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Factors associated with resection volume and reoperation rates in breast-conserving surgery

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ABSTRACT

Background: Achieving tumor-free margins without unintentional tissue loss is essential in breast-conserving surgery (BCS). Calculated resection ratio (CRR) and tumor eccentricity measuring tumor displacement from the specimen center have been proposed as complementary quality metrics to reoperation and mastectomy rates. The objective of this study was to identify factors influencing CRRs and reoperations in BCS.

Methods: The prospective, multi-center FIBRATIO study included 206 women undergoing unilateral BCS for invasive cancer and/or ductal carcinoma in situ across five Finnish centers. Tumor, specimen, and breast volumes were measured radiologically and histopathologically. CRRs, defined as total resection volume (TRV) divided by optimal resection volume, were calculated both radiologically (CRR^{rad}) and histologically (CRR^{pat}). Eccentricity and relative eccentricity (adjusted for tumor size) were also assessed. Associations with clinical and imaging variables, and reoperations were analyzed using multivariable analyses.

Results: Median CRR^{rad} was 2.3 [interquartile range (IQR) 1.5–3.7] and CRR^{pat} 2.4 (IQR 1.4–3.7). Relative eccentricity was 1.0 (IQR 0.5–2.0), higher in smaller tumors and correlated with CRRs. Reoperation occurred in 14% of patients and was associated with larger lesion size and lower CRRs. High CRRs were associated with large breast volume, non-dense breasts, and non-palpable tumors. CRRs decreased with increasing tumor size. Tumor spiculation was associated with higher CRR^{rad}. Statistically significant inter-surgeon and inter-center variability in CRRs and reoperation rates was observed.

Abbreviations: BC, breast cancer; BCS, breast-conserving surgery; BMI, body mass index; BrV, breast volume; CRR, calculated resection ratio; DCIS, Ductal carcinoma in situ; FIBRATIO, Factors Influencing Breast cancer Resection And Their Impact on treatment Outcome; OPBCS, oncoplastic breast-conserving surgery; PRO, patient-reported outcome; ORV, optimal resection volume; REDCap, Research Electronic Data Capture; QoL, quality of life; SPSS, Statistical Package for the Social Sciences; TMDmax/min, maximum/minimum tumor–margin distance; TRV, total resection volume; WLE, wide local excision.

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Conclusions: BCS is associated with variable and often excessive resection of healthy tissue. Identifying patients at risk for over-resection may improve surgical planning. Incorporating CRR into quality metrics alongside reoperation and mastectomy rates could enhance benchmarking.

1. Introduction

Excellent survival rates in locoregional breast cancer (BC) emphasize optimizing the long-term quality of life (QoL). Breast-conserving surgery (BCS) aims to obtain tumor-free margins with minimal impact on patient's QoL. Guidelines endorse a 2 mm margin for ductal carcinoma in situ (DCIS) [1–3]. Although up to 76% of invasive BCs contain a DCIS component [4], the consensus for optimal margins in such cases is not clear.

Cosmetic outcome and patient satisfaction following BCS correlate with excision volume, tumor location, radiotherapy, and reoperation status [5,6]. Historically, specimen volumes exceeding 50–85 cm^3 impaired cosmetic outcome [7,8]. Although oncoplastic techniques have reduced this effect, resections exceeding 15–20% of breast volume often require volume replacement or contralateral symmetrization [9–11].

The surgeon aims for a uniform 10 mm macroscopic margin, which defines the optimal resection volume (ORV). Ideally, the ratio of total resection volume (TRV) and ORV is 1.0 [12,13]. This "calculated resection ratio" (CRR) is a good technical quality metric for excision [12,13]. Due to tumor irregularity and limitations in intraoperative margin assessment or preference to wider margins to avoid reoperations, reported CRRs are often higher, ranging from 1.0 to 4.8. Higher CRRs are linked to higher BMI, smaller or non-palpable tumors, microcalcifications, use of MRI, oncoplastic BCS (OPBCS), and lobular histology [12–18]. Most previous studies on resection volumes excluded cases with a preoperative diagnosis of pure DCIS, DCIS as a component of invasive cancer, or multifocality [12,13,15,19,20]. However, it is crucial to examine the surgical accuracy in these populations as they comprise a substantial share of BCS cases, and their lesions could be more complex to excise. While the surgeon aims to center the tumor within the excised specimen, histology often reveals an eccentric resection with clear disparity between the widest and narrowest microscopic margins, increasing the CRR without necessarily ensuring margin clearance [12,13,17]. Eccentricity therefore provides an additional quality metric [17].

Both CRR and eccentricity are inherently linked to the rate of involved margins and subsequent reoperations, which vary widely among surgeons and units [21]. Recent studies generally report reoperation rates of approximately 20% [22,23]. In Finnish studies, reoperation rates appear lower (3–16%) [24–26] potentially explained by higher mastectomy rates (41–49%) [26,27] as compared to European certified breast units (25%) [28] and US centers (37-42%) [29].

The assessment of CRR and its correlation with patient-, treatment- and QoL-related metrics could aid in optimizing care. In this study, we evaluate preoperatively available metrics that could benefit surgical planning and examine postoperative quality metrics to compare different practitioners and centers. This study includes comprehensive assessment of radiological and histological factors and tumor types commonly excluded from previous studies.

2. Material and methods

This study is part of FIBRATIO (Factors Influencing Breast cancer Resection And Their Impact on treatment Outcome) study conducted across five Finnish breast centers. The study received approval from the Tampere University Ethics Committee and is registered on ClinicalTrials.gov (NCT05257577). The study protocol is available in the supplementary material (Appendix S1, Figure S1). Data were collected and managed with REDCap electronic data capture tools hosted at Tampere University Hospital [30,31].

From March 2022 to March 2024, 207 women underwent unilateral standard wide local excision (WLE) or volume displacement OPBCS for primary, unifocal, or multifocal invasive BC and/or DCIS. The exclusion criteria included prior BC, prior breast surgery, neoadjuvant treatment, inability to provide informed consent, multiple concurrent resections within one breast, and planned contralateral symmetrization. One patient was excluded from data analysis due to missing multifocal tumor span data.

The decision between WLE and OPBCS was at the surgeon's discretion. The treatment protocols adhered to national and international guidelines. During the study period, the Finnish guideline recommended surgical margins of "no ink on tumor" for invasive carcinoma and 2 mm for pure DCIS and DCIS as a component of invasive carcinoma. The molecular subtyping followed ESMO guidelines with a unified Ki67 threshold of 20% across units (local thresholds 14–30%) [1].

2.1. Calculation of volumes, resection ratio and eccentricity

Breast volume (BrV) was estimated using mammographic measurements as described by Kalbhen et al. [32]. The radiological tumor size and extent of multifocal tumors (tumor span), was measured by the largest dimension across three axes, using the imaging method that provided the largest dimensions. The radiological volume of the tumor/tumor span was calculated as an ellipsoid. Additionally, the mammographic appearance of the tumor was classified as spiculated or non-spiculated. All tumors were detectable on at least one preoperative imaging modality, and radiologically occult disease was therefore not represented in the study cohort.

Histological lesion size and volume were determined using pathologist-provided dimensions for a single tumor or an aggregate area of multifocal tumors. This approach differs from the pTNM pathological classification, in which the pT category is determined by the largest tumor in a multifocal area, and pure DCIS as its own entity (pTis) [33].

Total resection volume (TRV) was measured using the submersion method described by Fujiwara et al. [34]. Fresh specimens were weighed and measured to determine the TRV if the submersion method was not employed [35]. Additional tissue excised during surgery was included in the TRV.

Optimal resection volume (ORV) was defined as the ellipsoidal tumor/tumor span surrounded by a 10 mm margin of healthy tissue, calculated both radiologically (ORV^{rad}) and histologically (ORV^{pat}). This margin was previously chosen by Krekel et al. based on technical feasibility and acceptable cosmesis [13]. For spiculated tumors, the extent of the spicules was included in ORV^{rad}, but no additional 10 mm margin was added beyond the spicules.

Calculated resection ratio (CRR) was defined as TRV/ORV and determined both radiologically (CRR^{rad}) and histologically (CRR^{pat}).

Actual (**ARR** = TRV/BrV) and **optimal** (**ORR** = ORV^{rad}/BrV) **resection ratios** were calculated to quantify excision volume relative to breast size. Their difference reflects excess tissue resected.

Additionally, tumor volume and ORV^{pat} were calculated using only the largest histological diameter, as done in most previous CRR^{pat} studies. Results are reported using ellipsoidal volume estimates.

Surgical specimens were oriented by the operating surgeon using sutures, clips, or a combination of both, according to institutional practice. In the pathology laboratory, the specimen surfaces were painted with insoluble dye according to the markings of the surgeon, enabling the microscopic identification of margins in the principal anatomical planes. **Microscopic margins** were reported in six directions (lateral, medial, cranial, caudal, anterior, and posterior) for invasive carcinoma and DCIS. The **maximum tumor-margin distance**

(TMDmax) denotes the widest side margin from invasive carcinoma or DCIS to the resection surface and the **minimum tumor–margin distance (TMDmin)** the narrowest such margin.

Large **tumor eccentricity** indicates that the tumor is located far from the specimen's center, reflected by a large difference between TMDmax and TMDmin. In case of the same absolute eccentricity, smaller tumors appear to be more eccentrically located within the specimen compared to larger tumors. To ensure accurate comparison across different tumor sizes, **relative tumor eccentricity** was calculated by dividing the absolute eccentricity by the tumor's microscopic diameter. This standardized metric allows consistent comparison of tumor positioning across varying tumor sizes [17]. Examples are illustrated in Fig. 1.

Volumetric calculations are detailed in the supplementary material (Appendix S2).

2.2. Sample size and statistical analysis

Sample size calculation was based on previous studies on tumor-to-specimen ratios and was performed using R version 4.0.2, function ss.1way [36]. The study was powered to detect approximately 25% differences in CRR between centers and individual surgeons ($\alpha = 0.05$, $\beta = 0.2$, effect size = 0.3), accounting for 20% loss to follow-up at the 2-year primary endpoint. The null hypothesis was that there is no difference in CRR between centers and individual surgeons. A minimum of 20 procedures per surgeon was expected.

Statistical analyses and figures were conducted using SPSS (version 29, IBM Corp) and Python 3.11 with Matplotlib 3.7.1. A p-value <0.05 was considered statistically significant. Continuous variables were presented as medians with interquartile ranges (IQR). Group comparisons were performed using the Mann-Whitney *U* test or Kruskal-Wallis test, as appropriate. Spearman's rank correlation coefficient (rho) with 95% confidence intervals (CI) was used to describe the difference between two continuous variables. Associations of categorical variables were tested using Pearson chi-square or Fisher's exact test. Differences between skewed related distributions were tested using the related samples Wilcoxon signed-rank test.

Before multivariable-adjusted analyses, skewed variables were normalized using natural logarithm or square root. Linear regression models were applied to identify independent predictors of CRR^{rad} and CRR^{pat}. Results were shown by betas with 95% CI. Reoperation was analyzed using logistic regression. Odds ratios (OR) with 95% CIs were

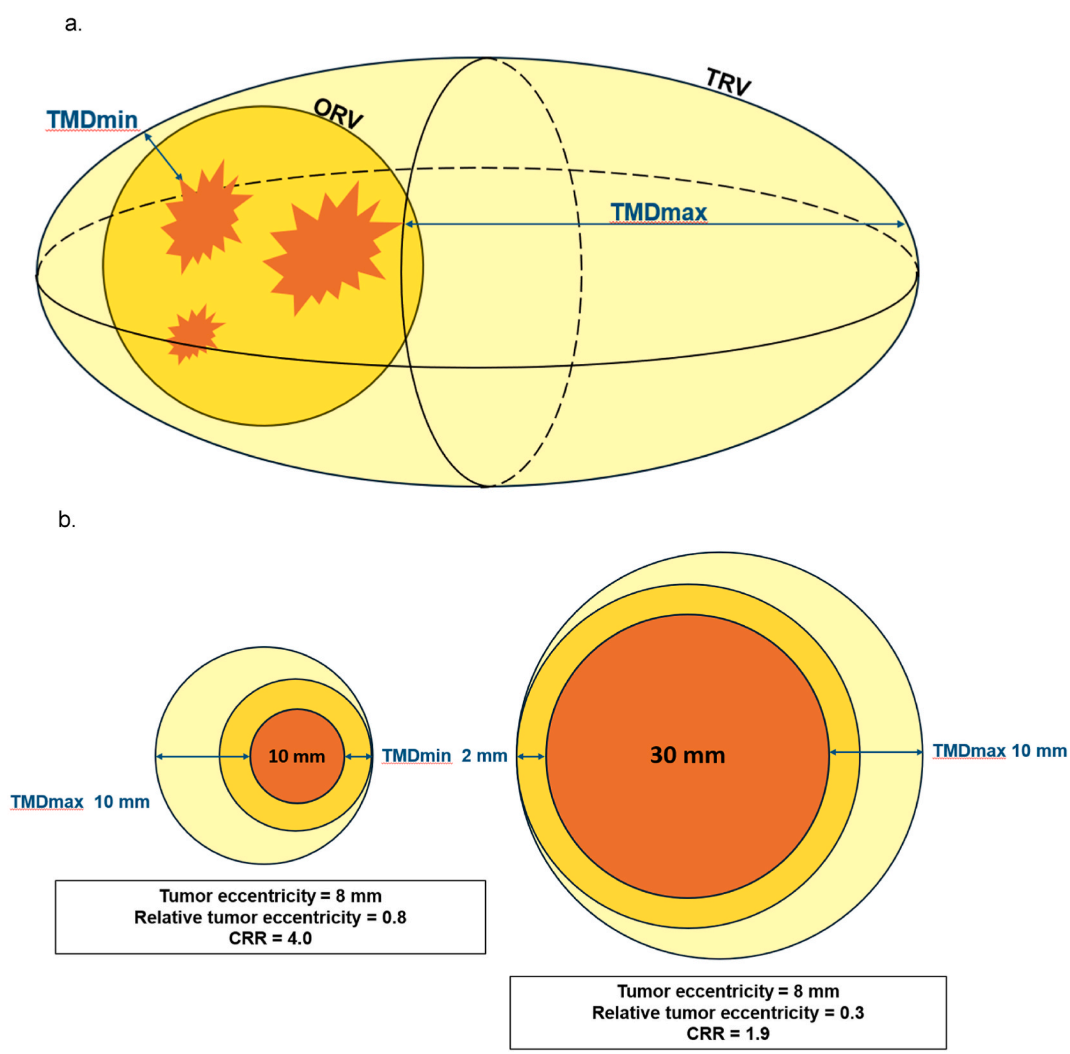


Fig. 1. Examples of eccentric resections. **(a)** A large TRV compared to the ORV. The multifocal tumor area is eccentrically located resulting in a discrepancy between the largest (TMDmax) and smallest tumor-to-margin distance (TMDmin). **(b)** An absolute tumor eccentricity of 8 mm illustrated for tumors measuring 10 mm and 30 mm in diameter. This corresponds to a relative eccentricity of 0.8 and a CRR of 4.0 for the 10 mm tumor, and 0.3 and 1.9, respectively, for the 30 mm tumor. The example demonstrates that, with equal absolute eccentricity, proportionally more excess tissue is removed in smaller tumors than in larger ones.
Abbreviations: CRR, calculated resection ratio; ORV, optimal resection volume; TMDmax, maximum tumor-to-margin distance; TMDmin, minimum tumor-to-margin distance; TRV, total resection volume.

Table 1
Patient, tumor and surgery-related characteristics (N = 206).

Recruiting site, n (% of total)	A	68	(33)
	B	62	(30.1)
	C	46	(22.3)
	D	20	(9.7)
	E	10	(4.9)
Patient-related characteristics			
Age in years, median (IQR)		62	(56-69)
Body mass index in kg/m^2, median (IQR)[a]		27	(23.5-30.6)
Breast volume in cm^3, median (IQR)		947	(625-1367)
SN-N distance in cm, median (IQR)		26.5	(24-29)
Breast density, n (%)	Low (BI-RADS A-B)	132	(64.1)
	High (BI-RADS C-D)	74	(35.9)
Tumor-related characteristics			
Spiculated tumor in mammogram, n (%)	Yes	109	(52.9)
	No	97	(47.1)
Preoperative MRI, n (%)	Yes	43	(20.9)
	No	160	(79.1)
Palpable lesion, n (%)	Yes	73	(35.5)
	No/vaguely palpable	133	(64.5)
Lateralization, n (%)	Right breast	104	(50.5)
	Left breast	102	(49.5)
Tumor location, n (%)	Upper outer quadrant	108	(50.2)
	Upper inner quadrant	42	(19.5)
	Lower inner quadrant	20	(9.3)
	Lower outer quadrant	30	(14.0)
	Central/retroareolar	15	(7.0)
Multifocal tumor, n (%)	Mammogram	12	(5.8)
	Histopathology	25	(12.1)
Lesion diameter in mm, median (IQR)	Radiological[b]	20	(13.0-26.0)
	Histological[b]	16	(10.5-23.1)
Histology, n (%)	NST	144	(69.9)
	Lobular	18	(8.7)
	Other[c]	24	(11.7)
	Pure DCIS	20	(9.7)
DCIS component, n (%)[d]	Yes	110	(59.1)
	No	76	(40.9)
Nuclear grade, n (%)	1	52	(28.0)
	2	98	(52.7)
	3	36	(19.4)
Intrinsic subtype, n (%)	Luminal A	99	(53.2)
	Luminal B, HER2 negative	68	(36.6)
	HER2 enriched	11	(5.9)
	Triple negative	8	(4.3)
Tumor stage, n (%)	pTis	19	(9.2)
	pT1mi	2	(1.0)
	pT1a	9	(4.4)
	pT1b	46	(22.3)
	pT1c	92	(44.7)
	pT2	37	(18.0)
	pT3	1	(0.5)
Surgery-related characteristics			
Type of BCS, n (%)	Simple WLE	124	(60.2)
	OPBCS[e]	82	(39.8)
Axillary surgery, n (%)	Sentinel node biopsy	196	(95.1)
	Axillary dissection	3	(1.5)
	None	7	(3.4)
TRV in cm^3, median (IQR)		45.9	(32.8-72.6)
Excess tissue resection in cm^3, median (IQR)		26.2	(10.0-37.2)
ARR in %, median (IQR)		5.3	(3.6-7.2)
Excess resection in %, median (IQR)[f]		2.4	(1.2-4.3)
Tumor-to-margin distance in mm, median (IQR)	Max	23.5	(18.0-30.0)
	Min	5.3	(3.0-10.0)

Abbreviations: ARR, actual resection ratio; BCS, breast-conserving surgery; BI-RADS, Breast Imaging Reporting and Data System; CNB, core needle biopsy; DCIS, ductal carcinoma in situ; HER2, human epidermal growth factor receptor 2; IQR, interquartile range; MRI, magnetic resonance imaging; NST, invasive cancer non-specific type (ductal); OPBCS, oncoplastic BCS; SN-N, sternal notch-to-nipple distance; WLE, wide local excision.

[a] Calculated as weight in kilograms divided by height in meters squared.
[b] Largest radiological/histological diameter of the lesion.
[c] Other refers to mixed, mucinous, medullary, apocrine and tubular types of breast cancer.
[d] DCIS as a component of invasive cancer detected in final histopathology.
[e] Volume displacement OPBCS.
[f] Excess resection relative to breast volume.

presented. Center- and surgeon-based variation was not included in multivariate analysis due to their multiclass nature.

3. Results

3.1. Demographics

Patient (n = 206) characteristics are presented in Table 1. All patients underwent mammography, ultrasound imaging, and preoperative core needle or vacuum-assisted tumor biopsy. MRI was performed in 21% of patients, with statistically significant inter-center variation (5−60%). Eight consultant breast surgeons and two senior residents each operated on a median of 22 patients (range 10−25). Surgeons reported an annual volume of 40−100 BC cases. Participating centers managed 250−600 new BC cases annually. Among centers, mastectomy rates were 18-48%, and the use of oncoplastic techniques 15-82%. Histological tumor sizes were similar in WLE and OPBCS groups, whereas OPBCS was more frequent in patients with smaller breast volumes. A detailed comparison of WLE and OPBCS is presented in the supplementary material (Table S1).

3.2. Tumor volume, CRR, and eccentricity

The median specimen volume (TRV) was 45.9 cm^3 (IQR 32.8–72.6), corresponding to a median of 5.3% (IQR 3.6–7.2) of breast volume (ARR). The median ORVrad was 20.5 cm^3 (IQR 13.0–29.7), corresponding to a median ORR of 2.4% (IQR 1.3–2.4). The median paired difference, representing excess tissue resection, was 24.3 cm^3 (IQR 10.7–46.5), equivalent to 2.4% (IQR 1.2–4.3) of breast volume, and was statistically significant ($p < 0.001$).

CRR^{rad} and CRR^{pat} were strongly correlated, supporting the accuracy of radiological measurements (rho 0.79, 95% CI 0.73–0.83, $p < 0.001$). The median overall CRR^{rad} was 2.3 (IQR 1.5–3.7) and CRR^{pat} 2.4 (IQR 1.4–3.7) using ellipsoidal measurements; the median CRR^{pat} using only the largest tumor diameter was 2.0 (IQR 1.0–3.7). Overall, the ranges of all specimen parameters were wide with multiple outliers.

TRV and both CRRs correlated positively with BMI and breast volume, which were themselves strongly correlated (supplementary material, Table S2). TRV did not significantly increase in lesions up to 20 mm, but larger lesions were associated with an increase in TRV (rho 0.32, 95% CI 0.19–0.44, n = 206, $p < 0.001$).

Both CRRs correlated inversely with lesion size and were lower in multifocal tumors (Table 2 and Fig. 2).

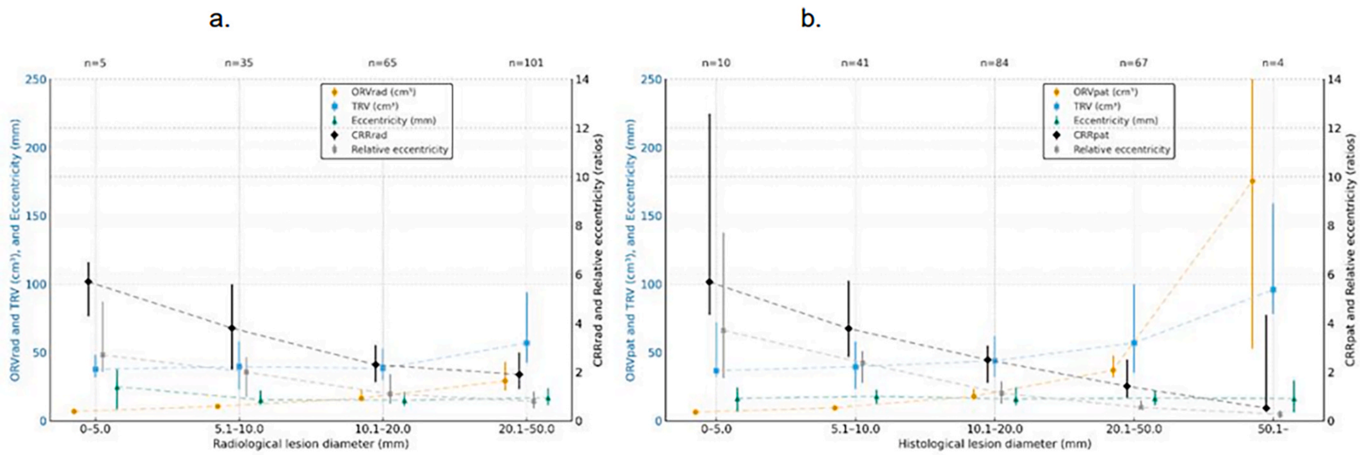
Clinically relevant characteristics related to CRRs are presented in Table 2. CRRs were higher in non-dense (BI-RADS A−B) than dense (BI-RADS C−D) breasts. Centrally located tumors were associated with higher CRRs, while tumors in the lower outer quadrant showed a lower CRR^{pat}. Palpable tumors had significantly lower CRRs than non-palpaple lesions. Preoperative MRI was associated with a lower CRR^{rad}, whereas a similar trend with CRR^{pat} was non-significant. The type of BCS had no significant impact on the TRV or CRRs. Reoperation was associated with significantly lower CRRs.

CRRs varied significantly between surgeons and centers but were not associated with surgeon or center caseload (supplementary material, Fig. S2). Surgical residents had higher CRR^{rad} values compared to specialists.

Table 2
Comparison of characteristics within radiological and histological calculated resection ratios (CRR) (N = 206). Results are shown by medians (Md) with interquartile ranges (IQR). Differences between groups were tested using the Mann-Whitney test.

Findings		Radiological/CRR^{rad}		Histological/CRR^{pat}	
		Md (IQR)	p value	Md (IQR)	p value
Tumor volume (cm^3)	Ellipsoid	2.2 (0.7-5.8)		1.3 (0.3-4.0)	
	Spherical	4.9 (1.4-11.5)		2.1 (0.6-6.5)	
ORV (cm^3)		20.5 (13.0-30)		19.7 (12-34)	
CRR	Ellipsoid	2.3 (1.5-3.7)		2.4 (1.4-3.7)	
	Spherical	1.7 (1.1-2.8)		2.0 (1.0-3.3)	
		Factors affecting CRR			
Breast density	Non-dense	2.6 (1.7-4.1)	**<0.001**	2.7 (1.7-4.4)	**<0.001**
	Dense	1.6 (1.1-2.5)		1.7 (1.1-2.7)	
Preoperative MRI	Yes	1.6 (1.0-2.8)	**0.004**	1.9 (1.2-3.2)	0.130
	No	2.3 (1.6-3.7)		2.6 (1.4-3.8)	
Tumor location	UOQ	2.4 (1.5-4.1)	0.145	2.6 (1.5-3.8)	0.140
(one vs. other four)[a]	UIQ	1.9 (1.3-2.7)	0.068	2.4 (1.2-3.3)	0.508
	LIQ	2.0 (1.1-3.6)	0.254	1.5 (1.2-4.3)	0.241
	LOQ	2.0 (1.5-2.9)	0.127	1.7 (1.2-2.8)	**0.048**
	Central	3.8 (2.0-5.0)	**0.014**	3.5 (2.2-5.5)	**0.041**
Palpable tumor	Yes	1.6 (1.2-2.5)	**<0.001**	1.5 (1.0-2.6)	**<0.001**
	No	2.6 (1.7-4.3)		2.7 (1.8-4.7)	
Operative technique	Simple WLE	2.3 (1.5-3.9)	0.432	2.5 (1.3-4.1)	0.655
	OPBCS	2.1 (1.4-3.3)		2.3 (1.4-3.4)	
Tumor focality (histopathological)	Unifocal	2.3 (1.5-3.6)	0.724	2.6 (1.5-3.8)	**0.010**
	Multifocal	2.1 (1.2-3.9)		2.0 (0.7-2.7)	
Spiculated tumor	Yes	2.6 (1.8-3.8)	**0.009**	2.7 (1.5-4.0)	0.232
	No	1.9 (1.3-3.0)		2.2 (1.3-3.5)	
Reoperation	Yes	1.7 (1.2-2.6)	**0.041**	1.2 (0.6-2.3)	**<0.001**
	No	2.3 (1.5-3.7)		2.6 (1.5-4.3)	
Center[b]	Highest	3.3 (1.9-5.0)	**0.008**	3.3 (2.0-6.9)	**<0.001**
	Lowest	1.7 (1.2-2.5)		1.6 (1.0-2.7)	
Surgeon[b]	Highest	3.3 (1.9-5.1)	**0.004**	3.3 (2.0-5.6)	**<0.001**
	Lowest	1.2 (0.8-2.0)		1.2 (0.8-2.0)	
Surgeon training	Specialist	2.2 (1.5-3.5)	0.505	2.3 (1.3-3.3)	**0.032**
	Resident	2.5 (1.4-3.7)		3.0 (1.7-4.8)	

Abbreviations: BCS, breast-conserving surgery; BI-RADS, Breast Imaging Reporting and Data System; $CRR^{rad/pat}$, radiological/histological calculated resection ratio; IQR, interquartile range; MRI, magnetic resonance imaging; OPBCS, oncoplastic BCS; ORV, optimal resection volume; Tumor locations: UOQ; upper outer quadrant; UIQ, upper inner quadrant; LIQ, lower inner quadrant; LIQ, lower inner quadrant; WLE, wide local excision.
[a]Tumor location comparisons were performed by comparing each anatomical location against the combined group of all other locations.
[b]Center/surgeon with highest and lowest CRR values Statistically significant p-values ($p < 0.05$) were shown as boldface.



c.

Radiological findings					Histological findings				
0-5.0	5.1-10.0	10.1-20.0	20.1-50	Lesion diameter (mm)	0-5.0	5.1-10.0	10.1-20.0	20.1-50	> 50
n (%)	n (%)	n (%)	n (%)		n (%)	n (%)	n (%)	n (%)	n (%)
2 (40)	4 (11)	4 (6)	18 (14)	Reoperations	0	0	8 (10)	17 (25)	3 (75)
1 (20)	11 (31)	26 (40)	44 (54)	OPBCS	2 (20)	18 (44)	32 (38)	28 (42)	3 (75)
Md (IQR)	Md (IQR)	Md (IQR)	Md (IQR)		Md (IQR)	Md (IQR)	Md (IQR)	Md (IQR)	Md (IQR)
0.03 (0.02-0.05)	0.26 (0.18-0.40)	1.4 (0.8-2.1)	5.8 (3.4-9.9)	Lesion volume (cm^3)	0.02 (0.003-0.05)	0.12 (0.09-0.23)	1.0 (0.6-1.9)	4.8 (3.6-8.1)	61.7 (10.0-105.0)
3.6 (2.8-4.7)	4.9 (3.4-6.5)	5.4 (3.3-6.9)	6.0 (4.3-8.2)	Resection ratio (%)	3.9 (3.3-5.3)	5.0 (3.6-6.8)	5.0 (3.3-7.0)	6.0 (4.8-7.8)	11.1 (9.5-14.8)
2.7 (2.2-3.9)	3.1 (1.7-4.3)	2.2 (1.2-4.4)	2.3 (0.1-4.4)	Excess resection (%)	3.0 (2.4-4.2)	2.7 (1.2-4.6)	2.1 (1.3-4.6)	2.3 (0.9-4.3)	4.1 (0.6-7.7)

Fig. 2. a-c. Variables categorized by lesion size. a) Five variables (TRV, ORV^{rad}, CRR^{rad}, eccentricity, and relative eccentricity) in relation to radiological lesion size categories. The left y-axis shows TRV and ORV^{rad} (cm^3) and absolute eccentricity (mm); the right y-axis shows CRR^{rad} and relative eccentricity (ratios). Values are presented as medians with interquartile ranges (IQRs). b) The corresponding variables (TRV, ORV^{pat}, CRR^{pat}, eccentricity, and relative eccentricity) in relation to histological lesion size categories. (c) Additional variables categorized by radiological and histological lesion size, including reoperation rate, OPBCS rate, resection ratio, and excess resection. Here, *resection ratio* corresponds to the actual resection ratio (ARR) as defined in the Methods.
Abbreviations: ARR, actual resection ratio; $CRR^{rad/pat}$, radiological/histological calculated resection ratio; IQR, interquartile range; Md, median; OPBCS, oncoplastic breast-conserving surgery; $ORV^{rad/pat}$, radiological/histological optimal resection volume; TRV, total resection volume.

No association between CRRs and patient age, tumor histology, DCIS component, nuclear grade, or biological subtype was found.

The median largest and smallest tumor-free margins were 24 mm and 5 mm, respectively (Table 1), yielding a median eccentricity of 16 mm for all lesions, without variation across lesion size groups ($p = 0.984$). The median relative eccentricity was 1.0 and was significantly higher in smaller lesions up to 10 mm ($p < 0.001$) (Fig. 2). Both absolute and relative eccentricity correlated with CRRs, with a stronger association for relative eccentricity (Table S2 and Fig. 2). Relative eccentricity was higher (median 1.1, IQR 0.7–2.2) in WLE compared to OPBCS (median 0.8, IQR 0.5–1.6), ($p = 0.012$).

In multivariable-adjusted analysis (Table 4), breast volume, histological lesion size, TRV, palpable tumor, and spiculation were independently associated with both CRRs. Tumor location in the upper quadrants was associated with CRR^{pat}, while radiological lesion size and reoperation were associated with CRR^{rad}.

3.3. Reoperations

Reoperation was required in 14% of patients ($n = 28$), of which three underwent mastectomy. A third operation was needed in 1.5% ($n = 3$), all mastectomies. All patients with inadequate margins underwent reoperation. Four patients were reoperated on due to close margins (range 0.2–0.7 mm) from invasive carcinoma. We observed a non-significant trend of fewer reoperations in NST and rare carcinoma subtypes (range 8–13%) as opposed to lobular carcinoma and DCIS (range 20–22%).

The association of tumor and surgical characteristics with reoperation is presented in Table 3. TRVs were similar despite reoperation status, but CRRs were lower in reoperated cases. Increasing histopathological size was strongly associated with reoperation in univariate and multivariable-adjusted analyses (Table 4). The median tumor diameter was 26 mm in reoperated cases and 15 mm in non-reoperated ones. There was a trend towards more frequent reoperations in radiologically

Table 3
Association of tumor and surgical characteristics with reoperation. The difference between reoperated and non-reoperated patients was tested using Mann-Whitney, Pearson Chi-square, or Fisher's exact test.

		Reoperation (N = 28; 13.6%)		No reoperation (N = 178; 86.4%)		p-value
		Md	(IQR)	Md	(IQR)	
Lesion diameter (mm)	Radiological	23	(16.0-30.8)	20	(13.0-25.0)	0.066
	Histological	26	(17.5-43.3)	15	(9.4-22.0)	**<0.001**
Lesion volume (cm^3)	Radiological	3.5	(1.0-11.9)	2.1	(0.7-5.6)	0.061
	Histological	4.0	(1.9-9.2)	1.0	(0.2-3.2)	**<0.001**
ORV (cm^3)	Radiological	24.8	(18.2-40.4)	19.7	(12.8-28.8)	0.069
	Histological	33.8	(23.2-53.4)	17.9	(11.1-29.5)	**<0.001**
TRV (cm^3)		45.8	(32.3-72.6)	45.9	(33.3-72.0)	0.736
CRR	Radiological	1.8	(1.2-2.6)	2.3	(1.5-3.7)	**0.041**
	Histological	1.2	(0.4-1.1)	2.6	(1.5-4.3)	**<0.001**
Eccentricity (mm)		17.9	(14.3-24.7)	16.0	(11.0-23.0)	0.190
Relative eccentricity		0.7	(0.04-1.1)	1.1	(0.6-2.0)	**0.020**
		n	(%)	n	(%)	
Spiculated tumor	Yes	15	(15.6)	81	(84.4)	0.542
	No	13	(11.8)	97	(88.2)	
Preoperative MRI	Yes	9	(20.9)	34	(79.1)	0.114
	No	19	(11.7)	144	(88.3)	
Tumor location[a]	UOQ	11	(10.2)	97	(89.8)	0.134
	UIQ	10	(23.8)	32	(76.2)	**0.030**
	LIQ	4	(20.0)	16	(80.0)	0.488
	LOQ	4	(13.3)	26	(86.7)	1.000
	Central	1	(6.7)	14	(93.3)	0.699
Multifocal tumor	Yes	9	(36.0)	16	(64.0)	**0.002**
	No	19	(10.5)	162	(89.5)	
DCIS component	Yes	17	(15.5)	93	(84.5)	0.212
	No	7	(9.2)	69	(90.8)	
Surgeon[b)]	Lowest	0	(0)	20	(100.0)	**0.048**
	Highest	7	(30.4)	16	(69.6)	
Breast center[b)]	Lowest	0	(0)	20	(100.0)	**0.033**
	Highest	13	(21.0)	49	(79.0)	

Statistically significant p-values ($p < 0.05$) shown as boldface.
Abbreviations: CRR, calculated resection ratio; DCIS, ductal carcinoma in situ; IQR, interquartile range; MRI, magnetic resonance imaging; ORV, optimal resection volume; TRV, total resection volume; Tumor locations: UOQ; upper outer quadrant; UIQ, upper inner quadrant; LIQ, lower inner quadrant; LIQ, lower inner quadrant.
[a] Tumor location comparisons were performed by comparing each anatomical location against the combined group of all other locations.
[b] Surgeon/center with lowest and highest rate of reoperation.

larger lesions (p = 0.066). Unexpectedly, the median relative eccentricity was lower in reoperated cases (0.7 vs.1.1), and this finding remained statistically significant in multivariable-adjusted analysis (Table 4).

We found no association between reoperation and age, BMI, breast volume or density, tumor palpability, mammographic spiculation, DCIS component, nuclear grade, biological subtype, operative technique, or absolute eccentricity in univariable analysis. Preoperative MRI imaging was more common in reoperated cases (32% vs. 19%). Reoperation rate varied among tumor locations: 24% in the upper medial quadrant; 20% in the lower medial quadrant; and 10–13% in the lateral quadrants but the findings remained non-significant.

Reoperation rates also varied considerably between surgeons and centers (Table 3). Notably, no reoperations occurred among patients operated on by resident surgeons, whereas specialists exhibited reoperation rates ranging from 10% to 30%. Reoperation rates were not associated with annual center caseload but an unexpected non-significant trend toward higher reoperation rates among high-caseload surgeons was observed (supplementary material, Table S3 and Fig. S3).

4. Discussion

The core finding of our study is that both CRR and relative eccentricity decreased with increasing tumor size. This likely explains the unexpected observation that reoperated cases had not only lower CRRs but also lower relative eccentricity, as most reoperations involved tumors larger than 2 cm. Additionally, CRRs were significantly lower in cases with positive resection margins. Substantial variations in these metrics were observed between centers and individual surgeons.

CRR^{pat} is a valuable metric for surgical precision. Our median CRR^{pat} for 1–2 cm lesions was 2.5, which is lower than the 3.0 reported by Corsi et al. [37]. The difference is likely explained by difference in lesions. While Corsi et al. focused on typically non-palpable microcalcifications, our cohort compriced a broader spectrum of radiologically visible lesions, including mass-forming tumors, and lesions that were clinically palpable. When calculated using only the largest tumor diameter, our CRR^{pat} decreased to 2.0, lower than Krekel et al.'s median of 2.5 for pT1–2 tumors [13].

In contrast to previous previously reported higher CRR^{rad} values of up to 5.7 in OPBCS, we observed similar values with both techniques [18]. This may be explained by the inclusion of only volume displacement techniques, exclusion of contralateral symmetrization and that OPBCS was performed in patients with smaller breast volumes than WLE. In terms of eccentricity, small tumors (<10 mm) were associated with higher relative eccentricity, supporting findings by Veluponnar et al., while absolute eccentricity remained constant across tumor sizes [17]. Both tumor eccentricity and CRR should be interpreted in light of surgical strategy. Geometric centricity can be pursued in volume replacement procedures, such as chest wall perforator flaps, eccentricity may be intentional in volume displacement techniques, reflecting planned tissue redistribution rather than imprecise tumor excision. Notably, this did not translate into higher eccentricity in OPBCS in our cohort, where eccentricity was lower than in WLE. This likely reflects the exclusion of contralateral symmetrization, which would have enabled more extensive and deliberately eccentric resections while preserving bilateral volume symmetry. In unilateral surgery, resection extent is inherently constrained to avoid postoperative asymmetry.

Higher CRRs were associated with larger breasts, non-dense breast

Table 4
Multivariable-adjusted predictors for radiological (CRR^{rad}) and histogical (CRR^{pat}) calculated resection ratios and for reoperations (N = 206). CRR's were modeled using linear regression, results shown by betas with 95% confidence intervals (CI). Factors associated with reoperations were modeled using logistic regression showing results by odds ratios (OR) and 95% CI.

		CRRpat *Mean 0.36 (Sd 0.33)		CRRrad *Mean 0.35 (Sd 0.29)		Reoperation n = 28 (14%)	
		Adjusted R^2 = 0.92		Adjusted R^2 = 0.90		Nagelkerke R^2 = 0.51	
		Beta	(95% CI)	Beta	(95% CI)	OR	(95% CI)
BMI, mean (Sd)	27.8 (5.7)	0.001	(-0.002-0.004)	−0.001	(-0.005-0.002)	0.96	(0.83-1.12)
Breast volume†, mean (Sd)	2.96 (0.24)	**0.117***	**(0.020–0.215)**	**0.281****	**(0.184–0.379)**	3.78	(0.05-286)
Breast density, n (%)							
Low (BI-RADS A-B)	132 (64)	1.000		1.000		1.00	
High (BI-RADS C-D)	74 (36)	−0.001	(-0.031-0.030)	−0.006	(-0.037-0.024)	0.62	(0.16-2.33)
Spiculated tumor, n (%)	96 (47)	**−0.050****	**(-0.079- -0.021)**	**0.062****	**(0.034–0.091)**	1.66	(0.40-6.97)
Preoperative MRI, n (%)	43 (21)	0.005	(-0.029-0.038)	−0.022	(-0.056-0.012)	2.85	(0.65-12.5)
Tumor location, n (%)							
Upper outer quadrant	108 (52)	**0.069***	**(0.001–0.136)**	−0.022	(-0.089-0.045)	0.76	(0.06-10.3)
Upper inner quadrant	42 (20)	**0.088***	**(0.021–0.156)**	−0.033	(-0.100-0.035)	4.02	(0.30-53.1)
Lower inner quadrant	20 (10)	0.040	(-0.042-0.121)	−0.011	(-0.092-0.071)	3.51	(0.17-71.0)
Lower outer quadrant	30 (15)	0.053	(-0.021-0.127)	−0.021	(-0.094-0.053)	0.99	(0.04-22.1)
Central/retroareolar	15 (7)	0.057	(-0.020-0.133)	−0.030	(-0.106-0.047)	0.31	(0.01-14.9)
Palpable tumor, n (%)	73 (35)	**−0.052****	**(-0.082- -0.023)**	**−0.060****	**(-0.089- -0.030)**	1.34	(0.36-4.91)
Type of BCS, n (%)							
Simple WLE	124 (60)	1.000		1.000		1.00	
OPBCS	82 (40)	0.021	(-0.007-0.050)	0.001	(-0.027-0.029)	1.39	(0.36-5.45)
Multifocal tumor, n (%)	25 (12)	−0.008	(-0.052-0.036)	0.017	(-0.026-0.061)	0.39	(0.07-2.03)
DCIS_component, n (%)	110 (47)	0.009	(-0.018-0.036)	−0.006	(-0.033-0.022)	0.87	(0.26-2.91)
Lesion size, radiological, mean (Sd)	20.6 (9.9)	0.001	(-0.002-0.003)	**−0.013****	**(-0.015- -0.011)**	1.06	(0.92-1.24)
Lesion size, histological††, mean (Sd)	4.09 (1.25)	**−0.210****	**(-0.230- -0.189)**	**−0.035****	**(-0.056- -0.014)**	**9.11***	**(1.80–46.1)**
TRV,††mean (Sd)	7.23 (2.24)	**0.090****	**(0.076–0.104)**	**0.048****	**(0.034–0.062)**	**0.38***	**(0.15–0.95)**
Excess resection %†, mean (Sd)	0.03 (0.03)	**1.307****	**(0.621–1.993)**	**3.738****	**(3.052–4.424)**	Not	included
Relative eccentricity†, mean (Sd)	0.49 (0.19)	−0.005	(-0.110-0.099)	−0.008	(-0.112-0.097)	**0.001***	**(<0.001–0.18)**
Reoperation, n (%)	28 (14)	−0.002	(-0.045-0.042)	0.054	(0.011-0.098)	Not	included
CRR pat†, Mean (Sd)	0.36 (0.33)	Not	included	Not	included	0.18	(0.001-53.8)
CRR rad†, Mean (Sd)	0.35 (0.29)	Not	included	Not	included	158	(0.59-42001)

R square: varies between 0 and 1, where 1 means perfect model. Statistically significant results were shown using boldface (*$p < 0.05$, **$p \leq 0.001$). Skewed distributions were normalized before modelling using natural logaritm† or square-root†† transformations.[a]Excess resection %: percentage of the breast volume excised unnecessarily.
Abbreviations: BCS, breast-conserving surgery; BI-RADS, Breast Imaging Reporting and Data System; BMI, body mass index; $CRR^{rad/pat}$, radiological/histological calculated resection ratio; DCIS, ductal carcinoma in situ; MRI, magnetic resonance imaging; OPBCS, oncoplastic BCS; TRV, total resection volume; WLE, wide local excision.

tissue, as well as small and non-palpable tumors. Breast volume and density were inversely related, with only volume remaining significant in multivariable analysis. Larger breasts allow wider excision without compromising aesthetics. However, small and non-palpable tumors are more difficult to localize, particularly in large breasts, leading to higher relative eccentricities, and consequently larger resections. To our knowledge, the relationship between CRR, breast volume and mammographic density has not previously been systematically examined. Also, our findings reaffirm that palpable tumors are associated with lower CRRs, likely due to more accurate intraoperative margin identification [12,13].

Higher CRR values in centrally located tumors likely reflect the greater glandular thickness in this region, as resections were performed through the full thickness of the gland. The medial and the lower quadrants are thinner limiting excessively wide anterior-posterior margins resulting in lower CRRs [38]. Additionally, these quadrants are more sensitive to volume loss, which may restrict resection [39].

Preoperative MRI was associated with a lower CRR^{rad} in univariable analysis; however, this association did not persist in multivariable analysis. Interestingly, the center with the highest MRI usage had the lowest CRRs, yet the highest reoperation rates. While it remains unclear whether MRI use or institutional practices drove this finding, the data suggest that excessively low CRRs may increase the risk of reoperation.

Tumor spicules were associated with a higher CRR^{rad}, likely due to the calculation method for ORV^{rad}, which did not include an additional 1 cm margin for spiculated tumors. This approach was based on Finnish data indicating that, in most spiculated invasive tumors, additional tumor foci were located closer to the main mass than the visible extent of spicules on mammography [40]. Notably, CRR^{pat} did not differ significantly between spiculated and non-spiculated tumors, supporting the measurement method. However, the CRR patterns suggest that surgeons may, in practice, resect with a 1 cm margin beyond the spicules.

Our overall reoperation rate of 14% aligns with prior Finnish data, though inter-center variation was substantial. Notably, one in four reoperations could have been avoided with adherence to updated national guidelines on DCIS margins aligned with the SSO-ASTRO recommendations.

In contrast to previous reports, histological subtype was not associated with reoperations [12,13]. We observed a reoperation rate of 15% for pure DCIS, which is lower than those reported in earlier studies and only marginally higher than our overall reoperation rate [41,42]. Although DCIS component was more common in reoperated patients, the difference was not statistically significant. These findings suggest that DCIS may not independently increase the risk of reoperation, contrasting with conclusions drawn from several retrospective series [26,42,43].

We observed substantial variation in CRRs between individual surgeons and centers. This finding is supported by Pantiora et al., who reported significant center-level variation in CRR^{rad} (medians 1.5–2.9)[14]. Despite these differences, large-scale studies specifically addressing the variation in CRR remain scarce. Although reoperation rates varied between individual surgeons, these differences did not reach statistical significance, likely due to the limited number of events. Procedures performed by trainees were characterized by higher CRRs and absence of reoperations. While the limited number of reoperations precludes firm conclusions, this pattern is consistent with observations by Srour et al., who reported larger excision volumes among senior residents without differences in positive margin rates, suggesting a more conservative excisional approach prioritizing oncologic safety [44].

We observed no connection between the caseload of the surgeon or the center and CRR or reoperation rates, suggesting that procedural volume alone does not explain variability in excisional accuracy or the risk of reoperation. Curiously, we observed a non-significant trend toward higher reoperation rates among surgeons with higher annual caseloads. This contrasts with the established inverse correlation between caseload and adverse outcomes [45]. Previously, no correlation between caseload and CRR was observed [46]. Overall, these findings suggest that surgical outcomes are influenced by factors beyond caseload, including surgical expertise, technique, and intraoperative decision-making. Future studies should therefore focus on identifying specific surgical and organizational determinants of excisional precision rather than relying on caseload as a surrogate marker of quality.

Based on ORV, only 6% of patients would have required TRV exceeding 85 cm^3, whereas this threshold was exceeded in 19% of cases, indicating potential overtreatment in a subset of patients. CRR reflects TRV relative to an optimal estimate and therefore directly indicates excisional efficiency. While low CRR values were associated with reoperation risk, excessively high CRR values indicate unnecessary tissue removal. Improving excisional precision, reflected by lower CRR values without compromising margin status, may therefore allow BCS to be extended to larger tumors that might otherwise require mastectomy.

The strengths of this study include its prospective, multi-center design, and the use of precise volumetric measurements. The comparison between radiological and histopathological assessments provides further insight into measurement accuracy. The use of CRR offers a valuable approach to account for the influence of excision volumes on reoperation rates. An unexpected trend toward higher reoperation rates was observed among surgeons with higher annual caseloads. This may reflect residual confounding or case-mix differences rather than a true volume–outcome relationship. However, the relatively small sample size may limit generalizability, although the study was powered to detect clinically meaningful findings.

5. Conclusions

Surgical precision in BCS remains variable between surgeons and institutions. Balancing the risk of reoperation against overtreatment—such as excessive tissue removal or unnecessary mastectomy—is critical, particularly given the survival advantage of BCS over mastectomy. Improving excisional accuracy requires advances in imaging, localization, real-time margin assessment, and surgical training. Although oncoplastic techniques have expanded the scope of BCS and reduced mastectomy rates, greater precision in WLE and level 1 OPBCS is essential to maximize their benefits.

Our findings support CRR as a meaningful indicator of surgical precision. This framework enables systematic evaluation of excisional practice beyond conventional endpoints. As reoperation and mastectomy rates do not fully reflect excessive resections, it is important to address the relation between CRR and patient-reported outcomes (PRO). Given the established association between TRV and PROs and aesthetic outcomes, evaluation of PROs in relation to CRR represents a critical next step before CRR can be considered as a complementary quality indicator of surgical performance. CRR can be derived using routinely available clinical data, supporting its feasibility for retrospective assessment and benchmarking. In the future, further analyses within this cohort are planned to identify specific surgical and organizational factors underlying variability in excisional precision, moving beyond surrogate markers such as caseload. In contrast to CRR, eccentricity seems to hold limited potential in this role.

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Data availability statement

Data is not available. Data is solely used in Tampere University Hospital.

Declaration of AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-5 (OpenAI) to assist with revising Fig. 2. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of competing interest

All authors declare no competing interests within the scope of the present work. Ulla Karhunen-Enckell is a consultant for MSD and Novartis. Antti Roine and Niku Oksala are shareholders and employees of Olfactomics Ltd., a medical device company that develops novel technology for intraoperative surgical margin assessment. For the remaining authors, no conflicts of interest relevant to this study are declared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejso.2026.111735.

References

[1] Cardoso F, Kyriakides S, Ohno S, et al. Early breast cancer: ESMO Clinical practice guidelines for diagnosis, treatment and follow-up. Ann Oncol 2019;30(8):1194–220. https://doi.org/10.1093/annonc/mdz173.
[2] Rashmi Kumar N, Schonfeld R, Gradishar WJ, et al. NCCN guidelines version 2.2024. Breast Cancer 2024. https://www.nccn. [Accessed 9 May 2024].
[3] Finnish Breast Cancer Group. Rintasyövän valtakunnallinen diagnostiikka- ja hoitosuositus. https://rintasyoparyhma.yhdistysavain.fi/hoitosuositus/. [Accessed 9 January 2024].
[4] Tot T. Clinical relevance of the distribution of the lesions in 500 consecutive breast cancer cases documented in large-format histologic sections. Cancer 2007;110(11):2551–60. https://doi.org/10.1002/CNCR.23052.
[5] Vos EL, Koning AHJ, Obdeijn IM, et al. Preoperative prediction of cosmetic results in breast conserving surgery. J Surg Oncol 2015;111(2):178–84. https://doi.org/10.1002/JSO.23782.
[6] Dahlbäck C, Manjer J, Rehn M, Ringberg A. Determinants for patient satisfaction regarding aesthetic outcome and skin sensitivity after breast-conserving surgery.

World J Surg Oncol 2016;14(1):1–11. https://doi.org/10.1186/S12957-016-1053-8.
[7] Taylor ME, Perez CA, Halverson KJ, et al. Factors influencing cosmetic results after conservation therapy for breast cancer. Int J Radiat Oncol Biol Phys 1995;31(4):753–64. https://doi.org/10.1016/0360-3016(94)00480-3.
[8] Vrieling C, Collette L, Fourquet A, et al. The influence of patient, tumor and treatment factors on the cosmetic results after breast-conserving therapy in the EORTC "boost vs. no boost" trial. Radiother Oncol 2000;55(3):219–32. https://doi.org/10.1016/S0167-8140(00)00210-3.
[9] Gardfjell A, Dahlbäck C, Åhsberg K. Patient satisfaction after unilateral oncoplastic volume displacement surgery for breast cancer, evaluated with the BREAST-Q^{TM}. World J Surg Oncol 2019;17(1):96. https://doi.org/10.1186/s12957-019-1640-6.
[10] Chan SWW, Chueng PSY, Lam SH. Cosmetic outcome and percentage of breast volume excision in oncoplastic breast conserving surgery. World J Surg 2010;34(7):1447–52. https://doi.org/10.1007/S00268-009-0278-X.
[11] Gozali A, Piper M. Optimizing outcomes in oncoplastic breast-conserving surgery. Journal of Clinical Medicine 2025 2025;14(13):4806. https://doi.org/10.3390/JCM14134806.
[12] Haloua MH, Volders JH, Krekel NMA, et al. A nationwide pathology study on surgical margins and excision volumes after breast-conserving surgery: there is still much to be gained. Breast 2016;25:14–21. https://doi.org/10.1016/J.BREAST.2015.11.003.
[13] Krekel N, Zonderhuis B, Muller S, et al. Excessive resections in breast-conserving surgery: a retrospective multicentre study. Breast J 2011;17(6):602–9. https://doi.org/10.1111/j.1524-4741.2011.01198.x.
[14] Pantiora E, Jazrawi A, Hersi AF, et al. Magnetic seed vs guidewire breast cancer localization with magnetic lymph node detection: a randomized clinical trial. JAMA Surg 2024;159(3):239–46. https://doi.org/10.1001/JAMASURG.2023.6520.
[15] Krekel NMA, Zonderhuis BM, HBAC Stockmann, et al. A comparison of three methods for nonpalpable breast cancer excision. Eur J Surg Oncol 2011;37(2):109–15. https://doi.org/10.1016/j.ejso.2010.12.006.
[16] Staradub VL, Rademaker AW, Morrow M. Factors influencing outcomes for breast conservation therapy of mammographically detected malignancies. J Am Coll Surg 2003;196(4):518–24. https://doi.org/10.1016/S1072-7515(02)01833-1.
[17] Veluponnar D, Dashtbozorg B, Guimaraes MDS, Peeters MJT, Boer LL de, Ruers TJM. Resection ratios and tumor eccentricity in breast-conserving surgery specimens for surgical accuracy assessment. Cancers (Basel) 2024;16(10). https://doi.org/10.3390/CANCERS16101813.
[18] Aristokleous I, Öberg J, Pantiora E, et al. Effect of standardised surgical assessment and shared decision-making on morbidity and patient satisfaction after breast conserving therapy: a cross-sectional study. Eur J Surg Oncol 2023;49(1):60–7. https://doi.org/10.1016/J.EJSO.2022.08.021.
[19] Krekel NMA, Haloua MH, Lopes Cardozo AMF, et al. Intraoperative ultrasound guidance for palpable breast cancer excision (COBALT trial): a multicentre, randomised controlled trial. Lancet Oncol 2013;14(1):48–54. https://doi.org/10.1016/S1470-2045(12)70527-2.
[20] Shin YD, Choi YJ, Kim DH, et al. Comparison of outcomes of surgeon-performed intraoperative ultrasonography-guided wire localization and preoperative wire localization in nonpalpable breast cancer patients undergoing breast-conserving surgery: a retrospective cohort study. Medicine (United States) 2017;96(50). https://doi.org/10.1097/MD.0000000000009340.
[21] Lovrics PJ, Cornacchi SD, Farrokhyar F, et al. Technical factors, surgeon case volume and positive margin rates after breast conservation surgery for early-stage breast cancer. Can J Surg 2010;53(5):305–12. http://www.ncbi.nlm.nih.gov/pubmed/20858374.
[22] Kim Y, Ganduglia-Cazaban C, Tamirisa N, Lucci A, Krause TM. Contemporary analysis of reexcision and conversion to mastectomy rates and associated healthcare costs for women undergoing breast-conserving surgery. Ann Surg Oncol 2024;31(6):3649–60. https://doi.org/10.1245/S10434-024-14902-Z/TABLES/3.
[23] Van Leeuwen MT, Falster MO, Vajdic CM, et al. Reoperation after breast-conserving surgery for cancer in Australia: statewide cohort study of linked hospital data. BMJ Open 2018;8(4). https://doi.org/10.1136/bmjopen-2017-020858.
[24] Ojala K, Meretoja TJ, Leidenius MHK. Aesthetic and functional outcome after breast conserving surgery – comparison between conventional and oncoplastic resection. Eur J Surg Oncol 2017;43(4):658–64. https://doi.org/10.1016/j.ejso.2016.11.019.
[25] Meretoja TJ, Svarvar C, Jahkola TA. Outcome of oncoplastic breast surgery in 90 prospective patients. Am J Surg 2010;200(2):224–8. https://doi.org/10.1016/J.AMJSURG.2009.09.026.
[26] Lepomäki M, Karhunen-Enckell U, Tuominen J, et al. Tumor margins that lead to reoperation in breast cancer: a retrospective register study of 4,489 patients. J Surg Oncol 2022;125(4). https://doi.org/10.1002/jso.26749.
[27] Ojala K, Meretoja TJ, Mattson J, et al. The quality of preoperative diagnostics and surgery and their impact on delays in breast cancer treatment e A population based study. Breast 2016;26:80–6. https://doi.org/10.1016/j.breast.2015.12.009.
[28] Garcia-Etienne CA, Tomatis M, Heil J, et al. Mastectomy trends for early-stage breast cancer: a report from the EUSOMA multi-institutional European database. Eur J Cancer 2012;13(48):1947–56. https://doi.org/10.1016/j.ejca.2012.03.008.
[29] Nelson JA, Rubenstein RN, Haglich K, et al. Analysis of a trend reversal in US lumpectomy rates from 2005 through 2017 using 3 Nationwide data sets. JAMA Surg 2022;157(8):702–11. https://doi.org/10.1001/JAMASURG.2022.2065.
[30] Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: building an international community of software platform partners. J Biomed Inf 2019;95. https://doi.org/10.1016/J.JBI.2019.103208.
[31] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)–a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inf 2009;42(2):377–81. https://doi.org/10.1016/J.JBI.2008.08.010.
[32] Kalbhen CL, McGill JJ, Fendley PM, Corrigan KW, Angelats J. Mammographic determination of breast volume: comparing different methods. AJR Am J Roentgenol 1999;173(6):1643–9. https://doi.org/10.2214/AJR.173.6.10584814.
[33] Hortobagyi G, Connolly J, D'Orsi C, et al. AJCC cancer staging manual. In: Amin MB, Edge SB, Greene FL, editors. AJCC cancer staging manual. 1024. eighth ed. Springer; 2017. p. 589–634. https://cancerstaging.org/references-tools/deskreferences/Documents/AJCC8thEditionBreastCancerStagingSystem.pdf. [Accessed 30 November 2020].
[34] Fujiwara T, Yano K, Tanji Y, Hosokawa K. Simple and accurate volume measurement of mastectomy specimens. Eur J Plast Surg Springer 2013;36(4):275–6. https://doi.org/10.1007/s00238-012-0773-4.
[35] Krekel NMA, Van Slooten HJ, Barbé E, De Lange De Klerk ESM, Meijer S, Van Den Tol MP. Is breast specimen shrinkage really a problem in breast-conserving surgery? J Clin Pathol 2012;65(3):224–7. https://doi.org/10.1136/JCLINPATH-2011-200392.
[36] Sharek D, Zuley ML, Yue Zhang J, Soran A, Ahrendt GM, Ganott MA. Radioactive seed localization versus wire localization for lumpectomies: a comparison of outcomes. Am Journal Rev 2015;204:872–7. https://doi.org/10.2214/AJR.14.12743.
[37] Corsi F, Bossi D, Sartani A, et al. Radio-guided and clip-guided preoperative localization for malignant microcalcifications offer similar performances in breast-conserving surgery. Breast J 2019;25(5):865–73. https://doi.org/10.1111/TBJ.13354.
[38] Ellis H, Mahadevan V. Anatomy and physiology of the breast. Surgery (Oxford) 2013;31(1):11–4. https://doi.org/10.1016/J.MPSUR.2012.10.018.
[39] Pukancsik D, Kelemen P, Újhelyi M, et al. Objective decision making between conventional and oncoplastic breast-conserving surgery or mastectomy: an aesthetic and functional prospective cohort study. Eur J Surg Oncol 2017;43(2):303–10. https://doi.org/10.1016/J.EJSO.2016.11.010.
[40] Tuomainen H, Sudah M, Joukainen S, et al. Mammographically detected spicules associated with malignant breast tumors frequently harbor additional tumor foci. Radiol Oncol 2025;59(2):168–75. https://doi.org/10.2478/RAON-2025-0041.
[41] Kim Y, Ganduglia-Cazaban C, Tamirisa N, Lucci A, Krause TM. Contemporary analysis of reexcision and conversion to mastectomy rates and associated healthcare costs for women undergoing breast-conserving surgery. Ann Surg Oncol 2024;31(6):3649–60. https://doi.org/10.1245/S10434-024-14902-Z.
[42] Jeevan R, Cromwell DA, Trivella M, et al. Reoperation rates after breast conserving surgery for breast cancer among women in England: retrospective study of hospital episode statistics. Br Med J 2012;345(7869). https://doi.org/10.1136/BMJ.E4505.
[43] Langhans L, Jensen MB, Talman MLM, Vejborg I, Kroman N, Tvedskov TF. Reoperation rates in ductal carcinoma in situ vs invasive breast cancer after wire-guided breast-conserving surgery. JAMA Surg 2017;152(4). https://doi.org/10.1001/jamasurg.2016.4751.
[44] Srour MK, Manguso N, Mirocha J, Chung A, Giuliano AE, Amersi F. Impact of resident and fellow participation on surgical outcomes in breast conserving surgery for invasive breast cancer. J Surg Educ 2020;77(1):144–9. https://doi.org/10.1016/J.JSURG.2019.07.014.
[45] de Camargo Cancela M, Comber H, Sharp L. Hospital and surgeon caseload are associated with risk of re-operation following breast-conserving surgery. Breast Cancer Res Treat 2013;140(3):535–44. https://doi.org/10.1007/s10549-013-2652-5.
[46] Baliski C, Hughes L, Bakos B. Lowering Re-excision rates after breast-conserving surgery: unraveling the intersection between surgeon case volumes and techniques. Ann Surg Oncol 2021;28(2):894–901. https://doi.org/10.1245/S10434-020-08731-Z.