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ORIGINAL ARTICLE

Reducing Radiotherapy Risks for Breast Cancer Patients Using "Breast Cup Fixation": A Comparative Study

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OBJECTIVE

Breast-conserving therapy (BCT), including lumpectomy followed by radiation therapy (RT), is a standard treatment for early-stage breast cancer. In patients with large, pendulous breasts, traditional supine positioning can increase treatment field size and elevate radiation doses to critical organs. This study evaluates the effectiveness of breast cups in improving RT outcomes in such cases.

METHODS

Simulations and treatment plans were performed with and without the Alderson Treatment Brassiere, a transparent plastic breast cup designed to shape the breast and reduce field expansion. Dosimetric parameters were compared between setups.

RESULTS

Eighteen patients with large, pendulous breasts were included. Use of the breast cup significantly reduced radiation doses to organs at risk, including the lungs and heart. Statistically significant reductions were observed in lung NTCP ($p=0.001$), mean lung dose ($p<0.001$), V20 and V5 (both $p<0.001$), heart NTCP ($p=0.008$), mean heart dose ($p<0.001$), heart V25 ($p<0.001$), and LAD dose ($p=0.008$). Target coverage remained similar; however, boost D95 ($p=0.033$) and TCP ($p=0.001$) improved.

CONCLUSION

Breast cups may enhance RT precision by improving target conformity and reducing critical organ exposure. Further validation with larger cohorts and modern techniques is warranted.

Keywords: Alderson treatment brassiere; breast cup; breast conservation therapy; immobilization; radiotherapy.

INTRODUCTION

Early-stage breast cancer diagnoses have increased due to widespread screening programs, leading to improved survival rates through early detection and treatment.[1] Breast-conserving therapy (BCT), which involves lumpectomy followed by whole breast radiotherapy (RT), is the standard treatment for these cases.[2] Whole breast RT (WBRT) is typically administered post-surgery, often with a boost to the surgical cavity and lymph node irradiation when necessary.[3] However, traditional supine positioning during RT presents challenges for patients with large, pendulous breasts, due to infra-mammary folds and tissue displacement. These factors contribute to expanded irradiation fields and increased doses to critical organs, such as ipsilateral lungs, heart in left-sided irradiation or the liver in right-sided cases.[4]

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A significant clinical gap exists in optimizing RT positioning for patients with large or pendulous breasts. Various immobilization techniques—such as thermoplastic shells, adhesive tape, and wireless bras—have been introduced to improve positioning. However, these methods have limitations in standardization, reproducibility, and patient comfort. While prone positioning and deep inspiration breath-hold (DIBH) techniques can reduce radiation exposure to critical organs, their complexity and setup reproducibility limit adoption in clinical practice.[5]

To enhance dose conformality and reduce organ exposure, advanced RT techniques such as intensity-modulated RT (IMRT) and volumetric arc therapy (VMAT) have been implemented. For left-sided breast irradiation, DIBH increases lung volume, creating additional separation between the breast and heart, thereby reducing radiation exposure. However, standardization challenges remain, particularly in cases requiring lymph node irradiation.[6]

A systematic review by Probst et al.[7] evaluated different immobilization methods, including thermoplastic shells, adhesive tape, wireless bras, breast rings, stockings, vacuum bags, and L-shaped breast plates. Among these, breast cups have been proposed as a practical, reproducible solution for minimizing treatment field expansion and reducing radiation exposure in supine positioning. By stabilizing the breast within a fixed structure, breast cups improve dosimetric accuracy, treatment reproducibility, and organ sparing, offering an effective alternative to prone positioning. Breast cups can also be coupled with DIBH techniques and enhance dosimetric outcomes even more.

This study evaluates the dosimetric impact of breast cups in breast cancer patients undergoing RT, focusing on their role in minimizing critical organ exposure, improving target dose conformity, and enhancing treatment reproducibility.

MATERIALS AND METHODS

In this study the Alderson Treatment Brassiere (CIVCO RT, Iowa, USA) was utilized, referred to as the "breast cup" for simplicity (Fig. 1). These breast cups are transparent, semi-rigid plastic devices made of Polyethylene Terephthalate Glycol (PETG). Their thickness varies from 0.50 mm for small cups to 0.63 mm for large cups.

The breast cups are classified into four size groups and are designed for separate use on the left and right breasts. Each cup is labeled according to size group (S, M, L, XL), body side (R or L). Breast cup selection was based on the patient's chest breadth (ranging from 27 cm to over 42 cm), with additional markings on the patient's skin to ensure consistent positioning. Small holes in the medial, lateral, and superior areas of the cup flange are used to mark these reference points.

Patients were positioned on a supine breast board with the ipsilateral arm raised. Two sets of CT images were acquired: One with the breast cup and the other without the breast cup.

RT plans were generated for both conditions. If the radiation doses exceed normal tissue tolerances without the breast cup, the patient was treated using the breast cup.

The appropriate cup size was selected based on chest breadth, and the strap lengths were adjusted to provide

Fig. 1. Alderson treatment brassiere (CIVCO RT, Iowa USA).

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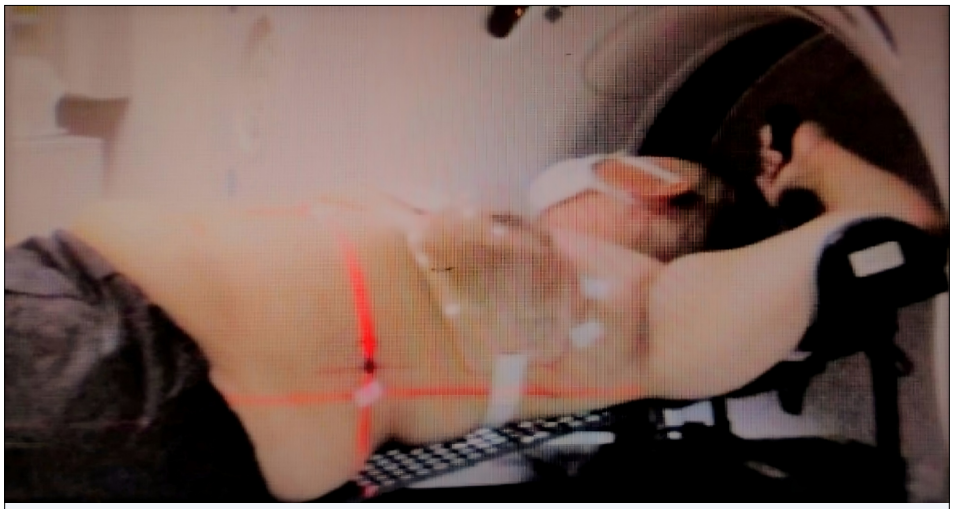

Fig. 2. Typical setup of the breast cups.

full coverage. The straps also exerted gentle pressure on the contralateral breast, helping to move it out of the radiation field. Markings were applied to indicate the inner and outer limits of the cup, along with strap attachment points, ensuring repeatable positioning (Fig. 2).

Target volumes and organs at risk (OARs) were delineated according to the RTOG atlas consensus guidelines for breast radiotherapy. The clinical target volume (CTV) included the whole breast and, when indicated, the regional lymph node levels (I–III), supraclavicular fossa, and internal mammary chain. A formal planning target volume (PTV) was not generated in accordance with the RTOG atlas; however, for consistency with existing literature, the target parameters were referred to as PTV50 and PTV95% throughout the manuscript.

Patients were treated using conventional inner and outer tangential fields with field-in-field RT. The whole breast received a dose of 50 Gy in a conventional fractionation scheme of 2 Gy per fraction. The boost dose to the surgical cavity ranged from 10 to 16 Gy, depending on the surgical margin status. The Boost Planning Target Volume (Boost PTV) was created by adding a 0.7–1 cm margin around the seroma, clips, and cavity contoured as Boost CTV.

Nodal irradiation to the supraclavicular fossa and axillary levels 1, 2, and 3 was administered using a conventional scheme of 2 Gy per fraction, totaling 50 Gy.

The study was approved by the Antalya Training and Research Hospital ethics committee under the rules of Helsinki Convention.

Statistical Analysis

Data was analyzed using the Shapiro-Wilk test to assess normality. Continuous variables were summarized as mean ± standard deviation for normally distributed data and as median (IQR: 25^{th}–75^{th} percentile) for non-normally distributed data. Wilcoxon Signed Ranks test and Paired Samples t-test were used to compare dosimetric differences between treatment plans with and without the breast cup. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY). A two-sided p-value of <0.05 was considered statistically significant.

RESULTS

This study included eighteen breast cancer patients with pT1-3 and N0-2 disease. Among them, five patients received whole breast irradiation, while the remaining thirteen required both lymph node and whole breast irradiation. After simulation in the standard supine position, patients with large, pendulous breasts who did not meet lung and/or heart dosimetric criteria were selected for inclusion. Treatments were performed between 2020 and 2023 in the Radiation Oncology Department of Antalya Training and Research Hospital, following simulation and treatment planning procedures. Of the 18 patients, two were treated for right-sided breast cancer, and 16 for left-sided breast cancer.

In this study, PTV50 refers to the planning target volume receiving 50 Gy, which includes the whole breast and regional lymphatics when applicable. PTV95% indicates the volume receiving at least 95% of the prescribed dose. Boost represents the planning target volume of the surgical cavity, typically receiving an additional 10–16 Gy. MI denotes the internal mam-

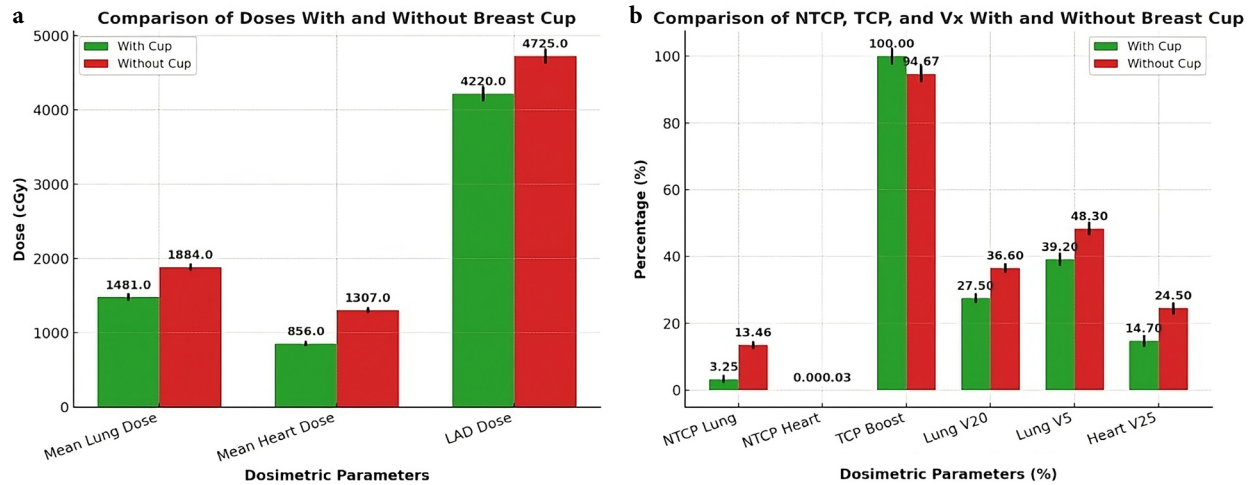

Fig. 3. Comparison of dosimetric parameters with and without breast cup. (a) Comparison of doses (cGy) with and without breast cup. omparison of NTCP, TCP and Vx with and without breast cup. (b) Comparison of NTCP, TCP and Vx with and without breast cup.
NTCP: Normal tissue complication probability; TCP: Tumor control probability.

mary chain target volume when included. Organs at risk (OARs) were delineated, including the ipsilateral lung, contralateral breast, liver, heart, and left anterior descending artery (LAD).

All treatment plans were calculated to meet target coverage criteria. Additionally, Tumor Control Probability (TCP) and Normal Tissue Complication Probability (NTCP) values were calculated using the Lyman–Kutcher–Burman (LKB) model, which estimates complication probability based on the dose–volume histogram (DVH) data of each organ. For TCP, the Poisson statistics-based model using the equivalent uniform dose (EUD) method was applied.

Figure 3 and Table 1 presents the dosimetric differences observed with and without the breast cup. Target dosimetric values remained statistically similar for SCF (p=0.812), Level 1 (p=0.473), Level 2 (p=0.847), Level 3 (p=0.987), PTV50 (p=0.872), PTV 95% (p=0.124), Boost (p=0.098) and MI (p=0.721).

Although contralateral breast dose was reduced with the use of the breast cup, the differences were not statistically significant. Contralateral breast D2 (near-maximum dose, minimum dose encompassing 2% volume): p=0.306 and, contralateral breast V5 (volume receiving 5 Gy): p=0.554.

However, the breast cup demonstrated significant improvements in key dosimetric parameters:

Reductions in lung dose:

- Mean lung dose: 1481±264 cGy with cup vs. 1884±315 cGy without (p<0.001).
- Lung V5: 39.2±7.9 % vs. 48.3±7.3 % (p<0.001).
- Lung V20: 27.5±5.0 % vs. 36.6±7.0 % (p<0.001).
- NTCP Lung: 3.25 (1.11–6.07) vs. 13.46 (10.27–34.67) (p=0.001).

Reductions in Heart Dose:

- Heart mean dose: median 856 cGy (523–947) vs. 1307 cGy (1056–1594) (p<0.001).
- Heart V25: 14.7% (8.9–16.9) vs. 24.5% (19.6–32.8) (p<0.001).
- Mean LAD Dose: median 4220 cGy (3057–4625) vs. 4725 cGy (4483–4871) (p=0.008).
- NTCP Heart: 0 vs. 0.03 (0–5.1) (p=0.008).

Reduction in Normal Tissue Dose:

- Normal tissue mean dose: Median 260 cGy (204–299) vs. 306 cGy (262–360) (p=0.001).

Target Coverage improvements:

- Boost D95: 5967±422 cGy vs. 5884±489 cGy (p=0.033).
- TCP Boost: Median 100 vs. 94.67 (70.18–97.6) (p=0.001).

DISCUSSION

Breast cups offer several benefits for managing large, pendulous breasts during RT. By supporting and reshaping the breast, they help to limit tissue movement, reduce infra-mammary folds, and improve dose distribution. This results in more consistent target coverage,

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Table 1 Dosimetric results from both sides (Maximum contributing patients n=18)

Parameters	n	with Cup	w/o Cup	p
SCF (cGy)	13	4952±90	4939±154	0.812
Level 1 (cGy)	13	4682±165	4653±168	0.473
Level 2 (cGy)	13	4805±124	4796±168	0.847
Level 3 (cGy)	13	4740±102	4741±124	0.987
MI mean (cGy)	10	4650 (3968–5048)	4627 (4495–4840)	0.721
PTV D50 (cGy)	18	5017±63	5020±65	0.872
PTV D95 (cGy)	18	4690±98	4627±178	0.124
Boost (cGy)	13	6207±253	6165±304	0.098
Boost D95 (cGy)	13	5967±422	5884±489	**0.033**
TCP boost	13	100	94.67 (70.18–97.6)	**0.001**
NTCP ipsi lunge	18	3.25 (1.11–6.07)	13.46 (10.27–34.67)	**0.001**
Ipsi lung mean (cGy)	18	1481±264	1884±315	**<0.001**
Ipsi lung V20 (%)	18	27.5±5.0	36.6±7.0	**<0.001**
Ipsi lung V5 (%)	18	39.2±7.9	48.3±7.3	**<0.001**
Contra breast D2 (cGy)	18	572 (543–1377)	759 (471–3663)	0.306
Contra breast V5 (%)	18	0.09 (0–0.59)	0.16 (0.02–1.11)	0.554
Heart mean (cGy)	16	856 (523–947)	1307 (1056–1594)	**<0.001**
NTCP heart	16	0	0.03 (0–5.1)	**0.008**
Heart V25 (%)	16	14.7 (8.9–16.9)	24.5 (19.6–32.8)	**<0.001**
LAD mean (cGy)[g]	16	4220 (3057–4625)	4725 (4483–4871)	**0.008**
Normal tissue mean (cGy)	18	260 (204–299)	306 (262–360)	**0.001**

Values are expressed as means±standard deviation or median (IQR). Paired Samples t-test, Wilcoxon Signed Ranks test. p-value below 0.05 is considered statistically significant and highlighted in bold font. SCF: Supra clavicular fossa; MI: Mammaria Interna; PTV D50: Planning tumor volume, minimum dose encompassing 50% volume; TCP: Tumor control probability; NTCP: Normal tissue complication probability; Ipsi Lung V20: Ipsilateral lung, volume receiving 20 Gy; LAD: left anterior descending artery

especially in the boost and breast areas, where we observed improved dose conformity. Although statistical significance was only noted in the boost D95 and TCP boost parameters, these results may become more robust with larger patient groups.

Compared to prone positioning—which requires special equipment and trained staff—breast cups offer a more accessible solution while maintaining reproducibility. In our study, breast cups narrowed the beam eye view and lifted the radiation fields away from the chest wall, effectively reducing doses to the heart and ipsilateral lung. Although decreases were also seen in the liver and contralateral breast doses, these were not statistically significant, likely due to the small sample size. Nonetheless, the overall reduction in spillage dose suggests a lowered risk of secondary cancer, aligning with earlier observations.[8]

The treatment of women with larger or pendulous breasts poses unique challenges, especially in supine positioning, where the breast can shift laterally or upward. This often increases lung exposure and leads to dose heterogeneity and hot spots. Previous studies have linked these variations to breast volume, body weight, and chest wall separation, the latter being the most influential.[9,10] Breast cups address these challenges by creating a more uniform, round-shaped target and displacing the contralateral breast from the radiation field.

Concerns about patient discomfort or the need for manual adjustment have been raised,[11] but our findings showed high tolerability. Patients reported no discomfort during treatment, and follow-ups revealed excellent cosmetic outcomes with only grade 1 skin toxicity.

Our results are consistent with emerging evidence that dedicated immobilization solutions can significantly improve dosimetry and setup reproducibility in women with large or pendulous breasts undergoing radiotherapy. In a recent study, the use of a radiation-bra device significantly reduced breast volume as well as mean lung and heart doses in planning comparisons.[12] A Randomised Clinical Feasibility Trial of a Breast Immobilisation Device: The SuPPORT 4 All Bra demonstrated the feasibility of a custom S4A bra, showing improved patient comfort and dose parameters compared with standard care.

[13] In 2023, a study evaluating the Chabner XRT® Radiation Bra in 34 patients reported excellent setup reproducibility (median isocenter shift ≈ 0 cm) and minimal skin toxicity.[14] Furthermore, a 2022 study protocol on supine breast positioning described the use of the Carbon Fiber Adjustable Reusable Accessory (CARA) support device and outlined a phase III evaluation specifically for large or pendulous breasts, underscoring the growing clinical interest in this area.[15] In 2024, a case-based report documented the use of a dedicated breast cup and demonstrated lower mean heart doses in left-sided cases without compromising cosmetic or pain outcomes.[16] The Chabner bra was shown to produce significant reductions in lung and heart doses (e.g., approximately 7% decrease in mean lung dose and 9% decrease in heart V10Gy) in patients with large breasts.[17] From a clinical standpoint, breast cups support consistent positioning and dose delivery, making them a practical tool in RT.[18]

Taken together, our findings build upon this growing body of evidence by presenting both dosimetric and TCP/NTCP modeling results using a breast cup device in a cohort of patients with pendulous breasts following breast-conserving surgery. The consistency of reductions in heart and lung exposure, along with the associated potential for improved normal tissue complication probability (NTCP) and tumor control probability (TCP), supports further prospective research and encourages routine clinical implementation of such immobilization techniques in appropriately selected patients.

The breast cups could also be integrated smoothly into modern RT protocols, including IMRT, VMAT, and DIBH. Their potential role in adaptive RT and compatibility with automated contouring and image-guided protocols could further highlight their value in personalized care.

CONCLUSION

Breast cups provide significant dosimetric benefits for patients with pendulous breasts by reducing critical organ exposure, ensuring reproducibility, and enhancing target coverage. Their use minimizes infra-mammary folds, decreases total irradiation area, and dose to organs at risk. Additionally, they improve patient comfort and cosmetic outcomes. Further research with expanded patient cohort and advanced RT techniques will help solidify their role in modern RT.

Ethics Committee Approval: The study was approved by the Antalya Training and Research Hospital Clinical Research Ethics Committee (no: 3/1, date: 16/02/2023).

Informed Consent: All patients gave consent to participate after being individually informed. All patient identifiers and data were anonymized.

Conflict of Interest Statement: The authors declare no conflict of interest.

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