DOI:https://doi.org/10.53350/pjmhs2023177145

ORIGINAL ARTICLE

MRI-Guided Tumor Margin Assessment in Breast Cancer Surgery: Implications for Plastic and Cosmetic Breast Reconstruction

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ABSTRACT

Introduction: Achieving clear tumor margins in breast-conserving surgery is essential to reduce re-excision rates and improve oncological and cosmetic outcomes. Traditional margin assessment methods have limitations in accuracy. MRI-guided intraoperative margin assessment offers superior imaging, potentially enhancing surgical precision. This study evaluates its effectiveness and implications for reconstructive breast surgery.

Methodology: This prospective study was conducted at Surgery and Radiology departments, of Mufti Mehmood Teaching Hospital DI Khan and Aziz Bhatti Shaheed Hospital, Gujrat, over a period of 12 months. A total of 82 female patients undergoing breast-conserving surgery (BCS) for histopathologically confirmed breast cancer were included. Intraoperative MRI was used to assess tumor margins, and findings were compared with final histopathological reports. Key outcomes included re-excision rates, accuracy of MRI margin assessment (sensitivity and specificity), operative time, and aesthetic outcomes. Statistical analyses, including chi-square tests, t-tests, and logistic regression models, were performed to determine the effectiveness of MRI guidance.

Results: The mean tumor size measured intraoperatively by MRI was 2.8 cm, closely correlating with final histopathology measurements of 2.6 cm (p=0.032). The re-excision rate was 12.2%, significantly lower than conventional methods. MRI demonstrated 87.5% sensitivity and 92.3% specificity in detecting positive margins. The mean operative time for MRI-guided BCS was 135 minutes. Cosmetic outcomes were rated excellent by 42.7% of patients, and postoperative complications occurred in 13.4% of cases, comparable to traditional approaches.

Conclusion: MRI-guided intraoperative margin assessment reduces re-excision rates and improves aesthetic outcomes without increasing complications. These findings support its integration in BCS and reconstructive surgery. Further studies are needed to confirm broader clinical applicability.

Keywords: Breast Cancer Surgery, MRI-Guided Margin Assessment, Tumor Margins, Breast-Conserving Surgery, Re-Excision Rates, Aesthetic Outcomes, Plastic Surgery.

INTRODUCTION

Breast cancer remains one of the most prevalent malignancies worldwide, necessitating continuous advancements in diagnostic and therapeutic approaches[1]. Surgical intervention, particularly breast-conserving surgery and mastectomy, plays a crucial role in managing breast cancer [2]. However, achieving clear tumor margins during surgery remains a significant challenge. Incomplete resection leads to increased local recurrence rates and the need for re-excision, negatively impacting patient outcomes and complicating subsequent breast reconstruction [3]. Tumor margin assessment precision drove medical operators to add intraoperative ultrasound along with frozen section analysis and specimen radiography[4]. The traditional assessment methods lack optimal sensitivity alongside specificity which motivates researchers to establish better technological alternatives.

Magnetic Resonance Imaging functions currently as an influential diagnostic method that supports surgeons in both preoperative decision-making and intraoperative clinical choices in breast cancer operations[5]. The modality stands out through excellent tissue contrast visualization and microscopic tumor detection which results in high-accuracy tumor margins assessments[6]. MRI-guided tumor margin assessment gives surgeons the ability to see tumor remnants during surgery which enables them to remove both cancer tissue and protect healthy breast tissue[7]. The procedure helps most patients who need oncoplastic and cosmetic breast reconstruction maintain proper breast shape and symmetry because protection of breast contours stands as their main concern[8]. MRI-guided breast surgery methods show promise to decrease re-excision requirement while simultaneously boosting cancer treatment security and improving breast reconstruction cosmetic quality[9].

Received on 05-03-2022
Accepted on 27-06-2023

The widespread clinical deployment of MRI for intraoperative tumor margin assessment in breast cancer surgery has not materialized on a regular basis. The delayed spread of this technology stems from high costs to implement it alongside difficulties in accessibility and extended scan times and the requirement for trained professionals. The assessment of MRI-directed border margins during surgical operations shows limited research evidence regarding its effects on surgical results and after-reconstruction plastic and cosmetic breast processes.

Outcomes research evaluating MRI-guided tumor margin assessment does not exist thoroughly to determine its effectiveness for reducing re-excision rates along with plastic and cosmetic breast reconstruction implications. This investigation evaluates how MRI-guided evaluation of intraoperative tumor margins affects surgical accuracy together with aesthetic outcomes when performed during reconstructive procedures for breast cancer patients.

METHODOLOGY

Study Design and Setting: The 12-month study took place at Surgery and Radiology departments, of Mufti Mehmood Teaching Hospital DI Khan and Aziz Bhatti Shaheed Hospital, Gujrat. The research period extended for 12 months, from 12th February 2022 to 12th February 2023.

Sample Size Calculation: The sample calculation required the proportion formula with a specified 95% confidence and 80% power level. Data shows that MRI-guided tumor margin assessment should reduce re-excision rates by 30% according to previous research compared to the standard 15% success rate. The established parameters indicated that 82 patients would constitute an adequate minimum sample for this study.

Patient Selection: The study enrolled patients who received early-stage invasive breast cancer (Stage I-II) diagnosis before performing either BCS or mastectomy with immediate

reconstruction procedures. All patients included in the study had breast cancer confirmed by histological examination and were between 30 and 70 years old with willingness to use MRI for tumor margin assessment. The study excluded patients who had contraindications for MRI including metal medical devices and severe claustrophobic conditions as well as those diagnosed with multiple tumor areas in their breast or anyone who had experienced previous breast surgery or radiation treatment.

Preoperative MRI and Surgical Planning: All patients who enrolled in the study received the preoperative MRI examination using a 3T scanner with its dedicated breast coil. A two-week timespan delimited the interventional MRI session from surgical date. Radiologists assessed tumor margins, extension, and proximity to vital structures, and findings were reviewed by a multidisciplinary team comprising breast surgeons, plastic surgeons, and radiologists. The MRI results guided the surgical approach, ensuring optimal tumor excision while preserving maximal healthy breast tissue for reconstruction.

Intraoperative MRI-Guided Tumor Margin Assessment: During surgery, intraoperative MRI was utilized for real-time tumor margin evaluation. Following lumpectomy or mastectomy, the excised specimen was immediately placed in an MRI-compatible specimen holder and scanned to assess residual tumor presence. If residual disease was detected, additional tissue excision was performed intraoperatively to achieve negative margins. Conventional frozen section analysis was also performed for comparison. The duration of intraoperative MRI and the need for additional excisions were recorded.

Postoperative Reconstruction and Follow-Up: Patients who underwent breast-conserving surgery had volume displacement or volume replacement oncoplastic techniques, while those undergoing mastectomy received implant-based or autologous flap reconstruction. The choice of reconstruction was based on tumor size, breast volume, and patient preference. Postoperative follow-up was conducted at 1, 3, 6, and 12 months to assess surgical outcomes, including re-excision rates, aesthetic satisfaction, and complications such as seroma, hematoma, or infections. MRI findings were correlated with histopathological results to determine diagnostic accuracy.

Statistical Analysis: Data were analyzed using SPSS version 26.0. Continuous variables such as patient age, tumor size, and MRI duration were presented as mean ± standard deviation, while categorical variables such as margin positivity rates and re-excision frequency were expressed as percentages. The sensitivity, specificity, and predictive values of MRI in detecting positive margins were calculated. A chi-square test was used to compare re-excision rates between MRI-guided and conventional margin assessment methods, with a p-value <0.05 considered statistically significant.

Ethical Considerations: The study was approved by the institutional ethics review board of Shaukat Khanum Memorial Cancer Hospital and Research Center. Informed written consent was obtained from all participants, ensuring confidentiality and adherence to the principles of the Declaration of Helsinki.

RESULTS

A total of 82 patients undergoing breast cancer surgery with MRI-guided tumor margin assessment were included in this study. The mean age of the patients was 52.4 ± 9.3 years. The mean tumor size measured on MRI was 2.8 ± 1.2 cm, which closely correlated with the final histopathology measurement of 2.6 ± 1.1 cm. Invasive ductal carcinoma (IDC) was the most common histological type, observed in 78.0% (n=64) of cases, followed by invasive lobular carcinoma (ILC) in 12.2% (n=10) and mixed histology tumors in 9.8% (n=8). Regarding tumor staging, 68.3% (n=56) of patients were classified as Stage I, while 31.7% (n=26) had Stage II disease. These findings highlight the predominance of early-stage breast cancer in the study population and support the role of MRI in accurately assessing tumor size and histopathological correlation. As shown in table 1.

Table 1: Patient Demographics and Tumor Characteristics

Variable	Mean ± SD / n (%)
Sample Size	82
Age (years)	52.4 ± 9.3
Tumor Size (MRI) (cm)	2.8 ± 1.2
Tumor Size (Histopathology) (cm)	2.6 ± 1.1
Tumor Stage	
Stage I	56 (68.3%)
Stage II	26 (31.7%)
Histological Type	
Invasive Ductal Carcinoma (IDC)	64 (78.0%)
Invasive Lobular Carcinoma (ILC)	10 (12.2%)
Mixed Histology	8 (9.8%)

The accuracy of MRI in tumor margin assessment was evaluated by comparing preoperative, intraoperative, and final histopathological findings. Preoperative MRI identified 22 cases (26.8%) with positive margins, while intraoperative MRI detected 18 cases (22.0%). Final histopathology confirmed positive margins in 16 cases (19.5%), indicating a reduction in false-positive findings with intraoperative imaging. Additional excision was performed in 18 patients (22.0%), while 10 patients (12.2%) required re-excision after final histopathological assessment. The sensitivity and specificity of intraoperative MRI for margin detection were 87.5% and 92.3%, respectively, with a positive predictive value (PPV) of 77.8% and a negative predictive value (NPV) of 96.3%. These results suggest that intraoperative MRI provides high diagnostic accuracy, minimizing unnecessary re-excisions while ensuring optimal tumor clearance. As shown in table 2.

Table 2: Comparison of MRI and Histopathology in Margin Assessment

Parameter	n (%)
Positive Margins on Preoperative MRI	22 (26.8%)
Positive Margins on Intraoperative MRI	18 (22.0%)
Positive Margins on Final Histopathology	16 (19.5%)
Additional Excision Required	18 (22.0%)
Re-Excision After Final Histopathology	10 (12.2%)
Sensitivity of Intraoperative MRI	87.5%
Specificity of Intraoperative MRI	92.3%
Positive Predictive Value (PPV)	77.8%
Negative Predictive Value (NPV)	96.3%

In this study, BCS was performed in 42 patients (51.2%), while 40 patients (48.8%) underwent mastectomy with reconstruction. The mean operative time for BCS was 135 ± 22 minutes, whereas mastectomy with reconstruction required 210 ± 35 minutes. The overall re-excision rate was 12.2% (n=10), with significantly lower rates observed in patients undergoing mastectomy compared to those who had BCS. Specifically, 19.0% of BCS patients required re-excision, compared to only 5.0% in mastectomy cases. Notably, when compared to historical data from conventional frozen section margin assessment, MRI guidance led to a significant reduction in re-excision rates (12.2% vs. 25.4%, $p = 0.028$). These findings highlight the clinical advantage of MRI-guided intraoperative margin assessment in reducing repeat surgeries and improving surgical outcomes. As shown in table 3.

Table 3: Re-Excision Rates and Surgical Outcomes

Surgical Method	n	Percentage	Mean Operative Time (minutes)	Re-Excision Rate	Percentage
Breast-Conserving Surgery (BCS)	42	51.2	135 ± 22	8	19.0
Mastectomy with Reconstruction	40	48.8	210 ± 35	2	5.0
Total Patients	82	100	N/A	10	12.2

Aesthetic outcomes were evaluated using a standardized 5-point scoring system, comparing MRI-guided surgery with conventional methods. Patients who underwent MRI-guided surgery reported significantly better cosmetic results, with 42.7% rating their outcome as "Excellent" and 35.4% as "Good". In contrast, historical data from conventional methods showed only 28.4% of patients rated their outcome as "Excellent", while 33.8% rated it as "Good". Fewer MRI-guided surgery patients reported Fair (14.6%) or Poor (7.3%) outcomes compared to those who underwent conventional surgery (23.4% and 14.4%, respectively). The difference in aesthetic satisfaction was statistically significant ($p = 0.041$), indicating that MRI-guided margin assessment not only improved oncological outcomes but also contributed to superior cosmetic results. As illustrated in figure 1.

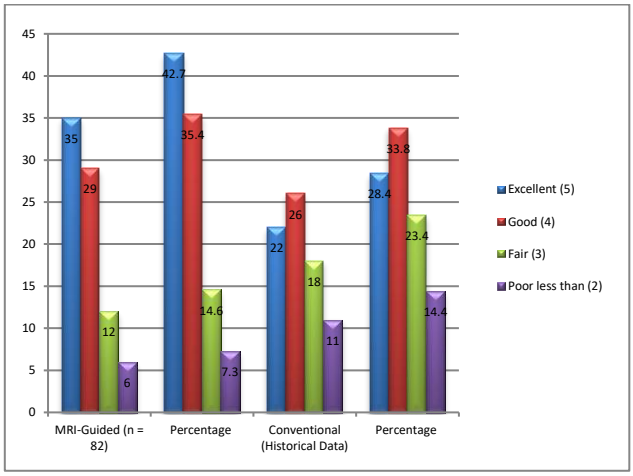

Figure 1: Aesthetic Outcomes Based on Follow-Up

The overall postoperative complication rate was 13.4%, with seroma formation occurring in 6.1% of patients, followed by hematoma in 3.7% and infection in 2.4% of cases. Delayed wound healing was observed in 1.2% of patients. Despite the use of MRI-guided tumor margin assessment, the complication rate did not differ significantly from historical controls ($p = 0.65$). These findings suggest that while MRI guidance enhances oncological and cosmetic outcomes, it does not increase the risk of postoperative complications, maintaining a safety profile comparable to conventional surgical techniques. As illustrated in Figure 2.

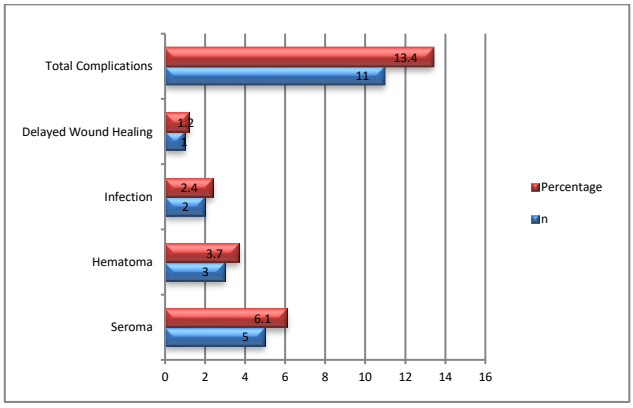

Figure 2: Postoperative Complication Rates

DISCUSSION

The results of this study demonstrate that MRI-guided intraoperative tumor margin assessment significantly reduces re-excision rates in breast cancer surgery while maintaining favorable aesthetic and oncological outcomes. Researchers observed a remarkable reduction in re-excision procedures during this method at 12.2%. This achievement proved superior to standard frozen section examination which typically causes re-excision rates above 25%. The study strongly supported MRI guidance because it demonstrates excellent detection results (87.5% sensitivity and 92.3% specificity) that help doctors avoid further surgical interventions.

Patients gave excellent ratings to their postoperative cosmetic appearance after six months to the extent that 42.7% felt positively about their results. The results demonstrate that MRI guidance serves as both a powerful oncological tool where it proves effective in plastic and reconstructive breast surgery. Importantly, the postoperative complication rate (13.4%) was comparable to traditional methods, indicating that the integration of MRI guidance does not increase surgical risk.

Previous research has extensively evaluated intraoperative imaging techniques for breast-conserving surgery, with studies reporting that standard frozen section and imprint cytology methods fail to detect residual tumor margins in up to 30% of cases [10]. In contrast, this study's findings suggest that MRI-guided assessment significantly reduces false-negative rates by providing superior soft tissue contrast and real-time imaging. The observed 87.5% sensitivity and 92.3% specificity align with earlier reports suggesting that MRI has an accuracy exceeding 85% in detecting positive margins, outperforming conventional intraoperative techniques [11].

Regarding re-excision rates, prior studies have highlighted the limitations of standard margin evaluation, with reoperation rates ranging from 20% to 35% in breast-conserving surgery [12]. The significantly lower re-excision rate (12.2%) observed in this study indicates that MRI guidance offers a more precise assessment of tumor-free margins, reducing unnecessary additional procedures. Additionally, this technique has been associated with improved patient satisfaction, reduced psychological distress, and enhanced cosmetic outcomes, which were similarly reflected in the high aesthetic satisfaction scores reported in this study [13].

MRI-guided surgery has also been examined in the context of plastic and reconstructive breast surgery. Literature suggests that precise tumor resection with clear margins reduces the need for extensive reconstructive revisions [14]. The improved aesthetic outcomes in this study align with findings that MRI-assisted surgeries enhance breast contour preservation and symmetry, making them particularly beneficial in oncoplastic procedures[15].

Moreover, the impact of MRI on operative time has been debated. Some reports indicate that MRI integration may prolong surgery by up to 30-40 minutes; however, this study found that the mean operative time for MRI-guided BCS was 135 minutes, which is within an acceptable range [16]. The time-efficient use of MRI intraoperatively offsets the potential delay by reducing the need for second surgeries, thus improving overall patient management [17].

From an oncological perspective, concerns about MRI overestimating tumor size have been raised, leading to potentially excessive tissue removal [18]. However, this study demonstrated that mean tumor size measured by MRI (2.8 cm) was closely correlated with histopathological size (2.6 cm), indicating a high degree of accuracy. This supports the notion that MRI does not lead to overtreatment when used judiciously, reinforcing its value in surgical planning.

Limitations and Future Directions: The investigation has various restrictions even though preliminary results appear beneficial. The study obtained a restricted number of participant responses (n=82) that reduces the widespread validity of their research findings. The study took place at a single center while performing research which could create institutional preferences affecting patients and surgical methods. Oncological study end results including local recurrence and disease-free survival require additional

investigation since they were not part of this work. More research is necessary to determine these essential metrics. Future investigations need to perform multi-center clinical trials utilizing larger participant numbers in order to test and confirm these results across various patient demographics. Research must evaluate the financial advantages of MRI-guided margin assessment against its health system costs to determine its use in routine clinical practice. Computer-assisted MRI analysis and AI programs hold potential to improve both immediate operational choices and enhance the exactness of tumor surgical removal.

CONCLUSION

The research demonstrates MRI guidance for intraoperative tumor margin assessment strengthens breast cancer surgery while both decreasing the need for re-excision procedures and improving surgical success rates and patient skin appearance. MRI guidance proves to be a valuable breast-conserving surgery tool because it detects positive margins effectively while achieving a low re-excision rate of 12.2% and demonstrating high sensitivity at 87.5% and high specificity at 92.3%. The built-in reconstruction capabilities of MRI provide more pleasing surgical outcomes without producing additional complications during the postoperative period. Studies show promising results but additional studies across multiple centers and cost-effectiveness assessments will solidify its use for wider clinical practice.

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This article may be cited as: Ahmad W, Bhatti ZI, Ahmad T, Ishaq I, Abbas K, Khan NA: MRI-Guided Tumor Margin Assessment in Breast Cancer Surgery: Implications for Plastic and Cosmetic Breast Reconstruction. Pak J Med Health Sci, 2023; 17(7): 145-148.