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ORIGINAL ARTICLE

Efficacy of Portable Bladder Ultrasound in Reducing CBCT Frequency During Pelvic Radiotherapy

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OBJECTIVE

The aim of this study was to investigate the effect of the use of bladder ultrasonography (USG) on time and workforce efficiency in patients with prostate, bladder, cervix, endometrium and rectal cancer undergoing curative pelvic radiotherapy (RT) in a radiation oncology clinic.

METHODS

The study included 142 patients who underwent pelvic RT. The prospective study group (n=71) underwent bladder USG, while the other patients included in the study (n=71) who received standard treatment were designated as the retrospective historical control group. All patients underwent planning tomography (CT), set-up verification was performed with cone beam computed tomography (CBCT) in the first 3 fractions and then evaluated with CBCT once a week. All analyses were performed using IBM SPSS Statistics Version 25 package program. A value of P<0.05 was determined as the significance level.

RESULTS

Patients who did not undergo USG underwent 846 CBCTs and patients who underwent USG underwent 809 CBCTs. Although not significant, fewer CBCTs were performed in the USG group. When patients with prostate cancer were analyzed; 37 patients with prostate cancer who did not undergo USG had a total of 476 CBCTs at the end of treatment. In 37 patients with prostate cancer who underwent USG, a total of 427 CBCTs were performed. The difference between these two groups was statistically significant (p=0.009).

CONCLUSION

In patients undergoing pelvic RT, both pre-planning CT and pre-treatment USG were used to determine bladder fullness.

Keywords: Cone beam computed tomography; pelvic neoplasms; radiotherapy; urinary bladder; ultrasonography.
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INTRODUCTION

Every year 150,000-300,000 people worldwide are treated with pelvic radiotherapy (RT), mostly for cancers of the rectum, bladder, prostate, cervix and endometrium.[1,2] While pelvic RT aims to eradicate cancerous tissues, it can also cause radiation-induced side effects on surrounding healthy organs and tissues. Hence, organ mobility and dose distribution should be carefully evaluated in treatment planning. In patients undergoing pelvic RT, rectum and bladder fullness are important determinants of organ doses at risk. Bladder fullness at the same volume as the planning computed tomography (CT) will ensure that the radiation dose

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received by organs at risk is at levels accepted during planning. In patients undergoing pelvic RT for curative purposes, it is recommended that the bladder be full during treatment in order to reduce intestinal doses.[3,4] For this purpose, patients who will undergo pelvic RT are asked to drink water in moderation before each treatment, and after waiting for a certain period of time and taking into account the patient's statement regarding urinary urgency, the treatment phase is started.[5] However, bladder fullness cannot always be achieved at the intended level due to many factors such as individual patient-related differences, changes occurring during the disease process, hydration level and physiologic responses to treatment, and this may prevent the lower intestinal doses provided by bladder fullness. In addition, since changes in bladder fullness may cause target organ movement, inadequate dose coverage will occur unless very large margins are used.[6] Failure to achieve adequate bladder fullness may cause undesired side effects and may present an undesirable therapeutic index with worse oncologic outcomes. With the bladder fullness protocols in clinics, pelvic RT is administered after drinking a certain amount of water and waiting for a standard period of time, taking into account the patient's statement, but in case of insufficient fullness, the completion time of each radiotherapy fraction is prolonged, more cone beam computed tomography (CBCT) is taken and this interrupts routine clinical processes and work. Especially in underdeveloped and developing countries, prolongation and delays in treatments are undesirable considering the access to RT machines and the number of patients per machine. Repeated CBCT imaging due to field mismatch will increase the total radiation dose received by patients and the risk of long-term side effects in these patients. Inadequate bladder filling may lead to increased bowel doses, while overfilling of the bladder may negatively affect patient comfort and lead to additional complications during the treatment process. In addition, the bladder volume on planning CT should be in the same position and fullness as on planning CT in each fraction for an accurate treatment. Therefore, it is of great importance to follow the bladder preparation protocol of the clinic and to measure bladder fullness with an objective assessment method and to manage the treatment process accordingly.

In our study, we evaluated bladder filling in patients undergoing curative pelvic RT using a portable handheld ultrasound (USG) device before the planning CT scan and before CBCT during RT sessions. We investigated whether the use of USG reduced the need for repeated CBCT scans when bladder filling was found to be inadequate. USG is a non-invasive and rapid method that allows for a more effective assessment of bladder fullness without negatively impacting the patient's treatment process. In our study, we aimed to evaluate whether the use of USG can be integrated into clinical practice to increase patient compliance and comfort, reduce unnecessary radiation exposure, and contribute to making treatment more efficient by shortening the treatment preparation process.

MATERIALS AND METHODS

Patient Characteristics

This non-randomized study included a total of 142 patients who underwent curative pelvic RT for prostate, endometrial, cervical, rectal, and bladder cancer. Inclusion criteria were age >18 years, Karnofsky Performance Status (KPS)>60, confirmation of a histopathologic diagnosis, and completion of curative pelvic RT. Patients with KPS<60, those who did not complete their treatment, and those who underwent palliative pelvic RT were excluded from the study.

The study utilized a prospective cohort with a retrospectively matched historical control group. The study group (n=71) undergoing pre-treatment mobile bladder USG assessment was enrolled prospectively through consecutive recruitment between January 2023 and October 2023. To form the control group without USG (n=71), medical records of patients who had previously received standard treatment between January 2022 and December 2022 were retrospectively screened.

To minimize selection bias, these historical control patients were matched 1:1 to the prospective study group based strictly on their primary diagnosis. Therefore, the distribution of the 71 patients was identical in both groups: 37 had prostate cancer, 14 had endometrial cancer, 10 had cervical cancer, 9 had rectal cancer, and 1 had bladder cancer.

Ethics committee approval was obtained from the institutional non-interventional clinical research ethics board on 18.01.2022 (Approval No: E-25403353-050.99-296077) and the study is conducted according to Declaration of Helsinki. This study was supported by an institutional scientific research project grant (Project No: TSA-2022-2416).

Set-Up and Treatment Planning

Planning CT scans were obtained using a Siemens Somatom Definition AS model with a 2.5 mm slice thick-

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ness, from the end of the liver to the middle of the femur. During treatment, patients were evaluated with CBCT in the first three fractions and subsequently once a week. According to our clinic protocol, patients were instructed to empty their bladder, drink 1 liter of water within 30 minutes, and wait for another 30 minutes before the planning CT scan. This procedure was repeated before each treatment session. Patients were treated with Varian Truebeam version 2.7 and Varian Trilogy version 9.1.1 devices.

Half of the patients included in the study (n=71) underwent a mobile bladder USG before the planning CT and each CBCT. The transverse diameter was measured by a single radiation oncologist in the outpatient treatment room just before the patient was taken to the treatment room to assess bladder fullness. A SeaMed C3 Handheld Ultrasound with a convex probe was used. If the bladder diameter measured during the planning CT was not reproduced within a tolerance limit of ±5 mm, treatment was not initiated, and the set-up process was repeated. The remaining patients (n=71), who did not undergo USG assessment, constituted the control group. The number of CBCT scans in the USG group was compared with that of the control group.

Statistical Analysis

Statistically, the conformity of continuous variables to normal distribution according to groups was evaluated by Kolmogorov-Smirnov normality test. In the comparison of continuous variables between groups, Student's t test was used for variables conforming to normal distribution and Mann-Whitney U test was used for variables not conforming to normal distribution. P<0.05 was set as the significance level. All analyses were performed using IBM SPSS Statistics Version 25 package program.

RESULTS

Our study included 142 patients who underwent pelvic RT for prostate, endometrium, cervix, rectum and bladder cancer. Of these patients, 87 (61.3%) were male and 55 (38.7%) were female. The median age of the patients was 67 years (min: 31-max: 83) The median KPS was 90 (min: 70-max: 100) Patient and tumor characteristics are summarized in Table 1. Of the 71 patients in each group with and without USG, 37 were diagnosed with prostate cancer, 14 with endometrial cancer, 10 with cervical cancer, 9 with rectal cancer and 1 with bladder cancer.

Table 1 Patient and tumor characteristics

Features	n	%
Sex	55	38.7
Female		
Male	87	61.3
KPS, median (min/max)	90 (70/100)	
Age, median (min/max)	67 (31/83)	
Diagnosis		
Prostate cancer	74	52.1
Bladder cancer	2	1.4
Cervical cancer	20	14
Endometrial cancer	28	19.6
Rectal cancer	18	12.5

KPS: Karnofsky performance score.

A total of 846 CBCT scans were performed in patients without USG and 809 CBCT scans were performed in patients with USG. The findings are available in Figure 1. Although not significant, fewer CBCTs were performed in the group that underwent USG (p=0.296). In the non-USG group, 96 CBCTs were performed due to bladder incompatibility, while 54 CBCTs were performed in the USG group.

When patients with prostate cancer were analyzed; 37 patients with prostate cancer who did not undergo USG had a total of 476 CBCTs at the end of treatment and the average number of CBCTs per person was 12.86. In 37 patients with prostate cancer who underwent USG, a total of 427 CBCTs were performed and the mean number of CBCTs was 11.54. Compared to the control group who did not undergo USG, it was observed that fewer CBCTs were performed in patients who underwent USG. The difference between these two groups was statistically significant (p=0.009). In the non-USG group, 41 CBCTs were performed due to bladder discordance. In the group that underwent USG, this value was 21. The graph is available in Figure 2.

Figure 3 shows how the bladder diameter was evaluated in the USG taken before planning CT, in the planning CT and in the CBCT image taken on the first day of treatment in a patient with prostate cancer.

DISCUSSION

Pelvic RT remains a cornerstone treatment for various pelvic malignancies including prostate, endometrial, cervical, rectal, and bladder cancers. Treating patients with a full bladder and maintaining this condition throughout the treatment is important for both treat-

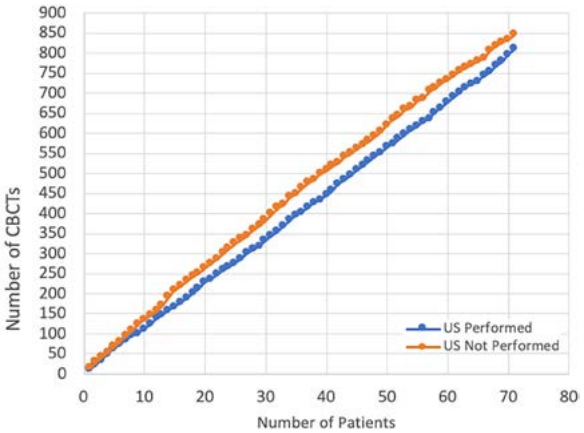

Fig. 1. Distribution of all patients.

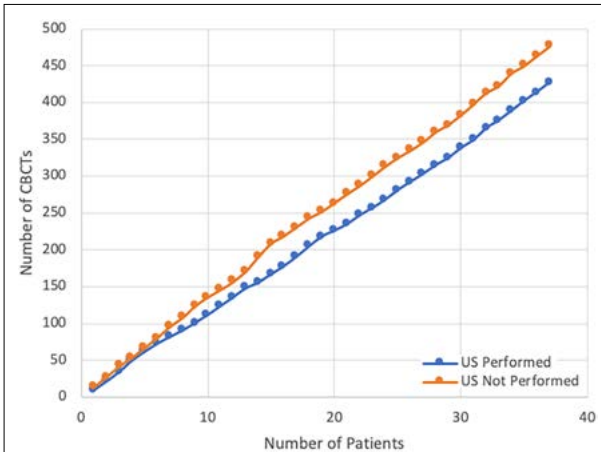

Fig. 2. Patients with prostate cancer.

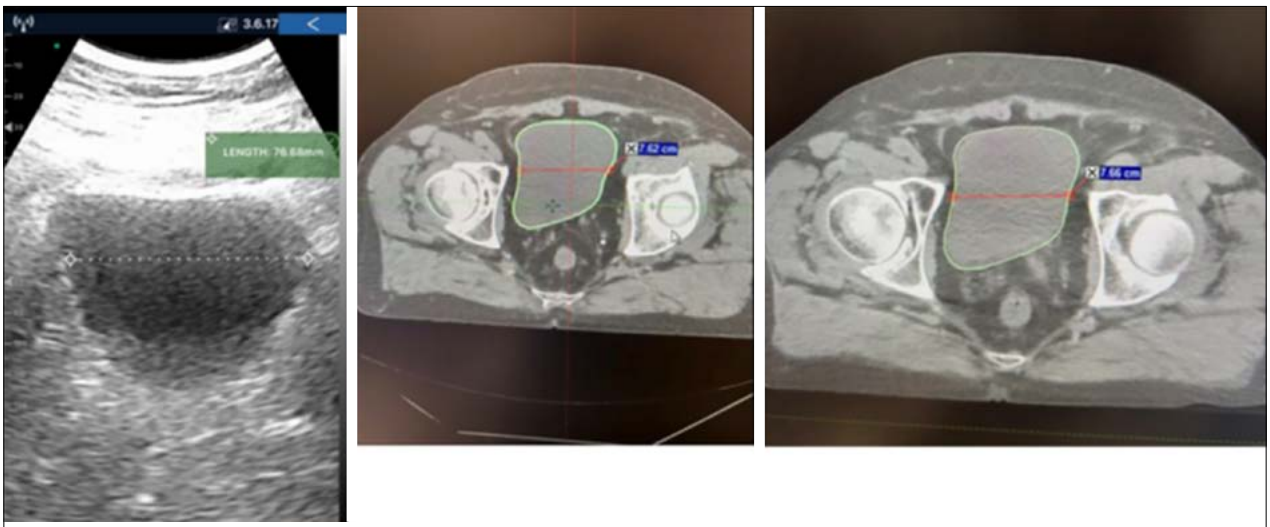

Fig. 3. Patient with prostate cancer. Bladder diameter as measured with USG: 76.6 mm; on planning CT: 76.2 mm; and on the first day of treatment with CBCT: 76.6 mm.

USG: Ultrasound; CT: Computed tomography; CBCT: Cone beam computed tomography.

ment efficacy and toxicity management. A full bladder significantly displaces the small intestine out of the radiation field, thereby reducing the risk of bowel toxicity.[7,8] Ensuring bladder fullness at the beginning of treatment and maintaining it throughout the treatment fractions is equally important. Changes in daily bladder filling can lead to intra- and inter-fraction target motion, affecting the dose delivered to the clinical target volume (CTV) and the planned target volume (PTV).[9–11] This may cause the desired ideal therapeutic index to be exceeded, resulting in worse oncological outcomes and greater toxicity.

Several studies have shown that bladder filling capacity decreases during pelvic RT.[12,13] Acute radiation-induced side effects and changes in patient habits during treatment are among the contributing factors. Radiation-induced inflammation of the bladder mucosa may lead to an increase in urinary frequency, which may make it difficult to fill the bladder to the desired level during the treatment process.[14] In addition, patients may change their fluid consumption habits while adapting to the treatment process over time, which may lead to differences in bladder filling levels between fractions. In the current literature, different methods have been investigated to assess and optimize bladder filling. Umesh et al.[15] performed bladder USG in 46 patients receiving curative RT for cervical cancer before planning CT and 45 minutes after emptying

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the bladder before treatment once a week and then at 15 minute intervals until a bladder volume of 300 ml was reached. They aimed to find the time required to reach an intermediate bladder volume by performing this procedure for 5 weeks. They demonstrated that this was reproducible by reaching intermediate bladder volume in an average of 65 minutes. This study emphasizes the importance of applying a standard bladder filling protocol to patients.

In a study by O'Doherty et al.[16] evaluating bladder filling changes in prostate cancer patients treated with RT, bladder USG was performed before planning CT and once a week before treatment. In this study, they found that bladder filling changed over the course of treatment and that smaller bladder volumes were more sustainable during planning. In this study, they also observed that providing patients with brochures with written bladder filling instructions given to the patients before treatment and practicing at home in this way were also important in maintaining bladder fullness. This finding shows that patient education and informational materials have an important place in the clinical process. In another study conducted by Luo et al.[17] with 22 patients undergoing RT, patients were divided into two groups: those who underwent pretreatment USG and those who did not. The group that received USG showed more consistent bladder fullness across fractions compared to planning CT. Another important finding of this study was that the CTV-PTV margin was reduced from 11.1 mm to 6.4 mm in the USG group by providing less displacement of the target volume. This study reveals that the use of USG is an important tool not only to assess bladder fullness but also to better establish treatment targets.

In the study by Reilly et al.[18] daily bladder ultrasound (USG) was shown to be highly effective in predicting whether target and organ doses would be met in patients receiving postprostatectomy radiotherapy. The researchers particularly emphasized that accurately estimating daily bladder volume with USG provides much of the information that would be seen on CBCT before starting treatment, thereby reducing the need for unnecessary CBCT scans. They noted that this approach both reduces the number of CBCTs performed on the patient and increases the utilization efficiency of the treatment device. Our study supports these findings and demonstrates that the use of USG not only increases dose conformity but also shortens treatment time and reduces workload by decreasing the number of CBCTs. Therefore, both studies demonstrate that integrating daily bladder USG into the pelvic radiotherapy workflow provides significant contributions in terms of both patient comfort and clinical efficiency.

Recent prospective data also support ultrasound as an effective tool for assessing bladder volume during pelvic radiotherapy. In a prospective study involving 22 patients undergoing treatment for prostate cancer, daily ultrasound measurements showed a very strong correlation (r=0.888) with bladder volume measurements obtained using CBCT. It was emphasized that daily ultrasound use could be an effective alternative to CBCT for monitoring bladder fullness during treatment, thereby reducing radiation exposure by decreasing the number of repeated CBCT scans.[19]

Interestingly, while the use of USG significantly reduced the number of CBCTs in prostate cancer patients, this effect did not reach statistical significance in the broader pelvic group. We attribute this discrepancy to the different primary sources of interfractional uncertainty among these malignancies. In prostate radiotherapy, anatomical uncertainty is predominantly driven by variations in bladder and rectal filling; therefore, verifying bladder volume with USG prior to setup effectively eliminated the main source of error, significantly reducing the need for extra CBCTs.[20] In contrast, for other pelvic tumors (particularly gynecological cases), interfractional anatomical changes are multifactorial. Even when bladder volume is strictly maintained within optimal tolerances using USG, treatment-related tumor regression, weight loss, significant soft-tissue deformation, and independent organ motion (e.g., shifts in uterine position) frequently occur.[21] Consequently, additional CBCT scans were still frequently required in this cohort to verify overall anatomical integrity and target position, entirely independent of bladder filling status. This multifactorial need for imaging overshadowed the potential benefit of USG, rendering its effect on reducing the total CBCT count statistically non-significant in the broader pelvic group.

It is thought that the use of pelvic ultrasound can reduce treatment time and costs by decreasing the use of CBCT, thereby improving patient compliance. In our clinic, an average CBCT session lasts approximately 7 minutes. The use of mobile bladder USG resulted in 42 fewer CBCT scans across the study group, saving a total of 294 minutes of treatment unit time. Since the USG procedure was briefly performed by the doctor in the outpatient room before the patient was taken to the treatment room, it did not occupy the treatment machine or disrupt the clinical workflow. Therefore, the time spent on the USG procedure itself can be considered negligible in terms of overall time efficiency.

To the best of our knowledge, our study is the first study in this field. Since USG is a noninvasive method and easy to use, its use before RT will reduce the time the patient will spend in the hospital and reduce the time to occupy the device by preventing extra CBCT.

Limitations of the study

Among the difficulties of the present study, especially in obese patients, it is difficult to accurately evaluate the bladder with USG due to subcutaneous adipose tissue. Obesity may prevent ultrasound waves from reaching deep tissues, which may decrease the quality of imaging. Especially in patients with cervical cancer, it may be difficult to accurately assess the diameter of the bladder due to compression of the bladder by the tumor. This emphasizes the effect of anatomical differences from patient to patient on the treatment process. In addition, the limited number of patients in our study suggests that the results obtained should be confirmed in a larger patient population. Future larger-scale and multicenter studies will help us better understand the efficacy and clinical benefits of mobile USG use. In particular, it is important to compare the accuracy rates of USG in different patient groups and to evaluate its effect on long-term oncologic outcomes.

CONCLUSION

In conclusion, our study demonstrates the clinical benefits of using mobile USG to assess bladder fullness in patients undergoing pelvic RT. This method has the potential to shorten treatment durations, reduce unnecessary CBCT usage, and improve patient compliance with the RT process. Specifically, our findings show a statistically significant reduction in unnecessary CBCT scans related to bladder fullness in prostate cancer patients.

Additionally, the non-invasive and easily applicable nature of USG makes it a practical tool for routine clinical use. However, further studies with larger patient cohorts are needed to evaluate the broader applicability of this method.

Ethics Committee Approval: The study was approved by the Eskişehir Osmangazi University Non-interventional Clinical Research Ethics Committee (no: E-25403353-050.99-296077, date: 18/01/2022).

Informed Consent: Written informed consent was obtained from the patients.

Conflict of Interest Statement: The authors declare that they have no conflict of interest.

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