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ORIGINAL ARTICLE

Limitations of abdominopelvic CT and multiparametric MR imaging for detection of lymph node metastases prior to radical prostatectomy

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Abstract

Purpose To investigate the performance of pre-surgery CT and multiparametric MRI (mpMRI) to identify lymph node (LN) metastases in the Michigan Urological Surgery Improvement Collaborative (MUSIC). Abdominopelvic CT and mpMRI are commonly used for intermediate- and high-risk prostate cancer (PCa) staging.

Methods Retrospective analysis of the MUSIC registry identified patients undergoing robot-assisted radical prostatectomy (RP) between 3/2012 and 7/2018. Patients were classified according to pre-surgery imaging modality. Primary outcomes were operating characteristics of CT and mpMRI for detection of pathologic LN involvement (pN1).

Results A total of 10,250 patients underwent RP and 3924 patients (38.3%) underwent CT and/or mpMRI prior to surgery. Suspicion for LN involvement was identified on 2.3% CT and 1.9% mpMRI. Overall, 391 patients were pN1(3.8%), including 0.1% low-, 2.1% intermediate-, and 10.9% high-risk PCa patients. Of 235 pN1 patients that underwent CT prior, far more had negative (91.1%) than positive (8.9%) findings, yielding sensitivity: 8.9%, specificity: 98.3%, negative predictive value (NPV): 92.1%, and positive predictive value (PPV): 32.3% for CT with regard to LN metastases. Similarly, more patients with pN1 disease had negative mpMRI (81.0%) then suspicious or indeterminate MRI (19.0%), yielding sensitivity: 19.0%, specificity: 97.3%, NPV: 95.9%, and PPV: 26.7%.

Conclusions Abdominopelvic CT and mpMRI have clear limitations in identifying LN metastases. Additional clinicopathologic features should be considered when making management decisions, as 2.1% and 10.9% with intermediate-and high-risk cancer had metastatic LNs. The majority of pN1 patients had a negative CT or a negative/indeterminate mpMRI prior to RP. Pelvic LN dissection should be performed in RP patients with intermediate- or high-risk PCa, independent of preoperative imaging results.

Keywords Prostate cancer · Magnetic resonance imaging · Computed tomography · Imaging · Lymph node · Pelvic lymph node dissection

Introduction

Prostate cancer (PCa) is the most common non-skin cancer among men, and the second leading cause of cancer-related deaths in men [1]. In PCa, lymph node (LN) staging is particularly important, as lymphatic involvement is a predictor of disease recurrence and progression, and directly influences treatment options [2, 3]. Once the cancer has distant metastases (stage M1), patients are typically managed with androgen deprivation therapy with or without other systemic agents, although paradigms are changing to include management of local tumor burden in select patients [4–6]. Therefore, accurate LN staging of PCa patients is critical in determining appropriate management. The two main

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methods for locoregional staging include preoperative imaging with abdominopelvic computed tomography (CT) and/or magnetic resonance imaging (MRI), or at the time of surgery with pelvic lymph node dissection (PLND).

Even as MRI is increasingly being used for assessment of the local PCa burden in patients being considered for treatment and surveillance, both MRI and CT are being used during staging of higher risk PCa. Despite improvements in these imaging techniques, the reported accuracy for metastatic LN detection is limited in both CT and MRI [7–9]. More PCa-specific imaging modalities, such as ^{18}F-fluciclovine PET-CT and prostate-specific membrane antigen (PSMA) PET-CT are redefining the field, but not currently indicated (or covered by insurance) in the initial staging of PCa patients [10, 11]. Previous studies have reported a wide range of sensitivity and specificity for CT detection of LN metastases, including sensitivity ranging from 5 to 77% and specificity ranging from 75 to 100% [2]. Literature regarding MRI indicates similarly broad estimates for sensitivity (6–68%) and specificity (78–97%) [2, 4, 12]. A recent meta-analysis by Hovels et al. showed sensitivities of 42% and 39%, and specificities of 82% each for CT and MRI, respectively, for the identification of LN metastases [5]. These studies, the majority of which were ascertained solely from academic centers, raise concerns about the reliability of imaging alone for accurate LN staging. The goal of this 'real world' study, which includes patients managed at a wide range of community and academic practices participating in the Michigan Urological Surgery Improvement Collaborative (MUSIC), is to investigate whether preoperative CT and MRI can reliably identify LN metastases of PCa.

Materials and methods

Study population

MUSIC was established in 2011 as a physician-led, Blue Cross Blue Shield of Michigan funded, quality improvement consortium. MUSIC consists of 45 practices across the state of Michigan, representing approximately 250 urologists. The primary goal of MUSIC is to improve the quality and cost efficiency of care for men with PCa. MUSIC quality improvement activities obtained exemption or approval from all local institutional review boards. Trained clinical data abstractors review the medical records of patients who underwent radical prostatectomy (RP) from all participating physicians and enter data elements into a web-based registry. Data elements include prostate-specific antigen (PSA), clinical stage, biopsy Gleason score, pathologic Gleason score, pathologic T stage, and pathological N+ disease.

Between March 2012 and July 2018, > 25,000 PCa patients were evaluated within MUSIC, including 28.3% with low-risk, 45.2% with intermediate-risk, and 24.3% with high-risk features according to D'Amico criteria; 3.3% of these patients had CT or MRI with clinical suspicion of LN metastases. Of all PCa patients, RP was performed in 42.3%, including 23.8%, 53.4% and 42.9% of those with low-, intermediate-, and high-risk PCa, respectively. Included in this study are the 10,250 patients undergoing RP. Patients were grouped by imaging performed prior to surgery: abdominopelvic CT, MRI (pelvic or abdominopelvic), MRI and CT, or neither of these studies. Until June 2016, data collection regarding MRI ($n = 611$) within the MUSIC registry was extremely limited, indicating only whether a study was 'positive' or 'negative' and were excluded from analysis in the present study. Subsequent to this, more detailed data collection began, permitting an assessment of MRI performance for LN metastasis ($n = 854$). CT and MRI were considered positive for LN metastases based on the radiologist interpretation, in general, when the short axis was > 8 mm for a round LN or > 10 mm for an oval LN [13, 14]. MRI studies interpreted as somewhat enlarged or concerning LNs (but not reaching 8 mm in short axis), i.e., not meeting criteria to be regarded as 'positive', were considered 'indeterminate'. In cases where there was ambiguity about the interpretation of the scan, medical records were reviewed by a senior urologist (JEM) at the MUSIC coordinating center. During the timeframe of the study, the decision to perform PLND was made by the operating surgeon; acknowledging the presence of several guidelines, the MUSIC coordinating center had not offered specific guidance in this regard. There was also no formalized template for PLND instituted during this timeframe and MUSIC did not record data regarding the number of LNs removed or whether a 'limited', 'standard', or 'extended' PLND was performed.

Statistical analysis

Pre-treatment and pathologic characteristics of patients were compared for those undergoing preoperative CT, MRI, MRI and CT, or no imaging using Wilcoxon rank-sum test for continuous measures and chi-square test for categorical variables. For patients that received CT or MRI, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of imaging were further computed based on clinical N stage (based on imaging) and pathological N stage. Given that the result of MRI can be positive, negative, or indeterminate, sensitivity analyses were performed where indeterminate was considered as either positive or negative when calculating sensitivity/specificity/PPV/NPV. Similar analyses were further done among a subgroup of patients who met the MUSIC Imaging Appropriateness Criteria for abdominal staging, which is defined as those with a preoperative PSA > 20 or biopsy Gleason ≥ 8 or clinical T3/T4 stage [15]. All statistical analyses were performed

using SAS, version 9.4 (SAS Institute) and statistical significance was set at 0.05.

Results

Using the MUSIC registry, 10,250 patients who underwent RP were identified, including 6326 (61.7%) without imaging prior. Prior to RP, 1138 had MRI (11.1%), 2459 had CT (24.0%), and 327 (3.2%) had undergone both. Significant differences between these four imaging groups were observed in pre-treatment and pathologic features (Table 1). D'Amico high-risk patients represented 8.3%, 20.4%, 59.7%, and 66.3% of the no imaging, MRI, CT, and MRI/CT cohorts, respectively ($p < 0.001$). Predominant Gleason pattern 4/5 disease (grade group 3–5) was present in 21.3%, 30.1%, 48.2% and 54.1% and pT3b/T4 cancer represented 5.6%, 8.3%, 20.8% and 24.2% of the no imaging, MRI, CT, and MRI/CT groups, respectively (both $p < 0.001$). Overall, there was a significant difference between imaging groups in the rate of pN1 at RP (CT/MRI: 9.2%, CT: 8.3%, MRI: 4.6%, no imaging: 1.6%, $p < 0.001$).

Radiographic suspicion for LN involvement was identified on 2.3% of CT (65/2786) patients and 1.9% of MRI (16/854). CT suspicion of LN+ was strongly associated ($p < 0.001$) with higher grade group (sGG5: 53% for N1

Table 1 Pre-treatment and pathologic features for patients undergoing RARP after no abdominal imaging, MRI, CT, or MRI and CT

Variable	Overall $n = 10,250$	No imaging $n = 6326$	MRI $n = 1138$	CT $n = 2459$	MRI and CT $n = 327$	P[a]
Age, mean (IQR)	63.4 (58.1–68.0)	63.0 (57.8–67.6)	63.3 (58.0–68.0)	64.2 (58.8–68.7)	64.3 (58.9–69.5)	< 0.001
Initial PSA, mean (IQR)	5.9 (4.4–8.6)	5.4 (4.2–7.3)	6.6 (4.7–9.6)	7.3 (5.0–12.0)	8.3 (5.7–14.7)	< 0.001
Initial clinical T-stage						
T1a–b	96 (0.9)	58 (0.9)	9 (0.8)	26 (1.1)	3 (0.9)	< 0.001
T1c	7343 (71.7)	4814 (76.2)	883 (77.7)	1466 (59.7)	180 (55.0)	
T2	2636 (25.7)	1396 (22.1)	225 (19.8)	887 (36.1)	128 (39.1)	
T3	125 (1.2)	32 (0.5)	14 (1.2)	67 (2.7)	12 (3.7)	
Unknown	39 (0.4)	19 (0.3)	5 (0.4)	11 (0.4)	4 (1.2)	
Biopsy grade group (Gleason score)						
1 (3 + 3)	2149 (21.3)	1737 (27.6)	199 (19.5)	197 (8.0)	16 (5.1)	< 0.001
2 (3 + 4)	4250 (42.2)	3142 (49.9)	467 (45.9)	566 (23.1)	75 (23.9)	
3 (4 + 3)	1915 (19.0)	1193 (18.9)	209 (20.5)	469 (19.1)	44 (14.0)	
4 (8)	1093 (10.8)	154 (2.4)	90 (8.8)	779 (31.8)	70 (22.3)	
5 [9–10]	672 (6.7)	70 (1.1)	53 (5.2)	440 (18.0)	109 (34.7)	
D'Amico risk group						
Low	1733 (17.2)	1443 (23.1)	159 (15.2)	124 (5.1)	7 (2.2)	< 0.001
Intermediate	5923 (58.9)	4287 (68.6)	672 (64.4)	862 (35.2)	102 (31.6)	
High	2406 (23.9)	516 (8.3)	213 (20.4)	1463 (59.7)	214 (66.3)	
Surgical grade group (Gleason score)						
1 (3 + 3)	1361 (13.5)	1123 (18.0)	102 (9.1)	126 (5.2)	10 (3.2)	< 0.001
2 (3 + 4)	5131 (50.9)	3581 (57.4)	635 (56.4)	816 (33.9)	99 (32.1)	
3 (4 + 3)	2206 (21.9)	1172 (18.8)	271 (24.1)	690 (28.7)	73 (23.7)	
4 (8)	534 (5.3)	186 (3.0)	46 (4.1)	280 (11.6)	22 (7.1)	
5 (9–10)	846 (8.4)	174 (2.8)	72 (6.4)	496 (20.6)	104 (33.8)	
Pathologic T stage						
T2	6809 (66.4)	4730 (74.8)	749 (65.8)	1212 (49.3)	118 (36.1)	< 0.001
T3a	2402 (23.4)	1243 (19.6)	294 (25.8)	735 (29.9)	130 (39.8)	
T3b/T4	1039 (10.1)	353 (5.6)	95 (8.3)	512 (20.8)	79 (24.2)	
Pathologic N stage						
Nx	2429 (23.7)	2018 (31.9)	175 (15.4)	222 (9.0)	14 (4.3)	< 0.001
N0	7430 (72.5)	4204 (66.5)	911 (80.1)	2032 (82.6)	283 (86.5)	
N1	391 (3.8)	104 (1.6)	52 (4.6)	205 (8.3)	30 (9.2)	

Cell values are *n* (%), unless otherwise specified

[a]For the comparison of characteristics between no imaging, CT and MRI groups

vs. 18% for N0/NX) and pT stage (pT3b/T4: 44% for N1 vs. 18% for N0/NX). Of the 65 patients suspicious for LN involvement on CT, only 32.3% (21/65) had pN1 disease at RP (Table 2). In addition, of the patients with pN1 at RP, 91% (214/235) had no suspicion for LN metastases on CT. This yields a sensitivity of 8.9%, specificity of 98.3%, NPV of 92.1% and PPV of 32.3%. Concordance of CT and MRI findings was assessed in the 193 patients having MRI with data regarding LN involvement. For these 193 patients, concordance was 94% with 186 having a negative CT and MRI and 1 patient regarded as positive on both CT and MRI. MRI identified two patients as having suspicious LNs not seen on CT, and CT identified four patients with suspicious LNs that were not mentioned on MRI.

There was a graded decrease in adverse pathologic features for positive vs. indeterminate vs. negative LNs on MRI (Supplemental Table 1). Six of the 16 patients with positive (37.5%), 2 of 14 indeterminate (14.3%), and 34 of 824 negative (4.1%) MRI had pN1 disease ($p < 0.0001$). Of the patients with pN1 at RP, 81% (34/42) had no suspicion for LN metastases by MRI and 4.8% more (2/42) were indeterminate. When considering only the six MRI with suspicious LN as positive, sensitivity was 14.3%, specificity was 98.8%, NPV was 95.7% and PPV was 37.5%, all of which were higher than with CT. Operating characteristics when 'indeterminate' and 'suspicious' LN on MRI were regarded as positive yielded sensitivity of 19.0%, specificity of 97.3%, NPV of 95.9%, and PPV of 26.7%.

Among patients with indications for cross-sectional staging (PSA > 20, or Gleason ≥ 8 or clinical stage T3/T4) [16], suspicion of LN involvement was identified on 3.5% of CT (56/1590) and 3.7% of MRI (8/217). Clinical N1 disease was suspected on only 0.8% of CT (9/1145) and 2.8% of MRI (15/534) performed in PCa patients not meeting these indications. Pathologic N1 disease was also more prevalent when staging was indicated, including 12.0% having CT (191/1590) and 12.8% having MRI (28/217), compared with 3.5% having non-indicated CT (41/1145) and 2.2% having non-indicated MRI (12/534). Differences in the operating characteristics of both CT and MRI were observed when comparing imaging in indicated and non-indicated situations, with reduced sensitivity and PPV in the non-indicated PCa patients (Table 3). In the indicated group, all operating characteristics were better with MRI than with CT. For example, sensitivity was 9.9% with CT and 17.9% with MRI, and PPV was 33.9% with CT and 62.5% with MRI. In the non-indicated patients, specificity and NPV were high (> 95%), but sensitivity and PPV were poor.

Discussion

Modern PCa imaging is moving in the direction of mpMRI and PCa-specific PET [11, 17, 18]. mpMRI is being increasingly used for men with low- to intermediate-risk PCa and during PCa screening to identify the extent of disease within the prostate gland. Recent comparisons indicate no significant differences in primary tumor localization by MRI and 68Ga-PSMA-PET/CT [19, 20]. Abdominopelvic CT and MRI are both commonly used for identification of LN metastases in PCa patients prior to treatment, especially for men at intermediate- or high-risk of metastatic disease [5, 15, 21]. In clinical practice, men with a PSA > 20 ng/ml or Gleason score ≥ 8 or clinical stage T3/T4 disease are recommended to undergo either CT or MRI to detect LN metastases [4, 21]. According to European guidelines, patients with stage T2 or less, PSA < 10 ng/ml, Gleason score ≤ 6, and < 50% positive biopsy cores have a < 10% likelihood of having nodal metastases, and do not need nodal evaluation [15, 21]. Although modern PET/CT with tumor-specific radiotracers, such as with choline and prostate-specific membrane

Table 2 Comparison between imaging (CT and MRI) and pathologic results for LN staging

CT result	Pathologic N stage		Total
	Negative	Positive	
Negative	2507	214	2721
Positive	44	21	65
Total	2551	235	2786
Sensitivity: 8.9%; Specificity: 98.3%; PPV: 32.3%; NPV: 92.1%			
MRI result	Pathologic N stage		Total
	Negative	Positive	
Negative	802	36	838
Positive	10	6	16
Total	812	42	854
Sensitivity: 14.3%; Specificity: 98.8%; PPV: 37.5%; NPV: 95.7%			

Table 3 Comparison between imaging (CT and MRI) and pathological results among indicated and non-indicated patients

CT Result	Pathologic N stage			
	Indicated[a] ($n=1590$)		Non-indicated ($n=1145$)	
	Negative	Positive	Negative	Positive
Negative	1362	172	1097	39
Positive	37	19	7	2
Indicated: Sensitivity: 9.9%; Specificity: 97.4%; PPV: 33.9%; NPV: 88.8%				
Non-indicated: Sensitivity: 4.9%; Specificity: 99.4%; PPV: 22.2%; NPV: 96.6%				
MRI Result	Pathologic N Stage			
	Indicated[a] ($n=217$)		Non-indicated ($n=534$)	
	Negative	Positive	Negative	Positive
Negative[b]	186	23	516	11
Positive	3	5	6	1
Indicated: Sensitivity: 17.9%; Specificity: 98.4%; PPV: 62.5%; NPV: 89.0%				
Non-indicated: Sensitivity: 8.3%; Specificity: 98.9%; PPV: 14.3%; NPV: 97.9%				

[a]Based on MUSIC Imaging Appropriateness Criteria for abdominal imaging, defined as PSA > 20 or Gleason ≥ 8 or Clinical T3/T4 (15)

[b]Includes prostate MRI with negative or indeterminate findings regarding LNs

antigen ligand, hold great promise for the identification of metastatic disease, they are not widely available at present and not generally performed at initial diagnosis with PCa [17].

The effectiveness of CT and MRI for LN staging has been questioned because of the limited ability to identify normal-sized LNs harboring micrometastases and the tendency to conservatively call LNs 'positive' based on nonspecific enlargement. These limitations affect treatment decisions and outcomes, because patients with undetected LN metastases may be under-treated and those with false positives may forego definitive local therapy or be over-treated. Previous studies have investigated the performance of MRI for identification of metastatic LNs, finding it to have similar performance to CT [2, 4, 5, 12]. A meta-analysis from over 10 years ago found the reported sensitivity and specificity of MRI to range from 6 to 68% and 78 to 97%, respectively [5]. Over the last decade, several developments have improved the performance of MRI for the detection of intraprostatic disease. However, standard mpMRI (like CT) is believed to have limited sensitivity for small LN at present [2]. Even with this limitation, CT and MRI are commonly used to evaluate for LN metastases, because they are noninvasive techniques with widespread availability [2, 4, 5, 12]. Of the two modalities, our data indicate that MRI appears to have only somewhat better operating characteristics with respect to staging of LN (and greater resolution for evaluation of intraprostatic findings) when compared to CT (Table 2). Performance is not even remotely similar to that of pathologic assessment of the LNs with PLND.

The sensitivity and specificity in our patient population of 8.9% and 98.3% for CT and 14.3% and 98.8% for MRI, respectively, fall within the previously reported ranges of 5–77% for sensitivity and 75–100% for specificity [2]. When examining only patients meeting MUSIC criteria for pre-treatment imaging, which decreased the inappropriate imaging rate by 7% when implemented statewide [22], the sensitivity and specificity in our study of 9.9% and 97.4% for CT and 17.9% and 98.4% for MRI also compare favorably with the previously reported ranges [22]. The lack of sensitivity for detecting LN metastases supports prior findings that these imaging modalities are limited in identifying smaller LN metastases [2, 4, 5]. Combining imaging and next-generation imaging techniques will play a role in the identification of LN metastases [23]. A recent systematic review and meta-analysis of the diagnostic accuracy of ^{18}F-fluocholine PET/CT for preoperative LN staging in newly diagnosed PCa found a pooled sensitivity of 57%, specificity of 94%. The authors concluded that even this modality is "only useful for confirmation of LN metastasis (when positive) in PCa patients [24]." In another study of 130 patients with intermediate- or high-risk disease, sensitivity, and specificity for LN detection on a template-based analysis have been reported to be 68.3% and 99.1%, respectively; sensitivity was significantly better than with conventional morphological imaging (27.3% and specificity of 97.1%) [18, 25]. Another group concluded after evaluating PSMA-PET/CT imaging findings in 280

treatment-naïve PCa patients that a formula based on clinical features alone 'can still be used for a quick assessment of potential lymphatic spread in daily clinical routine' [26]. Koerber et al. compared pelvic mpMRI with ^{68}Ga-PSMA-PET/CT and concluded that combining the advantages of both PSMA-PET and mpMRI modalities in hybrid PET/MRI scanners would be ideal [27]. Finally, Meiber et al. compared standard clinical 3T mpMRI with ^{68}Ga-PSMA-PET-CT for pelvic LN staging, concluding that prostate MRI represented an accurate tool for the detection of LN, particularly when ≥ 10 mm [28].

Overall, 38.3% of patients (and 78.6% of those with D'Amico high-risk cancer) underwent CT or MRI prior to RP. While suspicion for LN metastases on CT or MRI was predictive of higher risk disease, it was a poor predictor of the presence of LN metastases (PPV: 32.3–37.5%). This association may result from selection of patients for staging with CT/MRI based on high biopsy Gleason score, cT stage, and/or PSA, so there is a possibility of selection bias or the radiologist having a lower threshold for calling positive LN metastases in high-risk patients [4].

This study raises concerns both for patients with and without suspicion of LN metastasis on abdominopelvic CT and MRI. One concern is false-positive results in which, although there is suspicion of LN involvement, no LNs containing cancer are identified at RP. In this study, 67.7% (44/65) of the suspicious CTs and 62.5% (10/16) of the suspicious MRIs were false positives. False positive studies may affect treatment selection, because patients with suspicious LNs at imaging might be managed as having disseminated disease and not be offered definitive local treatment or over-treated for non-pathologically confirmed LN metastases [4, 6]. Pathologic confirmation of positive imaging studies (by PLND, or perhaps by percutaneous biopsy if surgery is not advisable) appears prudent to confirm radiographic LN suspicion. If patients are to undergo PLND, an extended PLND is recommended to provide the most accurate staging and prognostic benefit [29].

The other concern raised by this study are the false negative results, where the imaging is not suspicious (or indeterminate) for LN involvement, but patients are found to have positive LN metastases at RP/ PLND. In this study, 7.9% (214/2721) of the negative CTs and 4.3% (36/838) of the non-suspicious MRIs were false negatives. These patients, as well as, patients who do not undergo any preoperative imaging, may not receive PLND, because there is no reported suspicion; however, pathologic evidence indicated metastatic LNs in 2.1% and 10.9% of those with intermediate- and high-risk cancer at RP, respectively. This large proportion of missed LN involvement in our study highlights the low sensitivity of staging CT and MRI prior to RP also reported in previous studies [2, 4, 5]. The individual risk of finding positive LNs can be estimated using preoperative tools, such as the Briganti nomogram, or Roach formula (% N+ = 2/3 × PSA + 10 × (GS-6)) [12, 29, 30]. Taken together, PLND should be offered to surgical patients with intermediate- or high-risk cancer, independent of the findings on preoperative imaging, to confirm LN involvement.

The limitations of the present study include those inherent to any registry-based study, including variability in imaging and surgical practices across sites and urologists. In particular, there was no specific template used for PLND across the state, with the extent of dissection at the discretion of the surgeon. It is certain that this study underestimates the true LN positivity rates in this population due to the frequent use of a non-extended template for PLND, such as limited or obturator only PLND [29], and other patients underwent no PLND. In addition, some suspicious LNs may be in areas not routinely assessed even during extended PLND, such as perirectal or mesenteric LNs, and it was not possible to link the location of the suspicious LNs on imaging to the location of positive LNs at PLND. The different imaging fields between abdominopelvic CT and MRI, which was pelvic at some centers and abdominopelvic at others, is another limitation. The selection biases affecting use of pelvic imaging is another confounder that cannot be fully accounted for.

Conclusion

Our results indicate significant concerns with the accuracy of staging according to both CT and mpMRI, even using contemporary techniques and equipment. The data in this study have implications for patients with imaging displaying suspicious LNs, who might be managed as having disseminated disease without biopsy confirmation of metastases. Conversely, non-suspicious imaging may lead to under-treatment, with omission of treatment to the pelvic LNs based on imaging findings. Taken together, PLND should be offered to surgical patients with intermediate- or high-risk cancer, independent of the findings on preoperative imaging, to confirm either the presence or absence of LN involvement.

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Author contributions HP: data collection, manuscript writing. BR Lane: project development, data management, data analysis, manuscript writing/editing. JQ: data analysis. TK: data management, manuscript editing. JEM: project development, manuscript editing. AM: data management, manuscript editing. CMB: project development, data

management, manuscript editing. JM: project development; manuscript editing. Michigan Urological Surgery Improvement Collaborative: project development, data collection and management.

Compliance with ethical standards

Conflicts of interest The authors have no conflicts of interest.

Research involving human participants Each MUSIC practice obtained an exemption or approval for collaborative participation from a local Institutional Review Board.

Informed consent Not applicable as this is a quality improvement study.

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