

Comparison of Prostate and Bladder Volume Measurements from MRI and Pre- and Post-MRI Ultrasound Images

Milad Baradaran-Ghahfarokhi^{*•}, Mohammad Hadi Bagheri^{**}, Mehrzad Lotfi^{**},
Mohammad Amin Mosleh-Shirazi^{***♦}, Reza Faghihi^{*}, Kamal Hadad^{*},
Sedigheh Sina^{*}

**Medical Radiation Department, School of Mechanical Engineering,
Shiraz University, Shiraz, Iran*

*•Medical Physics and Medical Engineering Department,
School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran*

***Medical Imaging Research Center and Department of Radiology,
Shiraz University of Medical Sciences, Shiraz, Iran*

****Center for Research in Medical Physics and Biomedical Engineering and
Radiotherapy Department, Shiraz University of Medical Sciences, Shiraz, Iran*

Abstract

Background: Safe dose escalation is highly desirable in radiotherapy for prostate cancer. Prostate displacement due to bladder filling can be significant, so improved targeting of the prostate by ultrasound imaging potentially allows for a reduction in the target margin and consequently less toxicity. This study estimates the accuracy of ultrasound for prostate and bladder volume measurements by comparing ultrasound images taken immediately before and after magnetic resonance imaging to reduce the effect of organ filling on measurement accuracy.

Methods: Three patients with a wide range of prostate sizes underwent pelvic magnetic resonance imaging and ultrasound imaging. We tested the correlation between the two measurements and the differences between the ultrasound measurements before and after magnetic resonance imaging using statistical analysis.

Results: Based on a total number of 18 volume measurements, a strong linear correlation was found ($r=0.95$), but there were no significant differences between ultrasound imaging performed before and after magnetic resonance imaging ($P=0.809$).

Conclusion: Our results provide additional evidence that ultrasound imaging measures bladder and prostate volumes in a reproducible and accurate manner over a wide range of volumes, which enables its use with different fractions of prostate radiotherapy.

Keywords: Prostate cancer, Image-guided radiotherapy, Prostate volume, Bladder volume, Ultrasound imaging, MRI

♦Corresponding Author:

Mohammad Amin Mosleh-Shirazi, PhD
Radiotherapy Department,
Namazi Hospital
Shiraz University of Medical
Sciences
Shiraz 71936-13311, Iran
Tel: +98-711-612 5316
Fax: +98-711-647 4320
Email: amosleh@sums.ac.ir,
mosleh_amin@hotmail.com

Introduction

The implementation of conformal and more recently, intensity-modulated radiation therapy (IMRT) techniques has dramatically changed prostate cancer treatment with radiotherapy over the last decades.¹⁻³ Dose escalation is commonly performed with the advent of these modern treatment modalities. In order to safely achieve prostate doses above 60-75 Gy, there is a great demand to use tighter margins, especially posteriorly around the rectum, to reduce complications. The size of these margins is a compromise between the probability of target coverage and the need to spare neighboring sensitive structures.⁴

During radiotherapy, the interfraction positional changes of the pelvic structures in the treatment field can be different due to variations in patient position and internal organ displacement (such as bladder filling and rectal distension).^{5,6} A maximal prostate displacement of 12 mm in the anteroposterior direction due to bladder filling alone has been reported.⁷ Since the anatomic position of the prostate is related to bladder filling and rectal distension, by considering the stages of filling, one can make the choice of margin sizes and subsequently realign the prostate in the treatment field just before each treatment.

Currently, prostate treatment plans for external beam radiotherapy are typically based on the anatomy seen in the planning computed tomography (CT) scan.⁸ However, patient radiation protection issues and time and cost implications restrict its applicability before each treatment fraction.^{9,10}

Alternatively, ultrasound (US) imaging is simple, quick, noninvasive, painless and repeatable for radiotherapy application. Although found to be dependent on operator skill, US imaging has in general been found to provide reasonable accuracy.¹¹⁻¹³ Further, Langen et al. evaluated the use of US systems to improve the accuracy of positioning the prostate within the beam for daily alignment.¹⁴ Chandra et al. have reported their experience with the clinical issues relevant to the daily use of the BAT (B-mode acquisition and

targeting) US system.¹⁵ They observed that the quality of the daily US images was acceptable in 95% of patients. The BAT system was clinically effective and feasible in a 5-min imaging session. Stam et al. evaluated the use of a bladder US scanner in achieving a more reproducible bladder filling level during irradiation of pelvic tumors, and specifically in prostate cancer.¹⁶ Their reports showed that the bladder scanner is easy to use and an accurate tool to register these variations. Byun et al. compared the accuracy of a portable three-dimensional hand-held device called Bladder Scan and two-dimensional conventional ultrasonography in the estimation of bladder volumes.¹⁷ It has been shown that magnetic resonance imaging (MRI) is an accurate method to assess the prostate and its neighboring organs as it enables direct visualization of soft-tissue organs.^{8,18}

The aim of this study was to estimate the accuracy of US for prostate and bladder volume measurements by comparing US images taken immediately before and after MRI to reduce the effect of organ filling on measurement accuracy. To the best of our knowledge, no published articles have presented a study on this issue with the methodology and analysis described here.

Materials and Methods

We selected three patients with different prostate sizes (32-71 mL, mean 54.6) referred for transrectal prostate biopsy to Shahid Faghihi Hospital, Shiraz, Iran for this study. The Medical Imaging Research Center at Shiraz University of Medical Sciences approved the study protocol. All three patients gave written, informed consent to participate in the study and underwent diagnostic pelvic MRI and US imaging for staging purposes.

Each patient had their entire imaging scans on different days. For the imaging stages, we first obtained images for the initial bladder volume with the patient in the supine and left decubitus positions. Next, the patient was instructed to empty his bladder as much as possible and then a new set of images was obtained with the same protocol. After that, the patient drank one liter of fluid one hour before the third MRI. Each US

measurement was performed immediately before and after each MRI. We did not use a catheter to add water to the bladder.

Magnetic resonance imaging

A 1.5-Tesla MRI system (Siemens Medical Systems, Germany) was used to collect sequential axial and sagittal pelvic images at different stages of bladder fullness. All patients had normal pelvic lymph node and routine T1- and T2-weighted sequences with a pelvic coil were used. No MRI contrast agent was administered. For each patient, four sets of images each in three stages of bladder fullness were obtained: 1) Axial T1-weighted turbo factor (spin echo) sequence: field of view (FOV): 36 cm; matrix: 512×512; time repetition (TR)/time echo (TE): 718/10 ms; slice thickness (ST): 3 mm. 2) Axial T2-weighted turbo factor (spin echo) sequence: FOV: 36 cm; matrix: 512×512; TR/TE: 3200/73 ms; ST: 3 mm. 3) Sagittal T1-weighted turbo factor spin echo sequence: FOV: 25 cm; TR/TE: 350/12 ms; ST: 4 mm with 0 mm gap. 4) A sagittal T2 spin echo sequence was acquired to accurately position the prostate apex on the cranio-caudal axis.

The MR images were initially acquired using a separate program and then imported into a software package for organ position measurement on an Advantage Workstation v. 4.3 (G.E Medical Systems, Galloway, New Jersey, USA). A radiologist in prostate MRI interpretation reviewed all imaging sets and performed prostate and bladder contouring for each patient to measure their volumes in the imaging stages. The volumes were calculated by manually determining the prostate outline on every axial T1-weighted MRI slice. The operator drew a freehand contour around the prostate on each imaging slice. For each slice, the number of pixels within the contour was automatically established, and then the prostate and bladder volumes were calculated using the known in-plane resolution and slice thickness.

Ultrasound imaging

A US system (Logiq 500, GE Medical Systems) was used by a radiologist to measure prostate and bladder volumes in different stages

of bladder fullness. Ultrasound imaging was performed immediately before and after each MRI. The US device was equipped with a digital display screen and a handheld transabdominal scanning head. The scanning head was positioned at the midline above the pubic symphysis and the volume was calculated manually by the radiologist. Longitudinal and transverse scans of the greatest diameters were obtained with the transducer positioned above the symphysis pubis. The width (W), length (L) and cranio-caudal diameter [height (H)] in the sagittal plane were recorded. We used the empirical formula $V=H(W\times L)\times 0.52$ to calculate the bladder and prostate volumes (Figure 1).

Prostate volume was measured twice for each patient to evaluate the US accuracy in volume measurement of an almost spherical prostate.

Statistical analysis

Ultrasound measurements were performed immediately before (US1) and after (US2) each MRI. Ultrasound and MRI measurements were performed twice for each organ. The means of these measurements are denoted as V_{bl-US} and V_{pr-US} (bladder and prostate volume measured by US), and V_{bl-MRI} and V_{pr-MRI} (bladder and prostate volume measured by MRI). To evaluate the correlation between volumes measured with each technique we used linear regression analysis. Also, the Mann-Whitney U test was used to compare the differences between the US1 and US2 measurements. The data were analyzed using SPSS software version 10.0. $P\leq 0.05$ was considered statistically significant.

Results

All measurements were performed by trained radiologists. Overall acceptance and participation of the patients was good and the procedure did not cause discomfort in any patient. Table 1 shows the mean volumes of the bladder and prostate (and their standard deviation, SD) measured by MRI and US, and their mean discrepancy. Based on a total of 18 US measurements, a strong correlation ($r=0.95$) was found between V_{bl-US}

Table 1. Measured bladder and prostate volumes. US1 and US2 refer to ultrasound measurements performed immediately before and after magnetic resonance imaging, respectively.

Equipment	Bladder			Prostate		
	MRI	US1	US2	MRI	US1	US2
Volume range (mL)	48.4 – 402.1	13.0 – 375.7	20.6 – 390.0	32.0 – 71.0	31.0 – 64.0	31.0 – 62.0
Mean ± SD (mL)	171.5 ± 102.5	157.4 ± 98.4	163.5 ± 97.2	54.6 ± 20.3	57.0 ± 22.1	56.5 ± 21.9
Mean absolute discrepancy ^a (mL)	–	14.1	8.0	–	2.4	1.9
Mean percentage discrepancy ^b (mL)	–	8.2%	4.6%	–	4.3%	3.4%

^aMean absolute discrepancy = $|V_{MRI} - V_{US}|$

^bMean percentage discrepancy = $[|V_{MRI} - V_{US}| / V_{MRI}] \times 100\%$

and V_{pr-US} , and between V_{bl-MRI} and V_{pr-MRI} , indicating that the US measurements were highly accurate (Figure 2). The Mann–Whitney U test showed no significant difference between US1 and US2 ($P=0.809$).

Discussion

Conformal radiotherapy and IMRT are increasingly used for dose escalation in prostate cancer.^{2,3} With doses above 60-75 Gy and the sharper dose fall-off seen with IMRT techniques, it becomes crucial to ascertain that the planning target volume (PTV) is adequately covered, and that doses to the rectum and bladder are minimized. Prostate displacement due to bladder filling before each course of radiotherapy can be significant, so improved targeting of the prostate, such as is accomplished with US, potentially allows for a reduction in the PTV margins and consequently less toxicity.¹⁹⁻²¹

In external beam radiation therapy for prostate cancer, interfraction positional changes in the prostate can often lead to an increased field size. Therefore, it is better to perform radiation therapy with a constant bladder volume to maintain prostate position almost constant in order to deliver the dose with a small added margin for positional uncertainty. To ensure this, US is recommended. In this study, the authors evaluated the accuracy of bladder volume measurements obtained with US by comparing it with MRI.

Asking a patient to have a full bladder during irradiation may not result in constant bladder filling. Even more objective protocols that prescribe drinking a certain amount of fluid before irradiation or a minimum time between the last

micturition and irradiation have reported similarly large variations in bladder volume.^{11,22} In Table 1, the columns denoted US1 and US2 for the bladder show the volume of urine remaining in the bladder after voiding (range 13-20.6 mL).

In the absence of effective protocols to ensure a full bladder, one can only screen patients for large bladder filling variations. One could make weekly or daily CT scans, but the use of US as a screening tool would be easier and more cost-effective. This way, only patients with large differences in bladder volume during treatment and simulation could be identified for a repeat CT scan.²³

Our study provides information regarding accuracy for a wide range of probable volumes up to 402 mL, and can therefore provide information on the accuracy for low and high volumes. Ideally, a larger number of patients would have added to the strength of this study. However, time and financial constraints limited the number of patients we could include. It must be emphasized that for each patient 15 independent measurements of bladder volume were performed at different stages of bladder filling. A total of 36 (2×18) independent measurements for linear regression analysis and 30 independent measurements for the Mann–Whitney U test were made. It seems reasonable to consider the number of measurements as the sample size rather than the number of patients. Given the wide range of volumes, our results contain data about the accuracy of US relative to MRI for a broad range of bladder volumes.

Our results are in agreement with those reported by Schnider et al.,²⁴ who suggested that US

measurement with the formula noted above underestimated volumes at higher filling levels, although other investigators obtained different results.²⁵ The results of our investigation show a consistent underestimation of the US measurements compared with bladder volume measured by MRI. However, the volume measured by US was not significantly different from the MRI volume (within ± 14 mL), which means that in clinical practice calculations based on US measurements can be expected to be accurate for a wide range of volumes. To avoid bias, the US and MRI measurements were performed by two independent radiologists who were not aware of each other's measurements.

The BAT procedure described by Chandra et al. adds approximately 5 min to the total treatment time for each patient.¹⁵ The study by Serago et al.²⁶ also showed that the BAT procedure took an average of 5.6 min after initial training of the therapists. In our study, each US measurement took approximately 1 min for the bladder or prostate. However, it must be mentioned that we did not use a US probe-holding device such as that employed in the BAT system to improve interfraction reproducibility of the imaging setup. Treatments are scheduled typically for one 20-min

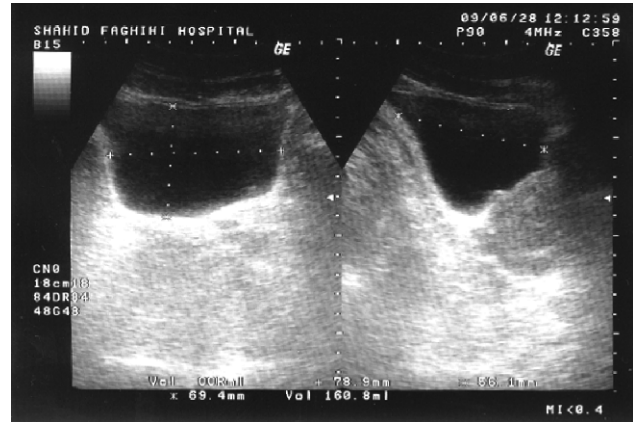


Figure 1. Measurements of bladder dimensions on longitudinal and transverse ultrasound scans for volume calculation.

time slot per patient, approximately. The additional time for BAT or US can be seen as relatively insignificant and worthwhile given the benefits of the measurements.

The use of a noninvasive technique such as US before each treatment fraction may be helpful to deliver more precise treatments and even dose escalations with minimal treatment-related morbidity. Daily BAT targeting has been shown to improve prostate treatment by compensating for interfraction prostate position variations resulting from combined setup error and internal organ displacement.^{15,16,26} In our experience, the US system is easy to use and image quality is usually good.

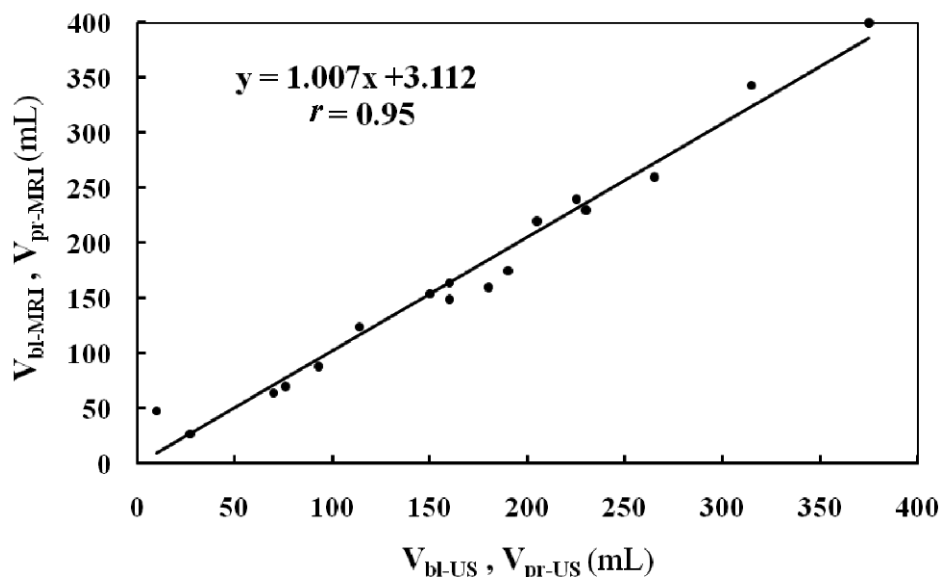


Figure 2. Linear correlation plot showing V_{bl-US} , V_{pr-US} (bladder and prostate volume derived from ultrasound images) versus V_{bl-MRI} , V_{pr-MRI} (bladder and prostate volume derived from magnetic resonance images).

Conclusion

Our results provide additional evidence that US imaging measures bladder and prostate volumes in a reproducible and accurate manner over a wide range of volumes. Ultrasound-based measurements can therefore be used at different fractions of prostate radiotherapy to monitor the anatomical positions of the pelvic organs.

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