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Feasibility of Intraoperative Breast MRI and the Role of Prone Versus Supine Positioning in Surgical Planning for Breast Conserving Surgery

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Abstract

We assessed the feasibility of supine intraoperative MRI (iMRI) during breast conserving surgery (BCS), enrolling 15 patients in our phase I trial between 2012–2014. Patients received diagnostic prone MRI, BCS, pre-excisional supine iMRI, and post-excisional supine iMRI. Feasibility was assessed based on safety, sterility, duration and image-quality. 12 patients completed the study; mean duration= 114 minutes; all images were adequate; no complications, safety, or sterility issues were encountered. Substantial tumor-associated changes occurred (mean displacement=67.7 mm, prone-supine metric, n=7). We have demonstrated iMRI feasibility for BCS and have identified potential limitations of prone breast MRI that may impact surgical planning.

Keywords

Breast Conserving Surgery; Margins; MRI; Image-Guided Therapy; Surgical Planning

Introduction

Standard treatment options for women with early stage breast cancer with equivalent survival include mastectomy and breast conserving surgery (BCS) plus radiation. A caveat of BCS is that between 15–40% of patients require more than one operation to achieve clear margins (1–3). Reoperations negatively impact patient care, and positive margins are associated with increased recurrence rates and decreased survival.

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BCS is limited by a surgeon's inability to reliably distinguish the malignant-benign breast interface intraoperatively, making complete tumor excision sub-optimal. A rapid, cost-effective, and accurate intraoperative technique for identifying residual tumor at margins has yet to be developed, therefore final histopathology remains the current standard for margin evaluation.

Breast magnetic resonance imaging (MRI) is a sensitive modality for identifying the size and extent of breast cancer (4). While studies have failed to show improvement in BCS-outcomes with preoperative MRI, these have focused on prone MRI obtained before surgery (5, 6). The limitations of using prone MRI for BCS planning, and the potential benefits of supine MRI, have not been well studied, and the ultimate role that intraoperative magnetic resonance imaging (iMRI) will play in BCS has yet to be established (7, 8). We sought to evaluate the feasibility of iMRI in the Advanced Multimodality Image Guided Operating (AMIGO) suite as a tool for margin evaluation during BCS, with the secondary objective of describing tumor-associated changes occurring between prone versus supine breast MRI.

Methods

Institutional Review Board approval and informed consent from all patients was obtained for this study. The trial design is described below (Figure 1).

Setting

All operations took place in the Advanced Multimodal Image Guided Operating (AMIGO) suite, which is part of the National Center for Image Guided Therapy, located at Brigham and Women's Hospital (9). This sterile three-room suite is equipped with multiple imaging modalities including a 3T MRI that moves on ceiling rails enabling iMRI capabilities (Siemens AG, Germany).

Patient Selection

Fifteen patients with clinical stage I–II breast cancer amenable to BCS were screened in our prospective phase I trial from April 2012–November 2014. Eligible patients were 18–74 years old and had core-biopsy-confirmed stage I–II invasive breast carcinoma, a preoperative mammogram, and a preoperative standard diagnostic prone MRI with measurable disease; three patients were excluded when more extensive disease than was known at enrollment was identified on diagnostic MRI.

Primary Endpoints

The primary endpoint for our study was feasibility of iMRI for BCS. We defined feasibility as the ability to successfully complete BCS in AMIGO. Feasibility was evaluated based on safety, sterility, and duration of procedure, as well as on iMRI-related criteria.

Secondary Endpoints

Tumor characteristics including but not limited to shape, size, and location on MRI were recorded, allowing for changes between prone and supine positions to be assessed. Operative durations, complications, and the total number of operations necessary to achieve clear

margins per patient were recorded. Margins were considered negative if no invasive tumor was within 0.2cm of margin, and no in situ tumor was within 0.2cm of margin.

Statistics

Based on a priori data, target accrual was set at fifteen patients and a success rate of 90% for feasibility was established.

Diagnostic MRI—Standard prone diagnostic dynamic-contrast-enhanced MRI was performed using a dedicated breast imaging coil and the maximum tumor size was identified; distances from tumor to skin, chest wall, and nipple were also determined.

Surgery and iMRI

Following induction, supine pre-excision iMRI was performed; BCS was then completed in standard fashion, and each lumpectomy cavity was then filled with normal saline to improve post-excisional iMRI image-quality, which was then performed using a 16-channel cardiac coil (IMRIS Inc., Canada) anteriorly positioned without causing compression(8). Images were reviewed for residual enhancement, suggestive of residual tumor. The lumpectomy cavity was re-opened, standard shave excisions were taken, incisions were closed and the operation ended.

Imaging Interpretation

One breast radiologist evaluated all iMRIs using CAD for imaging interpretation and tumor segmentation (10). Tumor metrics including maximum dimensions, volume, sphericity and surface area were recorded; distances from each tumor to nipple, chest wall and skin were calculated. Supine and prone images were superimposed to generate composite 3D-tumor displays (Figure 2).

Results

Study Population

Twelve patients completed the study with a mean age of 54.5 (range 34–68). Clinical stage I disease was present in 75.0% of cases; stage II in 25.0%. Tumor subtypes were 58.3% invasive ductal carcinoma, 8.3% invasive lobular carcinoma, 16.7% mixed invasive ductal and lobular carcinoma and 16.7% invasive papillary carcinoma.

Procedures

Mean surgery duration was 114 minutes (range 91–146 minutes). There were no breaks in sterility or intraoperative complications observed among the cohort. All utilized instruments were compatible within AMIGO and IV contrast doses were within acceptable dosing guidelines. Imaging of the breast in the supine position provided adequate quality based on qualitative assessment of resolution, tissue contrast, and delivery of IV contrast.

All patients (n=12) received a diagnostic MRI prior to surgery, and a post-excisional iMRI following BCS in AMGIO. Seven additionally received a dedicated supine MRI prior to excision. Analysis of patients with both prone and supine MRI revealed substantial

differences occurred in the positional, structural, and dimensional qualities of the tumors on prone-vs-supine images with an average tumor displacement of 67.7mm. Mean percent change data reflected changes in tumor volume (-20.3 ± 46.61), surface area (-3.4 ± 27.96), and sphericity (-0.3 ± 11.0), and changes in tumor distances from: chest wall (21.0 ± 10.2 mm), nipple (13.8 ± 12.7 mm), and skin (-0.1 ± 3.3 mm) (prone minus supine metric).

Histopathology

iMRI was suggestive of residual disease following primary BCS in 50% of patients; all had same-surgery shave margin re-excision. Clear margins were achieved in 10 of 12 patients; two required re-operation for DCIS found on final pathology, resulting in an ultimate reoperation rate for the cohort of 16.7%. Reoperation was successful in both cases.

Discussion

We have established the feasibility of iMRI during BCS based on patient safety, operative duration, sterility, and iMRI-related criteria, with an observed success rate of 100%. The mean operative duration was 114 minutes (range 91–146), which we anticipate will improve as the number of cases performed in AMIGO increases (average duration at our institution in a regular operating suite without iMRI= 78 minutes)s (11). As a secondary outcome we evaluated the number of reoperations to achieve clear margins for iMRI-BCS. The ultimate 16.7% reoperation rate compares favorably with our institutional reexcision rate (BCS without iMRI) of 41.5% (12). Although MRI is sensitive for breast cancer, a known limitation is its decreased sensitivity for ductal carcinoma in situ (DCIS). Both cases requiring reoperation in this study were for DCIS (13).

Although BCS is performed supine, traditional MRI is performed prone, and our results have shown that substantial tumor displacement occurs between these positions, with prone-imaged tumors consistently located further from the chest wall and nipple than supine-imaged tumors. These differences may result from breast compression and splaying out of the breast within the prone breast coil. Tumor deformity was also observed, and ongoing research is needed to better understand how imaging position influences tumor geometry. Ultimately, prone-only breast MRI's ability to accurately assist in surgical planning requires recognition and compensation for these changes. Further research on the addition of preoperative supine breast MRI sequences to existing prone-MRI protocols may better determine how better knowledge of tumor location/geometry in the operative supine position may affect BCS outcomes.

The integration of MRI into the operative setting represents the principles espoused by the emerging field of image guided therapy (IGT), which has gained momentum in the past decade as a means of overcoming challenges associated with conventional operative methods to allow for more targeted, less invasive, and more successful patient outcomes. We have used AMIGO as a platform for researching ways in which IGT can help overcome the numerous challenges associated with the performance of successful BCS operations, with the ultimate goal of generating knowledge translatable to the regular operative setting. While we recognize that it is neither plausible nor feasible to suggest performance of iMRI on all BCS patients, we suggest the importance of our results are that 1) we have emphasized the

overall feasibility of IGT for BCS, encouraging additional research into ways in which IGT may improve outcomes and 2) we have identified significant limitations with use of prone breast MRI that may affect BCS planning. Research into other IGT modalities, such as mass spectrometry, that could easily be translated outside of AMIGO is warranted, and a clinical trial evaluating both iMRI and mass spectrometry is underway at our institution.

This study was subject to several limitations. Our trial was designed as a feasibility study with a limited sample size thus our conclusions beyond feasibility are based on limited data and not powered for significance. Although iMRI in this trial was associated with reexcision rates less than previously observed at our institution, larger studies correlating iMRI findings to histopathology are needed. Additionally, shave margins were taken regardless of iMRI findings (a method used routinely by the primary investigator), and we did not account for the effect of this practice on reoperation rates. Our findings regarding tumor changes between prone-vs-supine positions were limited by sample size and warrant better characterization with larger studies, especially given the potential implications for surgical planning. Finally, and perhaps most importantly, we did not account for the costs and/or resources associated with iMRI; iMRI is costly and requires resources such as an iMRI-equipped operating suite that most institutions do not have. Our study was made possible through robust funding from the NIH and our designation as the National Center for Image Guided Therapy. Other techniques that are more readily made available may prove to be more beneficial, and research into more cost- and time-effective margin-analysis tools that could be more generally applicable remains warranted.

Conclusions

Our study has shown that iMRI is feasible during BCS in AMIGO and has identified substantial tumor-associated changes that occur between prone and supine MRI. Further efforts aimed at characterizing the role of preoperative supine breast MRI and its added value for surgical planning are needed. Additional studies examining the accuracy of iMRI for BCS margins are warranted, and research aimed at identifying intraoperative margin techniques translatable into regular operating rooms may be useful for improving BCS outcomes.

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Presentation History

- New England Surgical Society, 96th Annual Meeting, [RI] September 2015
- American Society of Breast Surgeons Conference 15th Annual Meeting [NV], May 2014; (multimedia description, [Golshan M, Sagara Y, Wexelman B et al. Pilot study to evaluate feasibility of image-guided breast-conserving therapy in the advanced multimodal image-guided operating (AMIGO) suite. *Ann Surg Oncol* 2014;2:3356-3357].

Figure 1.
Advanced Multimodality Image Guided Operating (AMIGO) Suite Trial Study Design

Figure 2. Comparison of Prone-to-Supine Imaging

Prone breast MRI overlaid on the corresponding supine breast MRI for a trial participant is displayed. Tumor models were generated using computer aided detection (CAD) software. Short wide arrow= prone MRI tumor; Long skinny arrow= supine MRI tumor. Patient's right = R, left=L