital volume and competition		Model B: survival model with continuous IQR scaled variables for hospital volume and competition	
	HR	95% CI	HR	95% CI
ER/PR receptor status				
–/–	1		1	
–/+	0.859**	0.765 to 0.965	0.858**	0.765 to 0.964
+/–	0.832**	0.802 to 0.862	0.832**	0.802 to 0.862
+/+	0.702**	0.680 to 0.723	0.702**	0.680 to 0.723

Also corrected for year of surgery.
*P<0.05, **p<0.01.
ER, oestrogen; PR, progesterone; TNM, tumour, node, metastases.

significantly improved 5-year and 10-year overall survival rates.

Hospital characteristics

In table 2, the hospital-level characteristics are described for the years 2004, 2009 and 2014. This comparison over time reveals that the number of Dutch hospitals performing surgery for IBC decreased from 96 in 2004 to 82 in 2014, mainly due to mergers. This decrease in number of hospitals predominantly occurred among the general hospitals, whereas the number of tertiary/university hospitals remained stable over the study period. The proportion of hospitals that performed 250 or more surgical procedures annually increased, whereas the proportion of hospitals performing <100 sharply decreased. An overall volume growth can also be derived from the median annual hospital, which increased from 118 in 2004 to 191 in 2014. At the start of the study period, the number of hospitals having three or less hospitals within a 30 km radius was equal to the number of hospitals having four or more proximate hospitals.

Multivariate analyses

For the multivariate analysis, male patients (n=859, <1%), patients with an unregistered surgery type (n=200, <1%) and patients who had an unknown TNM stage (n=230, <1%) were excluded. As a result, the final 11-year study cohort comprised 135 179 patients. Multivariate logistic regression results shown in table 3 indicate that surgical margins for patients who underwent a lumpectomy were mainly influenced by tumour-specific variables (left columns). Positive margins were significantly more often reported for invasive lobular carcinoma and for TNM stage 2 and 3. Differences in hospital volume or the number of proximate hospitals were not associated with significantly higher or lower probabilities for positive margins.

Hospital volume was associated with reduced re-excision rates within 90 days after surgery (table 3, right column). Patients who underwent surgery in a hospital performing 200–249 surgeries (OR 0.86) or 250 or more (OR 0.81) had lower re-excision rates compared with patients who underwent surgery in a hospital with 100–149 surgeries. Patients treated in hospitals performing 100 or less surgical procedures reported higher re-excision rates. These associations were not significant after clustering for intrahospital correlation. Patients who underwent a mastectomy during primary surgery seldom had a re-excision (OR 0.03). A significantly higher probability of re-excision was found for patients with a high socioeconomic status, patients who were diagnosed with an invasive lobular tumour and patients with TNM stage 2. Finally, a substantial and significant lower rate of re-excision was reported for patients with the age of 75 years and older.

The median follow-up for the cohort was 8.7 years. When studying the entire population in a multilevel model, survival was significantly higher when patients had surgery in a hospital with a three-year rolling average of 250 or more surgical procedures, compared with 100–149 annual surgeries (HR 0.94) (table 4). For patients who had surgery in a hospital with four or more proximate hospitals, that is, in a hospital facing stronger competition, survival was slightly higher compared with patients who had surgery in a hospital with none to three proximate hospitals (HR 0.97). After adjusting for comorbidity status as a sensitivity check, the relationship between hospital volume and survival weakened and did not remain significant for the largest volume group. However, the distribution of low-volume and high-volume hospitals substantially differed between the entire population and this substantially smaller, and regionally biased, subsample for which comorbidity status was available. When treating hospital volume and hospital competition as a continuous variable scaled for IQR, the direction of the relationship did not alter and remained significant (table 4, model B). Moreover, effect sizes and significance of the controls did not alter compared with model A.

Larger differences in survival became visible when inspecting patient, tumour and treatment-related variables. Higher age, a lower socioeconomic status, a diagnosis of an invasive ductal tumour, higher TNM stage or higher

Table 5 Sensitivity checks for surgical margins, 90 days re-excision and overall survival

	Surgical margins† (0=margins free, 1=focally positive)		90 days re-excision‡ (0=no re-excision, 1=re-excision)		Overall survival§	
	OR	P value	OR	P value	HR	P value
Hospital volume (rolling average as continuous variable)	0.99	0.60	0.99	0.09	0.99	0.00**
Number of other hospitals in the proximity of hospital *i* in 30 km radius (continuous variable)	0.99	0.72	0.98	0.03*	0.99	0.01*
Hospital volume (absolute volume as continuous variable)	0.99	0.61	0.99	0.07	0.99	0.00**
Number of other hospitals in the proximity of hospital *i* in 30 km radius (continuous variable)	0.99	0.72	0.98	0.03*	0.99	0.01*
Hospital volume (rolling average as continuous variable, scaled by IQR)	0.96	0.57	0.89	0.07	0.97	0.00**
Number of other hospitals in the proximity of hospital *i* in 30 km radius (continuous variable, scaled by IQR)	0.98	0.71	0.87	0.03*	0.97	0.01*
Hospital volume (absolute volume as continuous variable, scaled by IQR)	0.96	0.62	0.89	0.07	0.97	0.00**
Number of other hospitals in the proximity of hospital *i* in 30 km radius (continuous variable, scaled by IQR)	0.98	0.72	0.87	0.03*	0.97	0.01*
Hospital volume (rolling average as continuous variable, scaled by IQR)	0.95	0.55	0.89	0.08	0.97	0.00**
Number of other hospitals in the proximity of hospital *i* in 20 km radius (continuous variable, scaled by IQR)	0.95	0.45	0.88	0.08	0.97	0.00**
Hospital volume (rolling average as continuous variable, scaled by IQR)	0.96	0.58	0.89	0.07	0.97	0.00**
Number of other hospitals in the proximity of hospital *i* in 40 km radius (continuous variable, scaled by IQR)	0.99	0.98	0.87	0.05	0.97	0.02*

*P<0.05; **p<0.01.
†Logistic regression with clustered SEs. Corrected for age, socioeconomic status, morphology, TNM stage, tumour grade, hospital type, year of surgery.
‡Logistic regression with clustered SEs. Corrected for age, socioeconomic status, surgical procedure morphology, TNM stage, tumour grade, hospital type, year of surgery.
§Multilevel Cox proportional hazards model with hospital and year of surgery random effects, corrected for age, socioeconomic status, surgical procedure, morphology, TNM stage, tumour grade, hormone status, neoadjuvant chemotherapy, hospital type, year of surgery.
TNM, tumour, node, metastases.

tumour grade were all associated with reduced survival. From the sensitivity check where comorbidities were taken into account, it followed that having one or more comorbidities was independently associated with significantly reduced survival (HR 1.54, data not shown in table).

Several sensitivity checks were performed to assess the robustness of our findings for hospital volume and hospital competition (table 5). For this purpose, we used continuous variables for hospital volume and hospital competition instead of categorised variables. Based on these sensitivity analyses, it can be concluded that the direction and significance of therelationships presented in tables 3 and 4 did not change. Furthermore, the checks confirmed the small volume effect for both the scaled and uncorrected variables for three-year rolling average and absolute hospital volume. For the significant coefficients, effect sizes were somewhat larger for scaled variables, but overall very small. In the analyses with surgical margins and 90 days re-excision rates as patient outcomes, the use of continuous variables for hospital volume did not yield to significant findings, in line with table 3.

Lastly, when using alternative categories for measuring regional hospital competition, we found a significant association with survival for two or less versus three or more hospitals, while zero versus one or more hospitals was not significant. Changing the 30 km radius to a 20 km radius resulted in a small but significant improved survival effect for hospitals with four or more competitors, while an effect was absent when using 40 km radius.

DISCUSSION

The optimal design of oncological care provision in hospital markets requires taking into account both hospital-level and system-level factors. Our study aims to examine the relation between hospital surgical volume on the hospital level and the intensity of regional hospital competition on the system level. Both in relation to three different types of patient outcomes (surgical margins, re-excision and survival). After adjusting for confounders and intrahospital correlation, hospital volume and competition from neighbouring hospitals did not explain differences in surgical margins and re-excision rates, although re-excision rates were lower for higher volume groups. Surgery in higher volume hospitals with on average 150–200 or 250 or more surgeries per year was associated

with prolonged survival. This positive relationship was also visible when treating hospital volume as a continuous variable. However, differences were small, and the effect weakened after correction for comorbidity status which was available for 25% of the population. For the effect of hospital competition, it was found that patient survival was higher in hospitals with four or more (potential) competitors within a 30 km distance. However, this effect was small and not robust for changes in our proxy for hospital competition. Treatment type, patient and tumour-level characteristics explained most variation in outcomes after correction for confounding variables.

Overall, our findings for hospital volume are in accordance with earlier Dutch studies using comparable endpoints.[17 39] Furthermore, the relatively high volume threshold for effects on patient outcomes found in our study mirror the high cut-off points found in international research.[15 40] Three developments in the Dutch setting might explain the limited influence of hospital volume. First, the ongoing implementation of preoperative and post-operative multidisciplinary meetings, intensified regional collaboration and introduction of oncological care pathways and a strict quality assurance system may have reduced variation in care between hospitals.[3 32 41] Second, the share of low-volume hospitals during the study period was relatively low due to the elapsed time since the introduction of volume standard, as is also observed in other countries.[42] Three, hospital volume may not accurately reflect other attributes such as the level of specialisation or the use of novel treatments.

With regard to hospital competition, there are at least two plausible theoretical explanations for the absence of a robust relationship with patient outcomes. First, the role of competition among hospitals in breast cancer care is limited through the rare use of selective contracting by health purchasers in the Netherlands.[43] Additionally, hospital competition in this market does also not seem to be strengthened by active patient choice.[44] Recent research suggested that most breast cancer patients agreed on being referred to the nearest hospital by their general practitioner.[45] Second, as competition and collaboration often coexists in health systems, the competition-effect might be mitigated by an unobserved collaboration-effect or network-effect since neighbouring hospitals might work closely together within a regional network rather than compete with each other.[46]

Strengths and limitations

The key strengths of this study are its long follow-up, nationwide inclusion of all hospitals and patients and the use of a multilevel survival analysis. Also, the use of rolling average instead of hospital volume or each separate year enabled us to encompass the weighted scale effects in the two years before the surgery and has the benefit of smoothening potential non-recurring changes in hospital volume. In practice, minimum volume standards are often calculated based on the three-year average.[47] Furthermore, the additional operationalisation of hospital volume as a continuous variable next to the discrete categorisation facilitates comparability with other studies.

Our study suffers from at least five limitations. First, due to retrospective character there is some inconsistency with contemporary practice, such as collaboration and division of tasks in networks, as well as developments of quality indicators, such as the shift towards patient reported outcomes and quality of life measures.[32] Second, we were not able to account for the role of physician, patient and/or shared decision-making on treatment options. This may affect hospital variation, but does not necessarily imply differences in quality of care. Third, due to absence of data, it was not possible to calculate the follow-up from date of surgical procedure. Alternatively, we calculated survival from the date of diagnosis, which may have resulted in a small overestimation of length of survival, as all patients underwent a surgical procedure and thus survived up and until the date of surgery. However, it is not likely that this has resulted in a large source of bias, as the vast majority of patients in the Netherlands has been operated within five weeks of diagnosis[48]. Fourth, although commonly used, our measure for hospital competition is rather crude and may therefore not accurately reflect all competitive pressures faced by hospitals. Fifth, it was not possible to assess surgical margins, re-excision rates and the influence of comorbidity for the entire study cohort, since retrospective data were not fully available.

Implications

Overall, based on our selection of patient outcomes, hospital volume and regional competition appear to play only a limited role in the explanation of variation in IBC outcomes across Dutch hospitals. Hence, from a health policy perspective, based on our selection of outcomes, the present study provides no reasons to adjust volume standards or stimulate generic policy aimed at further centralisation of IBC surgical procedures. Although this study did not provide insight into the underlying mechanisms for quality improvement, it attemped to contribute to the longstanding volume-outcome debate in oncological care by including the influence of neighbouring hospitals.

From a methodological perspective, our study contributes to insight into the actionability of using patient outcomes as quality indicators. Although the conjoint use of three end points to assess hospital variation might be beneficial, the interpretation of the available patient outcomes in our study is accompanied by sensitivity problems and definition ambiguity.[35 48 49] Hence, it emphasises the need for routinely collected outcome measures for high-volume tumours to adequately assess quality variation. In our opinion, besides validity and reliability at least two cumulative conditions then need to be fulfilled. First, indicators should have explanatory power for both patients (to select their preferred hospital, as patients prefer to choose based on outcome information[50]), physicians (to disseminate effective feedback information and improve guidelines) and policymakers as well as third-party payers (to benchmark, monitor and potentially

select hospitals). There should thus be a multidisciplinary consensus about breast cancer care quality. Second, the collection and presentation of indicators should ideally be consistent over time and have an adequate coverage of hospitals across the health system to facilitate benchmarking and longitudinal research.

For future research, aimed at better understanding the interaction between hospital volume, competition across hospitals and quality for high-volume tumours, it is recommended to (i) assess the entire multidisciplinary process of care within the hospital, as well as care provided by other hospitals or providers in cancer networks, (ii) include a qualitative approach to take patient's and physician's decision-making on treatment choices into account and (iii) include more sophisticated measures for hospital competition, such as willingness-to-pay or the Logit Competition Index,[51] while taking into account collaboration in hospital networks.

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