

•Original Article•

## Using CT imaging to delineate the prostatic apex for radiation treatment planning

Xiao-Mei Li<sup>1</sup>, Xian-Shu Gao<sup>1</sup>, Xue-Mei Guo<sup>2</sup>, Ya-Gang Li<sup>1</sup>, Xiao-Ying Wang<sup>2</sup>

<sup>1</sup> Department of Radiation Oncology, Peking University First Hospital, Beijing 100034, P. R. China; <sup>2</sup> Department of Radiology, Peking University First Hospital, Beijing 100034, P. R. China

**[Abstract] Background and Objective:** In computed tomography (CT)-based radiotherapy planning for prostate cancer, it is difficult to precisely delineate the prostatic apex because of its relationship with the urogenital diaphragm and bulbospongiosus musculature. In this retrospective study, we analyzed the magnetic resonance imaging (MRI) and CT scans of the patients with prostate cancer to investigate the relationship between the prostatic apex and the anatomic structure visible on CT, and to provide evidence for localizing the prostatic apex in radiotherapy planning. **Methods:** MRI and CT scans of 108 patients with prostate cancer were analyzed to measure the distances between the prostatic apex and the bottom of ischial tuberosities, the bottom of obturator foramen, the bottom of pubic symphysis, and the bulb of the penis. The volume of the prostate was measured to analyze its relationship with the localization of the prostatic apex. **Results:** The prostatic apex was located ( $13.1 \pm 3.3$ ) mm above the bulb of the penis, ( $11.0 \pm 5.4$ ) mm above the bottom of the obturator foramen, ( $31.3 \pm 5.5$ ) mm above the ischial tuberosities, and ( $7.1 \pm 4.7$ ) mm above the bottom of the symphysis pubis. There was no correlation between the size of the prostate and the localization of the prostatic apex. **Conclusions:** The variance of the distance between the prostatic apex and the bulb of the penis is smaller than that of the distance between the apex and bony anatomy. Delineating the target to 6 mm above the bulb of the penis can cover the prostatic apex in 95% of the patients with prostate cancer, delineating to the bottom of obturator foramen can cover the prostatic apex in 100% of the patients.

**Key words:** Prostatic neoplasms, apex of prostate, CT, radiotherapy planning

Radiation therapy is the primary treatment of limited and locally advanced prostate cancer. Three-dimensional conformal radiotherapy (3D-CRT) and intensity-modulated radiation therapy (IMRT) are main radiotherapy techniques. Prostate cancer is often multifocal, and radiation target volume should include the entire prostate and its capsule.

CT simulation alone is used in treatment plan. Because the image of the prostatic apex is mixed with the urogenital diaphragm and the surrounding muscles, the location of the prostatic apex, which is the lower bound of the target, is more difficult to be accurately determined. If the prostate target volume is too large, the radiation injuries of surrounding normal tissues will be potentially increased; if it is too small, not including the entire prostate, the lesions will

be missed. Byar *et al.*<sup>[1]</sup> conducted a pathologic study on prostate cancer specimens, and found that about 75% of prostate cancers would violate the apex. To solve the above problem, currently, the international best method is fusing CT and MRI images, determining the location of the prostate apex on MRI images, and then making treatment plan on CT images<sup>[2,3]</sup>, or attempting to make treatment plan on MRI images directly<sup>[4,5]</sup>. However, some medical units do not have the conditions for image fusion, and image fusion increases the therapy cost, which is not entirely suited to Chinese national conditions. Some medical units use more advanced radiotherapy technology, such as image-guided radiation therapy (IGRT) and adaptive radiotherapy (ART). Most images obtained during treatment are CT images, and the fusion of CT and MRI images is difficult to be performed.

Since 1990s, many literatures about how to determine the location of the prostate apex on CT images have been published. Some early studies<sup>[6-9]</sup> promoted the use of retrograde urography to confirm the location of the prostate

Correspondence to: Xian-Shu Gao; Tel: +86-10-83575239; Fax: +86-10-66551788; Email: xsgao777@hotmail.com

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apex, but this is an invasive examination and is uncomfortable for patients, with many contentious issues. Therefore, some researchers<sup>[10-12]</sup> sought the anatomical structures easily identified on CT images around the prostatic apex, such as the ischial tuberosity and bulb of penis, by prostate seed implantation or injecting contrast agent in the prostate to identify the prostatic apex, and studied the relationship between the prostatic apex and the anatomical structures easily identified on CT images to explore the rule guiding target delineation. The above documents are from abroad with the patients from Western countries, whose shape and anatomical location of the prostatic apex may be different from those in Asian patients. Currently, there is no research data from Asian patients, and some errors exist in the process of identifying the prostatic apex in above literatures. We analyzed the CT and MRI images of 108 patients with prostate cancer treated in radiotherapy department in our hospital. Although CT and MRI have different imaging principles, preliminary results show little difference between these two methods, so the relationship between the prostate apex and surrounding structures on MRI images can also be applied on CT images. MRI is now recognized as the best identification method of the prostatic apex<sup>[13]</sup>. In this study, the relationships between the prostatic apex and surrounding structures easily identified on CT images, such as the lower edge of the obturator, the lower edge of the pubic symphysis, the lower edge of the ischial tuberosities and the bulb of penis, were analyzed on MRI images directly, to help to delineate the prostate target volume.

## Materials and Methods

### General information

A total of 108 patients were selected from the patients with prostate cancer treated in radiotherapy department of the First Hospital of Peking University between August 2005 and August 2009. The selection criteria included (1) non-surgical prostate cancer patients except those with significant prostatic apex violation; (2) those with MRI examination in our hospital within half a month before radiotherapy; (3) those without seed implantation therapy or indwelling catheter during MRI examination.

### Scanning technology

MRI scanning technology: the GE 115T Signa TwinSpeed magnetic resonance scanner was used. In pelvic MR examination, the body coil was used as radiofrequency transmit coil, and the abdominal phased array coil as receiver coil. For local prostate, axial and coronal pressure fat fast spin echo (FSE) T2WI scan was

conducted, with TR 3500 ms, TE 85 ms, echo train length (ETL) 19, slice thickness 5 mm, slice spacing 0.5 mm, FOV 24 cm × 24 cm, number of excitation (NEX) 4, matrix 320 × 256; and axial T1WI scan was also conducted, with TR 450 ms, TE 12 ms, slice thickness 5 mm, slice spacing 0.5 mm, FOV 24 cm × 24 cm, NEX 2, matrix 256 × 192. From the base of the prostate to the aortic bifurcation, axial T1WI scan was conducted, for median pelvic cavity sagittal T1WI scan was performed, with TR 450–500 ms, TE 12 ms, slice thickness 5mm, slice spacing 1–2 mm, FOV 28 cm × 40 cm, NEX 2, matrix 256 × 192.

CT scanning technology: the whole pelvic cavity was scanned by GE Hispeed NSI spiral CT, with slice thickness of 5 mm.

### Study method

CMS XIO 1.3.2 planning software was applied to fuse MRI and CT images. Since MRI and CT had different imaging principles, the images of bone signs were measured in both groups to evaluate the difference. The location of the prostatic apex was determined by combining prostatic MRI axial and coronal T2 images, and the apex plane was recorded. In order to avoid errors caused by organ movement during fusion process, the Efilm workstation 2.1 software was used to measure the distances between the prostate apex and the lower edge of the obturator, the lower edge of the ischial tuberosities, the lower edge of the pubic symphysis, and the top of the bulb of penis on MRI images directly. The diameters of the prostate on anterior and posterior, left and right, superior and superior directions were measured, and prostate volume was calculated in accordance with spherical volume formula, spherical volume =  $\frac{4}{3}\pi \times (\text{radius})^3$ . The radius was converted into 3 diameters and the formula was simplified: prostate volume =  $0.52 \times (\text{the product of 3 diameters})$ . These were carried out in collaboration by doctors from radiotherapy department and imaging department.

### Statistical analysis

All statistical analyses were performed by SPSS 13.0 statistical software. Measurement data are shown as mean ± standard deviation (SD).

## Results

### *The distance between the prostatic apex and the lower edge of the obturator (Figure 1, line a)*

The vertical distance between the plane of the prostatic

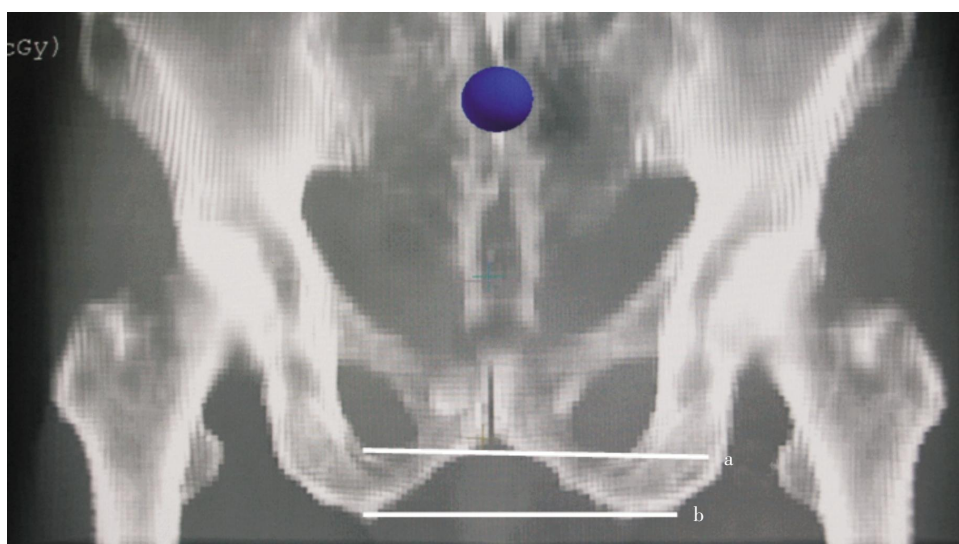


Figure 1 The distance between the prostatic apex and the lower edge of the obturator and the ischial tuberosities

a, bottom of obturator foramen; b, bottom of ischial tuberosities.

apex and the lower edge of the obturator was measured on sagittal MRI images (Figure 2, d1). The prostatic apex was located ( $11.0 \pm 5.4$ ) mm above the lower edge of the

obturator, maximum 24.0 mm, minimum 0.0 mm, with 95% of reference ranging from 0.4 to 21.6 mm.

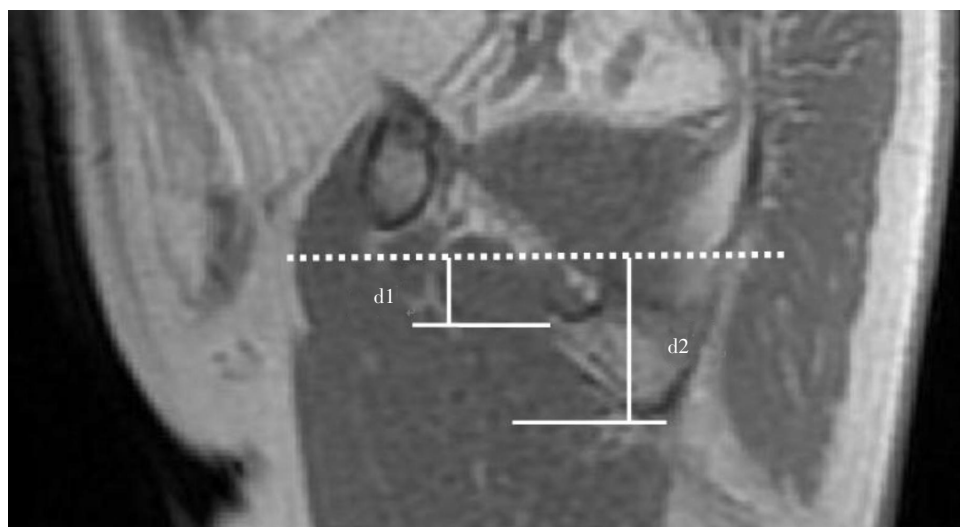


Figure 2 Sagittal magnetic resonance imaging (MRI) of a patient with prostate cancer

The bottom of the obturator foramen and the ischial tuberosities are clearly seen. The broken line indicates the layer of the prostatic apex. d1 indicates the distance from the obturator foramen to the apex. d2 indicates the distance from the ischial tuberosities to the apex.

***The distance between the prostatic apex and the lower edge of the ischial tuberosities (Figure 1, line b)***

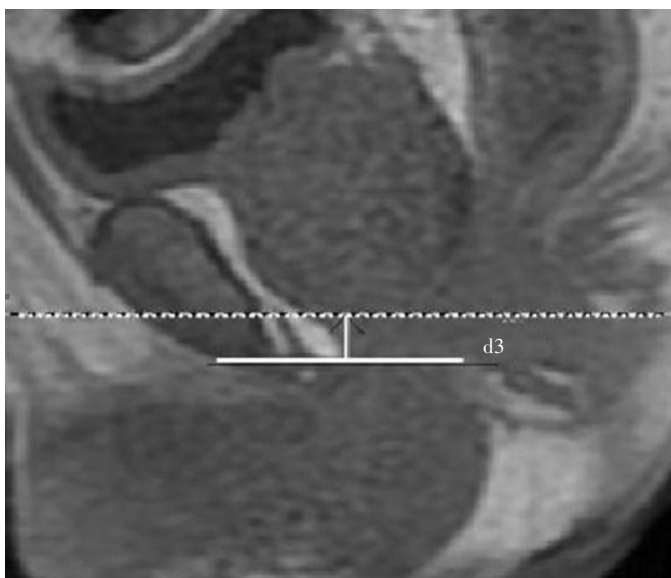
The vertical distance between the plane of the prostatic

apex and the lower edge of the ischial tuberosities was measured on sagittal MRI images (Figure 2, d2). The distance was ( $31.3 \pm 5.5$ ) mm, maximum 47.0 mm, minimum 20.0 mm, with 95% of reference ranging from 20.2 to 41.8 mm.

***The distance between the prostatic apex and the lower edge of the pubic symphysis***

The distance between the prostatic apex and the lower

edge of the pubic symphysis was measured on body midline sagittal MRI images (Figure 3, d3). The prostatic apex was located  $(7.1 \pm 4.7)$  mm above the lower edge of the pubic symphysis, maximum 19.0 mm, minimum 0.0 mm, with 95% of reference ranging from -2.2 to 16.2mm.



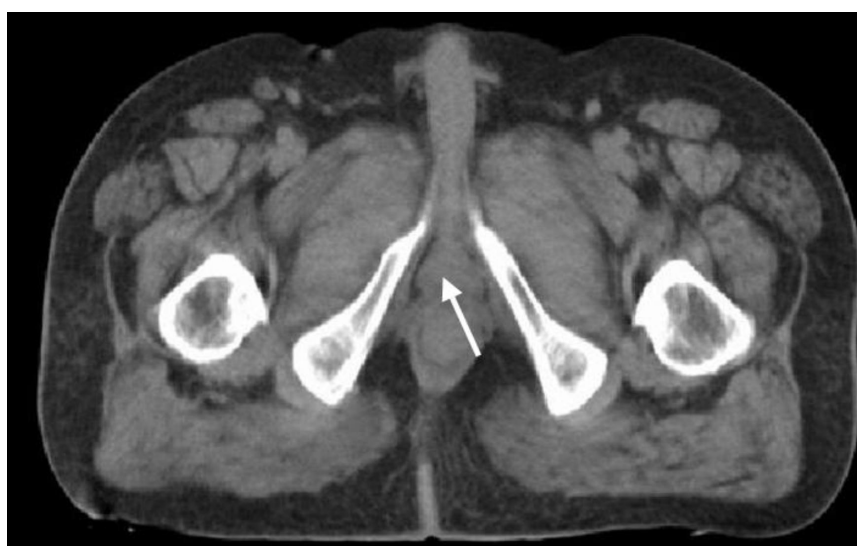
**Figure 3** Mid-sagittal MRI of a patient with prostate cancer

The broken line indicates the layer of the prostatic apex. d3 indicates the distance from the bottom of symphysis pubis to the apex.

***The distance between the prostatic apex and the top of the bulb of penis***

The bulb of penis could be easily identified on CT

images (Figure 4), which was teardrop-shaped and surrounded by a layer of low-density lipid film. The distance between the prostatic apex and the top of bulb of penis was measured on coronal MRI images (Figure 5, d4), which was  $(13.1 \pm 3.3)$  mm, maximum 20.0 mm, minimum 5.0 mm, with 95% of reference ranging from 6.5 to 19.5 mm.



**Figure 4** Transverse computed tomography (CT) image of a patient with prostate cancer

The penile bulb is clearly seen as a blob structure surrounded by clear low density signal (arrow).

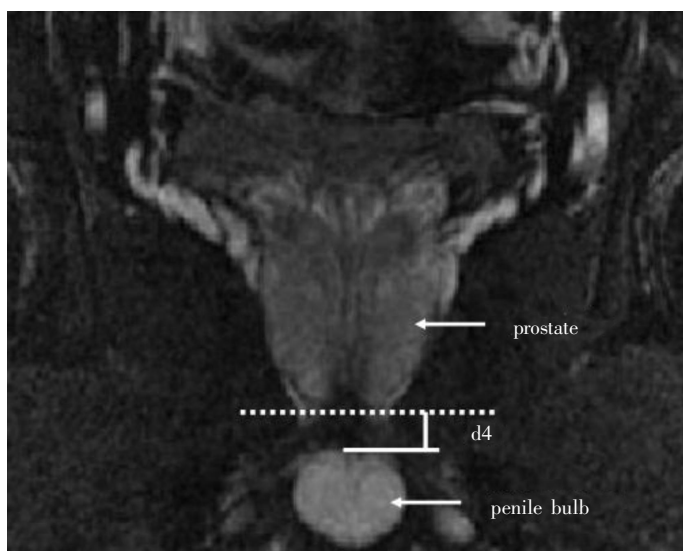


Figure 5 Coronal MRI of a patient with prostate cancer  
d4 indicates the distance from the prostatic apex to the proximal bulb of penis.

### Comparison of the deviations of above distances

The distances between the prostate apex and the lower edge of the obturator, the lower edge of the ischial

tuberosities, the lower edge of the pubic symphysis, and the top of the bulb of penis were compared, and the standard deviations were 5.4, 5.5, 4.7 and 3.3 mm, as shown by box-type diagram (Figure 6). The distance between the prostatic apex and the top of the bulb of penis had the minimal deviation.

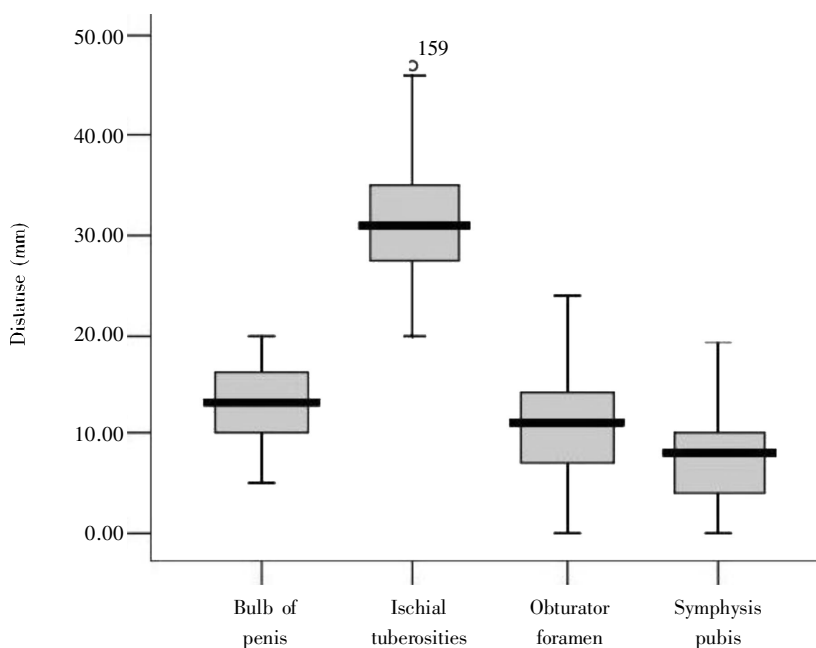


Figure 6 Comparison of the distances from the prostatic apex to the bulb, ischial tuberosities, obturator foramen, and symphysis pubis

Results are displayed by mean (thick black band), range (brackets), 75th quartile (top of box), and 25th quartile (bottom of box).

# *The correlation between prostate volume and the apex position*

Linear correlation analysis was performed between

prostate volume and the apex position, and showed that prostate volume had no significant correlation with the distance between the prostatic apex and the lower edge of the obturator and the distance between the prostatic apex and the bulb of penis (Figures 7 and 8), and correlation coefficients were 0.07 and -0.33 ( $|r|$  greater than 0.75 as the standard of significant linear correlation).

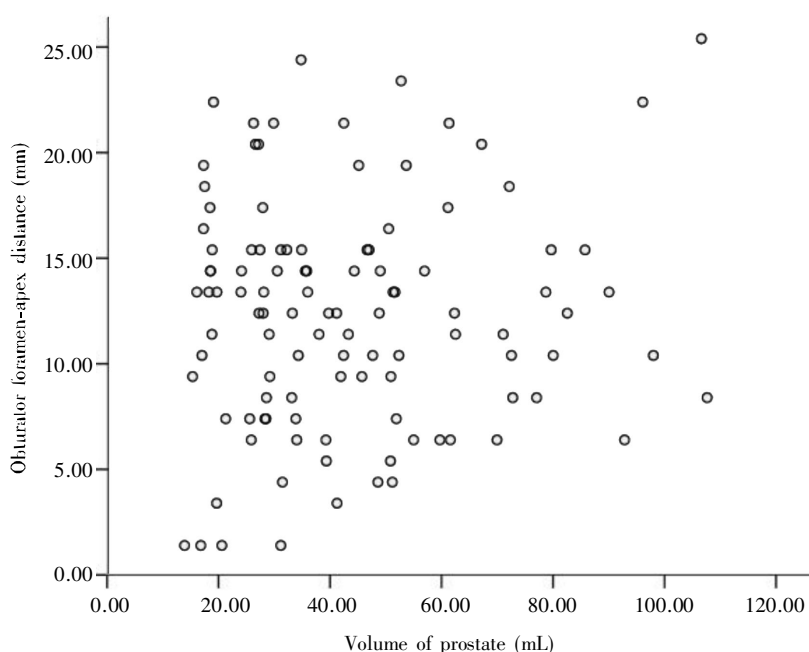


Figure 7 Scatter plot of prostatic volume and the distance from the prostatic apex to the bottom of the obturator foramen

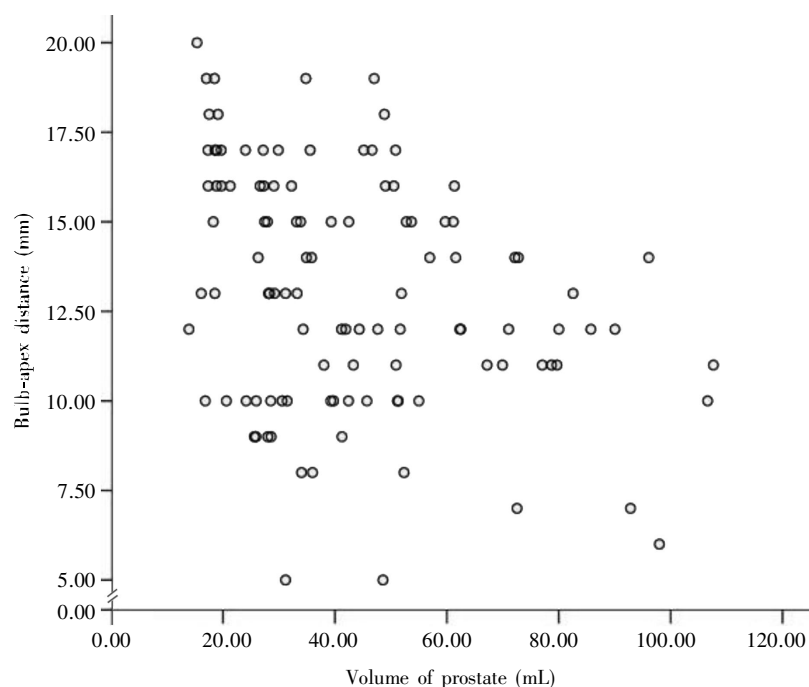


Figure 8 Scatter plot of prostatic volume and the distance from the prostatic apex to the bulb

## Discussion

The prostate apex, urogenital diaphragm, and the surrounding muscles are mixed on CT images and difficult to be confirmed. Since 1990s, many literatures about how to determine the location of the prostate apex on CT images have been published.

Some early studies promoted the application of retrograde urography to confirm the position of the prostate apex, but this method has many contentious issues. Roach *et al.*<sup>[6]</sup> thought the broken section with contrast agent gradually decreased was where membranous urethra passed through the urogenital diaphragm, and the prostate apex was located 1 cm above this area. Schild *et al.*<sup>[7]</sup> considered that the broken section with narrow contrast agent was the position of urethral sphincter, an integral part of the urogenital diaphragm, and the prostate apex was located at its top (0 cm). The two studies both considered a fixed relationship between the prostatic apex and the broken section with narrow contrast agent. But Sandler *et al.*<sup>[8]</sup> suggested that retrograde urethrography often misidentified the location of the prostatic apex, the location identified by this method was 5 to 20 mm lower than the actual location, and the patients with 20 mm error accounted for 30%<sup>[8,9]</sup>. They thought that the length of the urogenital diaphragm had apparent difference among patients, and the fixed relationship between the prostatic apex and the broken section with narrow contrast agent did not exist. Roach's study also suggested that due to a variety of technical reasons and poor contrast imaging, the location of the prostatic apex was difficult to be determined in 18% of cases. The examination could not be carried out in patients with urethral obstruction caused by infection, edema, and other reasons.

As many controversies existed in the method of retrograde urethrography determining the location of prostatic apex, some researchers sought the anatomy structures recognizable on CT images around the prostatic apex, studied the relationship between the apex and these structures, and explored the rule guiding target delineation. Wilson *et al.*<sup>[10]</sup> analyzed and summarized the distances between the prostatic apex and the lower edge of the ischial tuberosities in 153 patients with stage T1–3N0M0 prostate cancer. All patients received radioactive seed implantation therapy: 133 received suprapubic <sup>125</sup>I implantation when prostate was exposed during surgery, and 20 received transperineal <sup>125</sup>I implantation guided by rectum ultrasound. Plain film was taken after surgery, and the location of the prostatic apex was inferred based on the distance between the lowest <sup>125</sup>I particle on plain film and the lower edge of

the ischial tuberosities. The prostatic apex was located above the ischial tuberosities in 99.3% (152/153) of patients; the distance between the apex and the ischial tuberosities was less than 1.5 cm in 4.6% (7/153) of patients, and less than 1 cm in 2% (3/153) of patients. The study concluded that the lower edge of the ischial tuberosities could be used as the lower bound of radiotherapy field for prostate cancer, and the lower bound could expand the prostatic apex border more than 1.5 cm in 95.4% of patients. However, due to operational difficulties, the placed particles might be deviated from expectations, especially suprapubic implanted particles. The inadequacy of Wilson's research was that a certain error exists in using radioactive particles to infer the location of prostatic apex. Dudouet *et al.*<sup>[11]</sup> injected iodized oil contrast agent into the prostate by transrectal ultrasound to image the prostate, took X-ray film, measured the distance between the prostatic apex and the ischial tuberosities in 28 prostate cancer patients, and the results showed that the average distance was 2.28 cm (0.92–3.38 cm). This method was more complex and not suitable for wide clinical implementation. In our study, the distance between the prostatic apex and the ischial tuberosities was measured on MRI images directly. MRI is now recognized as the best identification method of the prostatic apex<sup>[13]</sup>. Measuring directly on MRI images also avoids the possible errors in identifying the prostatic apex in above-mentioned studies. Our results showed that the location of the prostatic apex was slightly 5 to 8 mm higher than Wilson and Dudouet's studies.

Plants *et al.*<sup>[12]</sup> used the bulb of penis, which could be easily identified on CT images, as the mark for determining the prostatic apex. They thought the distance from the top of the bulb of penis to prostatic apex was 15 to 18 mm, and the deviation of distance was smaller than that of distance from the prostatic apex to the ischial tuberosity (SD 6.6), therefore, they concluded that the bulb of penis was more suitable as the mark to identify the prostatic apex compared with bone structures. However, this result was obtained indirectly. Plants *et al.*<sup>[12]</sup> measured the distance from the peak of retrograde urethrography to the top of the bulb of penis, consulted the distance from the peak to the prostatic apex reported in other literatures, and then combined both to get the above conclusion. Although they also measured the distance from the prostate apex to the top of the bulb of penis on MRI images directly, it was a small sample, only 6 cases. In our study, the distances from the prostate apex to the top of the bulb of penis were measured directly on MRI images in 108 patients, and the result was  $13 \pm 3.3$  mm. The deviation of distance was larger than the results of Plants' study.

McLaughlin *et al.*<sup>[14]</sup> use another method to identify the prostate apex on CT images. They analyzed the CT and

MRI images in 300 prostate cancer patients, and found that because the muscles within the urogenital diaphragm had different shapes and directions, starting from the bulb of penis, the central organization images of urogenital diaphragm rendered triangle, circle and hourglass shape from up to down and then to the prostatic apex. According to these forms of graphics, the location of the prostatic apex could be inferred on CT. But we found that these shapes were more clearly shown on MRI images, and circle and hourglass shapes were often difficult to be distinguished on CT images. McLaughlin *et al.*<sup>[14]</sup> also believed that hourglass-shaped graphics was unclear on CT images in almost 50% of the patients.

Our study found that the deviation of distance between the prostatic apex and the bulb of penis (SD 3.3) was slightly smaller than that between the prostatic apex and the bone marks (SD 4.7–5.5), and the deviations of distances from the apex to the bone marks were basically the same. We propose using the bulb of penis firstly as the mark for delineating the prostatic apex, and combining the relationship with the bone marks. Among bone marks, the lower edge of the obturator is close to the prostatic apex and easily identifiable on CT cross section, showing

connected anterior and posterior ischial ramus (Figure 9). The target is usually delineated on cross section, and the lower edge of the obturator is proposed to be referenced firstly among bone marks. In our study, it was found that there was no significant correlation between the distance from the apex to the bulb of penis and to the lower edge of obturator. Delineating prostate target to 6 mm above the bulb of penis on CT images may include the prostate apex in 95% of patients. Delineating prostate target to the lower edge of obturator may include the prostatic apex in 100% of patients. In this study, the slice thickness of CT scan was 5 mm, and reconstructed sagittal and coronal CT images were rough, leading to imprecise measurements. Therefore, the distances were measured on sagittal and coronal MRI images directly. The sagittal and coronal MRI images were non-reconstructed and directly scanned images, and the distances were more accurately measured. CT scan thickness 5 mm had no relationship with the measured results. Since MRI and CT had different imaging principles, we measured two groups of images of bone marks' size to evaluate the difference firstly, and the error was small, which was  $(0.13 \pm 0.46)$  mm. The distances measured on MRI images can be applied on CT images.

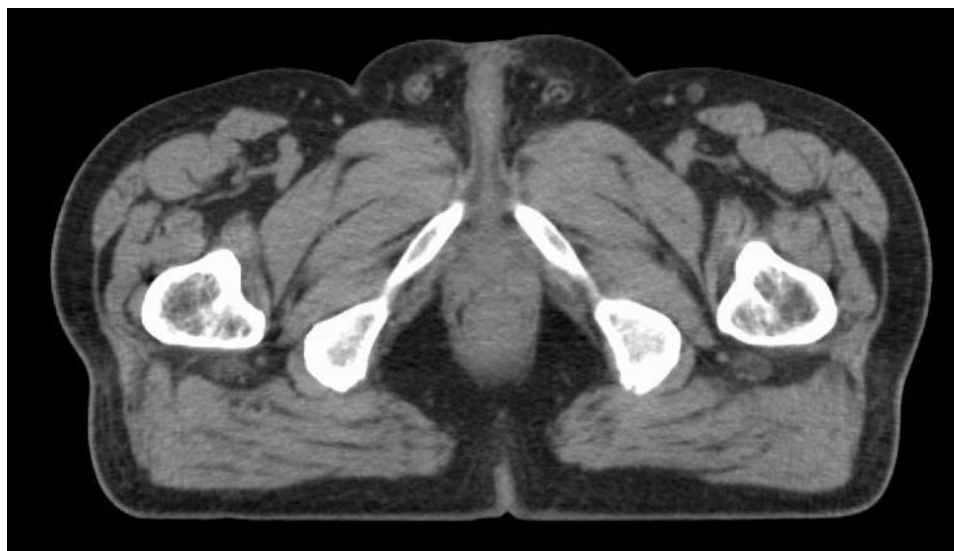


Figure 9 Bottom of obturator foramen on axial CT

About how to delineate the prostatic apex on CT images, we suggest that (1) 2–3 mm should be selected as CT slice thickness, with clearer image and smaller errors; (2) if the bulb of penis is shown clearly, delineate the prostatic apex to 6 mm above the top of bulb of penis; (3) if the bulb of penis is shown unclearly, or the top of the bulb of penis is located more than 6 mm below the lower edge of the obturator, delineate the prostatic apex to the lower edge of the obturator.

## References

- [1] Byar DP, Mostofi FK. Carcinoma of the prostate: prognostic evaluation of certain pathologic features in 208 radical prostatectomies. Examined by the step-section technique [J]. Cancer, 1972, 30(1):5–13.
- [2] Kagawa K, Lee WR, Schultheiss TE, et al. Initial clinical assessment of CT-MRI image fusion software in localization of the



- prostate for 3D conformal radiation therapy [J]. *Int J Radiat Oncol Biol Phys*, 1997, 38(2):319–325.
- [3] Roach M 3rd, Faillace-Akazawa P, Malfatti C, et al. Prostate volumes defined by magnetic resonance imaging and computerized tomographic scans for three-dimensional conformal radiotherapy [J]. *Int J Radiat Oncol Biol Phys*, 1996, 35(5):1011–1018.
- [5] Chen L, Price RA Jr, Nguyen TB, et al. Dosimetric evaluation of MRI-based treatment planning for prostate cancer [J]. *Phys Med Biol*, 2004, 49(22):5157–5170.
- [6] Chen L, Nguyen TB, Jones E, et al. Magnetic resonance-based treatment planning for prostate intensity-modulated radiotherapy: creation of digitally reconstructed radiographs [J]. *Int J Radiat Oncol Biol Phys*, 2007, 68(3):903–911.
- [7] Roach M 3rd, Pickett B, Holland J, et al. The role of the urethrogram during simulation for localized prostate cancer [J]. *Int J Radiat Oncol Biol Phys*, 1993, 25(2):299–307.
- [8] Schild SE, Buskirk SJ, Robinow JS. Prostate cancer: retrograde urethrography to improve treatment planning for radiation therapy [J]. *Radiology*, 1991, 181(3):885–887.
- [9] Sandler HM, Bree RL, McLaughlin PW, et al. Localization of the prostatic apex for radiation therapy using implanted markers [J]. *Int J Radiat Oncol Biol Phys*, 1993, 27(4):915–919.
- [10] Shipley WU. The advantage of an X-ray visible marker of the prostatic apex [J]. *Int J Radiat Oncol Biol Phys*, 1993, 27(4):985.
- Wilson LD, Ennis R, Percarpio B, et al. Location of the prostatic apex and its relationship to the ischial tuberosities [J]. *Int J Radiat Oncol Biol Phys*, 1994, 29(5):1133–1138.
- [11] Dudouet P, Portalez D, Lhez JM, et al. Trans-rectal ultrasonography (TRUS) with lipiodol injection for localization of the prostatic apex before radiotherapy planning [J]. *Radiother Oncol*, 2001, 61(2):135–141.
- [12] Plants BA, Chen DT, Fiveash JB, et al. Bulb of penis as a marker for prostatic apex in external beam radiotherapy of prostate cancer [J]. *Int J Radiat Oncol Biol Phys*, 2003, 56(4):1079–1084.
- [13] Milosevic M, Voruganti S, Blend R, et al. Magnetic resonance imaging (MRI) for localization of the prostatic apex: comparison to computed tomography (CT) and urethrography [J]. *Radiother Oncol*, 1998, 47(3):277–284.
- [14] McLaughlin PW, Evans C, Feng M, et al. Radiographic and anatomic basis for prostate contouring errors and methods to improve prostate contouring accuracy [J]. *Int J Radiat Oncol Biol Phys*, 2010, 76(2):369–378.