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Research Letter

National Patterns of Early Adoption of Magnetic Resonance Imaging–Guided Linear Accelerators in 2018 to 2019

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Abstract

Purpose: Adaptive magnetic resonance imaging–guided linear accelerators (aMRI-LINACs) are an emerging technology with the potential to improve radiation treatment for cancer through improved visualization and adaptive treatment. Given the competing forces of the increased cost, knowledge, and staff required for aMRI-LINAC therapy, it is unpredictable how rapidly and for whom aMRI-LINAC therapy is being adopted. Therefore, given that aMRI-LINAC therapy was granted approval from the Food and Drug Administration in late 2017, we evaluated the National Cancer Database (NCDB) to obtain a nationwide view of early aMRI-LINAC adoption in 2018 to 2019.

Methods and Materials: Forty-three disease sites were aggregated. A sample of patients who underwent intensity modulated radiation therapy (IMRT) from 2018 to 2019 were matched 1:1 by stage for the top 4 cancer sites. We then compared 9 characteristics of interest (age, % White [vs non-White], % residing in metro areas, % living in the greatest income quartile, % insured by Medicare, % uninsured or unknown insurance status, % treated at a comprehensive cancer center or academic center, % with no recorded Charlson-Deyo comorbidities, and % residing in an area with highest educational) between the 2 samples (aMRI-LINAC and matched IMRT).

Results: Only 171 patients were recorded as having been treated with aMRI-LINACs in the NCDB in 2018 to 2019. Fifty-six percent were male, 89% White, and 54% enrolled in Medicare. The most common sites of disease treated were lung (33 patients), pancreas (30 patients), prostate (29 patients), and breast (23 patients). There were no significant differences between aMRI-LINAC- and IMRT-matched patients except that patients with lung or breast cancer treated with aMRI-LINAC were significantly more likely to be treated at a comprehensive cancer center or academic center.

Conclusions: aMRI-LINAC adoption recorded in the NCDB after Food and Drug Administration approval was potentially underreported, slow, and attributed to academic sites of practice. Further longitudinal study will be needed to assess how practice patterns evolve with greater adoption.

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Research data are available through the Commission on Cancer (CoC) of the American College of Surgeons for CoC-affiliated sites. For more information, https://www.facs.org/quality-programs/cancer-programs/national-cancer-database/.

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Introduction

How new medical technology is adopted depends on multiple factors, including the capital cost, competition advantage the technology affords, the skills and knowledge required, the perception of "extra benefit" to the patient, the evidence base supporting the technology, a ready population of patients, and the return on investment.[1-3] Adaptive magnetic resonance imaging–guided linear accelerators (aMRI-LINACs) are an emerging technology with the potential to improve radiation treatment for cancer through improved soft-tissue and cancer visualization and adaptive treatment.[4] aMRI-LINACS are more expensive than standard LINACS, with greater relative capital cost, greater staff requirements, and longer treatment times.

Given the competing forces of the increased cost, knowledge, and staff required for aMRI-LINAC therapy versus the potential medical benefits, it is unpredictable how rapidly and for whom aMRI-LINAC therapy is being adopted. New technology adoption in radiation oncology can be disparate and favor those who are from wealthier areas, who are healthier, and who are more likely to identify as White.[5] Therefore, given that aMRI-LINAC therapy was granted approval by the Food and Drug Administration (FDA) in late 2017, we decided to evaluate the National Cancer Database (NCDB) to obtain a nationwide view of early aMRI-LINAC adoption in 2018 and 2019.

Methods and Materials

Description of the data

NCDB is a joint project of the Commission on Cancer (CoC) of the American College of Surgeons and the American Cancer Society that collects hospital registry data from more than 1500 accredited facilities. The database accounts for approximately 72% of patients with cancer in the United States.[6] The NCDB participant user file contains deidentified patient-level data from CoC-accredited programs. For this study, 43 disease sites were obtained for analysis encompassing the most common indications for radiation therapy (Table E1).

Sample construction

Given that MRI-LINACS were approved by the FDA in 2017, we analyzed only patients from 2018 to 2019 (the most recent years available) to minimize erroneous inclusion of misclassified patients. Further, facilities that recorded 5 or fewer cases were excluded, as we hypothesized that facilities that recorded 5 or fewer cases over 2 years were likely to have misclassified aMRI-LINAC cases.

Matching with IMRT

A sample of patients who underwent intensity modulated radiation therapy (IMRT) were constructed from the 43 disease sites. Only those patients receiving IMRT with the primary sites from the top 4 cancer site groups (lung, prostate, pancreas, and breast) were eligible for matching. A 1:1 propensity score by cancer type and stage (defined by the NCDB variable ANALYTIC_STAGE_GROUP) was performed using the STATA module psmatch2.[7] Staging was based on North American Association of Central Cancer Registries guidelines using pathologic stage group as defined by the American Joint Committee on Cancer or clinical stage when pathologic stage is not reported. Substage groups are collapsed into the general stage designation, and these general stage designations were used.

Construction of variables

aMRI-LINAC therapy was recorded via the PHASE_I_BEAM_TECH variable, indicating "MR-guided online adaptive therapy," specifically "[a]n external beam technique in which the treatment is adapted over the course of radiation to reflect changes in the patient's tumor or normal anatomy radiation using an MRI scan obtained at the treatment machine (online)."

Nine characteristics of interest were selected a priori to compare patients undergoing aMRI-LINAC with a stage-matched IMRT cohort: age of patients, % White (vs non-White), % residing in metro areas, % living in the greatest income quartile, % insured by Medicare, % uninsured or unknown insurance status, % treated at a comprehensive cancer center or academic center, % with no recorded comorbid illnesses, and % residing in an area with greatest educational achievement.

Metro areas were defined as counties with populations of more than 250,000 people. Greatest income quartile was defined in the NCDB using the 2016 American Community Survey data spanning 2012 to 2016 and indicated median household income within the ZIP Code of ≥$63,333. Percentage of residents who had not obtained at least a high school degree was also defined by the 2016 American Community Survey and was the measure of adults age 25 or older in the patient's ZIP Code who did not graduate from high school. Lowest quartile was <6.3%.

Statistical analysis

Descriptive analysis was performed. Per NCDB data use agreement, we suppress reporting of groups of less than 10 patients. Characteristics of interest are described

Table 1 aMRI-LINAC demographics (N = 171)

Characteristic	Value
Age (y), range, median, mean	20-87, 67, 65.6
Sex	
Male	96 (56%)
Female	75 (44%)
Race	
White	152 (89%)
Black or Chinese*	19 (11%)
Insurance	
Private insurance/managed care	67 (39%)
Medicaid/other government	11 (6%)
Medicare	93 (54%)
Primary site	
Lung	33 (19%)
Pancreas	30 (18%)
Prostate	29 (17%)
Breast	23 (13%)
Head and neck	15 (9%)
Nonliver nonbiliary GI/abdomen	15 (9%)
Brain/GYN	14 (8%)
Liver/biliary	12 (7%)
Stage grouping	
0-1	66 (39%)
2	35 (20%)
3	41 (24%)
4	17 (10%)
NA or unknown	12 (7%)
High school degree region (2012-2016)	
>17.6%	19 (11%)
10%-17.5%	42 (25%)
6.3%-10.8%	55 (32%)
<6.3%	37 (22%)
Median income quartile	
<40,227	21 (12%)
40,227-50,353	42 (25%)
50,354-63,332	42 (25%)
≥63,333	48 (28%)
Facility location	
Middle Atlantic (NJ, NY, PA)	14 (8%)
South Atlantic (DC, DE, FL, GA, MD, NC, SC, VA, WV)	22 (13%)
East North Central (IL, IN, MI, OH, WI)	57 (33%)
West North Central (IA, KS, MN, MO, ND, NE, SD)	66 (39%)
Pacific (AK, CA, HI, OR, WA) or NA/unknown*	12 (7%)

(*continued on next page*)

Table 1 (*Continued*)

Characteristic	Value
Facility type	
Community cancer program or unknown/unrecorded*	21 (12%)
Academic/research	119 (70%)
Integrated network cancer program	31 (18%)
Urban/rural	
Metro area >1 million	90 (53%)
Metro area 250,000-1 million	14 (8%)
Metro area <250,000	12 (7%)
Urban >20,000, adjacent to metro	16 (9%)
Urban 2500-19,999 or NA*	15 (9%)
Rural	0 (0%)
Charlson-Deyo score	
0	119 (70%)
1	27 (16%)
2	14 (8%)
3+	11 (6%)

Abbreviations: aMRI-LINAC = adaptive magnetic resonance imaging–guided linear accelerator; GI = gastrointestinal; GYN = gynecologic; NA = not available.
*Cells of <10 suppressed reporting, so categories were combined.

in the previous section. Within each unique matched set (prostate, breast, lung, pancreas), 9 comparisons were performed. The Sidak correction was applied for 9 comparisons, and so a P value of .0057 was considered statistically significant. STATA/SE 13 (StataCorp, College Station, TX) was used for all analysis.

Results

Only 171 patients were found to have been treated with aMRI-LINACs at NCDB CoC centers in 2018 to 2019. Fifty-six percent were male, 89% White, 54% enrolled in Medicare, and 39% insured by private insurance or managed care. The most common sites of disease treated were lung (33 patients), pancreas (30 patients), prostate (29 patients), and breast (23 patients). Most patients were stage 0 to 2. One hundred nineteen, or 70%, of patients were treated at academic centers or comprehensive cancer centers. There were no patients treated from rural areas of the country. Patients were generally otherwise healthy, with 70% having no recorded comorbid disease (Table 1).

For each of the 4 common disease sites, patients who underwent IMRT were successfully matched 1:1 to patients who underwent MRI-LINAC by stage. The patients treated with aMRI LINAC and patients treated with IMRT were balanced by stage (P = 1.000 for all 4 cancer groups). There were no significant differences between patients treated with aMRI LINAC and patients treated with IMRT for mean age, % White, % metro region of residence, % living in greatest income quartile, insurance status, % with no recorded Carlson-Deyo comorbidities, or % from an area of low educational attainment (Table 2). The only difference between the cohorts were the percentage treated at a comprehensive cancer center or academic center. Patients with lung or breast cancer treated with aMRI-LINAC were significantly more likely to be treated at a comprehensive cancer center or academic center compared with matched patients treated with IMRT. Patients with pancreatic cancer were equally likely to be treated at a comprehensive cancer center or academic center. The greater proportion of patients with prostate cancer treated with aMRI LINAC were treated at an academic center versus patients with prostate cancer treated with IMRT was of borderline significance (P = .007).

Discussion

In this study of early adoption of aMRI-guided LINAC treatment in the first 2 full years after FDA approval, we found that the most common sites of treatment were for

Table 2 Matching versus IMRT for top 4 cancers, with χ^2 *P* values comparing categories

Cancer	aMRI-LINAC	Stage-matched IMRT	*P* value
Lung	n = 33		
Mean age, y	71.9	70.9	NS
% White	94%	88%	NS
% Metro	70%	67%	NS
% Greatest income quartile	18%	27%	NS
% Medicare	76%	76%	NS
% Uninsured/unknown	0	3%	NS
% Comprehensive cancer center/academic	76%	27%	.000036
% Charlson-Deyo score = 0	42%	52%	NS
Highest high school quartile	12%	12%	NS
Pancreas	n = 30	n = 30	
Mean age, y	66.6	63.0	NS
% White	87%	80%	NS
% Metro	73%	70%	NS
% Greatest income quartile	17%	27%	NS
% Medicare	60%	50%	NS
% Uninsured/unknown	0	0	NS
% Comprehensive cancer center/academic	37%	43%	NS
% Charlson-Deyo score = 0	80%	63%	NS
Highest high school quartile	13%	13%	NS
Prostate	n = 29		
Mean age	68.1	80.0	NS
% White	86%	79%	NS
% Metro	65.5%	86.2%	NS
% Greatest income quartile	45%	28%	NS
% Medicare	55%	66%	NS
% Uninsured/unknown	0	3.5%	NS
% Comprehensive cancer center/academic	76%	41%	.007 (NS)
% Charlson-Deyo score = 0	86%	69%	NS
Highest high school quartile	31%	34%	NS
Breast	n = 23		NS
Mean age	62.1	59.1	NS
% White	91%	91%	NS
% Metro	52%	82%	NS
% Greatest income quartile	35.5	43%	NS
% Medicare	35%	35%	NS
% Uninsured/unknown	0	0	NS
% Comprehensive cancer center/academic	100%	40%	<.00001
% Charlson-Deyo score = 0	61%	83%	NS
Highest high school quartile	39%	26$	NS

Abbreviations: aMRI-LINAC = adaptive magnetic resonance imaging–guided linear accelerator; IMRT = intensity modulated radiation therapy; NS = not significant.

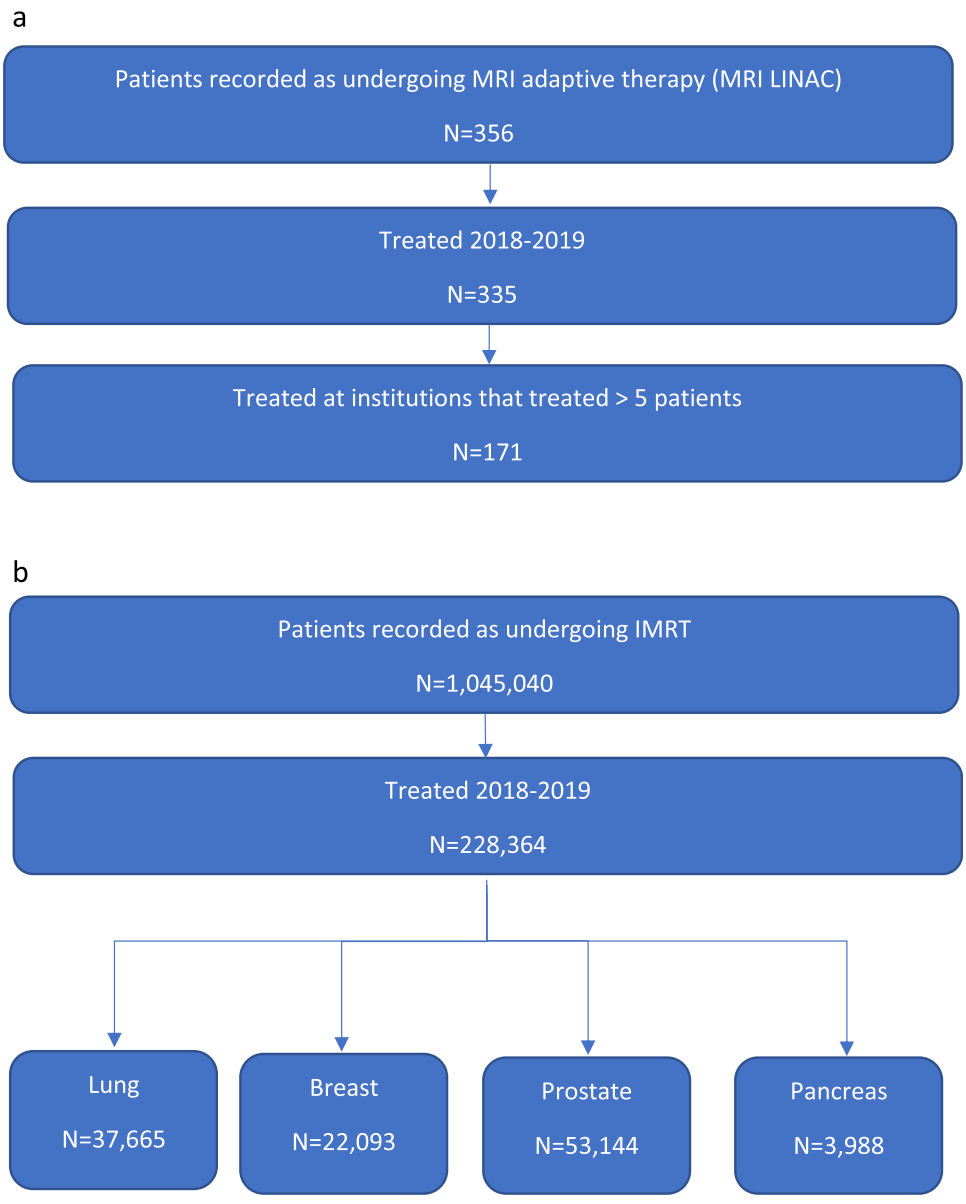

Figure 1 A, CONSORT diagram for patients treated with MRI adaptive radiotherapy. B, CONSORT diagram for patients treated with IMRT.

lung, pancreas, prostate, and breast cancer. Furthermore, we found that there were no differences between who received MRI-guided LINAC therapy and standard IMRT, other than treatment by an academic center for lung and breast cancer. There are several implications from these findings that affect future observational comparative effectiveness research, industry development, and patient access to new technology.

Relevant to future observational studies comparing aMRI-LINAC therapy and IMRT, we found that patients treated with aMRI-LINAC do not seem to be younger or in better health. This appears to be distinct from other radiation technology adoption, such as proton beam radiation therapy for prostate cancer, which seemed to be more adopted by patients who were younger, White, and with fewer comorbid illnesses.[5] However, future studies will still need to be aware of potential differences in early-adopting patients, particularly given differences in resources available at academic and comprehensive cancer centers versus other sites of practice.

Given aMRI-LINAC therapy represents significant local investment in health resources, it was gratifying to not find disparities in access, although our findings were based on very early adoption and small numbers of patients. Our findings suggest that access to academic centers is likely the most important factor promoting equal access to new aMRI-LINAC technology. If aMRI-LINAC technology is perceived to be more advantageous than IMRT, the continued access to the technology by all patients will increase in importance.

Our study has limitations associated with retrospective observational studies. The NCDB contains records from hospital cancer registries and may not include patients not affiliated with hospital-based treatment centers. Although there are a very large number of patients included in the NCDB, we only analyzed 171 patients (Fig. 1A, 1B). As a result, our study may be underpowered. It is possible that as the number of patients who undergo aMRI-LINAC–based therapy increases beyond the earliest adopters, other nuanced differences may be revealed. In addition, it is possible that we may have misclassified patients who did not undergo MRI-LINAC therapy due to errors in recording. Anomalous radiation data can occur in the NCDB, although most commonly total radiation dose and insufficient number of fractions were the most frequently anomalous data. Our analysis is limited by its focus on adaptive radiation therapy. MRI guided LINAC treatments are not necessarily adaptive, and in fact many major treatments (particularly for breast and prostate cancer) do not require adaptive planning. Thus, our analysis reflects a large underreporting of MRI LINAC use overall. Of note, MRI guided treatment may be beneficial for patients without adaptive radiation therapy planning. Finally, although modality of treatment (ie, IMRT or MRI adaptive therapy) seemed to be infrequently miscoded, but it is notable that the number of patients identified as having received aMRI-LINAC –based therapy is significantly lower than the number of patients reported from anonymized administrative data from US 0.35T-MRI-guided radiation therapy treatment systems.[8,9] A similar report from Europe and Asia recorded 1009 patients during 2018 to 2019 treated with adaptive MR-based therapy.[10] Of note, recent practice patterns also have been published using data extracted directly from industry groups.[11]

Conclusion

We found that the first 2 years of aMRI-LINAC adoption recorded in the NCDB was slow and attributed to academic sites of practice. Further study will be needed to assess how practice patterns evolve.

Acknowledgments

The National Cancer Database is a joint project of the Commission on Cancer of the American College of Surgeons and the American Cancer Society. The data used in the study are derived from a deidentified National Cancer Database file. The American College of Surgeons and the Commission on Cancer have not verified and are not responsible for the analytical or statistical methodology employed, or the conclusions drawn from these data by the investigator.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.adro.2022.101167.

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