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Permanent Prostate Brachytherapy Pubic Arch Evaluation with Diagnostic MRI

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Abstract

Background/Purpose—Pubic arch interference (PAI), when it occurs, is often a limiting factor for patients pursuing brachytherapy treatment of prostate cancer. Pre-brachytherapy pubic arch evaluation is often performed by CT or transrectal ultrasound (TRUS), but MRI has increasingly replaced these modalities for prostate cancer evaluation. The purpose of this study was to determine if staging MRI could be used to evaluate PAI and compare it to these other imaging methods.

Methods—Forty-one consecutive patients undergoing brachytherapy evaluation had pelvic MRI, CT, and TRUS based brachytherapy simulation. Pubic arch overlap on T2-weighted MRI and CT was determined by contouring the prostate gland on its largest axial slice and superimposing this contour onto the pubic arch bones. The largest degree of overlap of the prostate gland on MRI and CT was used to predict the existence of PAI as determined by TRUS based simulation. The correlation between prostate contour overlap was also compared between MRI and CT.

Results—Nineteen patients (48%) exhibited PAI on TRUS brachytherapy simulation evaluation. The average ($\pm$ standard error) amount of prostate contour overlap on the pubic arch on CT was 2.9 ± 0.6 mm and on MRI was 2.0 ± 0.6 mm (linear correlation, R, of 0.783, $p < 0.001$). CT and MRI were equally predictive of PAI on TRUS evaluation (AUC=0.75).

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Conflicts of interest: none

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Conclusion—Pre-brachytherapy pubic arch assessment with diagnostic MRI provides similar predictability of PAI compared to CT, potentially obviating the need for additional pre-brachytherapy CT in the setting of staging MRI.

Keywords

Pubic arch; brachytherapy; prostate; MRI

Introduction

Permanent prostate brachytherapy is one treatment option available to men diagnosed with prostate cancer which is able to provide excellent therapeutic outcomes with relatively minimal morbidity (1-3). Unfortunately some men are precluded from this treatment modality secondary to anatomic or patient specific factors such as prostate size or the presence of pubic arch interference (PAI) (4, 5). The assessment for pubic arch interference has been traditionally performed prior to brachytherapy implantation with the use of computed tomography (CT) and/or transrectal ultrasound (TRUS)(6, 7). For CT, a common method of PAI determination consists of outlining the prostate on the largest axial slice and superimposing this over the pelvic bones (6). Overlap of the prostate with the pubic rami of 1 cm has been proposed as a threshold value suitable for brachytherapy consideration (8). These methods are generally able to provide an approximate assessment of PAI prior to brachytherapy implantation, but can be subject to operator variability and often require additional testing/procedures in addition to the routine staging and workup for prostate cancer in the modern era.

In recent years magnetic resonance imaging (MRI) of the pelvis has often replaced CT as the modality of choice for imaging of the prostate and seminal vesicles due to its improved soft tissue delineation and improvements in MRI capabilities over the past decade. MRI is able to provide good sensitivity and specificity for detection of extracapsular extension or seminal vesicle involvement especially with the use of multiparametric MRI (9, 10), which can lead to altered treatment recommendations especially with regards to brachytherapy candidacy. The use of MRI in the pre-prostatectomy setting has been an area of active on-going research and implementation (11), but its routine clinical adoption in permanent prostate brachytherapy outside of staging purposes remains limited (12). The purpose of this study was therefore to investigate whether diagnostic MRI performed for the staging of prostate cancer is able to predict PAI in patients being considered for permanent prostate brachytherapy and compare these MRI results to traditional CT and TRUS based methods.

Methods

Forty one consecutive patients' charts being considered for brachytherapy at our institution received staging MRI, pre-brachytherapy CT, and TRUS based simulation. Clinical information such as demographics, prostate cancer stage, prostate gland size on TRUS, and imaging data were collected. All patients underwent pelvic MRI with a T2-weighted sequence with endorectal coil (inflated to 30-60 cubic centimeters) as part of their cancer staging. Patients are considered eligible at our institution for permanent prostate

brachytherapy monotherapy if they have low to intermediate prostate cancer with PSA < 10, and can be considered for permanent prostate brachytherapy boost along with external beam radiation for high risk prostate cancer. Prior to brachytherapy implantation, all potential candidate patients also underwent a CT scan in the supine position and TRUS evaluation in the dorsal lithotomy position for assessment of PAI.

TRUS evaluation for PAI consisted of performing a simulated brachytherapy implant, which is part of routine clinical practice at our institution. Specifically, patients were placed in the dorsal lithotomy position with ultrasound probe inserted into the rectum. The base of the prostate was identified on TRUS by the treating Radiation Oncologist and the US probe was moved inferiorly in 5 mm slices until the largest axial image of the prostate was obtained. Brachytherapy needle grid positions were aligned with rectal ultrasound probe and the center of the prostate gland. A stylet was then passed through all brachytherapy needle grid positions around the perimeter of the prostate as determined on ultrasound. The stylet was used to identify positions on the patient's perineum consistent with each grid position. The physician assessed for the presence of PAI at each of these positions using palpation, evaluating bone vs. soft tissue. Pubic arch interference was ultimately determined by the presence of bone at any of these grid positions which could preclude brachytherapy needle access.

CT and MRI evaluation for PAI consisted of contouring the prostate at its largest extent on axial CT/MRI scan slices and superimposing this contour to the level of the patients' pubic bones. Evaluation of ultrasound (US) prostate contour overlap was performed in a similar manner to CT and MRI on the 71% of patients in this cohort with archived US imaging, however, US assessment was performed with the patient in the dorsal lithotomy position as described during the TRUS simulation procedure. The largest amount of overlap of the prostate contour and the pubic arch was taken at a right angle to the pubic rami (Figure 1). All contouring and PAI assessment of US, CT and MRI was performed in MIM (MIM Software Inc, Cleveland OH). The amount of pubic arch overlap was compared between the imaging modalities, and they were compared to the definition of PAI via the simulated brachytherapy implant using TRUS. A student's t-test was used to determine if the amount of prostate contour overlap was different between CT and MRI, and logistic regression was used to test if US, CT, or MRI prostate contour pubic arch overlap was a significant predictor of PAI via TRUS based simulation. Linear correlations between CT and MRI prostate contour pubic arch overlap was also performed. SPSS version 23 (IBM, Armonk NY) was used for all statistical analyses with 2-sided *p*-values <0.05 were considered statistically significant.

Results

The average age for patients at the time of brachytherapy evaluation was 66 years old. All patients but one were classified as having intermediate risk prostate cancer. The patient with high risk prostate cancer was evaluated for brachytherapy implant in addition to external beam radiation. The average prostate size ($\pm$ standard error) on pre-brachytherapy ultrasound was 32.6 ± 2.33 mL. Full details of patient characteristics are summarized in Table 1.

Nineteen patients (46%) exhibited evidence of some PAI on TRUS based brachytherapy simulation procedure. The amounts of overlap of the prostate contour from the largest axial prostate slice for CT, MRI, and US are depicted for all patients in Figure 2. The average ($\pm$ standard error) amount of prostate contour overlap on CT was 2.9 ± 0.6 mm and on MRI was 2.0 ± 0.6 mm. These values were not statistically different between the 2 modalities ($p = 0.29$). Thirty patients (75%) had larger values of prostate contour pubic arch overlap on CT compared to MRI. In contrast the average ($\pm$ standard error) of prostate contour overlap with the pubic arch on US was -0.6 ± 0.5 mm, which was significantly different than both CT and MRI ($p < 0.06$).

CT and MRI were equally predictive of PAI on receiver operating characteristic (ROC) curve analysis with areas under the curve (AUC's) of 0.746 and 0.749 respectively, and both were slightly more predictive than US based prostate contour projection onto the pubic arch (AUC of 0.713). Using a cutoff of 0 mm of prostate contour overlap with the US technique, however, led to correct identification of PAI during TRUS simulation in 82% of the cases, while no single cutoff of prostate contour overlap on CT or MRI was able to identify more than 75% of cases correctly. No patients with full clearance of prostate contour with pubic arch (negative overlap) on CT (7 patients) or MRI (8 patients) exhibited evidence of PAI via TRUS simulation. On univariate logistic regression analysis CT pubic arch overlap, MRI pubic arch overlap, and US pubic arch overlap were predictive of PAI ($p < 0.039$). CT and MRI prostate contour overlap with pubic arch showed linear correlation of 0.783 ($p < 0.001$) with each other as depicted in Figure 3.

Discussion

This study is the first to our knowledge to evaluate pubic arch interference prior to permanent prostate brachytherapy implantation using MRI. Our results show that both MRI and CT provide similar estimates of pubic arch interference as determined by TRUS based brachytherapy simulation, and there was a strong linear correlation between quantitative values of MRI and CT based pubic arch interference. Furthermore, the ability of MRI to reliably predict lack of PAI was excellent if prostate contour showed no evidence of pubic arch overlap, but was less predictive when prostate contour overlap with the pubic arch measured 0-5 mm.

Multiple studies have shown that CT overestimates pubic arch interference by at least 1 cm and that prostate-pubic arch overlap of less than 1 cm are potential candidates for brachytherapy with larger degrees of overlap considered less suitable candidates for brachytherapy without further intervention such as pre-operative androgen deprivation (6). A study of 243 patients using only the 1 cm threshold on pre-brachytherapy CT scan and prostate size of <60 mL as criteria for brachytherapy found that 19.3% of patients experienced some degree of PAI intraoperatively (8). Of the needles which experienced PAI intraoperatively, none required adjustment of >0.5 cm, only 1.4% of all needles placed experienced interference, and post-implant dosimetric/clinical outcomes were not significantly different between patients requiring needle adjustment from PAI and those without PAI. While CT gives an approximate estimate of pubic arch interference it is often acquired in the supine position as opposed to the dorsal lithotomy position used during the

brachytherapy procedure, and many patients will still require pre-implant volume study or intraoperative ultrasound assessment for final brachytherapy planning.

In contrast, TRUS based pubic arch assessment is performed in the dorsal lithotomy position allowing for similar positioning of the patient's pelvis to the prostate brachytherapy procedure. TRUS based volume assessment alone does not lead to reliable predictions of PAI (6), but full TRUS based pubic arch assessment has been shown to produce low rates of intraoperative pubic arch interference. In particular Fukada et al found only 1/18 patients to have intraoperative PAI after showing no evidence of PAI on pre-implant TRUS (13), and no patients (0/50) in a series by Henderson et al required intraoperative adjustment of brachytherapy implants due to PAI when using pre-operative TRUS for pubic arch assessment (14). These studies are consistent with our present series, which found no incidences of PAI during brachytherapy implantation requiring significant adjustment of the brachytherapy needles when using TRUS based pre-operative PAI assessment, and using a cutoff of 0 mm of prostate contour overlap on US correctly identified PAI in 82% of cases. While TRUS based PAI can provide accurate evaluation of a patient's pubic arch, it is very user dependent highlighted by our institution's practice to have the treating radiation oncologist perform the pre-operative TRUS and can be uncomfortable for the patients consistent with some patients being unable to tolerate TRUS at our institution. These limitations of TRUS have ultimately led to our use of other axial imaging for PAI assessment.

The use of diagnostic MRI for evaluation of PAI in this study overall shows similar estimates of PAI compared to CT with strong linear correlation between the 2 methods (15). This would be expected as the procedure to determine PAI was similar between the two scans including the way the prostate contour is generated and projected and the supine positioning of the patients. At our institution staging MRI is performed in all patients as part of the prostate brachytherapy workup, therefore the ability of the pre-brachytherapy staging MRI to produce similar PAI assessment compared to CT may obviate the need for an additional pelvic CT scan for PAI assessment, thus reducing cost and low dose radiation exposure. Physicians at our institution have recently been exploring MRI based brachytherapy planning, which could also reduce the need for TRUS evaluation prior to brachytherapy implantation. The possibility of reducing pre-brachytherapy TRUS can be best appreciated in the subset of patients in this study who showed no PAI on MRI as they never showed PAI on TRUS simulation. These results suggest that using these or similar thresholds could reduce at least 20% of traditional ultrasound based PAI evaluation procedures at our institution.

The use of MRI only in the evaluation of PAI does present some challenges. First, the use of endorectal imaging coils such as an endorectal balloon to provide better prostate soft tissue resolution can cause pelvic distortion, and patient positioning is different between MRI and the brachytherapy implantation. For example, we have previously published results emphasizing the difficulty in MRI based brachytherapy planning with the use of endorectal balloons (16), and the presence of an MRI compatible endorectal balloon inflated to 100 cubic centimeters causes significant displacement of the prostate relative to bladder and rectal contours (17). Despite the known limitations of PAI assessment by axial imaging

(MRI or CT) and the differences in image acquisition between these modalities, the results from this paper suggest that MRI can be substituted for CT given the strong correlation ($R=0.783$, similar AUC's), and provide a quick easy test of PAI without the additional cost and low dose radiation exposure associated with a dedicated CT assessing for PAI. Furthermore, studies of prostate brachytherapy seed displacement caused by the presence of a transrectal device have demonstrated that the primary source of deformation from this device occurs in the posterior aspect of the prostate, which would not be expected to cause significant changes in pubic arch assessment (18, 19). Second, the use of TRUS based simulation in-lieu of attempted needle passage in an operating room to define PAI presents some potential concerns. In particular, this study was not able to evaluate the extent of PAI on TRUS simulation and therefore treated TRUS based PAI as a binary variable, and other differences (e.g. anesthesia use) between these settings could act as confounders. These factors likely overestimate the proportion of patients with brachytherapy limiting PAI (i.e. increased false positives) as small amounts of PAI can be amenable to patient or needle re-positioning techniques (20). We attempted to mitigate these differences by using the same dorsal lithotomy patient positioning and rectal ultrasound probe during TRUS simulation as is done in the operating room, and all patients who displayed absence of PAI were able to receive a brachytherapy implant (0% false negative rate). Given the time and costs associated with bringing a potential brachytherapy candidate to the operating room at our institution, we feel that our use of TRUS based simulation provides a beneficial compromise compared to full operating room evaluation in all brachytherapy candidates. Third, while MRI based prostate brachytherapy planning is becoming more common at our institution this has yet to become a part of routine clinical practice. If diagnostic MRI is not performed routinely then another method of PAI determination would still need to be undertaken such as CT or TRUS. Institutions that utilize pre-brachytherapy planning via US would still require pre-procedure TRUS/volume study, and could limit the general applicability of the method investigated in this study.

In conclusion, our study shows that MRI based PAI assessment using diagnostic MRI T2-weighted images is feasible and provides results consistent with CT assessment. If no PAI exists on MRI there may be little utility in performing additional pubic arch imaging except for radiation planning purposes, thus potentially decreasing the amount of scans or procedures required for brachytherapy evaluation. The implementation of MRI based pubic arch assessment into routine clinical practice will likely be correlated with the incorporation of MRI into prostate brachytherapy staging and planning, and further research refining the role of MRI in PAI assessment and brachytherapy planning will ultimately be needed in the future.

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Abbreviations

PAI	Pubic arch interference
TRUS	Transrectal ultrasound
US	Ultrasound
CT	Computed tomography
MRI	Magnetic resonance imaging
ROC	Receiver operating characteristic
AUC	Area under the curve

Figure 1.

Example of PAI determined on MRI and CT in the same patient. Panel A shows prostate contour (magenta) on the largest axial slice for both MRI and CT. Panel B shows projected prostate contour from (A) over the pubic arch with blue line indicating the amount of pubic arch overlap with prostate contour. These measurements were used to determine the extent of pubic arch overlap in each patient. A rectal balloon is in place posterior to the prostate in the MRI images.

Figure 2.

Evaluation of prostate contour overlap on CT, MRI, and US. The amount of overlap was determined by contouring the prostate on the largest axial prostate image and superimposing that contour to the level of the pubic arch. Negative values indicate prostate contour inside pubic arch, and positive values indicate evidence of pubic arch overlap with superimposed prostate contour.

Figure 3.

Comparison of the amount of prostate contour overlap on the pubic arch when determined by CT vs. MRI. Linear correlation coefficient, R , between the measurements is depicted next to scatterplot data.

Table 1**Patient Characteristics**

Age, mean $\pm$ S.E.	66 $\pm$ 1 years
PSA, mean $\pm$ S.E.	5.9 $\pm$ 0.4 ng/dL
Tumor Stage, n (%)	
T1c	36 (88%)
T2a	5 (12%)
Gleason Score, n (%)	
6 (3 +3)	4 (10%)
7 (3 + 4)	10 (25%)
7 (4 + 3)	26 (63%)
8 (4 + 4)	1 (2%)
Prostate Size on US, mean $\pm$ S.E.	32.6 $\pm$ 2.3 mL

S.E.: Standard error of the mean