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ORIGINAL RESEARCH

Positional Stability in Breast Cancer Radiotherapy: Assessing the Effect of Thermoplastic Immobilization Casts

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Abstract

Purpose: Adjuvant external beam radiotherapy (EBRT) plays a pivotal role in the management of breast cancer by reducing the risk of local recurrence and improving disease-free survival following surgery. Accurate radiation delivery depends on reproducible patient positioning throughout treatment. Thermoplastic immobilization casts are commonly used to enhance setup reproducibility; however, their routine use remains controversial. This study aimed to evaluate the effect of thermoplastic immobilization casts on positional stability during adjuvant EBRT for breast cancer patients. **Methods:** This prospective comparative study included 30 patients with histologically confirmed breast cancer who had undergone either modified radical mastectomy (MRM) or breast-conserving surgery (BCS) and subsequently received adjuvant radiotherapy between May 2023 and December 2024. Patients were randomly assigned to two treatment arms. In Arm A, simulation and treatment were performed using thermoplastic immobilization casts, whereas in Arm B, patient positioning relied solely on skin markings without cast immobilization. Daily cone beam computed tomography (CBCT) was used for image-guided verification and correction of setup errors along the X (lateral), Y (longitudinal), and Z (vertical) axes before each treatment fraction. Positional variations were recorded and compared between the two groups. **Results:** A statistically significant reduction in lateral (X-axis) setup variation was observed in patients treated with thermoplastic casts compared with those treated without casts ($p = 0.02$). No significant differences were identified in the Y- or Z-axis setup variations between the two groups. Within Arm B, patients who underwent breast-conserving surgery exhibited significantly greater longitudinal (Y-axis) variation than those treated with modified radical mastectomy ($p = 0.04$). This difference was not observed in Arm A. In the non-cast group, body weight and body mass index (BMI) demonstrated moderate positive correlations with X-axis variation ($r = 0.48$ and $r = 0.50$, respectively), suggesting increased lateral setup deviations among heavier patients. No significant correlations were identified in the cast group. **Conclusion:** Routine use of thermoplastic immobilization casts may not be necessary for all patients undergoing adjuvant breast radiotherapy. However, their use appears beneficial for patients undergoing breast-conserving surgery and for those with a higher BMI, as they improve setup reproducibility and may enhance treatment accuracy.

Keywords: Breast cancer, External beam radiotherapy, Thermoplastic immobilization, Cone beam computed tomography

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Introduction

Breast cancer is the most frequently diagnosed malignancy among women worldwide and remains a major public health concern. According to the GLOBOCAN 2022 estimates, approximately 2.3 million new cases of breast cancer were diagnosed globally, corresponding to an age-standardized incidence rate of 47.8 per 100,000 women [1]. In India, breast cancer has become the leading cancer among women, with recent national data indicating that approximately 70% of patients are diagnosed at an early stage, whereas nearly 22% present with locally advanced disease [2]. Established risk factors include increasing age, female sex, family history, inherited genetic mutations (particularly *BRCA1* and *BRCA2*), obesity, prolonged exposure to endogenous

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or exogenous estrogen, early menarche, late menopause, nulliparity, and delayed childbearing.

Advances in screening programs, imaging techniques, surgical management, systemic therapies, and radiotherapy have substantially improved survival outcomes among patients with breast cancer. Consequently, increasing attention has been directed toward optimizing treatment precision, minimizing radiation-related toxicity, and improving patient comfort throughout the treatment course.

Adjuvant external beam radiotherapy (EBRT) is an integral component of multidisciplinary breast cancer management. It significantly reduces the risk of local recurrence and improves disease-free and overall survival following breast-conserving surgery and in selected patients undergoing modified radical mastectomy (MRM), particularly those with large primary tumors, lymphovascular invasion, or nodal involvement [3- 5]. The effectiveness of EBRT depends on accurate and reproducible patient positioning throughout the treatment course to ensure adequate target coverage while minimizing radiation exposure to organs at risk (OARs), including the heart, lungs, and contralateral breast.

Because breast anatomy, respiratory motion, and daily patient positioning contribute to treatment uncertainty, various immobilization techniques have been developed to improve setup reproducibility. Commonly used devices include breast boards, vacuum cushions, arm supports, and thermoplastic immobilization casts. Although thermoplastic casts are widely used to reduce setup errors, they may also increase patient discomfort, anxiety, treatment preparation time, and overall resource utilization. Furthermore, recent studies have questioned whether rigid thermoplastic immobilization provides clinically meaningful improvements in positioning accuracy compared with simpler immobilization methods, particularly in the era of image-guided radiotherapy (IGRT) [6- 8]. Modern technologies such as daily cone beam computed tomography (CBCT), laser-guided positioning, indexed treatment couches, and surface-guided radiation therapy (SGRT) allow real-time correction of setup deviations, potentially reducing the need for rigid immobilization devices.

Despite these technological advances, evidence regarding the routine use of thermoplastic immobilization casts during adjuvant breast radiotherapy remains limited and inconsistent, especially in resource-constrained clinical settings. Determining whether these devices provide measurable improvements in setup accuracy is important for optimizing patient comfort, workflow efficiency, and treatment quality.

Therefore, this prospective comparative study aimed to evaluate the effect of thermoplastic immobilization casts on setup reproducibility during adjuvant external beam radiotherapy for breast cancer. Positional variations measured by daily cone beam computed tomography were compared between patients treated with and without thermoplastic cast immobilization to determine the clinical value of routine cast use and to identify patient subgroups that may derive the greatest benefit.

Materials and Methods

This prospective, randomized, two-arm comparative study was conducted to evaluate the effect of thermoplastic immobilization casts on setup reproducibility during external beam radiotherapy (EBRT) for breast cancer patients. Eligible participants were consecutively recruited from the Department of Radiation Oncology between May 1, 2023, and December 31, 2024.

Patients were eligible if they had histologically confirmed breast cancer, had undergone either modified radical mastectomy (MRM) or breast-conserving surgery (BCS), and were scheduled to receive adjuvant EBRT. Exclusion criteria included a previous history of thoracic radiotherapy, inability to maintain the treatment position, allergy to tattoo ink, or refusal to provide informed consent.

After enrollment, patients were allocated to one of two treatment arms by simple randomization. Arm A patients underwent CT simulation and treatment using individualized thermoplastic immobilization casts, whereas Arm B patients received treatment without thermoplastic immobilization using conventional skin markings for positioning. In both groups, patients were positioned supine on an indexed breast board with both arms elevated above the head using arm supports or cushions to ensure comfort and reproducibility. For patients in Arm A, a customized thermoplastic cast was molded over the thoracic region and laser reference marks were placed on the cast surface. In Arm B, laser alignment points were marked directly on the patient's skin.

Computed tomography (CT) simulation was performed without intravenous contrast using slice thicknesses of either 2.5 mm or 5 mm, extending from the angle of the mandible to the upper border of the first lumbar vertebra. Target volume delineation followed the Radiation Therapy Oncology Group (RTOG) contouring guidelines. The clinical target volume of the breast or chest wall (CTV-P) was contoured according to the surgical procedure performed. For node-positive patients, the supraclavicular nodal region (CTV-N) was delineated according to institutional protocols. In patients treated with breast-conserving surgery, the tumor bed was identified using surgical clips and contoured separately for boost irradiation.

Planning target volumes (PTVs) were generated by applying a uniform 7-mm expansion to the breast or chest wall CTV, followed by a 3-mm contraction from the external skin surface. A 5-mm expansion was applied to the supraclavicular nodal CTV. Organs at risk (OARs), including the ipsilateral lung, contralateral lung, heart, contralateral breast, and spinal cord, were contoured for all patients.

Treatment plans were generated using either the Monaco or Eclipse treatment planning systems with 6-MV photon beams. Patients received a hypo fractionated prescription dose of 40 Gy in 15 fractions delivered once daily, five fractions per week. Patients who underwent breast-conserving surgery subsequently received a sequential tumor bed boost of 10 Gy in five fractions.

Daily image-guided radiotherapy (IGRT) was performed using cone-beam computed tomography (CBCT) before each treatment fraction. Positional deviations were measured along the lateral (X), longitudinal (Y), and vertical (Z) axes. Required couch corrections were applied before radiation delivery, and the magnitude of each translational shift was recorded. The collected setup error data were subsequently compared between the two treatment arms to determine whether thermoplastic immobilization improved setup reproducibility.

Statistical analyses were performed using IBM SPSS Statistics version 19.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation (SD), whereas categorical variables are expressed as frequencies and percentages. Between-group comparisons were performed using the independent-samples t-test. Pearson's correlation coefficient was used to examine associations between setup errors and patient characteristics such as body weight and body mass index (BMI). All statistical tests were two-sided, and a P value < 0.05 was considered statistically significant.

Results

A total of 30 patients were enrolled and equally allocated to the two study arms (15 patients per arm). Baseline demographic and clinical characteristics are summarized in Table 1 and 2. The majority of patients (43.3%) were between 40 and 49 years of age. Overall, 20 patients (66.7%) underwent modified radical mastectomy (MRM), whereas 10 patients (33.3%) underwent breast-conserving surgery (BCS).

Most participants weighed between 60 and 69 kg (43.3%). According to the World Health Organization (WHO) body mass index (BMI) classification, 46.7% of patients were overweight and 23.3% were obese. No statistically significant differences were observed between the two treatment arms regarding age, body weight, height, breast volume, BMI, or type of surgery, indicating good baseline comparability.

Table 1. Baseline Demographic And Clinical Characteristics of the Study Population (N = 30)

Characteristic	Value
Age, years, median (range)	51 (31–76)
Weight, kg, median (range)	64.1 (46.4–94.7)
Body mass index (BMI), kg/m², median (range)	26.95 (19.6–39.4)
Breast volume in post-BCS patients (cm³), median (range)	821.8 (484–1112.6)
Surgery, n (%)	
Modified radical mastectomy (MRM)	20 (66.7)
Breast-conserving surgery (BCS)	10 (33.3)
Tumor stage, n (%)	
Stage I	5 (16.7)
Stage II	13 (43.3)
Stage IIIA	9 (30.0)
Stage IIIB	2 (6.7)
Stage IIIC	1 (3.3)

Table 2. Comparison of Baseline Characteristics between Arm A and Arm B

Variable	Arm A (n = 15) Mean ± SD	Arm B (n = 15) Mean ± SD	P value
Age (years)	54.06 ± 9.36	49.46 ± 10.56	0.217
Weight (kg)	65.27 ± 11.44	64.83 ± 12.25	0.92
BMI (kg/m²)	27.65 ± 4.63	27.00 ± 4.68	0.703

Independent-samples t-test.

Daily cone-beam CT (CBCT) measurements were analyzed to assess setup deviations in the lateral (X), longitudinal (Y), and vertical (Z) directions. As shown in Table 3, patients treated without thermoplastic immobilization (Arm B) demonstrated significantly greater setup variation along the lateral (X) axis compared with patients treated using thermoplastic casts (Arm A) ($p = 0.02$). In contrast, no statistically significant differences were observed between the two groups for longitudinal (Y-axis) or vertical (Z-axis) setup deviations (both $p > 0.05$).

Subgroup analysis according to surgical procedure revealed that, among patients treated with thermoplastic casts (Arm A), those who underwent breast-conserving surgery showed slightly greater lateral (X-axis) variation than patients who underwent modified radical mastectomy; however, this difference did not reach statistical significance ($p = 0.06$). No significant differences were observed in Y- or Z-axis setup deviations within this group (Table 4).

Among patients treated without thermoplastic immobilization (Arm B), those who underwent breast-conserving surgery exhibited significantly greater longitudinal (Y-axis) variation than patients treated with modified radical mastectomy ($p = 0.04$). No significant differences were identified in the X- or Z-axis measurements.

Correlation analysis demonstrated no significant relationship between BMI and setup deviations in any direction among patients treated with thermoplastic casts. In contrast, within Arm B, BMI showed a moderate positive correlation with lateral (X-axis) setup variation ($r = 0.50$, $p = 0.05$), indicating that patients with higher BMI experienced greater lateral positioning errors when immobilization casts were not used.

To determine whether the relationship between BMI and setup variation differed significantly between treatment arms, Fisher's Z transformation was performed. Although the correlation between BMI and lateral displacement appeared stronger in Arm B than in Arm A, the difference between correlation coefficients was not statistically significant ($z = -1.40$, $p = 0.15$).

Discussion

Breast cancer remains the most frequently diagnosed malignancy among women worldwide, accounting for approximately 2.3 million new cases in 2022 according

Table 3. Comparison of setup deviations between Arm A and Arm B

Axis	Arm	Mean shift (cm)	SD	SEM	P value
X-axis	Arm A	−0.05	0.21	0.05	0.02
	Arm B	0.12	0.18	0.04	
Y-axis	Arm A	−0.09	0.41	0.1	0.753
	Arm B	−0.05	0.23	0.06	
Z-axis	Arm A	−0.04	0.25	0.06	0.229
	Arm B	−0.16	0.24	0.06	

SEM, Standard Error of the Mean.

to GLOBOCAN estimates [1]. Adjuvant external beam radiotherapy (EBRT) is an integral component of multidisciplinary breast cancer management and has been shown to significantly reduce local recurrence while improving disease-free survival. Because the target volume lies adjacent to critical organs such as the heart and lungs, accurate and reproducible patient positioning is essential to ensure adequate target coverage while minimizing radiation exposure to surrounding normal tissues.

Various immobilization techniques have been introduced to improve setup reproducibility during breast radiotherapy, including thermoplastic casts, breast boards, vacuum cushions, and customized positioning devices. However, the clinical benefit of rigid thermoplastic immobilization remains controversial. In the present prospective study, thermoplastic casts significantly reduced setup variation in the lateral (X-axis) direction, whereas no significant improvements were observed in the longitudinal (Y-axis) or vertical (Z-axis) directions.

Our findings differ partially from those reported by Agostinelli et al. [8], who demonstrated that thermoplastic immobilization primarily reduced vertical setup variation without significantly affecting the lateral or longitudinal directions. Conversely, Shah et al. [9] reported only minimal differences in interfraction positioning between immobilized and non-immobilized patients, suggesting that rigid immobilization alone may have limited influence on treatment accuracy. These discrepancies may be explained by differences in patient characteristics, immobilization techniques, imaging frequency, and treatment protocols across studies.

Strydhorst et al. [10] demonstrated that despite the use of thermoplastic immobilization, considerable interfraction variability remained, emphasizing the importance of daily image guidance. Similarly, in our study, daily cone-beam CT enabled correction of positioning errors before each treatment fraction, supporting the concept that image-guided radiotherapy (IGRT) plays a more critical role in treatment accuracy than immobilization alone.

An important finding of our study was the influence of surgical procedure on setup reproducibility. Among patients treated without thermoplastic casts, those who underwent breast-conserving surgery exhibited significantly greater longitudinal setup variation than patients who underwent modified radical mastectomy. The presence of residual breast tissue following breast-conserving surgery may increase soft-tissue mobility, making reproducible positioning more challenging in the absence of external immobilization. In contrast, no significant differences were observed among patients treated with thermoplastic casts, suggesting that immobilization may be particularly beneficial in this subgroup. These findings are consistent with those of Mulla et al. [11], who reported improved positioning accuracy among patients with larger or pendulous breasts when thermoplastic immobilization was employed.

Body habitus also appeared to influence treatment reproducibility. In patients treated without thermoplastic casts, body mass index demonstrated a moderate positive correlation with lateral setup variation, whereas no such association was observed in patients treated with immobilization. Although the difference between groups did not reach statistical significance, these findings suggest that patients with higher BMI may derive greater benefit from thermoplastic immobilization because increased soft tissue can contribute to positioning variability.

Recent technological advances have further reduced dependence on rigid immobilization devices. Surface-guided radiation therapy (SGRT) enables real-time patient monitoring with submillimeter accuracy while improving patient comfort and workflow efficiency. Recent studies have shown substantial reductions in setup variability when SGRT is incorporated into breast radiotherapy protocols [12]. Consequently, institutions equipped with advanced image-guidance technologies may safely reduce routine use of thermoplastic casts without compromising treatment precision.

From a clinical perspective, our findings suggest that individualized immobilization strategies may be preferable to routine application of thermoplastic casts for all patients. Patients undergoing modified radical mastectomy with favorable body habitus may achieve excellent setup reproducibility using appropriate arm

Table 4. Comparison of Setup Deviations between Post-MRM and Post-BCS Patients

Study Arm	Axis	Surgery	Mean (cm)	SD	P value
Arm A	X	MRM	−0.12	0.17	0.06
		BCS	0.08	0.22	
	Y	MRM	−0.15	0.26	0.81
		BCS	−0.12	0.18	
	Z	MRM	−0.14	0.17	0.41
		BCS	0.13	0.31	
Arm B	X	MRM	0.08	0.2	0.31
		BCS	0.19	0.13	
	Y	MRM	−0.01	0.27	0.04
		BCS	−0.13	0.47	
	Z	MRM	−0.17	0.17	0.81
		BCS	−0.14	0.36	

SD, Standard Deviation

supports, skin markings, and daily image guidance alone. Conversely, patients undergoing breast-conserving surgery or those with elevated BMI may benefit from additional immobilization to improve positioning consistency.

The strengths of this study include its prospective design, randomized allocation, standardized treatment protocol, and the use of daily CBCT for objective assessment of interfraction setup variation. The comparable baseline characteristics between study arms also minimized potential confounding. Nevertheless, several limitations should be acknowledged. First, the sample size was relatively small and derived from a single institution, which may limit the generalizability of the findings. Second, only translational setup errors were evaluated, whereas rotational errors were not assessed. Third, breast volume and respiratory motion, both of which may influence setup reproducibility, were not analyzed. Finally, long-term clinical outcomes such as local control, toxicity, and cosmetic results were beyond the scope of this investigation. Future multicenter studies with larger patient populations and incorporation of advanced image-guidance technologies such as surface-guided radiotherapy are warranted.

In conclusion, thermoplastic immobilization casts may not be necessary for all patients receiving adjuvant breast radiotherapy. However, they appear to improve setup reproducibility in selected patient populations, particularly those undergoing breast-conserving surgery and those with higher body mass index. Individualized immobilization strategies combined with daily image guidance may optimize treatment precision while improving patient comfort and workflow efficiency.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

Ethics Approval

This prospective study was approved by the Institutional Ethics Committee of Ramaiah Medical College Hospital, Bangalore, India. Approval No.: MSRMC/EC/PG-15/04-2023. All procedures involving human participants were conducted in accordance with the ethical standards of the institutional research committee and the Declaration of Helsinki.

Informed Consent

Written informed consent was obtained from all participants before enrollment in the study.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon request.

Authors' Contributions

Conceptualization: K.S., M.K.S; Methodology: K.S., M.K.S; Data Collection: K.S., L.L., J.G.M; Data Analysis: K.S., M.K.S,A.P.T.R; Writing – Original Draft: K.S, MKS; Writing – Review & Editing: All authors; Supervision: M.K.S; All authors read and approved the final manuscript.

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