Journal of Medical Radiation Sciences

Open Access

ORIGINAL ARTICLE

Definition and visualisation of regions of interest in post-prostatectomy image-guided intensity modulated radiotherapy

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Keywords
CBCT, IGRT, post prostatectomy, radiotherapy, regions of interest

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Funding Information
No funding information provided.

Received: 18 December 2013; Revised: 15 April 2014; Accepted: 28 May 2014

Journal of Medical Radiation Sciences **61** (2014) 166–175

doi: 10.1002/jmrs.58

Abstract

Introduction: Standard post-prostatectomy radiotherapy (PPRT) image verification uses bony anatomy alignment. However, the prostate bed (PB) moves independently of bony anatomy. Cone beam computed tomography (CBCT) can be used to soft tissue match, so radiation therapists (RTs) must understand pelvic anatomy and PPRT clinical target volumes (CTV). The aims of this study are to define regions of interest (ROI) to be used in soft tissue matching image guidance and determine their visibility on planning CT (PCT) and CBCT. **Methods:** Published CTV guidelines were used to select ROIs. The PCT scans (n = 23) and CBCT scans (n = 105) of 23 post-prostatectomy patients were reviewed. Details on ROI identification were recorded. **Results:** Eighteen patients had surgical clips. All ROIs were identified on PCTs at least 90% of the time apart from mesorectal fascia (MF) (87%) due to superior image quality. When surgical clips are present, the seminal vesicle bed (SVB) was only seen in 2.3% of CBCTs and MF was unidentifiable. Most other structures were well identified on CBCT. The anterior rectal wall (ARW) was identified in 81.4% of images and penile bulb (PB) in 68.6%. In the absence of surgical clips, the MF and SVB were always identified; the ARW was identified in 89.5% of CBCTs and PB in 73.7%. **Conclusions:** Surgical clips should be used as ROIs when present to define SVB and MF. In the absence of clips, SVB, MF and ARW can be used. RTs must have a strong knowledge of soft tissue anatomy and PPRT CTV to ensure coverage and enable soft tissue matching.

Introduction

Prostate cancer is the most prevalent cancer in men in Australia[1] with radical prostatectomy the most common treatment.[2] It is now standard of care to consider adjuvant[3–6] or salvage[7–9] radiotherapy to the prostate bed (PB) in patients with high-risk features or PSA failure following surgery.

Standard practice for image verification during post-prostatectomy radiotherapy (PPRT) is to align to bony anatomy on either kV or CBCT imaging. However, it has been found that the PB can move independently of the bony anatomy, therefore making bony anatomy a poor surrogate for PB position.[10]

Cone beam computed tomography (CBCT) scans can be used to visualise anatomy and enable soft tissue matching for post-prostatectomy patients. This is due to the soft tissue definition on the CBCT scans.[11] This extra soft tissue definition would enable matching to be changed from bony anatomy to soft tissue matching in these patients, which could potentially increase treatment accuracy. It is also important to acknowledge the difference in image quality between the CBCT scan taken at the linear accelerator and the diagnostic quality CT scans that are used by the radiation oncologists to delineate the clinical target volume (CTV). The surgical clips that are often placed in the PB during surgery can help with the identification of areas needing to be treated but they can also hinder this identification due to the image artefacts that they can cause. Both of these factors need to be taken into account when considering implementing soft tissue matching.

It is important for radiation therapists (RTs) to have a strong knowledge of soft tissue pelvic anatomy and the post-prostatectomy CTV as seen on CBCT scans. This allows them to ensure that the CTV is adequately covered when aligning to bony anatomy, and once suitable processes are established, enables soft tissue matching independent of bony alignment.

The aims of this study are to define regions of interest (ROI) that could be used as part of an imaging guidance program for post-prostatectomy patients and to determine whether these structures can be visualised on both planning CT (PCT) and CBCT scans. A secondary aim is to develop an atlas to be used in training RTs in the identification of the ROIs.

Methods

Ethics approval was granted by the Hawkesbury Research Ethics Committee of Northern Sydney Central Coast Health (0912-377M) and the University of Sydney Executive Committee of the Research Ethics Committee (12622).

Surgical clips might or might not be used during prostatectomy surgery. Therefore, ROI for patients both with and without surgical clips need to be identified.

Guidelines on CTV delineation in PPRT were used to select appropriate ROI.[12,13] When selecting ROIs, the CTV was divided into upper and lower portions. The division was made where the anterior CTV volume moved away from the posterior symphysis pubis. In the upper and lower portions of the PB, ROIs were selected to represent the anterior–posterior, superior–inferior and lateral portions of the CTV (see Table 1). A training atlas was made by a RT (L. B.) and two radiation oncologists (A. K. and T. E.). This atlas documented each of the ROIs in descriptive wording and in PCT and CBCT illustrations.

The PCT and CBCT data sets of 23 post-prostatectomy patients who were treated with the intensity modulated radiotherapy (IMRT) between 2007 and 2008 at the Northern Sydney Cancer Centre were selected sequentially from the database.

Each of the patients had a PCT acquired as a part of his radiotherapy treatment simulation. All patients also had CBCT images acquired using the Varian On-Board Imager Version 1.3 (Varian Medical Systems, Palo Alto, CA) as a part of their standard course of treatment. The number of scans acquired per patient ranged from 3 to 9 scans. The range of scan numbers was due to changes in the CBCT imaging protocol over this time period. A total of 23 PCT scans and 105 CBCT scans were reviewed.

Training was provided to a RT (L. B.) by two radiation oncologists (A. K. and T. E.) in the identification of the ROIs on both PCT and CBCT scans to ensure correct identification. This training involved studying the guidelines for CTV delineation, training sessions with the radiation oncologists using PCT and CBCT scans to identify the structures and the process of developing the training atlas, which was then checked by the radiation oncologists.

A RT (L. B.) identified each ROI using the Varian Eclipse (Varian Medical Systems) treatment planning system, both on the PCT and on each subsequent CBCT image. Details of ROI identification for each image were recorded. Any other relevant observations made, such as information on image processing that improved visualisation of a structure and patient dimensions, were also recorded.

Data analysis was completed using Microsoft Excel (Microsoft Corporation, Redmond, WA) and Statistical Package for the Social Sciences (SPSS) (IBM Corporation, Armonk, NY).

Results

A total of 23 PCT scans and 105 CBCT scans were reviewed. Eighteen (78%) of the 23 patients had surgical clips in situ and 5 (22%) did not.

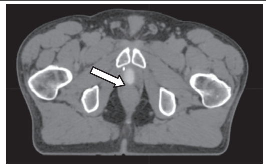
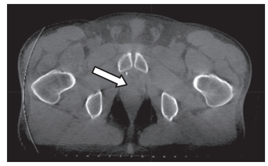
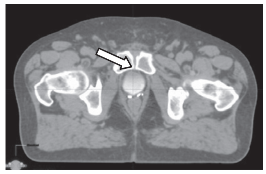
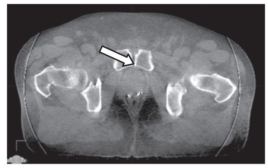
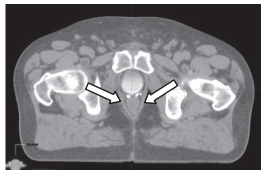
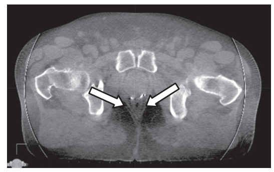
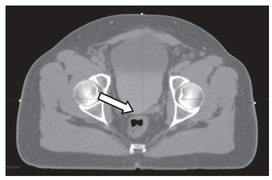
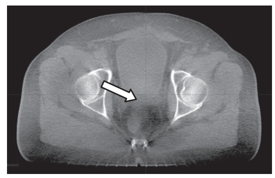
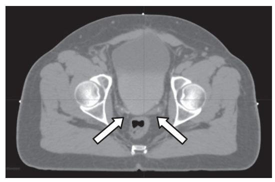
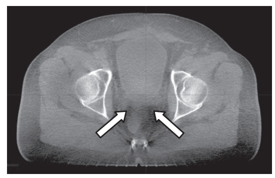
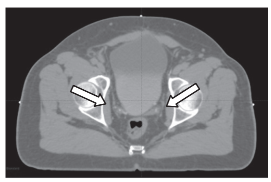
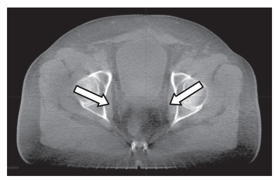
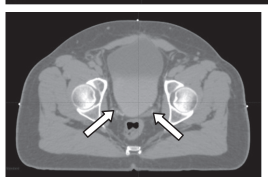
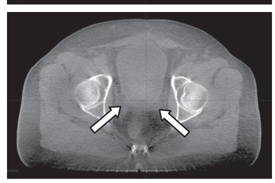
Training atlas development

A training atlas was developed after the ROIs were selected. This atlas described each ROI in words and with illustrations of the ROIs using both PCT and CBCT scans.

Patient dimensions

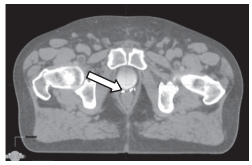
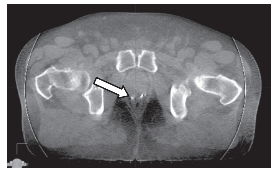
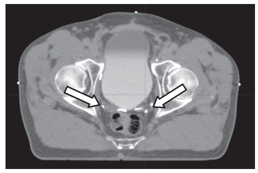
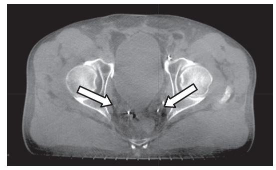
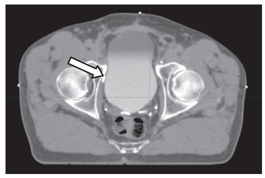
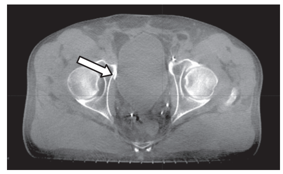
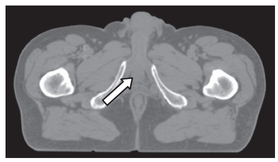
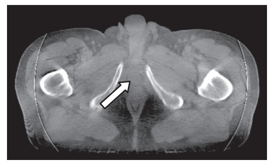
Patient dimension was assessed by measuring the left–right width and anterior–posterior depth at isocentre on

Table 1. Summary of regions of interest and the area of the clinical target volume they represent.

ROI name	Area of CTV being identified	Used for patients with surgical clips	Used for patients without surgical clips	Planning CT	CBCT scan
Anterior rectal wall	Lower – posterior	✓	✓		
Posterior pubic symphysis	Lower – anterior	✓	✓		
Levator ani muscle	Lower – lateral	✓	✓		
Posterior bladder	Upper – anterior	✓	✓		
Mesorectal fascia	Upper – posterior	✓	✓		
Pelvic muscles	Upper – lateral	✓	✓		
SV bed	Upper – posterior	✓	✓		

(*Continued*)

Table 1. Continued.

ROI name	Area of CTV being identified	Used for patients with surgical clips	Used for patients without surgical clips	Planning CT	CBCT scan
Para-rectal surgical clips	Lower – anterior	✓	✖		
SV surgical clips	Upper – posterior	✓	✖		
Other vascular clips	Area not to be covered	✓	✖		
Penile bulb	Lower – inferior	✓	✓		

Details of the ROI selected to be identified in the planning CT and CBCT scans and the regions of the CTV they represent. ROI, region of interest; CTV, clinical target volume; CBCT, cone beam computed tomography; SV, seminal vesicle.

the PCT. The width ranged from 27.6 to 38.8 cm (mean = 35.9 cm, median = 36.1 cm) and the depth ranged from 19.3 to 26.3 cm (mean = 22.6 cm, median = 22.8 cm).

Grey scaling of PCT and CBCT images

When viewing both the PCT and CBCT scans it was noted that when a setting was used to visualise bony anatomy well, the posterior bladder, surgical clips, seminal vesicle (SV) bed, levator ani, pubic muscles, and the mesorectal fascia could all be visualised. The grey scale needed to be darkened to see the anterior rectal wall. Table 2 suggests a grey scale range for best viewing of the ROI on both imaging types.

ROI identification in all patients

The rates of identification of the ROI on (a) PCT and (b) CBCT scans for all patients are shown in Figure 1. The levels of identification were divided into four categories: identified, not identified, difficult to identify and not applicable (N/A). ROIs that were able to be identified but took a long time to find or required imaging processing to be seen were classified as difficult to identify.

On the PCT scans (Fig. 1A) most ROIs could be identified. The penile bulb could not be identified on one scan because the scan length did not cover this area.

Most of the ROIs could be identified on the CBCT scans (see Fig. 1B). For the entire group, the percentage of images where ROIs were clearly identified are anterior rectal wall (82.9%), posterior pubic symphysis (100%), levator ani muscle (96.2%), posterior bladder (99%), mesorectal fascia (18.1%), pelvic muscles (100%), SV bed (20%) and penile bulb (69.5%). When present the para-rectal surgical clips, SV surgical clips and other vascular clips were always identified.

ROI identification in patients without surgical clips

The rates of identification of ROIs on (a) PCT and (b) CBCT scans for patients without surgical clips are shown in Figure 2.

Table 2. Suggested grey scale ranges.

	Planning CT scan		Cone beam CT scan	
ROI	Upper grey scale (HU) (95% CI)	Lower grey scale (HU) (95% CI)	Upper grey scale (HU) (95% CI)	Lower grey scale (HU) (95% CI)
Anterior rectal wall	471 to 585	−122 to −105	754 to 1008	−201 to −157
Pubic symphysis	394 to 502	−200 to −173	619 to 812	−287 to −243
SV bed	394 to 502	−200 to −173	482 to 806	−295 to −227
Surgical clips	380 to 513	−203 to −174	614 to 837	−290 to −237
Levator ani muscle	394 to 502	−200 to −173	619 to 812	−287 to −243
Posterior bladder	394 to 502	−200 to −173	619 to 812	−287 to −243
Mesorectal fascia	394 to 502	−200 to −173	431 to 901	−311 to −223
Pelvic muscles	394 to 502	−200 to −173	619 to 812	−287 to −243
Penile bulb	384 to 508	−171 to −97	567 to 703	−223 to −172

Suggested grey scale range for best viewing of each of the ROI using a 95% confidence interval range. ROI, region of interest; SV, seminal vesicle.

On the five PCT scans (Fig. 2A) all ROIs could be identified successfully.

Most of the ROIs could be identified on the 19 CBCT scans (see Fig. 2B). The percentage of images where ROIs could be identified are anterior rectal wall (89.5%), posterior pubic symphysis (100%), levator ani muscle (100%), posterior bladder (94.7%), mesorectal fascia (100%), pelvic muscles (100%), SV bed (100%) and penile bulb (73.7%). The anterior rectal wall and posterior bladder wall were not clearly visualised in a small number of images, due to artefacts caused by rectal gas.

ROI identification in patients with surgical clips

The rates of identification of ROI on (a) PCT and (b) CBCT scans for patients with surgical clips are shown in Figure 3.

On the 18 PCT scans (Fig. 3A) most ROIs could be identified. The penile bulb (5.6%) was the only ROI that could not be identified in all images, which was due to the scan length being too short.

The percentage of images where ROIs were clearly identified on the 86 CBCT scans are posterior pubic symphysis (100%), levator ani muscle (95.3%), posterior bladder (100%), pelvic muscles (100%), para-rectal surgical clips (95.3%), SV surgical clips (100%), other vascular clips (96.5%) and penile bulb (68.6%). Two ROIs, the mesorectal fascia (2.3%) and SV bed (15.1%) were not easily identifiable in a large number of images, due to the artefact caused by the surgical clips in this area. The anterior rectal wall was only identified in 81.4% of images when clips were present compared with 89.5% when clips were not present.

Discussion

We have found that predetermined ROIs as defined by published post-prostatectomy guidelines[12,13] can be identified on both PCT and CBCT images taken during radiotherapy treatment. The concept of ROIs to aid measurement of set-up error is not new, and has been used in other clinical areas such as head and neck cancer,[14] who found that ROIs improved the identification of movement in this area.

Previous authors have reported that the PB moves independently of bony anatomy,[15–19] and in a number of these studies CBCT scans were used to assess this movement.[10,20,21] This has implications for daily image guidance techniques applied during radiotherapy treatment in post-prostatectomy patients. The use of the IMRT treatment technique makes treatment accuracy even more important, due to the highly conformal dose distributions achieved.[22] Bony anatomy matching will therefore be suboptimal in a number of patients/fractions and to minimise this error, techniques such as soft tissue matching or fiducial marker placement will be required.[17] As with other disease sites, such as cancer of the bladder,[23] it is likely that RTs will be responsible for the online soft tissue match if required. The ROIs identified in this paper will assist RT training and quality assurance for post-prostatectomy online soft issue matching.

As expected, we found the ROIs were more easily identified on the higher quality PCT scan than the CBCT scans. It should be noted that the CBCT images used for this study were acquired using an older version of the Varian On-Board Imaging software than is currently used in clinical practice and the quality of CBCT images available has and will continue to be improved.

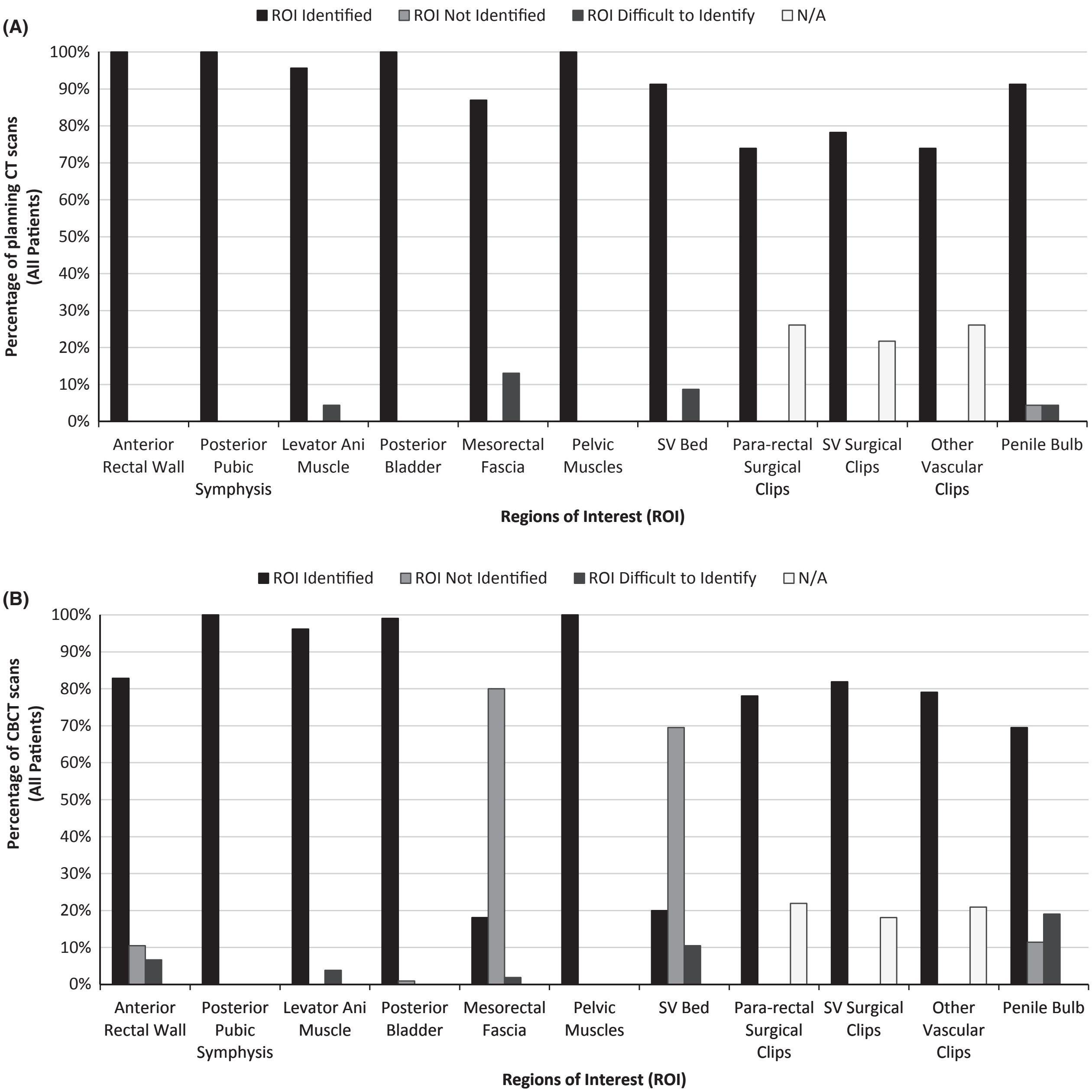


Figure 1. Region of interest (ROI) identification on all patients. ROI identification rates for all patients on the (A) planning CT and (B) CBCT scans. N/A, not applicable; SV, seminal vesicle; CBCT, cone beam computed tomography.

Visualisation of the ROIs was affected by random and systematic factors, some of which could be corrected. Systematic factors include patient size and the presence of surgical clips. Patient size affected the image quality of the CBCT scans (1) if the body contour did not fit in the field of view and (2) by decreasing signal to noise ratio creating grainy images. The surgical clips cause artefacts in the CBCT images which interfere with the visualisation of soft tissue. A common random factor is rectal gas. Moving rectal gas causes streaking artefacts that make it difficult to see the ROIs (see Fig. 4). Factors that can be corrected include PCT scan length, isocentre placement, CBCT centre, and bow-tie filtre placement. The PCT scan length influenced the visualisation of some of the ROIs, including the penile bulb. The limited length of 16 cm for the CBCT scan means that plan isocentre placement and CBCT centre position all affected the visualisation of some ROIs, as they were not always in the scanned area.

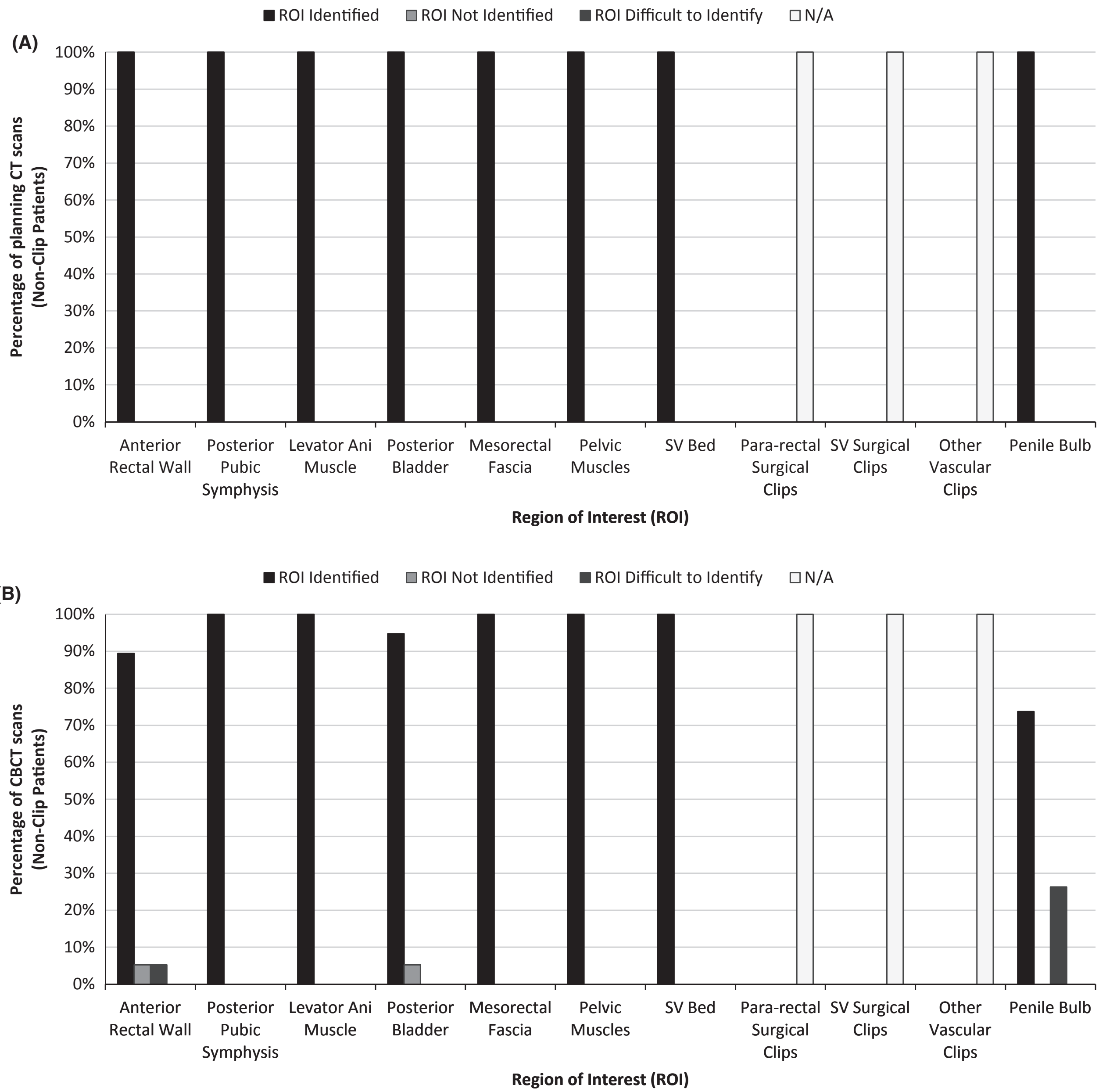


Figure 2. Region of interest (ROI) identification on patients without surgical clips. ROI identification rates for patients without surgical clips on the (A) planning CT and (B) CBCT scans. N/A, not applicable; SV, seminal vesicle; CBCT, cone beam computed tomography.

Artefacts caused by incorrect or lack of bow-tie filter placement also reduced the image quality of the CBCT scans, which influenced ROI identification.

All the factors that influence errors need to be considered when developing a soft tissue matching protocol. The artefacts seen in the CBCT scans of larger patients could mean that these patients are not suitable for reduced margins because the matching technique would be compromised. Perhaps these patients should be reviewed over the first five fractions with CBCT or have fiducial markers implanted to increase the accuracy of online matching. The artefacts caused by metallic surgical clips mean that soft tissue matching could be difficult. Therefore, patients with clips should have ROIs specific to the clips and for those without clips the ROI should be the SV bed. The artefacts caused by moving rectal gas could be overcome by repeating the CBCT. PCT scan length should be controlled by the use of a scanning protocol that ensures that all ROIs are in the scan. The limitation of the CBCT scan length can be overcome by

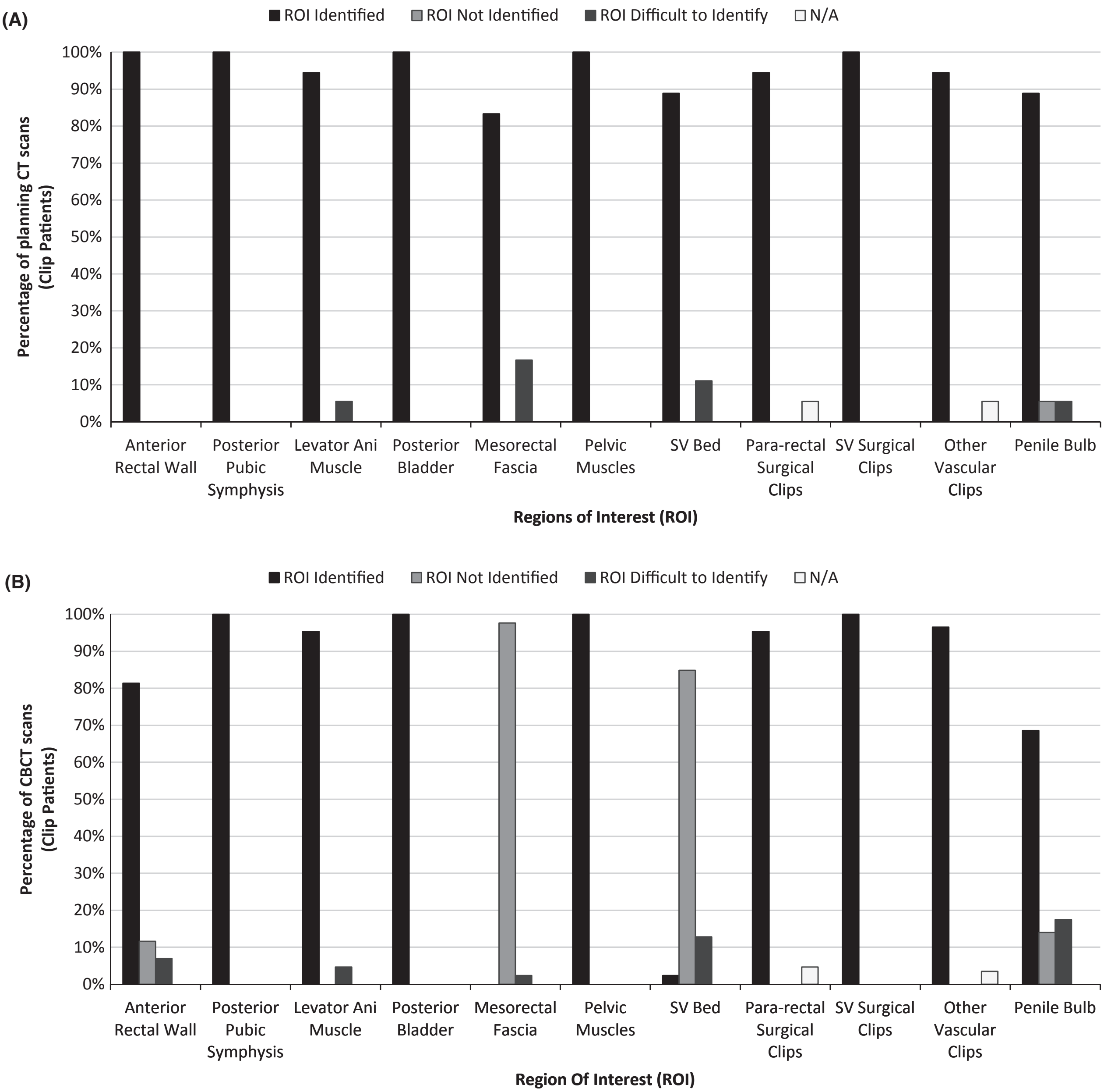


Figure 3. Region of interest (ROI) identification on patients with surgical clips. ROI identification rates for patients with surgical clips on the (A) planning CT and (B) CBCT scans. N/A, not applicable; SV, seminal vesicle; CBCT, cone beam computed tomography.

taking this into account when determining the plan isocentre during the planning process. The CBCT centre can also be used at the time of CBCT acquisition to ensure that all ROIs are inside the CBCT scan length. Incorrect or lack of bow-tie filtre could be prevented by the addition of an interlocking system on the treatment machine. Until this is available, more care needs to be taken to ensure that the filtre is correct.

A limitation of this study is that it is a single-observer study. This study was designed to define ROIs that could be used to identify the PB if a soft tissue image guidance policy was to be used and determine whether these structures could be visualised on PCT and CBCT scans. A training atlas was developed during this study and used to test inter-observer variability in ROI identification and determine the effectiveness of the training atlas.[24] In a pre-test, 31 RTs were asked to identify the ROIs on two sets of patient images, one with surgical clips and one without. The RTs were then given the atlas before repeating the ROI identification. It

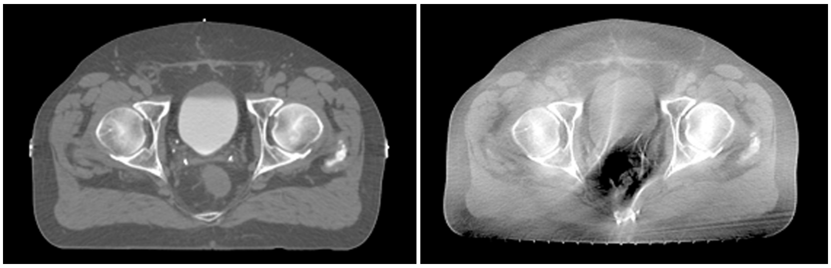


Figure 4. Artefact caused by moving rectal gas. Moving rectal gas causes streaking artefacts that make it difficult to see the regions of interest (ROIs). Moving rectal gas can be seen in the CBCT scan (right) which has made it difficult to see the ROIs seen in the planning CT scan (left). CBCT, cone beam computed tomography.

was found that the atlas significantly increased the identification rate of the ROI, leading to more accurate target alignment.

Another limitation of this study is that only the ROI that could be used to ensure coverage of the CTV have been discussed. The surrounding organs at risk (OARs) have not been assessed. It has been noted that the upper portion of the PB moves more than the lower portion,[10] which results in a tilting of the CTV. This would mean that an averaged match would need to be applied to the PB, so over coverage of surrounding OAR such as the rectum could occur. Caution must therefore be taken to assess both CTV coverage and OAR avoidance when using image guidance.

Conclusion

ROIs for post-prostatectomy soft tissue matching have been defined from CTV guidelines and were successfully identified on both PCT and CBCT scans for patients with and without surgical clips. These ROIs can be used in conjunction with a soft tissue matching image guidance program and have been compiled as an atlas for training purposes.

Acknowledgement

The authors gratefully acknowledge all the staff at Northern Sydney Cancer Centre.

Conflict of Interest

The authors declare no conflict of interest.

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