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Predicting pubic arch interference in prostate brachytherapy on transrectal ultrasonography-computed tomography fusion images

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We investigated the usefulness of the fusion image created by transrectal ultrasonography (TRUS) and large-bore computed tomography (CT) for predicting pubic arch interference (PAI) during prostate seed brachytherapy. The TRUS volume study was performed in 21 patients, followed by large-bore computed tomography of patients in the lithotomy position. Then, we created TRUS-CT fusion images using a radiation planning treatment system. TRUS images in which the prostate outline was the largest were overlaid on CT images with the narrowest pubic arch. PAI was estimated in the right and left arch separately and classified to three grades: no PAI, PAI positive within 5 mm and PAI of >5 mm. If the estimated PAI was more than 5 mm on at least one side of the arch, we judged there to be a significant PAI. Brachytherapy was performed in 18 patients who were evaluated as not having significant PAI on TRUS. Intra-operative PAI was observed in one case, which was also detected with a fusion image. On the other hand, intra-operative PAI was not observed in one case that had been evaluated as having significant PAI with a fusion image. In the remaining three patients, TRUS suggested the presence of significant PAI, which was also confirmed by a fusion image. Intra-operative PAI could be predicted by TRUS-CT fusion imaging, even when it was undetectable by TRUS. Although improvement of the reproducibility of the patients' position to avoid false-positive cases is warranted, TRUS-CT fusion imaging has the possibility that the uncertainty of TRUS can be supplemented.

Keywords: prostate cancer; brachytherapy; seed implantation; pubic arch interference; fusion image

INTRODUCTION

Permanent radioactive seed implantation has been established as one of the standard therapies for localized prostate cancer, along with surgery or external beam radiation therapy [1–3]. Accurate seed configuration has been realized by transrectal ultrasonography (TRUS)-guided transperineal implantation. When using this approach, the pubic arch, located on the pelvic floor, sometimes prevents needle insertion to the prostate, known as pubic arch interference (PAI) [4–8]. PAI has been reported to be observed in the presence of a narrow pubic arch, even in patients with a small prostate volume [4, 5]. Presence of this overlap interrupts accurate seed placement, resulting in dose reduction for the lateral and ventral quadrants of the prostate gland near the apex [4, 8]. Bellon *et al.* have reported that PAI is highly variable among patients, and that the degree of interference cannot be determined by TRUS alone [5]. Visualization of the narrowest part of the pubic arch is comparatively difficult by TRUS, although the prostate zone structure can be clearly identified by this modality. Meanwhile, computed tomography (CT) offers the advantage of excellent visualization of the bony anatomy without operator dependence. Hence, it is expected evaluation of PAI can become simple and certain by combining these two modalities.

Routine CT is performed with the subject in the normal supine position, which is different from the intra-operative

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lithotomy position. Previous studies have reported that CT in the supine position for the evaluation of PAI tends to overestimate PAI, suggesting that the accuracy of evaluation of the PAI would differ depending on the patient position during imaging [6, 7].

In this study, pubic study was performed with both TRUS and large-bore CT (LBCT), with the subject in the lithotomy position. The usefulness of the fusion images created by TRUS and LBCT for predicting intra-operative PAI was analyzed.

MATERIALS AND METHODS

Patient selection

This study was conducted on patients with localized prostate cancer who were scheduled for seed implantation therapy in 2007. The procedure was explained and informed consent was obtained from all the patients. The patient eligibility criteria for this therapy included clinical stage T1–T2 cancer, a Gleason score of ≤7 and serum prostate specific antigen (PSA) <20 ng/ml. We performed CT and constructed TRUS-LBCT fusion (TCF) images in 21 consecutive patients, whose characteristics are summarized in Table 1. Risk classification for prostate brachytherapy was conducted using the Seattle technique [9], and the clinical staging was performed in accordance with the 1992 American Joint Committee on Cancer (AJCC) staging system [10].

Table 1. Patient characteristics ($n = 21$)

Patient characteristics	$n = 21$
Age	
Median (range)	71 (58–77)
Risk group	
Low	10
Intermediate	11
High	0
PSA (ng/ml)	
<5	5
5–10	13
10–15	3
Gleason score	
≤6	13
7	8
Local stage	
T1c	6
T2a	12
T2b	3
Volume (ml)	
15–25	7
25–35	11
35–45	3
Neoadjuvant hormonal therapy	
−	7
+	14

TRUS and CT

About 1 month before the seed implantation therapy, TRUS (Logiq; General Electric Healthcare Japan, K.K. Tokyo, Japan) was performed using a Micro-Touch stepper unit (CIVCO Medical Solutions, Kalona, IA, USA), for volume study and preplanning. For the TRUS, serial axial images of the prostate were obtained at 5-mm intervals from the base of the gland to the apex. The prostate contour was outlined at each level. The planning target volume included the prostate gland with a 3- to 5-mm margin all around. The treatment planning was performed using the radiation treatment planning (RTP) system (VariSeed^{TM}, version 7.1, Varian Medical Systems, Inc., Palo Alto, CA, USA).

Following TRUS, CT images were acquired by LBCT (Aquilion/LB^{TM}, Toshiba Medical Systems, Corporation, Otawara, Japan), which has an effective scanning range of 70 cm, enabling scanning of patients in the lithotomy position. We constructed a fixing unit from styrofoam to fix the patients in the lithotomy position (Fig. 1). This device consisted of an upper (30 cm height, 30 cm length and 70 cm width) and lower unit (10 cm height, 90 cm length and 70 cm width), with the upper unit movable on the lower unit to adjust the leg position. Grooves were dug to allow both legs to remain on the board. LBCT of the pelvis was performed in the transaxial plane with an image thickness of 3 mm, after inserting a dummy rectal ultrasound

Fig. 1. Self-made leg-positioning device.

probe made from plastic-covered wood. A urethral catheter was kept indwelling during the examination, from the time of the preplanning by TRUS.

Creation of TRUS-LBCT fusion image and assessment of PAI

Acquired CT images were transferred to the RTP system. We selected three anatomical points on axial slices of both CT and TRUS images; urethra and the ventral and dorsal aspects of the rectum (Fig. 2). The RTP recognized these points and automatically created the TCF images. We verified the accuracy of the fusion images by comparing the organ position on both images. We delineated the prostate, rectal anterior wall and urethra on the TRUS images and the pubic bone on the CT images. The TRUS image in which the prostate outline was the largest was overlaid on the LBCT section in which the pubic arch was the narrowest.

We performed a phantom study to verify the accuracy of the fusion images using prostate phantom for ultrasound (Tissue Equivalent Ultrasound Prostate Model 053, Computerized Imaging Reference Systems, Inc, Norfolk, VA, USA). The prostate outline was contoured separately on acquired TRUS and CT images, and then the TCF image was created in the procedure described above. The error of contoured diameter (transverse, longitudinal) was <2 mm.

We evaluated PAI on TRUS, LBCT and TCF images separately for comparison. Figure 3 shows an example of evaluation of PAI on TRUS and LBCT images. The largest prostate contour was outlined on each modality and overlaid to the narrowest pubic arch. The pubic arch interference was measured at both the right and left angles to the inner border of the pubic rami reported by others [5, 10]. Hence, the maximum length of the overlap portion was measured as PAI. Evaluated PAI was graded by the degree of interference on a 3-grade scale: 0, no interference; 1, ≤5 mm interference; 2, >5 mm interference. Although there are no standard definitions for minimal or significant PAI, we expected significant intra-operative PAI if grade 2 interference was observed on more than one side. The angle of the vertical line and inner border of the right (α) and left (β) pubic rami were measured separately. The angles on the TRUS images were compared with those on the LBCT images, to verify the reproducibility of the lithotomy position.

RESULTS

The results of estimation of the PAI and treatment procedure are summarized in Fig. 4.

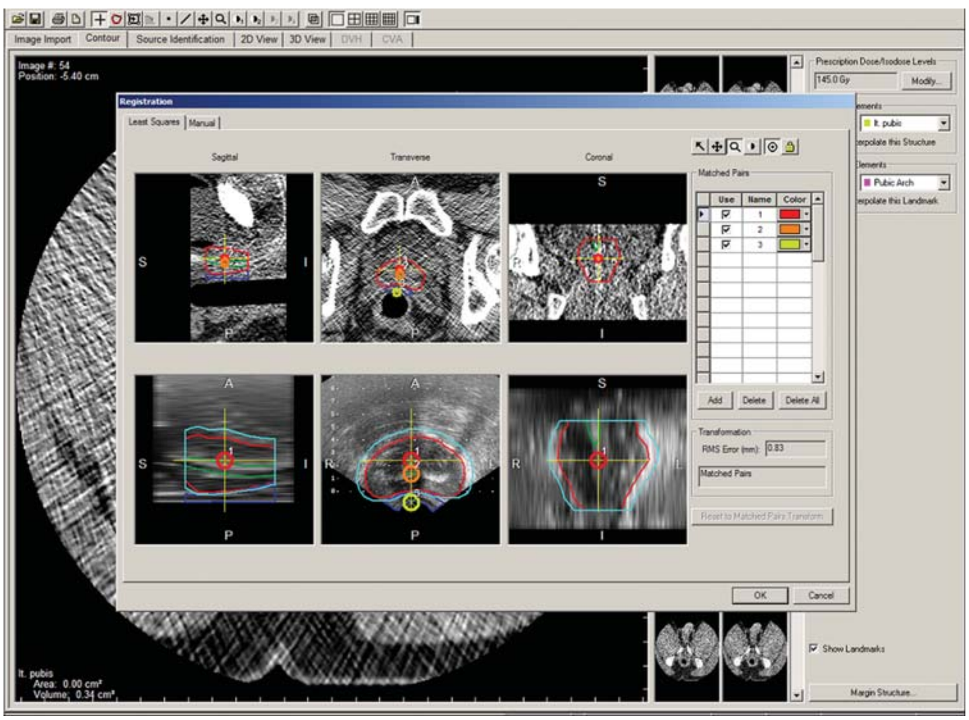

Fig. 2. An example of fusion registration using a radiation treatment planning system. The urethral anterior wall (red), urethral posterior wall and anterior rectal wall (yellow) were selected as the points for fusion registration. We could validate the anatomical landmarks (urethra, rectal anterior wall and prostate) on both TRUS and CT. Contour: urethra (green), rectal anterior wall (blue), prostate outline (red) and planning target volume of the prostate (cyan).

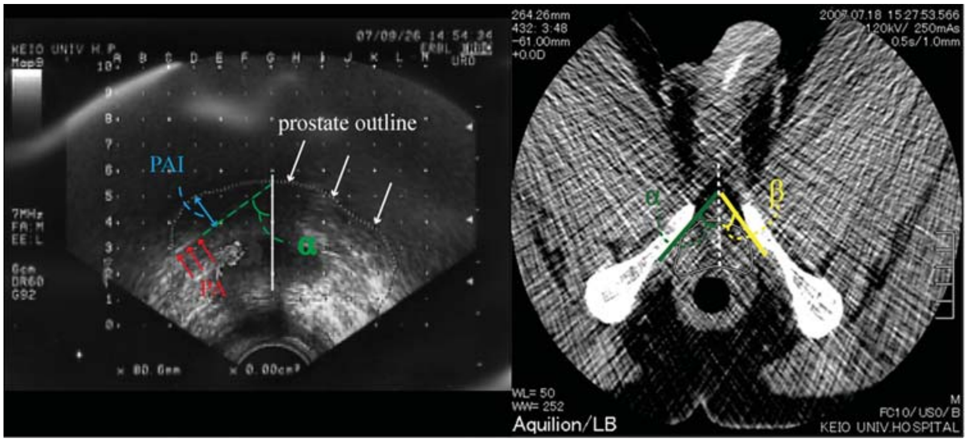

Fig. 3. An example of measurement of PAI by TRUS (left) and LBCT (right). The TRUS image with the largest prostate outline was overlaid on that with the narrowest pubic arch. Right pubic arch (PA), PAI and angle of the right pubic arch (α) are indicated. The LBCT image with the narrowest pubic arch section was overlaid on that with the largest prostate outline in one patient. No overlap was observed between the prostate outline and the pubic arch. The angles of the right and left pubic arches are indicated by α and β.

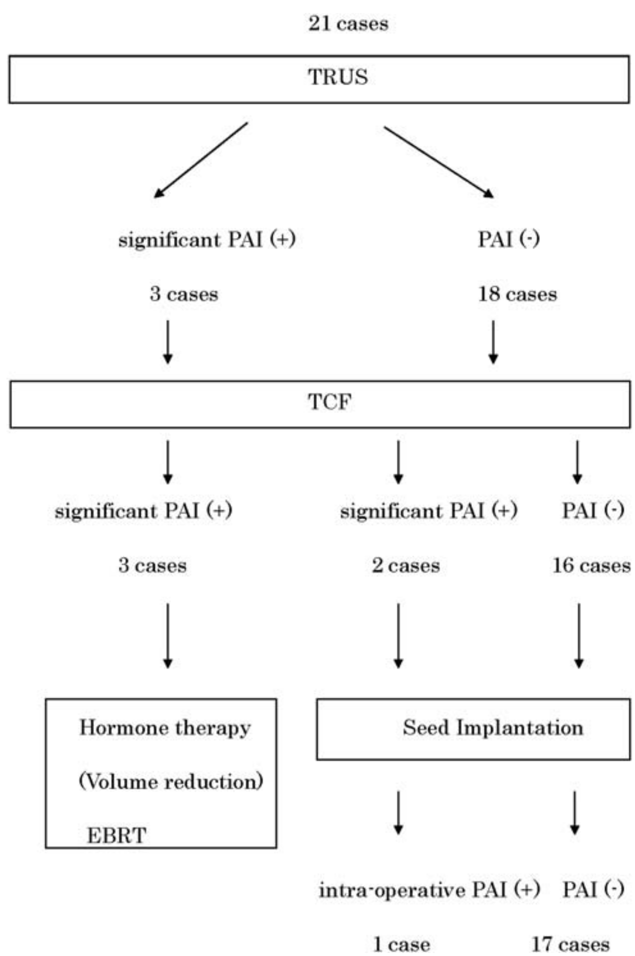

Fig. 4. Summary of the treatment procedure based on the results of PAI as predicted by TRUS and TCF. Abbreviations: TRUS = transrectal ultrasonography; PAI = pubic arch interference; TCF = TRUS-LBCT fusion; EBRT= external beam radiotherapy.

TRUS volume study

The results of estimation of the prostate volume, angles of the pubic arch and PAI in the patients by TRUS are summarized in Table 2; they revealed the absence of significant PAI in 18 cases and the presence of significant PAI in the remaining three patients. The median prostate volume and angle of the pubic arch as evaluated by TRUS were 28.5 cm^3 and 45° (range 35–60°).

Prediction of PAI by LBCT and TCF

The results of evaluation of the PAI and of the angle of the pubic arch on the LBCT and TCF images are also shown in Table 2. This evaluation required less than 25 min for each patient. LBCT was successfully performed with the patients in the lithotomy position. The pubic arches were clearly visualized in all of the patients. Significant PAI was detected on the LBCT and TCF in six and five cases, respectively. The median prostate volume and angle of the pubic arch on the LBCT was 29.5 cm^3 and 40° (range, 20–55°).

Intra-operative PAI and comparison of the results

We performed seed implantation in the 18 patients in whom no significant PAI was detected by TRUS. Among these patients, significant intra-operative PAI was observed in one patient (Case 7), which was predicted by TCF (Fig. 5). On the other hand, TCF also yielded one false-positive result (Case 18). LBCT showed two false-positive cases (Case 4 and Case 18).

We did not perform seed implantation in the remaining three patients (Cases 11, Case 12 and Case 16) in whom significant PAI was detected by TRUS. In these patients, the significant PAI was also detected by TCF. Two patients

Table 2. Results of pubic study by three modalities

Case	Volume (cm^3)		Right pubis						Left pubis						PAI (total)		
			PAI			Angle			PAI			Angle					
	TRUS	LBCT	TRUS	LBCT	TCF	TRUS	LBCT	Difference	TRUS	LBCT	TCF	TRUS	LBCT	Difference	TRUS	LBCT	TCF
1	28.6	27.5	1	1	1	60	40	–20	0	0	0	50	40	–10	–	–	–
2	37.0	39.9	1	1	0	50	45	–5	1	1	0	45	40	–5	–	–	–
3	17.6	23.3	0	0	0	55	40	–15	0	0	0	55	35	–20	–	–	–
4	23.4	23.6	0	2	0	50	20	–30	0	0	0	60	30	–30	–	+	–
5	42.2	35.4	1	0	0	50	45	–5	0	0	0	45	40	–5	–	–	–
6	32.6	31.3	0	0	0	55	55	0	0	0	0	50	40	–10	–	–	–
7	19.5	19.0	0	2	2	45	35	–10	0	1	1	45	45	0	–	+	+
8	25.7	33.9	0	1	0	50	45	–5	0	1	0	45	45	0	–	–	–
9	29.4	29.0	0	1	0	45	40	–5	1	1	1	45	40	–5	–	–	–
10	20.1	22.0	0	0	0	40	40	0	1	0	1	45	35	–10	–	–	–
11	35.0	37.5	1	1	1	55	45	–10	2	2	2	45	35	–10	+	+	+
12	28.7	25.9	2	2	2	40	40	0	2	2	2	35	30	–5	+	+	+
13	19.5	19.4	0	1	0	50	55	5	0	0	0	55	50	–5	–	–	–
14	36.1	36.0	0	0	0	45	45	0	1	0	0	40	40	0	–	–	–
15	27.3	29.5	0	1	0	40	45	–5	1	1	1	40	45	5	–	–	–
16	31.5	31.9	2	2	2	55	40	–15	1	1	1	45	35	–10	+	+	+
17	24.6	24.8	0	0	0	45	35	–10	0	1	0	40	30	–10	–	–	–
18	27.8	31.3	0	2	2	45	35	–10	0	2	2	50	45	–5	–	+	+
19	22.7	22.5	0	0	0	60	55	–5	1	1	0	45	50	–5	–	–	–
20	28.5	30.6	0	1	0	60	45	–15	0	1	0	45	50	5	–	–	–
21	32.7	30.8	1	0	0	55	45	–10	1	0	0	45	50	5	–	–	–

PAI = 0, no interference; 1, ≤5 mm interference; 2, >5 mm interference; Angle = angle (°) made by the pubic arch; PAI (total) = overall evaluation of PAI: +, significant PAI; –, no significant PAI.

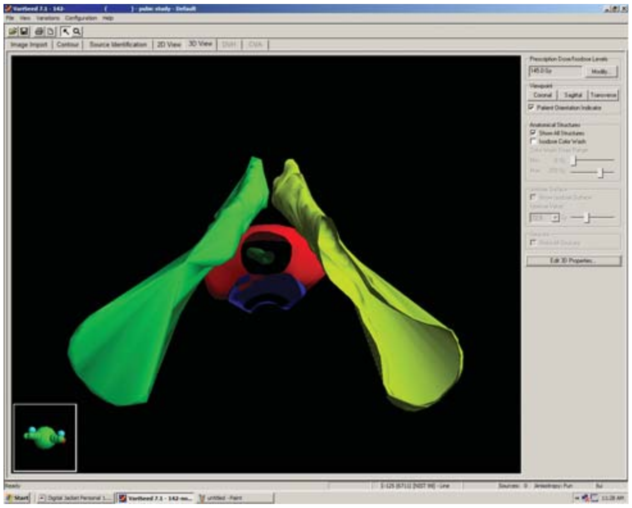

Fig. 5. A case with significant intra-operative pubic arch interference predicted by TCF. Pubic arch delineated on LBCT was overlaid on the prostate outline delineated on TRUS. Contour: urethra (green), rectal anterior wall (blue), prostate outline (red), right pubic arch (light green) and left pubic arch (yellow). Abbreviations: TCF = TRUS-LBCT fusion.

underwent external beam radiotherapy. Short-term neoadjuvant hormonal therapy for volume reduction and performed seed implantation was performed in one.

Comparison of the angle of the pubic arch as evaluated by TRUS and LBCT

The differences in the angles between the LBCT and TRUS are shown in Table 2. The angle was determined to be larger by LBCT than by TRUS in three arches, was equal in both modalities for seven arches, and was judged to be smaller (by >15° in seven arches) according to TRUS in 32 arches.

DISCUSSION

We investigated the usefulness of TCF based on TRUS and LBCT images for determining PAI in prostate brachytherapy. The results of the evaluation of PAI by the three modalities: LBCT, TRUS and TCF, were compared. The procedures for acquiring TCF images were not complicated or time-consuming. It was considered feasible to integrate TCF imaging into clinical practice.

Among the patients who underwent brachytherapy and who were judged as having no significant PAI by TRUS, one was found to have significant PAI intra-operatively (Case 7). We could observe the pubic arches in all the patients with TRUS, although the visualization of the narrowest part was sometimes difficult, because it often existed in the apex. In this study, we found a case of intra-operative PAI with a small prostate and a wide pubic arch angle. CT was useful for detecting the bony shapes and positions clearly and objectively.

TCF and LBCT overestimated PAI in one (Case 18) and two (Cases 4 and 18) patients, respectively. We speculate that this may have been caused by inadequate reproduction of the patients' leg positions. We created a simple two-compartment board with adjustment in the cranio-caudal direction to allow the patients to adequately bend their knees, but not all the patients opened their legs fully wide on the device. This explanation is supported by the fact that the angle of the pubic arch was larger as evaluated by TRUS than as evaluated by LBCT in a number of cases. This problem may be circumvented by the development of a more sophisticated device for maintaining the leg position. In addition, the angle of needle insertion, leg position and pressure of the TRUS probe could be made adjustable intra-operatively. As one more possible reason, we defined 5 mm or more as grade 2 PAI. In general, intra-operative PAI is considered to be clinically significant if the PAI results in alteration of the needle position by 5 mm [8]; however, even overlaps of 5–10 mm may be adjustable during the operation. It has recently been reported that the use of a CT-based PAI of 1.0 cm as a selection criterion for the pubic bone is a simple and reliable method for minimizing the incidence of intra-operative PAI [11]. An additional case with significant PAI (Case 4) was detected by LBCT as compared with the number of cases detected by TCF. This may be attributable to prostate outline overestimation because of the difficulty of contouring the prostate gland on CT images. TCF imaging allows accurate evaluation of the prostate outline based on TRUS, which resolves the uncertainty of prostate outline evaluation by CT alone.

In this study, the results of intra-operative PAI in patients with positive PAI as judged by TRUS were not analyzed. Further study is, however, needed to resolve this issue.

TCF predicted a case to have significant intra-operative PAI, which was underestimated by TRUS. Improvement of reproducibility of the patient position is necessary, but, this aside, TCF has the potential to be a useful supplementary diagnostic tool reducing uncertainty around TRUS interpretations.

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