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Review Article

A systematic review of prostate bed motion and anisotropic margins in post-prostatectomy external beam radiotherapy

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ABSTRACT

Background: Prostate bed (PB) motion may lead to geographical miss of the target volume in post-prostatectomy radiotherapy (RT). Optimal clinical target volume (CTV) to planning target volume (PTV) margins prevent geographical miss and unnecessary irradiation of normal tissue. There is little data available informing appropriate CTV to PTV margins in the post-prostatectomy setting. The purpose of this review was to quantify the inter-fraction and intra-fraction motion of the PB and draw a conclusion regarding the use of anisotropic CTV to PTV margins for post-prostatectomy RT treatment.

Methodology: A search of PubMed and EMBASE databases was carried out using keywords (prostate bed [Title/Abstract]) AND (motion [Title/Abstract]). All study types assessing inter-fraction and/or intra-fraction motion of the PB based on imaging of soft tissue anatomy were included. Data on patient preparation, immobilisation, and image guidance was abstracted from the included studies. Magnitude of PB motion along with the estimated CTV to PTV margins calculated was also tabulated. Quality of studies was assessed using the MINORS tool.

Results: Seventeen studies were included in the analysis. The largest magnitude of inter-fraction PB motion occurs in the anterior-posterior direction. This motion is attributed to the influence of the bladder and rectal volume on the PB. The PB moves independently of bone and the magnitude of motion varies between the superior and inferior portions of the prostate bed.

Conclusion: Anisotropic CTV to PTV margins are appropriate for use in the post-prostatectomy setting and their implementation for treatment planning purposes are warranted based on the evidence reviewed.

Introduction

Adjuvant and salvage radiotherapy (RT) have a well-established role in the treatment of prostate cancer. In recent years, numerous studies have demonstrated the benefits of salvage RT for decreasing patient toxicity and improving overall treatment outcomes [1–3]. In the case of post-prostatectomy radiotherapy, the delineation of the target volume and the precision of dose delivery become critical for effective radiotherapy. As there is no gross tumour volume remaining post-prostatectomy, the clinical target volume (CTV) is defined by the surrounding deformable soft tissue and areas where there is a high probability of recurrence. Latorzeff et al., [4] has previously highlighted the difficulties of prostate bed (PB) CTV delineation, referring to the post-prostatectomy CTV as "an invisible target" and emphasising the potential for geographical miss of the target volume. To this date, five expert consensus guidelines have been published to aid CTV delineation [5–9].

The precision and accuracy of dose delivery relies on key aspects of the RT process, such as patient positioning and immobilisation, patient preparation and image guidance techniques. Defining the optimal CTV to planning target volume (PTV) margin which accounts for systematic and random errors of the PB remains a challenge. Although CTV to PTV margins are institution specific, dependant on the individual potential for systematic and random errors to occur during treatment, many of the consensus guidelines for delineation of the PB have also put forward recommendations for optimal CTV to PTV margins. The most recently published guideline by ESTRO-ACROP recommends a minimum of a 5.0 mm isotropic expansion of the CTV to create the PTV [5].

With advanced imaging capabilities that allow for soft tissue visualisation, we are now better able to understand the complexity of the PB as a target and it's motion during treatment, thereby better informing us of the required CTV to PTV margins. Considering the inter-fraction and intra-fraction motion of the PB will help optimise these margins.

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Optimal CTV to PTV margins decrease the risk of geographical miss of the target volume where large amounts of motion is expected whilst also reducing unnecessary irradiation of the surrounding normal tissue [10]. Anisotropic margins are commonly used in radiotherapy treatment, particularly in areas where there is a significant level of internal motion that is not equal in all three planes [11]; the implementation of which can be adapted to any image guided radiotherapy (IGRT) strategy [10].

The correction of target positioning errors is critical for the safe delivery of external beam radiotherapy (EBRT). For post-operative prostate RT, radiobiological models have predicted an expected proportional gain in the biochemical-relapse free survival rate of 3 % per incremental Gray [12]. With more conformal treatment techniques such as intensity modulated radiotherapy (IMRT) allowing for a high dose fall off outside of the PTV and the potential benefit of dose escalation in the post-operative setting, development of CTV to PTV margins that are reflective of the complexity of the PB as a target should be considered to optimise treatment outcomes.

The aim of this review is to synthesise current literature in order to quantify the inter-fraction and intra-fraction motion of the PB and draw a conclusion regarding the use of anisotropic CTV to PTV margins for post-prostatectomy radiotherapy treatment. This review will include published literature on inter-fraction and intra-fraction motion of the PB, IGRT techniques and CTV to PTV margins.

Methodology

Search strategy for identification of studies

This systematic review followed the PRISMA methodology. Studies were identified using the PubMed and EMBASE databases. A combination of (prostate bed [Title/Abstract]) AND (motion [Title/Abstract]) were used to identify key literature for use in the review.

All study types published in English were included, including prospective and retrospective cohort, cross-sectional, and case-control studies. There was no limitation on publication date, and the last search was conducted on the 17/09/2023. Patients receiving salvage or adjuvant radical radiotherapy treatment to the PB following a radical prostatectomy were included. All publications assessing the inter-fraction and/or intra-fraction motion of the PB were included. All publications must have assessed the motion of the PB by the use of an imaging modality that allows for soft tissue visualisation or the use of a suitable surrogate. The screening process was conducted by the first author (TH). In the event of uncertainty, the senior author (EF) was consulted, and a consensus was reached. The senior author then approved the final list of included studies prior to data collection and analysis.

Type of outcomes and data analysis

Information regarding patient positioning, immobilisation, bladder and rectal preparation were extracted and collated using data collection tables. Prostate bed motion is defined as the change in position of the PB or surrogate marker relative to bony anatomy [13–16]. Inter-fraction and intra-fraction PB motion must have been reported as the mean and/or standard deviation of the motion in the superior-inferior (SI), anterior-posterior (AP) and left–right directions (LR). Studies that separated the PB into the superior and inferior PB were included.

Estimated CTV to PTV margins that were calculated based on the motion of the PB were included. The simplified Van Herk formula ($2.5\sum + 0.7\,\sigma$), where $\sum$ is the systematic error and σ is the random error, was used to estimate CTV to PTV margins based on the information provided in the study if the calculation was not performed [17].

The methodological index for non-randomised studies (MINORS) was used to assess the quality of the included studies in order to rank the studies included in the systematic review [18].

Results

The initial search yielded 64 records across both databases. One record was identified through hand-searching. Following removal of duplicates and title/abstract screening, 18 records underwent a full-text assessment, where one record was identified as inappropriate for inclusion based on the inclusion criteria. This resulted in a total of 17 papers to be included in the review (Fig. 1). The results from the MINORS quality assessment indicate that the majority of the studies included in this review are of a similar standard [18]. With scores ranging from 7 to 14 out of 16, and a median score of 12, the evidence reviewed can be considered moderate quality. The detailed results from this assessment are reported in supplementary material (S1).

Patient positioning and preparation

Patient positioning and immobilisation

Nine studies reported the patient positioning and immobilisation [13,14,19–25]. In all nine studies, patients were positioned supine. Four studies used a customised thermoplastic foam cast device, used from the patient's waist to mid-thigh [16,21,22,25]. Three studies reported using a Vac-Loc cushion, used from the patient's knees down [13,14,23]. Song et al., [24] reported using an indexed combi-fix. Joo et al., [20] reported using a knee immobilisation device, either with or without ankle immobilisation, similar to that of a combi-fix.

Bladder and rectal preparation

Twelve studies reported information regarding the bladder preparation protocol that was followed by patients daily prior to their radiation treatment [13–16,19–21,23,24,26–28]. Seven studies reported that the patients were required to have a full bladder prior to treatment, but did not give any specific protocol that must be followed [13,14,16,21,23,24,26]. Two studies required the patients to drink 500 ml of water one hour prior to treatment and waiting until after treatment was completed to void the bladder [15,19]. Bell et al., [27] reported that patients were required to drink 600 ml of water prior to treatment, with no information on hold time. Ost et al., [28] reported that patients were required to drink 750 ml of water one hour prior to treatment, void the bladder 15 min before treatment and drink a further 350 ml of water prior to treatment. Joo et al., [20] was the only study which required patients to have an empty bladder for treatment.

Eleven studies reported information regarding rectal preparation prior to treatment [13–16,19–21,23,24,27,28]. All studies required the rectum to be empty for CT simulation and all subsequent treatments. Bell et al., [27] provided patients with dietary advice, promoting a high magnesium diet. If the rectum was larger than 3.5 cm diameter in the AP plane at CT simulation, an enema was used to empty the rectum. Chao et al., [19] also made use of an enema for CT simulation as well as for the first ten treatment fractions. After the first ten treatment fractions, patients were evaluated on a patient by patient basis with regards to continuation of enema use. Ost et al., [28] provided patients with a glycerine suppository, evaluated on a patient by patient basis. Verma et al., [13] provided laxatives to patients who struggled to empty their rectum naturally to ensure the rectum was empty. Joo et al., [20] employed the use of an *endo*-rectal balloon (ERB) for all patients to help standardise the rectal volume.

Prostate bed motion

Inter-fraction motion

Sixteen studies, including a total of 346 patients, reported inter-fraction motion of the PB [13–16,19–30]. The results as reported in the literature are presented in Table 1. Eight studies used kilovoltage cone-beam computed tomography (KV CBCT) [14,15,19,20,24,26–28], five studies used orthogonal pair kilovoltage imaging [14,21,23,25,30], two studies used computed tomography (CT) on rails [13,22], one study

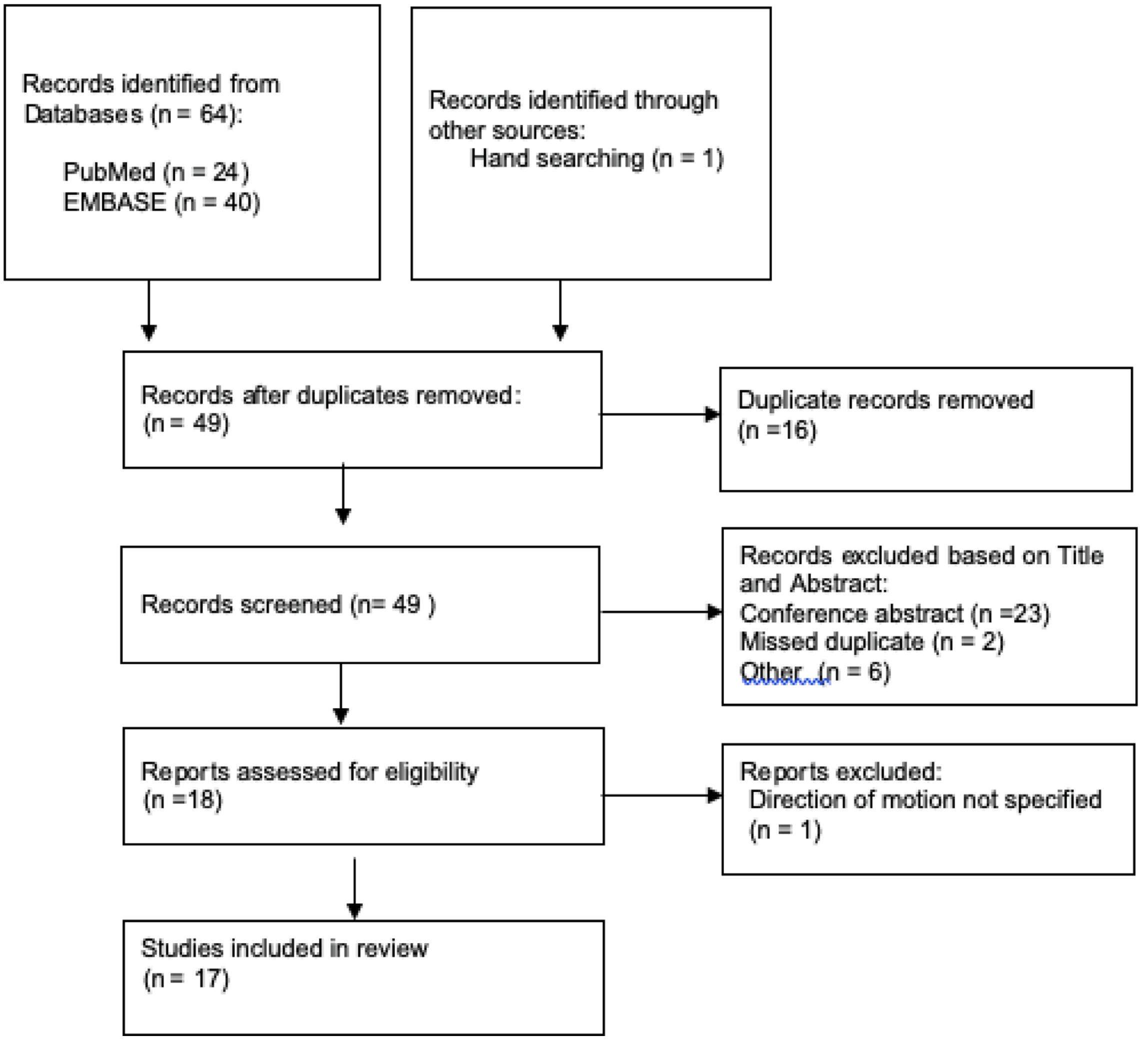

Fig. 1. Search Strategy PRISMA Flow Diagram [46].

used mega-voltage (MV) orthogonal pair images [16] and one study used MV cone-beam CT [29] to visualise the PB. All imaging modalities that did not allow for high quality soft tissue visualisation used a suitable surrogate to evaluate PB motion such as: surgical clips, calypso transponders and gold seed fiducials. Motion was measured either based on the PB itself (using soft tissue, the posterior bladder wall and/or anterior rectal wall) or by use of fiducial markers as a surrogate for the PB. Three papers split the PB into two portions, the superior and inferior PB, separated at the level of the superior boarder of the pubic bone [13,24] or by a superior and inferior surgical clip [27]. For the studies that considered the PB as a single total volume, the mean inter-fraction PB motion as reported in the literature ranged from −0.9 mm to 3.6 mm in the SI, −1.1 mm to 5.1 mm in the AP and −0.1 mm to 2.8 mm in the LR directions.

Intra-fraction motion

Two studies, including a total of 60 patients, examined intra-fraction motion of the PB [15,31]. The results as reported are presented in Table 2. Both studies used KV CBCT as the imaging modality. Huang et al., [15] used surgical clips to evaluate the intra-fraction motion of the PB over the course of each treatment, with one image taken after patient set up, one after implementing moves post image matching and one image taken post treatment. Bell et al., [31] used soft tissue to evaluate intra-fraction PB motion, with one pre-treatment image and one image post-treatment. The largest mean motion was detected in the AP direction.

Estimated CTV to PTV margins

The recommended CTV to PTV margins based on the inter-fraction and intra-fraction motion of the PB are reported in Table 3. Eight papers reported the recommended margins that should be used to account for PB motion based on the results of the study [15,19–21,24–26,28]. In all eight studies, the Van Herk formula was used to estimate these margins [17]. Bell et al., [27] reported the systematic and random error of the PB motion in the superior and inferior PB in the AP, SI and LR directions. These reported errors were used in this review to calculate the estimated CTV to PTV margins using the Van Herk formula. The imaging modality and imaging frequency is reported to reflect the IGRT protocol that was used to assess PB motion. The recommended margins based on the Van Herk formula, as reported in the literature, range from 4.0 mm to 15.8 mm in the AP, 3.3 mm to 13.0 mm in the SI and 1.4 to 6.0 mm in the LR directions.

Discussion

This systematic review summarises the results from 17 studies that highlight the issue of inter-fraction and intra-fraction motion of the PB and the influence of PB motion on CTV to PTV margins.

The results from the quantification of inter- and intra-fraction PB

Table 1
Inter-fraction prostate bed motion. *Mean or standard deviation reported only. E-NAL = Extended No Action Level protocol; kV = kilovoltage; MV = mega voltage; CBCT = cone beam computer tomography; SI = superior/inferior; AP = anterior/posterior; LR = left/right; PB = prostate bed.

Author's Name and Citation	Year	No. of Patients	Imaging Modality	Imaging Frequency	Measurement Method	Mean and (standard deviation) (mm)		
						SI	AP	LR
Ålander [26]	2014	13	kV CBCT	Daily	Gold seed fiducials	0.7 (2.1)	0.8 (1.6)	0.0 (0.5)
			kV CBCT	Daily	Soft Tissue	0.4 (0.9)	0.1 (0.5)	0.1 (0.4)
Bell [27]	2013	40	kV CBCT	E-NAL	Surgical clips	Superior PB 2.8 (2.6)	5.0 (5)	1.0 (1.2)
						Inferior PB 1.8 (1.7)	1.8 (1.6)	0.8 (1.0)
Chao [19]	2019	45	kV CBCT	Daily	Hydrogel tissue fiducial marker	0.1 (1.72)	0.8 (1.81)	−0.1 (0.53)
Huang * [15]	2012	14	kV CBCT	Daily	Surgical clips	−0.9	1.9	0.0
Joo * [20]	2016	46	kV CBCT	Daily	Anterior rectal wall	−0.1	(−0.3)	(−0.3)
Klayton [21]	2012	20	Orthogonal kV pair	Once Weekly	Calypso transponders	3.6 (4.2)	2.5 (3.2)	1.3 (1.8)
Kupelian [29]	2006	4	MV CBCT	Daily	Surgical clips	0.4 (0.8)	0.9 (1.0)	0.1 (0.4)
Ost [28]	2011	15	kV CBCT	Daily	Anterior rectal wall	0.9 (1.4)	2.7 (3.0)	0.6 (0.9)
Paskalev* [22]	2005	9	CT on rails	Twice Weekly	Anterior rectal wall and Posterior bladder wall	3.0	5.1	3.2
Sandhu [23]	2008	26	Orthogonal kV pair	Daily	Surgical clips	2.4 (2.1)	2.7 (2.1)	1.0 (1.7)
Schiffner [16]	2007	10	Orthogonal MV pair	Daily	Gold seed fiducials	0.4 (2.4)	−1.1 (2.1)	0.3 (0.9)
Simpson [14]	2010	23	kV CBCT	Daily	Soft Tissue	0.5 (1.5)	0.9 (1.6)	0.4 (0.9)
		27	Orthogonal kV pair	Daily	Surgical clips	2.4 (0.4)	2.6 (0.9)	1.0 (0.4)
Song [24]	2019	11	kV CBCT	Daily	Surgical clips	Superior PB −0.6 (2.3)	0.1 (2.5)	0.2 (0.3)
						Inferior PB −0.1 (2.1)	0.8 (1.3)	0 (0.3)
Song [25]	2012	17	Orthogonal kV pair	Twice Weekly	Surgical clips	2.5 (1.4)	3.1 (2.3)	2.3 (0.7)
Verma [13]	2016	8	CT on rails	Daily	Soft Tissue	total 0.3 (2.4)	0.0 (3.1)	0.2 (1.4)
						Superior PB 0.5 (2.3)	0.0 (5.0)	0.3 (1.8)
						Inferior PB 0.5 (2.2)	0.2 (2.5)	0.1 (2.8)
Vlachaki [30]	2019	18	Orthogonal kV pair	Daily	Gold seed fiducials	3.4 (3.1)	3.1 (2.9)	2.8 (2.5)

Table 2
Intra-fraction prostate bed motion. kV = kilovoltage; CBCT = cone beam CT; SI = superior/inferior; AP = anterior/posterior; LR = left/right.

Author Name and citation	Year	No. of Patients	Imaging Modality	Image Frequency	Measurement Method	Mean (mm)		
						SI	AP	LR
Bell [31]	2021	46	kV CBCT	Pre and Post treatment	Soft tissue	1.0	1.5	0.8
Huang [15]	2012	14	kV CBCT	Post set up, Post image matching, Post treatment	Surgical clips	−0.4	0.2	0.1

Table 3
Estimated CTV to PTV margins based on the motion of the prostate bed calculated by the Van Herk formula.

Author and citation	Year	No. of Patients	Target measured	Imaging Modality	Imaging Frequency	Margins (mm)		
						SI	AP	LR
Ålander [26]	2014	13	Inter-fraction PB motion	kV CBCT	Daily	5.9	5.9	1.4
					E-NAL	6.5	6.6	2.4
Bell [27]*	2013	40	Inter-fraction PB motion	kV CBCT	E-NAL	8.7	Superior PB 15.8	3.5
						5.9	Inferior PB 5.7	3.1
Chao [19]	2019	45	Inter-fraction PB motion	kV CBCT	Daily	5.9	6.6	2.3
Huang [15]	2012	14	Inter- and Intra-fraction PB motion	kV CBCT	Daily	4.6	4.8	3.1
					No IGRT	6.1	6.3	3.9
Joo [20]	2016	46	Inter-fraction PB motion	kV CBCT	Daily	5.0	4.0	2.0
Klayton [21]	2012	20	Inter-fraction PB motion		No IGRT	13.0	15.0	9.0
				Orthogonal kV pair	Weekly	13.0	9.0	5.0
Ost [28]	2011	15	Inter-fraction PB motion	kV CBCT	Daily	3.3	7.9	1.8
Song [24]	2019	11	Inter-fraction PB motion	kV CBCT	Daily	7.0	Superior PB 9.0	2.0
						7.0	Inferior PB 4.0	2.0
Song [25]	2012	17	Inter-fraction PB motion	Orthogonal kV pair	Twice Weekly	8.0	9.0	6.0

E-NAL = extended no action level protocol; IGRT = image guided radiation therapy; kV = kilovoltage; CBCT = cone beam computer tomography; PB = prostate bed
*Calculated using the simplified Van Herk Formula from information provided in the study.

motion showcases the variation in magnitude and direction of motion that occurs between and throughout treatment fractions. The PB moves independent of bone and on average the largest motion was detected in the AP direction. Robust patient positioning and immobilisation is fundamental to limiting motion and reducing systematic and random errors during RT treatment [10]. In many cases, PB motion has been attributed to the influence of the bladder and rectal volume on the PB [20,21,27,30]. Bell et al., [27] attributed the larger amounts of motion observed in the superior portion of the PB to this factor, as the superior portion is primarily defined by the bladder and rectal walls. Conversely, the motion in the inferior portion of the PB was found to be significantly less due to the less deformable anatomical boundaries of the inferior portion such as the pubic symphysis. An investigation by Showalter et al., [32] found that the daily variation in organ filling resulted in corresponding variations in the distance between the bladder and rectum. This variation therefore causing displacement and deformation of the PB volume. The investigation by Joo et al., [20] further supports this, as it was found that using an ERB limited PB motion by ensuring a consistent rectal volume throughout the course of treatment. Joo et al., [20] was the only study included in this review that required the patients to have an empty bladder for treatment. Although maintaining an empty bladder is a consistent protocol that has been reported to have non-inferior treatment outcomes compared to patients treated with a full bladder in the definitive setting, concerns about small bowel and urinary toxicity arise in the absence of a bladder filling protocol [33,34]. Whilst assessing intra-fraction PB motion, Bell et al., [31] found that bladder filling in the time between the pre-treatment and post-treatment CBCT acquisition occurred in 61 % of the images where a marginal miss was detected. Consistent and practical bladder and rectal filling protocols as part of the IGRT strategy are paramount to limiting PB motion, reducing the likelihood of geographical miss of the target volume and irradiation of surrounding normal tissue [35–37].

The influence of surrounding soft tissue structures on PB motion amplifies the importance of soft tissue visualisation or the use of a suitable soft tissue surrogate during image registration. As previously stated, the PB moves independently of bone and therefore bony registration only is not a sufficient image matching technique for this complex target. This is supported by the ESTRO-ACROP guidelines, stating that an absence of IG or use of CBCT with alignment to bony anatomy is not a recommended IGRT strategy for RT post-prostatectomy [5]. It is important to utilise IGRT techniques that can accurately and reproducibly localise the PB and ensure optimal coverage of the CTV whilst avoiding unnecessary irradiation of the surrounding organs at risk. The use of soft tissue surrogates, where imaging techniques that provide soft tissue visualisation are unavailable, may provide an adequate replacement but have their own associated shortcomings. Chao et al., [19] reported a 27 % loss of tissue fiducial marker volume during the course of treatment. Klayton et al., [21] found the mean change in measured Calypso inter-transponder distances relative to CT simulation was 1.3 mm. The comparison of gold seed fiducial markers and soft tissue visualisation provided by Ålander et al., [26] showcases that motion calculated from the gold seeds, which were implanted near to the posterior wall of the PB, delineates mainly the movement of the rectal wall whilst soft tissue registration defines the average movement of the PB and other soft tissues. Therefore, the use of gold seeds may lead to the underdosage of the anterior PB. Song et al., [24] reported that surgical clips tend to concentrate at the posterior portion of the PB and without soft tissue visualisation a similar problem could arise. The use of implanted fiducial markers is not supported by ESTRO-ACROP [5]. The benefit of Magnetic Resonance Imaging (MRI) to aid the detection of recurrence and delineation of the target volume for RT post-prostatectomy has been indicated in recently published literature [4,38,39]. The use of MRI guided RT, although not utilised in any of the studies included in this review, has been seen to improve toxicity and quality of life outcomes and furthermore enable the reduction of CTV to PTV margin size in the post-prostatectomy setting [40,41]. With current ongoing trials such as SHORTER (NCT04422132) investigating hypofractionated treatment techniques utilising MRI guided RT post-prostatectomy, there is a potential for more research into this area [40]. Using MRI to evaluate inter- and intra-fraction PB motion may be useful to enhance the current evidence base and further optimise CTV to PTV margins.

There is little data to guide radiation oncologists on appropriate margin selection in the post-prostatectomy setting. Despite the observations made in the majority of the studies reviewed here demonstrating that there is a significant level of internal motion that is not equal in all three planes, all consensus guideline recommendations suggest using an isotropic expansion of the CTV [5–7]. The recommended margin size varies between 5.0–10.0 mm with suggestions to crop back the posterior margin to a minimum of 5.0 mm to meet rectal dose volume constraints [5–7]. Song et al., [25] compared the use of a 5.0 mm and a 10.0 mm isotropic CTV to PTV margin. It was found that although a 5.0 mm margin decreased the rectal and bladder dose, it is not sufficient to ensure the CTV is covered by 95 % of the prescribed dose in 90 % of cases, based on the Van Herk Formula [17,25]. It is important to acknowledge the limitations of the Van Herk Formula, specifically its application in the post-prostatectomy setting [17]. The Van Herk formula was derived for a smooth CTV and Gaussian uncertainties. Therefore uncertainties in target volume definition should not be overlooked. The complexity of target definition that is evident in the post-prostatectomy setting should be considered when applying the Van Herk formula in an isotropic manner. Furthermore, based on the motion of the PB, Song et al., [25] suggested the use of an anisotropic non-uniform CTV to PTV expansion with the largest margin in the AP direction. A recommendation of the use of anisotropic margins was also put forward by three other papers that were included in this review; a concept not considered in the ESTRO-ACROP guidelines published just this year [5,27,30,31].

Three papers separated the PB into the superior and inferior PB [13,24,27]. The results reported by Song et al., [24] and Bell et al., [27] suggest that the superior and inferior PB move independently of each other and of bone, with statistically significant differences in superior and inferior PB motion in the AP direction. Although caution should be taken when drawing comparisons with other treatment sites, a similar case is observed in the definitive prostate setting with the prostate and seminal vesicles. Seminal vesicles display a high degree of motion in the AP and SI directions, move independently from the prostate and the motion is strongly correlated with the rectal volume, similar to the superior PB [42–44]. Less motion is observed from the intact prostate, similar to the results observed in the inferior PB [27,45]. It is now recommended to contour the seminal vesicles and prostate separately and applying different CTV to PTV margins to each structure to achieve a final PTV [45]. With these techniques being utilised in the definitive setting to account for the varying motion across the target volumes, similar techniques could be considered in the post-prostatectomy setting for the superior and inferior PB. Given this philosophy has not yet been transferred to the current PB delineation guidelines, there is potential for more research into the superior and inferior PB as independent structures and its implication on CTV to PTV margins.

Considering the PB as a whole structure, the evidence suggests that an anisotropic approach should be implemented. Utilising an anisotropic expansion will help account for the variation in magnitude and direction of the inter- and intra-fraction PB motion. Based on the results from this review, the CTV to PTV margins required to account for motion in the AP direction was on average 2.3 times larger than the corresponding margin in the LR direction. A uniform isotropic margin expansion that provides sufficient coverage in the AP direction could lead to unnecessary irradiation in the SI and LR directions. An anisotropic expansion, considering the motion of the PB in each plane and creating CTV to PTV margins according to the potential for systematic and random errors, could decrease the likelihood of geographical miss of the target volume whilst simultaneously decreasing normal tissue irradiation. As CTV to PTV margins are institutional specific and should be calculated based off the potential for systematic and random errors during treatment, a recommended margin size would not be appropriate; however, the evidence presented in this review can act as a guide, prompting clinicians to review their current practices. An anisotropic approach can be adapted to any IGRT protocol. There is an opportunity for more research into the superior and inferior PB as separate structures and consideration of this concept in future guidelines.

Conclusion

The largest magnitude of PB motion occurs primarily in the AP direction due to the influence of bladder and rectal volumes on the PB. This motion may cause geographic miss of treatment delivery when standard isotropic margins are used. Optimising bladder and rectal filling protocols in the post-prostatectomy setting is critical to limiting PB motion. Soft tissue visualisation or the use of a suitable surrogate is paramount for effective PB IGRT. Anisotropic margins are applicable for use in post-prostatectomy RT and should be strongly considered to prevent geographical miss of the target volume and limit normal tissue irradiation. There is potential for more research in this area, with a focus on considering the superior and inferior PB as separate structures.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tipsro.2024.100287.

Data availability

Data will be made available on request.

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