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Prostate Volume and Landmark Analysis: Comparison of MRI Measurements Obtained with Endorectal Coil and with Phased-array Coil

Y. Mazaheri^{1,2,*}, A. A. Afaq², S. I. Jung², D. A. Goldman⁴, L. Wang², H. Aslan², M. J. Zelefsky³, O. Akin², H. Hricak²

¹Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

²Department of Radiology, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

³Department of Radiation Oncology, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

⁴Department of Epidemiology & Biostatistics, Memorial Sloan-Kettering Cancer Center, New York, NY, USA

Abstract

AIM—To compare prostate volumes and distances between anatomical landmarks on MRI images obtained with a phased-array coil (PAC) only and with a PAC and an endorectal coil (ERC).

MATERIALS AND METHODS—Informed consent was waived for this Health Insurance Portability and Accountability Act-compliant study. Fifty-nine men underwent PAC-MRI and ERC-MRI at 1.5 ($n=3$) or 3 T ($n=56$). On MRI images, two radiologists independently measured prostate volume and distances between the anterior rectal wall (ARW) and symphysis pubis at the level of the verumontanum; ARW and symphysis pubis at the level of the mid-symphysis pubis; and bladder neck and mid-symphysis pubis. Differences between measurements from PAC-MRI and ERC-MRI were assessed with the Wilcoxon RANK SUM test. Inter-reader agreement was assessed using the concordance correlation coefficient (CCC).

RESULTS—Differences in prostate volume between PAC-MRI and ERC-MRI [median: -0.75 mm^3 ($p=0.10$) and median: -0.84 mm^3 ($p=0.06$) for readers 1 and 2, respectively] were not significant. For readers 1 and 2, median differences between distances were as follows: -10.20 and -12.75 mm , respectively, ARW to symphysis pubis at the level of the verumontanum; -6.60 and -6.08 mm , respectively, ARW to symphysis pubis at the level of the mid-symphysis pubis; -3 and -3 mm respectively, bladder neck to mid-symphysis pubis. All differences in distance were significant for both readers ($p < 0.0005$). Distances were larger on PAC-MRI ($p < 0.0005$). Inter-reader agreement regarding prostate volume was almost perfect on PAC-MRI (CCC: 0.99; 95%

*Guarantor and correspondent: Y. Mazaheri, Departments of Medical Physics and Radiology, Memorial-Sloan Kettering Cancer Center, New York, NY, USA. Tel.: +1 212-639-6913. mazahery@mskcc.org.

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CI: 0.98–1.00) and ERC-MRI (CCC: 0.99; 95% CI: 0.99–1.00); inter-reader agreement for distance measurements varied (CCCs: 0.54–0.86).

CONCLUSION—Measurements of distances between anatomical landmarks differed significantly between ERC-MRI and PAC-MRI, although prostate volume measurements did not.

INTRODUCTION

To optimize MRI of prostate cancer, an endorectal coil (ERC) is used in conjunction with a pelvic phased-array coil (PAC) (1–3). Prior studies found that, compared to the use of a PAC alone, the use of both an ERC and a PAC (a combination referred to hereafter as ERC) produces significantly higher accuracy and specificity at 1.5 (1–3) and 3 T (2) by markedly increasing the signal-to-noise ratio (SNR) and, thus, spatial resolution. However, the use of an endorectal coil, which consists of an outer sheath covering an inner balloon that must be inflated in the rectum, causes deformation and displacement of the prostate and surrounding soft tissues.

Heijmink *et al.* (4) found that insertion of an endorectal coil filled with 50 ml of fluid increased the prostate diameter by 5.5 mm (15.7%) in the anteroposterior (AP) direction, decreased it by 3.5 mm (7.7%) in the right-to-left (RL) direction, and decreased it by 2.2 mm (6.3%) in the craniocaudal (CC) direction. They also found a significant mean change in prostate volume from PAC-MRI to ERC-MRI.

Radiation treatment planning for prostate cancer is commonly performed using CT images, which show bony structures and provide information pertinent to dose delivery. However, CT is not ideal for prostate or tumor localization because of its low soft-tissue contrast. ERC-MRI provides excellent soft-tissue resolution, but because of the change in shape (deformation) and the displacement of the prostate caused by inflation of the balloon, ERC-MR images are not representative of the prostate configuration during radiation therapy. More precise localization of the prostate with ERC-MRI could allow the use of smaller margins during radiation treatment, reducing treatment toxicity. In addition, it could be of value for target delineation for dosepainting (5). Without reliable information regarding the location of the tumor(s) within the prostate, the entire prostate must be treated with a uniform dose.

Recent studies have investigated the use of deformable image registration algorithms to register ERC-MRI images to MRI images obtained using only PACs, which more accurately reflect the shape of the prostate during radiation therapy (6–11). However, in order to develop a robust registration method, it is important to characterize the nature of the deformation and displacement that occurs with the use of an endorectal coil. Therefore, the purpose of the present study was to determine the validity of changes in prostate volume reported by Heijmink *et al.* (4) and measure the displacement of major anatomical landmarks close to the prostate caused by the insertion and inflation of the endorectal probe.

MATERIALS AND METHODS

The Institutional Review Board waived the requirement for informed consent for this retrospective study, which was compliant with the Health Insurance Portability and Accountability Act. Between January 2009 and October 2011, 59 patients (median age: 62.3 years; range: 45.1–75.8 years) underwent an MRI examination that included both PAC-MRI and ERC-MRI (i.e., in which imaging was performed once with a PAC and once with both a PAC and an ERC). The median serum prostate-specific antigen (PSA) level for the cohort was 4.80 ng/ml (range: 0–16.22 ng/ml).

MRI data acquisition

MRI examinations were performed using a 1.5 T ($n=3$) or a 3 T ($n=56$) whole-body MRI unit (GE Medical Systems, Milwaukee, WI, USA). Imaging was first performed using the body coil for excitation and a pelvic 32-channel PAC for signal reception. The sequences acquired included a transverse T2-weighted (T2W) fast spin-echo sequence (TR/effective TE, 3000–5600 ms/90–137 ms, 12–16 echo train length, 3–4 mm section thickness, no inter-section gap, 16–20 cm field of view, 512×512 reconstructed matrix) of the prostate and seminal vesicles.

Upon completion of this imaging sequence, a commercially available balloon-covered expandable ERC (Medrad, Pittsburgh, PA, USA) was inserted into the patient's rectum and inflated with 60–80 ml of air. A body coil was used for excitation, and the pelvic 32-channel PAC was used in conjunction with the endorectal coil for signal reception. As per the standard clinical prostate MRI examination at the Memorial Sloan-Kettering Cancer Center, the images obtained included transverse T1W images (TR/TE = 400–1100 ms/6–14 ms, 5 mm section thickness, no intersection gap, 24–38 cm field of view, 320×224 matrix) and transverse, coronal, and sagittal T2W fast spin-echo images (TR/effective TE, 3200–4800 ms/90–122 ms, 12–16 echo train length, 3 mm section thickness, no inter-section gap, 16 cm field of view, 512×512 matrix) of the prostate and seminal vesicles. The time between the transverse T2W acquisitions using PAC and ERC was within 20 min.

Image analysis

In separate sessions, two radiologists (-- and --, who had 1 and 8 years of experience, respectively) took measurements on each set of T2W images displayed on a PACS workstation (Centricity RA 1000, GE Healthcare). For each patient, the radiologists performed volumetry by tracing the prostate circumference on each section that contained prostate. The areas outlined on the image sections were recorded from the PACS workstation, multiplied by the section thickness, and then summed to obtain an estimate of the volume of the prostate (Fig. 1).

Each radiologist measured distances in the transverse plane (1) from the anterior rectal wall to the symphysis pubis at the level of the verumontanum, (2) from the anterior rectal wall to the symphysis pubis at the level of the mid-symphysis pubis (Fig. 2), and (3) from the bladder neck to the mid-symphysis pubis.

Statistical analysis

Medians and ranges were used to describe measurements for ERC-MRI and PAC-MRI. For each reader, Bland–Altman plots were created (12) to graphically represent the relationship between measurements on ERC-MRI and measurements on PAC-MRI, and the mean difference and 95% limits of agreement (LOA) were provided to quantify the graphical display. Concordance correlation coefficients (CCC) along with asymptotic 95% CI were generated to further quantify the agreement between ERC-MRI and PAC-MRI (13). Lin's CCC ranges from -1 , perfect discordance, to 1 , perfect concordance. Reproducibility is indicated by how close the CCC is to 1 . To calculate the difference between measurements, PAC-MRI measurements were subtracted from ERC-MRI measurements. The Wilcoxon signed rank test was used to determine the significance of the differences in volume and distance measurements derived from ERC-MRI and PAC-MRI images.

Similar to the agreement between techniques, the agreement between measurements taken by the two readers was quantified using the CCC and their asymptotic 95% CI. Due to the low sample size of 1.5 T patients, differences among values between magnet strengths were not assessed. A p -value of <0.05 indicated statistical significance. All statistical analyses were performed with SAS 9.2 (SAS Institute, Cary, NC, USA) and Stata 11 (StataCorp, College Station, TX, USA).

RESULTS

Volume analysis

Using the Bland–Altman Plots, a pattern was not detected between difference in distance and average volume. As illustrated in the plots, the mean and 95% LOA volume differences between ERC-MRI and PAC-MRI were -1.07 (95% LOA: $-9.51, 7.36$) for reader 1 and -1.73 (95% LOA: $-12.99, 9.52$) for reader 2 (Fig. 3). The 95% LOA for reader 1 spans 16.9 cc, whereas that for reader 2 spans 22.5 cc, and the CCC between the two techniques were very close to 1 with 0.99 (95% CI: $0.98-1.00$) for reader 1 and 0.98 (95% CI: $0.97-0.99$) for reader 2. Similarly, the difference between prostate volumes measured with ERC-MRI and those measured with PAC-MRI was not significant for either reader, although the difference in the measurements of reader 2 approached significance ($p=0.10$ and $p=0.06$ for readers 1 and 2, respectively; Table 1).

Distance analysis

Table 2 summarizes the median distance measurements made by the two readers on ERC-MRI and PAC-MRI images. For each distance evaluated, the difference between ERC-MRI and PAC-MRI measurements was significant for both readers. The distances measured on PAC-MRI were larger than those measured on ERC-MRI ($p = 0.0005$). The Bland–Altman plots in Figs. 4–6 graphically represent the results of the landmark analysis. For all three measurements for both readers, the Bland–Altman plot patterns do not suggest a relationship between length of distance and degree of discrepancy between ERC-MRI and PAC-MRI. The plots show that a majority of the data points are below zero for both readers, indicating (similarly to the Wilcoxon rank sum test results) that distances measured on PAC-MRI were larger than those measured on ERC-MRI.

For readers 1 and 2, mean and 95% LOA differences in the distance from the anterior rectal wall to the symphysis pubis at the level of the verumontanum were -9.73 (95% LOA: $-23.77, 4.32$) and -12.30 mm (95% LOA: $-24.54, -0.07$), respectively; the CCC between ERC-MRI and PAC-MRI was 0.14 (95% CI: $0.01-0.28$) for reader 1 and 0.16 ($0.03-0.28$) for reader 2. The mean differences in the distance from the anterior rectal wall to the symphysis pubis at the level of the mid-symphysis pubis were -6.55 mm (95% LOA: $-18.05, 4.95$) and -6.08 ± 4.87 mm (95% LOA: $-15.83, 3.66$), respectively, and the CCCs were 0.43 (95% CI: $0.29-0.57$) and 0.45 (95% CI: $0.32-0.59$) for readers 1 and 2, respectively. The mean differences in the distance from the bladder neck to the mid-symphysis pubis were -2.39 mm (95% LOA: $-12.53, 7.75$) and -4.20 mm (95% LOA: $-12.72, 4.31$), and the CCCs were 0.78 (95% CI: $0.69-0.88$) and 0.71 (95% CI: $0.60-0.82$) for readers 1 and 2, respectively. Concordance between ERC-MRI and PAC-MRI was highest (although far from perfect) for the distance from the bladder neck to the mid-symphysis pubis, whereas it was lowest for the distance from the anterior rectal wall to the symphysis pubis at the level of the verumontanum.

Inter-reader measurement agreement

Table 3 summarizes the levels of agreement between the two readers as measured by the CCCs and corresponding 95% CI. For volume measurements, inter-reader agreement was high on PAC-MRI (CCC: 0.99 ; 95% CI: $0.98-1.00$) and ERC-MRI (CCC: 0.99 ; 95% CI: $0.99-1.00$). For distance measurements, consistency between the two readers was higher for ERC-MRI measurements than for PAC-MRI measurements. For instance, the distance from the anterior rectal wall to the symphysis pubis at the level of the verumontanum had a CCC of 0.54 (95% CI: $0.38-0.71$) for PAC-MRI and a CCC of 0.86 (95% CI: $0.79-0.93$) for ERC-MRI. This suggests higher reproducibility for distance measurements on ERC-MRI as compared to PAC-MRI.

DISCUSSION

The present study compared prostate volume and the distances between intra- and periprostatic landmarks at ERC-MRI and PAC-MRI. Measurements of total prostate volume made on ERC-MRI did not significantly differ from those made on PAC-MRI for either reader in the present study. However, for both readers, the distances between the landmarks differed significantly between ERC-MRI and PAC-MRI, which suggests that the deformation and/or displacement of the prostate caused by the insertion of an ERC are substantial. The distances measured were generally longer on PAC-MRI than on ERC-MRI.

The present findings regarding prostate volume measurements contrast with those of Heijmink *et al.*,⁴ who found that total prostate volumes were lower on ERC-MRI than on PAC-MRI in all patients and determined that the mean decrease in total prostate volume was significant ($p < 0.05$). In the present study, for both readers, prostate volume measurements were lower on ERC-MRI than on PAC-MRI in only 56% of patients (33/59), whereas in the remaining 44% of patients, the opposite was true. Certain differences between the present study and the earlier study may explain the differences in outcome. First, whereas in the present study the balloon was filled with air, in the study by Heijmink *et al.*⁴ the balloon was

filled with fluid (such as demineralized water or perfluoropolyether). The present study population was somewhat larger (59 patients versus 44 patients). Finally, non-parametric analyses were performed to account for the not-normally distributed data, whereas Heijmink *et al.*⁴ used parametric statistics, assuming the data from their population followed a normal distribution.

Heijmink *et al.*⁴ measured prostate dimensions and found significant differences between those on ERC-MRI and PAC-MRI, suggesting that the coil significantly deforms the prostate. The present landmark analysis provides additional evidence that the prostate is deformed and/or displaced by the ERC. However, contrary to the suggestions put forth by Heijmink *et al.*,⁴ the present volumetry results indicate that neither the compression of the tissue nor the expulsion of fluid is sufficient to significantly reduce the total prostate volume when the coil is inserted.

The decision to measure distances to anatomical landmarks rather than prostate dimensions in the present study was motivated by clinical considerations. For example, for prostate seed implantation in brachytherapy registration algorithms, such landmarks are customarily used as reference points during patient set-up and target localization; furthermore, quantification of the displacement of the gland relative to these landmarks could be helpful for planning external-beam radiation therapy. The results of the present analysis support the idea that without registration that accounts for the displacement and deformation of the prostate by the ERC, ERC-MRI may not be suitable for radiation treatment planning.

Reliable measurement of prostate volume and distances between anatomical landmarks has several clinical implications (14, 15). Clinically, prostate volume impacts the decision of whether prostate brachytherapy is performed in most centres. Prostate brachytherapy is typically limited to gland volume of 50–60 ml, as larger prostates may be impacted by lower urinary tract symptoms (LUTS). Another consideration in limiting brachytherapy to prostate volumes of 50 ml, is that in men with larger prostates, portions of the gland might be positioned behind the pubic arch, causing obstruction of the seed implantation. In the present study, the Bland–Altman plots (Fig. 3) comparing prostate volumes measured on T2W images obtained with ERC-MRI and with PAC-MRI suggest a trend of increasing differences in ERC-MRI and PAC-MRI volume measurements for volumes >50 ml; thus, it appears that prostate volume measurements may not be reproducible across ERC-MRI and PAC-MRI for volumes above this threshold.

Accurate distance measurements have important implications in treatment planning, especially if MRI is to be fused with CT images for target delineation and early evaluation of radiotherapy effects. The present Bland–Altman plots for distance measurement (Figs. 4–6) suggest that the insertion of the coil causes discrepancies between measurements made with ERC-MRI and PAC-MRI, which must be addressed to minimize the volume of normal tissue exposed to higher radiation doses and reduce the extent of the required margins. A number of deformation methods have been developed (16, 17), and the present results suggest that deformation of prostate MRI images obtained with ERC-MRI is necessary if the images are to be used as part of treatment planning.

The present study found a high level of concordance between the two readers for total volume measurements, but not for distances to landmarks. A recent study investigating inter-reader variability for prostate volume measurements made with transrectal ultrasound (TRUS) found that measurements varied more between readers when patients had larger prostates or readers had different levels of experience (18). It was often difficult for the readers to determine the margin of the prostate apex, primarily because the anatomical border between the prostate and the urethra was unclear on TRUS. The higher level of interobserver agreement found likely reflects the greater ability of MRI to depict the prostate anatomy. It should be noted that the present study did not examine inter-reader agreement separately for the base, mid, and apex, so further analyses to examine variability on TRUS versus MRI for prostate sextants is warranted.

One limitation of the present study was that the true volume of the prostate on pathology was not used to assess the accuracy of prostate volume measurements from imaging, as the main objective of the study was to assess the impact of the ERC on the prostate shape and location on imaging. However, the ability of MRI to measure true prostate volume has far-reaching clinical implications. A second limitation of the present study was the time delay of up to 20 min between the acquisition of transverse T2W images using the ERC and using the PAC. During this time, the potential filling of the bladder could impact the shape of the prostate and the location of the landmarks.

In conclusion, although total prostate volume measured on ERC-MR images did not differ significantly from that measured on PAC-MR images, the insertion of the coil significantly displaced and deformed the prostate. The present landmark analysis could be useful for applying ERC-MRI in radiation treatment planning.

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Highlights

- Measurements of prostate geometry are compared on MRI with two coil arrangements.
- Prostate volume did not differ significantly between the two coil arrangements.
- Distances differed significantly between the two coil arrangements.

Figure 1. Comparison of corresponding sections from (a) PAC-MRI and (b) ERC-MRI transverse T2W fast spin-echo sequences on which a radiologist outlined the prostate circumference during calculation of the prostate volume.

Figure 2.

Comparison of the measured distances (a) from the anterior rectal wall to the symphysis pubis at the level of the verumontanum on PAC-MRI (46.5 mm) and ERC-MRI T2W fast spin-echo images (40.3 mm) and (b) from the anterior rectal wall to the symphysis pubis at the level of the mid-symphysis pubis on PAC-MRI (41.5 mm) and ERC-MRI T2W fast spin-echo images (35.3 mm; distances shown are from only one reader).

Figure 3.

Bland–Altman plots show comparisons between prostate volumes measured on T2W images obtained with ERC-MRI and with PAC-MRI for (a) reader 1 and (b) reader 2. The mean volumes measured by readers 1 and 2 were 47.83 and 48.6 mm³, respectively, on ERC-MRI and 48.9 mm³ and 50.33 mm³, respectively, on PAC-MRI.

Figure 4.

Bland–Altman plots show comparisons between distances from the anterior rectal wall to the symphysis pubis at the level of the verumontanum measured on T2W images obtained with ERC-MRI and with PAC-MRI for (a) reader 1 and (b) reader 2. The mean distances measured by readers 1 and 2 were 38.42 and 39.21 mm, respectively, with ERC-MRI and 48.15 and 51.51 mm, respectively, with PAC-MRI.

Figure 5.

Bland–Altman plots show comparisons between distances from the anterior rectal wall to the symphysis pubis at the level of the mid-symphysis pubis measured on T2W images obtained with ERC-MRI and with PAC-MRI for (a) reader 1 and (b) reader 2. The mean $\pm$ 95% LOA distances measured by readers 1 and 2 were 34.78 and 34.06 mm, respectively, with ERC-MRI and 41.34 and 40.14 mm, respectively, with PAC-MRI.

Figure 6.

Bland–Altman plots show comparisons between distances from the bladder neck to the mid-symphysis pubis measured on T2W images obtained with ERC-MRI and with PAC-MRI for (a) reader 1 and (b) reader 2. The mean $\pm$ 95% LOA distances measured by readers 1 and 2 were 12.25 and 8.27 mm, respectively, with ERC-MRI and 14.64 and 12.47 mm, respectively, with PAC-MRI.

Table 1.

Comparison of total gland volume measurements ($n=59$) made from PAC-MRI and ERC-MRI images by the two readers

Reader	Median volume, mm ³		Volume difference median (range), mm ³	<i>p</i> -Value
	ERC-MRI	PAC-MRI		
1	38.18	40.53	−0.75 (−19.88–6.78)	0.10
2	39.95	40.87	−0.84 (−24.96–6.73)	0.06

PAC, phased-array coil only; ERC, PAC and endorectal coil.

Table 2

Comparison of distance measurements ($n = 59$) made from PAC-MR and ERC-MR images by the two readers.

Landmark	Reader	Median distance, mm		Distance difference median (range), mm	<i>p</i> -Value
		ERC-MRI	PAC-MRI		
Anterior rectal wall to symphysis pubis at verumontanum	1	38.40	47.00	-10.20 (-24.60-5.80)	<0.0001
	2	38.44	51.95	-12.75 (-30.43-0.62)	<0.0001
Anterior rectal wall to symphysis pubis at mid-symphysis pubis	1	34.00	40.80	-6.60 (-22.10-8.80)	<0.0001
	2	34.07	40.44	-6.08 (-19.36-3.73)	<0.0001
Bladder neck to mid-symphysis pubis	1	9.00	15.00	-3.00 (-12.00-15.00)	0.0005
	2	6.00	12.00	-3.00 (-13.00-8.00)	<0.0001

PAC, phased-array coil only; ERC, PAC and endorectal coil.

Table 3.

Agreement between prostate measurements made by the two readers, as represented by the concordance correlation coefficient (CCC)

Measurement	Technique	CCC	95% CI
Total volume	ERC-MRI	0.99	0.99, 1.00
	PAC-MRI	0.99	0.98, 1.00
Anterior rectal wall to symphysis pubis at verumontanum	ERC-MRI	0.86	0.79, 0.93
	PAC-MRI	0.54	0.38, 0.71
Anterior rectal wall to symphysis pubis at mid-symphysis pubis	ERC-MRI	0.84	0.77, 0.92
	PAC-MRI	0.79	0.69, 0.88
Bladder neck to mid-symphysis pubis	ERC-MRI	0.81	0.73, 0.88
	PAC-MRI	0.79	0.69, 0.88

PAC, phased-array coil only; ERC, PAC and endorectal coil.