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

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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 muscle. 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 ± 3.3) mm above the bulb of the penis, (11.0 ± 5.4) mm above the bottom of the obturator foramen, (31.3 ± 5.5) mm above the ischial tuberosities, and (7.1 ± 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.

Keywords: Prostatic neoplasms, apex of prostate, CT, radiotherapy planning
apex, but this is an invasive examination and is uncomfortable for patients, with many contentious issues. Therefore, some researchers \(^{[10-12]}\) 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 exit 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 prostatic 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\(^{[10]}\). 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 5 mm, 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 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 = 4/3π × (radius)\(^3\). The radius was converted into 3 diameters and the formula was simplified: prostate volume = 0.52 × (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...
apex and the lower edge of the obturator was measured on sagittal MRI images (Figure 2, d1). The prostatic apex was located (11.0 ± 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 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 ± 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 ± 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 16.2 mm.

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 ± 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).
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.
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.\(^\text{[7]}\) 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.\(^\text{[8]}\) 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.\(^\text{[9]}\) 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\%\(^\text{[8,9]}\). 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.\(^\text{[10]}\) 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\(^\text{125}I\) implantation when prostate was exposed during surgery, and 20 received transperineal\(^\text{125}I\) 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\(^\text{125}I\) 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.\(^\text{[11]}\) 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\(^\text{[12]}\). 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.\(^\text{[13]}\) 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.\(^\text{[15]}\) 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 prostatic 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 prostatic apex to the top of the bulb of penis were measured directly on MRI images in 108 patients, and the result was 13 ± 3.3 mm. The deviation of distance was larger than the results of Plants’ study.

McLaughlin et al.\(^\text{[14]}\) 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.\textsuperscript{[14]} 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 ± 0.46) mm. The distances measured on MRI images can be applied on CT images.

![Figure 9](image_url)  
**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


