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Partial breast irradiation after sentinel lymph node biopsy omission: Is it a valid alternative to whole breast Irradiation? Analysis of the dose to the sentinel lymph node region during whole breast irradiation vs. partial breast irradiation

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ABSTRACT

Background: Sentinel lymph node biopsy (SLNB) can be safely omitted in selected early-stage, clinically node-negative breast cancer (BC) patients. While these patients are also candidates for partial breast irradiation (PBI), the dosimetric effects of PBI on the sentinel lymph node region (SLNs) and axillary levels remain unclear.
Methods: In this study, SLNs were identified and contoured in 100 BC patients using pre- and postoperative imaging. Axillary levels were contoured following ESTRO guidelines. Dose distribution to the SLN (n = 9000 data points) and axillary levels (n = 270 data points) were analyzed for whole breast irradiation (WBI) and PBI across different techniques (3D-conformal radiation therapy [3D-CRT] vs. volumetric modulated arc therapy [VMAT]), deep inspiration breath-hold [DIBH] vs. free breathing [FB]), and anatomical variations (breast size, tumor site, and upper breast border).
Results: WBI provided full therapeutic dose coverage (>95 % of the prescribed dose) to 65 % of SLNs, compared to only 10 % (3D-CRT) and 3 % (VMAT) with PBI. DIBH significantly reduced dose distribution to SLN and axillary levels compared to FB. Lower incidental dose coverage was also observed in patients with medial/central tumors, smaller breasts, and lower upper breast borders.
Conclusion: These results demonstrate that PBI delivers substantially lower incidental dose to the SLN than WBI. Since patients in the INSEMA and SOUND trials were predominantly treated with WBI, combining SLNB omission with PBI should not be considered a standard approach and warrants further investigation.

1. Introduction

Patients with early-stage breast cancer undergoing breast-conserving surgery (BCS) generally have favorable outcomes [1]. In recent years, increasing efforts have been made to further personalize treatment in order to reduce therapy-related toxicity. De-escalation strategies have therefore been investigated across all domains of local treatment, including surgery and radiation oncology.

In radiation oncology, several trials have explored the complete omission of postoperative radiation therapy (RT) following BCS in elderly patients with low-risk tumors [2–5]. Recurrence rates remained low in most trials involving endocrine therapy alone and shorter

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follow-up periods [2,3]. In randomized trials with longer follow-up periods of 10 years [4], no difference in overall survival was found between patients who received RT and those who did not, but the 10-year local relapse rate was ten times higher in patients who omitted RT. Given the relatively low long-term toxicity of RT and its minimal impact on quality of life [6], most gup8idelines continue to recommend RT after BCS, even in low-risk patients [7,8].

For these patients however, instead of whole breast irradiation (WBI), partial breast irradiation (PBI) has emerged as a well-established de-escalation technique. By targeting smaller volumes localized to the tumor bed, PBI enables better sparing of organs at risk such as the heart and lungs, thereby reducing the risk of late toxicities including cardiac events and secondary malignancies [9]. More than 10,000 selected, early breast cancer patients have been included in PBI trials, which have demonstrated comparable oncologic outcomes to WBI [9–13]. Based on randomized trials on PBI, the ideal candidates are patients aged ≥40–50 years with estrogen receptor (ER) -positive, node-negative, grade 1–2 tumors, ≤2 cm in size and clear surgical margins [7,13–16].

Surgical de-escalation has also continuously evolved over the last years and decades. Recently, based on evidence from large trials such as SOUND and INSEMA [17,18], clinical practice has shifted towards an omission of sentinel lymph node biopsy (SLNB) in selected low-risk patients with early breast cancer. In the recently published patient reported outcome analysis of the BOOG 2013-08 trial, SLNB led to a temporary decline in arm function compared to the SLNB omission group [19]. In the INSEMA trial, omission of SLNB lowered the rates of lymphedema (1.8 % vs. 5.7 %), preserved arm/shoulder mobility and reduced pain [20]. According to the 2025 ASCO guideline, SLNB can be safely omitted in postmenopausal women aged ≥50 years with hormone receptor–positive, HER2-negative tumors ≤2 cm, grade 1–2, and negative findings on preoperative axillary ultrasound who undergo BCT [14]. Notably, in both the SOUND and INSEMA trials, all patients received RT, with 90 % and 100 % undergoing WBI, respectively [17,18,21]. Since approximately 10 % of patients had macroscopic lymph node metastases in the SLNB arm (8.7 % in SOUND, 11.6 % in INSEMA) [17,18], the incidental RT of axillary lymph nodes in the no-SLNB arm may have contributed to the excellent locoregional control observed despite SLNB omission.

Thus, despite the overlap in eligibility criteria for SLNB omission and PBI, it remains highly controversial whether both de-escalation strategies can be safely combined. This is reinforced by the fact that the vast majority of patients enrolled in PBI trials were pathologically node-negative, and comparisons of WBI and PBI performed as intraoperative radiotherapy (IORT) revealed increased regional recurrence rates [22,23].

To better understand the implications of SLNB omission in combination with PBI, the current study investigates the incidental dose distribution of external beam PBI in the SLN compared to WBI.

2. Material & methods

The study was approved by the local institutional review board (2017-247-S-KK) and is part of a project funded by the German Cancer Aid (Deutsche Krebshilfe).

2.1. Patient selection and delineation of the sentinel lymph node region

We screened the institutional picture and archiving system (PACS) for breast cancer patients, that underwent BCS and SLNB followed by postoperative RT of the breast between 2022 and 2025. Patients were excluded if there was any tumor infiltration in chest wall/skin or inflammatory breast cancer (T4) or if 4 or more lymph nodes were removed during SLNB [24]. After screening of 850 patients, 129 patients with early, clinically node-negative T1-T3 breast cancer undergoing SLNB with removal of 1–3 sentinel lymph nodes were included in the cohort. Based on the pre-operative staging CT and the planning-CT, the location of the former SLN was contoured manually for every patient in the Varian Eclipse® 16.1 treatment planning system (Varian Medical Systems, Palo Alto, CA, USA). This is shown in Fig. 1.

2.2. Accumulation of sentinel lymph node regions

In order to compare the location of SLN across different patients, a patient with average body mass index (BMI) and no anatomical abnormalities got selected as a reference anatomy (BMI 21.1 kg/m^2; breast size 576 ml). All 100 contoured SLN were automatically transferred to this single reference patient using a multi-step workflow of rigid and non-rigid image registration techniques. The implementation of the workflow in MATLAB2023b utilizes the open-source image registration algorithms *ANTS* (https://picsl.upenn.edu/software/ants/)-SyN (Version 2.5.4)- and the *plastimatch* (http://www.plastimatch.org) B-Spline (Version 1.9.4) algorithm to achieve the best 3D-transformation of the SLN to the reference patient. Right sided SLN were flipped to the left side by applying a transformation matrix inverting the x-axis of the CT-Volume. After 3D-transformation, every SLN localization was verified by two different radiation oncologists, which resulted in a sentinel lymph node atlas including 100 SLN from 100 different patients on one single reference patient CT.

2.3. Accounting for anatomical variations and radiation therapy techniques

After creation of this SLN atlas, 15 different template patients were selected using the following criteria:

- Five patients each with medial, central or lateral tumor localization.
- Within each group, the distribution of breast volume was balanced between small (<450 ml), medium (450–650 ml) and large (>650 ml) breasts.
- The distance between the upper border of the visible breast tissue and the humeral head was balanced between low (<2 cm), medium (2–4.5 cm) and high (>4.5 cm).

The SLN atlas was transferred to the deep inspiration breath-hold (DIBH) and free breathing (FB) CT of every template patient based on deformable image registration. Six different treatment plans for postoperative irradiation of the left breast were created for each of those 15 template patients (see Supplementary Fig. S1 for treatment plans for one patient):

- PBI in FB with volumetric modulated arc therapy [VMAT] (FB_PB_VMAT)
- PBI in FB with 3D-conformal radiation therapy [3D-CRT] (FB_PB_3D)
- PBI in VMAT in DIBH (DIBH_PB_VMAT)
- PBI in 3D-CRT in DIBH (DIBH_PB_3D)
- WBI in 3D-CRT in FB (FB_WB_3D)
- WBI in 3D-CRT in DIBH (DIBH_WB_3D).

The treatment technique was based on the specifications outlined in publications from the Florence trial for VMAT PBI [16] and on IMPORT LOW for 3D PBI [9]. Treatment planning was done for Varian TrueBeam® in Varian Eclipse® 16.1, using the Varian Acuros® XB 16.1 dose calculation algorithm.

Prescribed dose was a median dose of 40.05 Gy in 15 fractions to the whole or partial breast without inclusion of the locoregional lymphatic regions [9,25]. Whole breast and partial breast target volumes as well as locoregional lymphatic regions were delineated separately following ESTRO consensus guidelines [26,27].

2.4. Data export and statistical analysis

Dose-volume-histograms (DVH) of all 90 plans (15 template patients

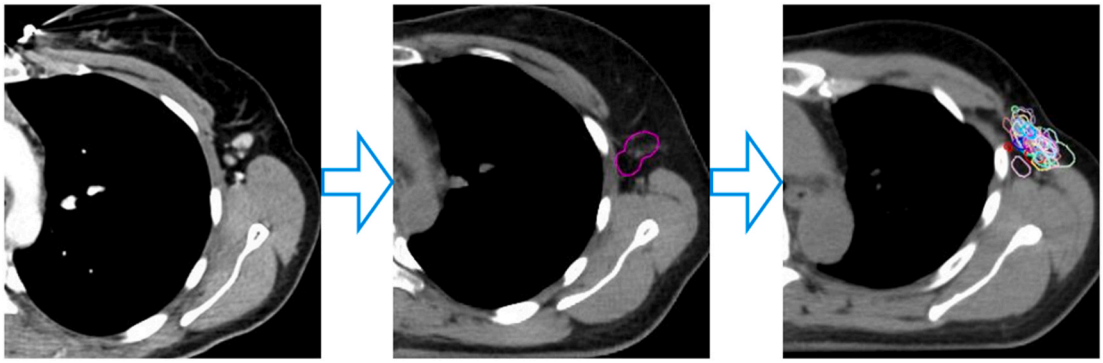

Fig. 1. Graphical illustration of methods for the sentinel atlas: 1. Location of sentinel lymph node(s) in pre-operative staging CT (left); 2. Determination and delineation of sentinel lymph node region (SLN) in post-operative planning CT (center; purple); 3. Accumulation of 100 SLN on standard template patient (right).

with 6 different treatment plans each) were exported including mean doses of every SLN (n = 9000 data points, sentinel atlas with 100 distinct SLN localizations from 90 plans) and the axillary levels I-III (+interpectoral) using an R package web application for DVH metrics [28]. Statistical analysis was performed using SPSS version 26.0 (IBM SPSS Statistics, Armonk, NY, USA) and GraphPad Prism software (version 10.2.3, GraphPad software Inc., San Diego, CA, USA).

The primary endpoint of this analysis was the difference in mean doses to the SLN and the axillary ESTRO levels between WBI and PBI. Second endpoints were differences in mean incidental doses between VMAT vs. 3D-CRT and in FB vs. DIBH, and the influence of additional criteria such as tumor site, breast volume and distance between the upper breast border and humeral head.

The differences were tested for statistical significance using the *t*-test and the Wilcoxon test. Statistical significance was defined as $P < 0.05$.

3. Results

The sentinel sample collective included 100 patients with a median age of 55 years. The postoperative tumor size was <2 cm in 87 %, the median number of removed sentinel lymph nodes was 2 with 87 % of patients being pN0. Further patient characteristics of the patients included for SLN definition are listed in Table 1.

3.1. Location of sentinel lymph node region

The spatial distribution of SLNs is demonstrated in Fig. 2 as a SLN atlas. Regarding the ESTRO lymph node levels, only 5 % of the defined SLN were completely outside of level I CTV based on the ESTRO contouring guideline [26]. Sixty-two percent of SLN were partially overlapping (10–90 %) with level I and 33 % of SLN were completely covered by level I.

3.2. Evaluation of dose to the sentinel lymph node region

Evaluation of the dose in the SLN revealed high dose coverage for the WBI plans, both in FB and DIBH (Table 2, Fig. 3). Specifically, 76 % of the SLN in FB and 68 % of the SLN in DIBH received a mean dose of at least 85 % of the prescribed dose, while 64 % in FB and 55 % in DIBH received a mean dose of at least 95 % of the prescribed dose.

For PBI on the other hand, incidental doses to the SLN were generally low (mean dose ≤10 Gy). The highest doses were observed for 3D PBI in FB with 15.3 % of SLN receiving ≥ 85 %. The doses in the SLN during VMAT PBI or DIBH were significantly lower, with only 3 % (VMAT FB) and 4 % (VMAT DIBH) of SLN receiving ≥ 95% of the prescribed dose. Likewise, differences between all other plans were statistically significant.

Stratification based on tumor site showed that lateral tumors resulted in higher SLN doses compared to medial tumors; the mean dose was still drastically lower compared to WBI (Fig. 4). This was also the case for stratification based on breast size and upper border of the breast.

Table 1
Patient characteristics of the sentinel sample collective (n = 100). (y)pT = postoperative tumor size, if applied after primary systemic therapy; HR+ = hormone receptor positive (either estrogen receptor and/or progesterone receptor positive); HER2- = Her2neu receptor negative; HER2+ = Her2neu receptor positive; TNBC = triple negative breast cancer.

Patient Characteristics		n
Sex	Female	100
Age (Years)	Median	55 (34–84)
(y)pT	0/is	7
	1	80
	2	12
	3	1
Tumor Site	Medial	22
	Central	27
	Lateral	51
Positive Sentinel Nodes	0	87
	1	12
	2	1
Resected Sentinel Nodes	1	39
	2	30
	3	31
Lymphatic invasion	No	95
	Yes	0
	Unknown	5
Vascular invasion	No	100
	Yes	0
Perineural invasion	No	95
	Yes	5
Molecular Subtype	HR+/HER2-	86
	HER2+	6
	TNBC	8
Grading	1	26
	2	62
	3	10
	Unknown	2

3.3. Evaluation of incidental dose to the axillary levels I-III

Evaluation of mean doses in the axillary levels I-III revealed large differences between WBI and PBI: the median of mean doses in Level I was 23.3 Gy (8.1–36.9; 58.1 % of the prescribed dose) and 20.6 Gy (5.6–38.8; 51.5 % of the prescribed dose) respectively for WBI in FB and DIBH. For PBI, the median of mean doses was <5 Gy in Level I irrespectively of FB vs. DIBH or irradiation technique (Table 2).

4. Discussion

This study on the incidental dose to the SLN in patients undergoing postoperative breast RT revealed two key findings:

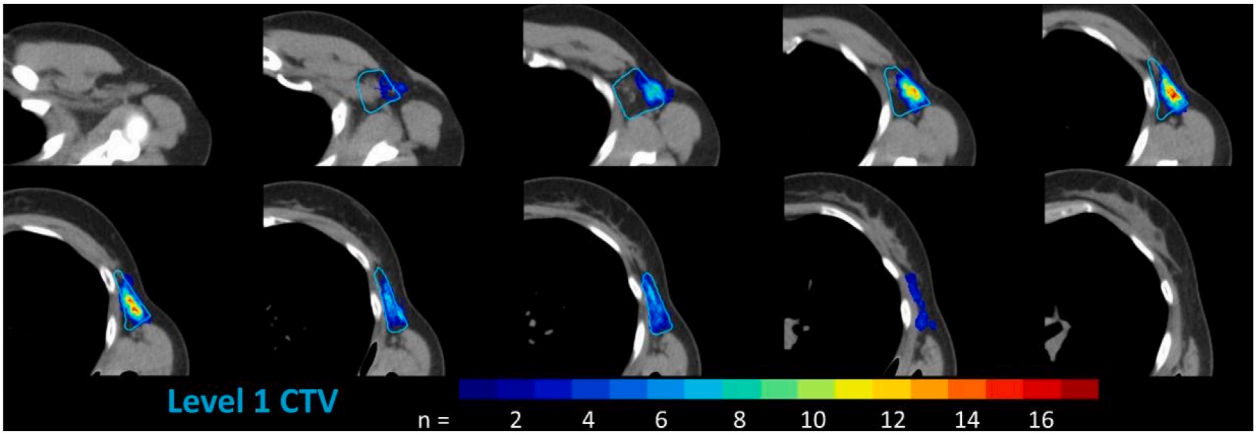

Fig. 2. Sentinel Lymph Node Atlas - Heat map indicating the absolute spatial frequency of transferred sentinel lymph node regions (SLN) within the axillary levels. Color intensity represents frequency — areas with higher concentrations of SLNs are marked with warmer colors (e.g., red/yellow), whereas regions with fewer transferred SLNs are marked with cooler colors (e.g., blue).

Table 2
Summary statistics of mean incidental doses to the axillary levels I-III and to the sentinel node region (SLN) described in percent of total prescribed dose for the primary target volume for each treatment plan. FB = free breathing; DIBH = deep inspiration breath-hold; PB = partial breast irradiation; WB = whole breast irradiation; 3D = tangential irradiation plans; VMAT = volumetric modulated arc therapy; SD = standard deviation; Q1 = first quartile; Q3 = third quartile.

Incidental doses	PBI				WBI	
	FB		DIBH		FB	DIBH
Axillary Level I mean dose (%)	FB_PB_3D	FB_PB_VMAT	DIBH_PB_3D	DIBH_PB_VMAT	FB_WB_3D	DIBH_WB_3D
Mean	9.06	11.26	6.89	11.29	62.05	55.56
SD	13.08	15.53	10.74	15.06	20.60	23.67
Median	1.05	5.49	0.95	6.52	58.10	51.49
Range	0.27–37.05	0.27–55.71	0.25–33.91	0.22–50.74	20.22–92.03	13.93–97.08
Q1-Q3	0.47–15.38	0.57–17.28	0.37–11.49	0.45–15.53	46.51–79.15	36.55–82.35
Axillary Level II mean dose (%)	FB_PB_3D	FB_PB_VMAT	DIBH_PB_3D	DIBH_PB_VMAT	FB_WB_3D	DIBH_WB_3D
Mean	3.52	5.24	2.92	5.79	39.50	40.35
SD	6.54	10.39	5.27	12.41	27.34	25.59
Median	0.75	0.95	0.72	0.92	28.51	37.60
Range	0.15–24.77	0.17–40.50	0.17–20.47	0.17–47.94	1.92–87.62	9.91–91.49
Q1-Q3	0.25–3.05	0.30–6.79	0.20–4.22	0.27–5.14	21.37–72.16	18.65–55.76
Axillary Level III mean dose (%)	FB_PB_3D	FB_PB_VMAT	DIBH_PB_3D	DIBH_PB_VMAT	FB_WB_3D	DIBH_WB_3D
Mean	0.50	0.82	0.50	0.97	11.66	15.18
SD	0.52	1.27	0.55	1.87	15.46	21.52
Median	0.42	0.50	0.40	0.50	4.12	3.02
Range	0.12–2.22	0.12–5.32	0.12–2.25	0.15–7.64	0.85–53.48	0.92–64.97
Q1-Q3	0.17–0.60	0.20–0.77	0.17–0.65	0.20–0.75	1.95–22.82	1.90–25.59
Sentinel Node Region Dose (%)	FB_PB_3D	FB_PB_VMAT	DIBH_PB_3D	DIBH_PB_VMAT	FB_WB_3D	DIBH_WB_3D
Mean	26.64	23.14	21.21	24.86	85.62	81.72
SD	36.35	29.19	31.96	29.71	26.29	28.04
Median	3.22	5.14	2.68	8.89	97.70	96.45
Range	0.12–41.76	0–102.60	0.10–106.09	0.10–102.70	1.02–104.32	0.90–104.27
Q1-Q3	0.80–49.76	0.77–42.05	0.72–31.84	0.77–42.92	87.64–100.17	72.03–99.60
% ≥ 95 %	10.0	3.33	7.40	4.40	64.0	55.8
% ≥ 85 %	15.33	5.20	9.87	6.67	76.53	68.73

First, the incidental dose to the SLN region during WBI was significantly higher than the dose delivered to the entire axillary level I. In both DIBH and FB techniques, the majority of SLNs received more than 95 % of the prescribed dose. This supports the hypothesis that incidental SLN irradiation may have contributed to the excellent locoregional control reported in recent trials such as INSEMA and SOUND.

Second, the incidental dose in the SLN during external PBI was consistently low. Depending on factors such as tumor location, breast size and the radiation technique used (3D-CRT vs. VMAT), only 3–10 % of SLNs received full therapeutic doses.

The extent and effect of incidental irradiation of the axillary region during WBI have been thoroughly examined in prior studies [22,29,30]. It is well established that the incidental dose distribution to the axilla during WBI is highly dependent on patient anatomy, field design, RT-technique, and target volume [30,31]. In the quality assurance cohorts of the INSEMA and BOOG trials, the mean dose to axillary level I was 67.6 % and 60 % of the prescribed dose, respectively [21,32]. In our study, similar mean values were observed for FB, supporting the generalizability of our dosimetric findings to clinical trial settings. Additionally, our study confirms previous reports that DIBH reduces axillary exposure [31] as mean doses to level I were 62.1 % in FB and 55.6 % in DIBH in our cohort.

In the context of omitting axillary lymph node dissection (ALND) following a positive SLNB [29], the radiation dose to the entire level I

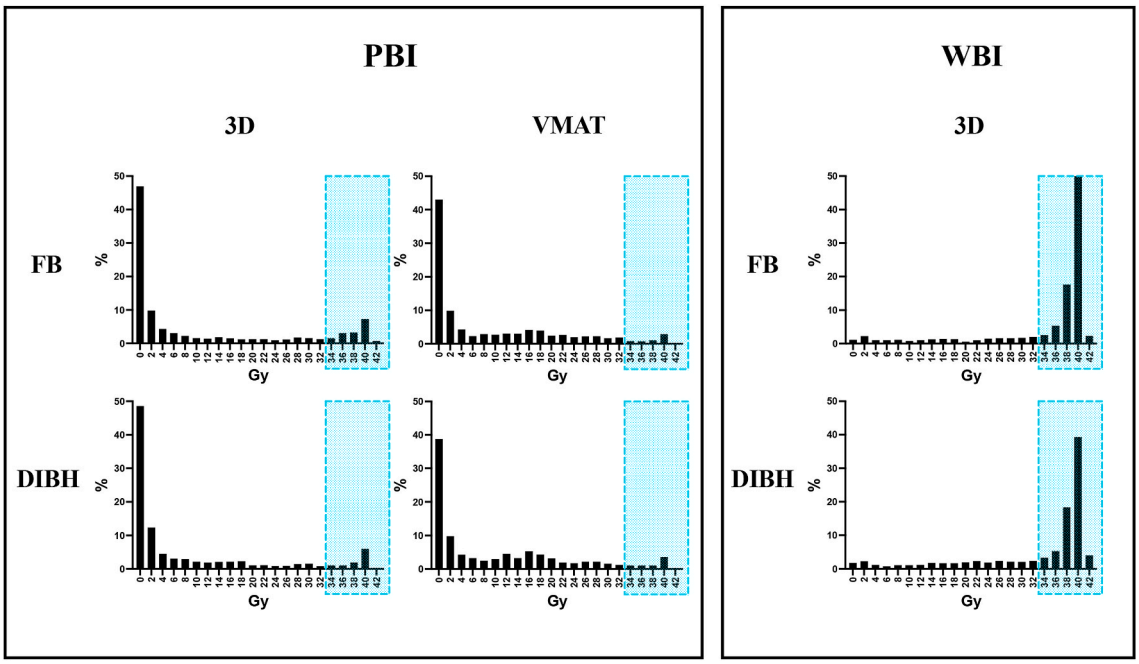

Fig. 3. Histogram showing the proportion of sentinel lymph node regions (SLN) (%) receiving a certain dose in Gy during whole breast irradiation (WBI) and partial breast irradiation (PBI) in free breathing (FB) and deep inspiration breath hold (DIBH). The blue box indicates the proportion of SLN that received at least 34 Gy (85 % of the prescribed dose). 3D = tangential irradiation plans; VMAT= Volumatic modulated arc therapy.

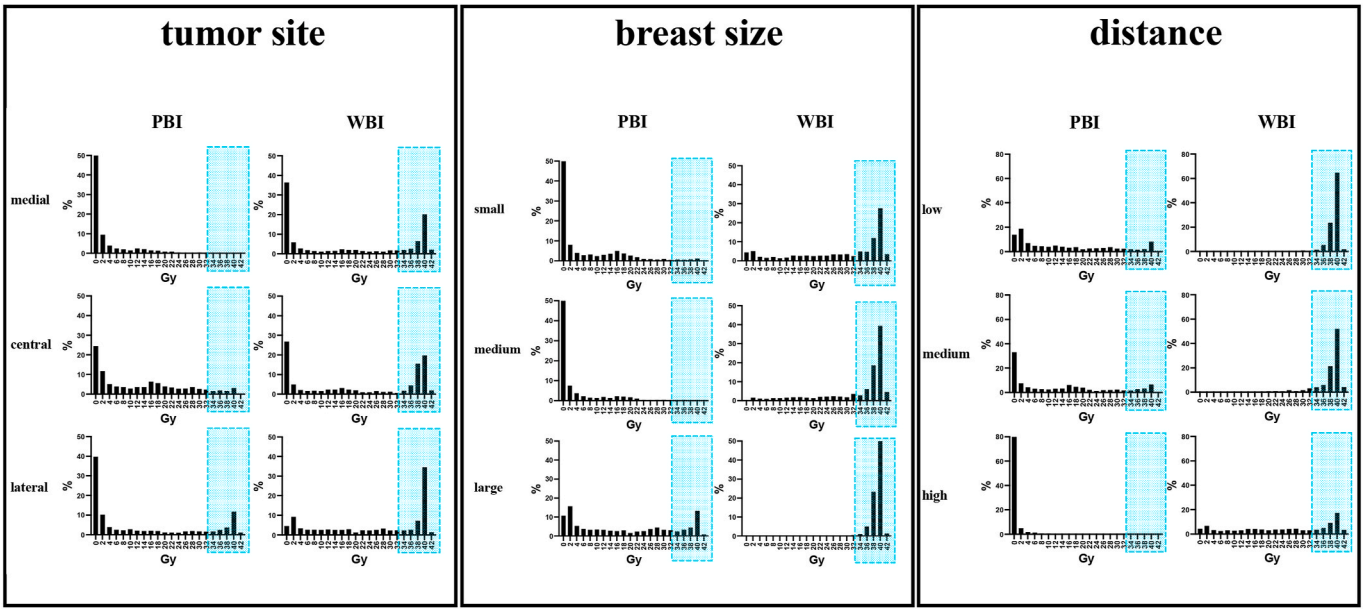

Fig. 4. Histogram showing the proportion of sentinel lymph node region (SLN) (%) receiving a certain dose in Gy for different treatment plan stratified for tumor site (left), breast size (central) and distance between the upper breast border and the humeral head (right) for whole breast irradiation (WBI) and partial breast irradiation (PBI) treatment plans. The blue box indicates the proportion of SLN that received at least 34 Gy (85 % of the prescribed dose).

axilla is of particular interest. However, after omission of SLNB, the dose to the (non-dissected) sentinel lymph node region becomes especially relevant, as this lymphatic region is at highest risk of harboring micro- or macroscopic residual disease.

Notably, in the INSEMA and SOUND trials, 11.6 % and 8.7 % of patients in the SLNB arms had macrometastases, yet axillary recurrence occurred in only 1 % and 0.4 % of patients in the no-SLNB arms, respectively [17,18]. This suggests that incidental dose coverage to the SLN region may have played a role in eradicating residual disease. Our results show that SLNs tend to cluster within a well-defined area of level I that receives substantially higher doses during WBI compared to the rest of the level. In fact, the majority of SLNs received full therapeutic dose coverage.

This observation is important, as studies have shown in different oncologic situations that postoperative radiation therapy may be effective even when macroscopic residual nodal disease is present [33–36]. Furthermore, evidence suggests that subtherapeutic doses may also have a cytotoxic effect on micrometastatic disease [22,37,38]. In our study, approximately two-thirds of SLNs received more than 85 % of the prescribed dose. Based on these findings, a reanalysis of the INSEMA and

BOOG trial datasets — either using our SLN atlas or a similar individualized contouring approach — may yield important insights into the clinical relevance of incidental SLN dose distribution.

The primary aim of our study was to analyze the incidental SLN dose during PBI. It should be emphasized that our analysis focused exclusively on external beam radiotherapy (EBRT) techniques. Although EBRT is widely used and readily available in clinical practice [39], brachytherapy (BT) and IORT are equally important but were not addressed in this study. Due to the steep dose gradients of both BT and IORT, it can be assumed that incidental doses in the SLN with BT or IORT are even lower than with conformal EBRT techniques such as VMAT [15,22], but this is beyond the scope of the current study.

Overall, SLN doses in external PBI plans were low in our cohort. However, still significant differences were observed between techniques: compared to VMAT, 3D-CRT plans resulted in substantially higher SLN dose coverage. In FB e.g., the differences were approximately threefold. This can be explained by the more conformal dose distribution during VMAT resulting in “steeper lateral dose gradient”, whereas in 3D-CRT PBI plans (using "mini-tangent" fields) often include a larger portion of the SLN region [9] (see Supplementary Fig. 1). The authors of the IMPORT Low trial already hypothesized that the treatment techniques (3D-CRT) used in that trial contributed to the excellent locoregional controls of PBI [9]. Even if there is evidence that lower doses may be sufficient to treat subclinical disease [37,38], it should be noted most SLN during PBI received very low doses of <6 Gy which are unlikely to have a positive oncologic effect.

The clinical relevance of incidental dose in the axillary region during PBI is underscored by meta-analyses reporting increased axillary recurrences in patients treated with PBI [10,11,40,41]. Although the absolute number of recurrences is low in randomized PBI trials [9,12,15,16,23], most patients in these trials were pathologically node-negative (pN0), and recurrence rates could be higher in cohorts with an estimated 10 % residual macroscopic disease. In the INSEMA trial, PBI was not permitted, and in the SOUND trial, only 11 % of patients underwent IORT [17,18,21]. However, dosimetric data and subgroup outcomes for IORT in the SOUND trial remain unpublished, limiting definitive conclusions about the safety of combining PBI with SLNB omission.

A randomized clinical trial investigating the combination of SLNB omission and PBI is unlikely to be available in the near future. Until more robust data are available, our findings suggest that combining SLNB omission with PBI should be approached with caution. Our results support the recent recommendations by the DEGRO Breast Cancer Expert Panel [42], which advise against routine use of PBI in patients who forgo SLNB. Incidental irradiation of the SLN during PBI is minimal, and relying solely on endocrine therapy for macroscopic nodal disease may be insufficient.

Randomized trials have shown that endocrine therapy alone, even after surgery with negative margins and pN0 status, is associated with a tenfold increase in local recurrences at 10 years, with the steepest rise observed after 5 years [4] — the approximate follow-up duration of the SOUND and INSEMA trials. Furthermore, studies evaluating the effectiveness of endocrine therapy alone in patients with macroscopic breast cancer have reported a median progression-free survival of only 50 months [43]. Adherence to endocrine therapy also varies considerably, with some studies reporting compliance rates of less than 50 % at 5 years [44]. However, these concerns are not yet supported by solid clinical evidence specifically in the context of SLNB omission, and the role of incidental RT may be less significant than assumed by the authors. To better understand the true impact of postoperative treatment in the setting of SLNB omission, the following steps would be valuable:

- An individualized analysis of SLN coverage in the BOOG, INSEMA, and SOUND trials correlated with regional recurrence rates and long-term outcomes beyond endocrine therapy.
- Subgroup analyses of patients who received IORT in the SOUND trial or were excluded from the primary analyses in INSEMA due to not receiving WBI.
- Oncologic outcome analysis in forthcoming trials such as EUROPA [45], which investigates PBI as a potential alternative to endocrine therapy and permits SLNB omission.

Until then, rather than a one-size-fits-all solution, individualized treatment decisions based on patient risk factors and preferences are likely most appropriate. For example, patients with cardiac comorbidities may benefit from SLNB followed by PBI, while patients at risk of lymphedema or with pre-existing shoulder dysfunction may prefer SLNB omission with WBI. In elderly patients with limited life expectancy, endocrine therapy alone—without SLNB or RT—may also be considered, accepting an elevated risk of local recurrence. Further studies are warranted to define the optimal combinations of de-escalated treatments and to identify patient populations who derive the greatest benefit.

A key limitation of our study is the potential inaccuracy in localizing the SLN. Although all 100 SLNs were identified after thorough review of preoperative CT scans and contouring was verified by two experienced radiation oncologists, some degree of uncertainty remains. However, the sample size and consistent methodology reduce the likelihood that any individual mislocalization significantly affected the overall results or conclusions.

5. Conclusion

Our findings indicate that the incidental radiation dose to the SLN and axillary lymph node levels during external beam PBI is negligible in the vast majority of cases. WBI on the other hand, which was predominantly used in the INSEMA and SOUND trials, results in therapeutic dose coverage to the SLN in approximately ¾ of cases. Given these results, the combined approach of SLNB omission and PBI should currently not be considered a standard treatment strategy for patients with early-stage breast cancer. Further studies are needed to answer this question.

CRediT authorship contribution statement

Sophie T. Behzadi: Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rebecca Moser:** Writing – review & editing, Validation, Project administration, Methodology, Data curation, Conceptualization. **Mathias Düsberg:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Maximilian Aigner:** Writing – review & editing, Validation, Formal analysis, Data curation. **Jana Nano:** Writing – review & editing, Validation, Formal analysis. **Sophia Kiesl:** Writing – original draft, Validation. **Jacqueline Lammert:** Writing – review & editing, Validation. **Evelyn Klein:** Writing – review & editing, Validation. **Georg P. Schmidt:** Writing – review & editing, Validation. **Marion Kiechle:** Writing – review & editing, Validation. **Thomas Huber:** Writing – review & editing, Validation. **Stefanie Corradini:** Writing – review & editing, Validation. **Stephanie E. Combs:** Writing – review & editing, Validation, Supervision. **Kai J. Borm:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Data sharing statement

Research data are stored in an institutional repository and will be shared upon request to the corresponding author.

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Declaration of competing interests

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.breast.2025.104523.

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