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Review

A critical literature review on the use of bellyboard devices to control small bowel dose for pelvic radiotherapy

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ABSTRACT

Delivering curative radiotherapy doses for rectal and gynaecological tumours has historically been complicated by the dose tolerance of the small bowel. Acute radiation-induced small bowel toxicity includes side effects such as abdominal pain, nausea and diarrhoea. With the advent of new treatment delivery modalities, such as IMRT (Intensity modulated radiotherapy) and VMAT (Volumetric modulated Arc radiotherapy), there has been an expectation that small bowel doses can be better controlled with the use of these technologies. These capabilities enable the creation of treatment plans that can better avoid critical radiosensitive organs. The purpose of this review is to look beyond advances in linear accelerator technology in seeking improvements to small bowel dose and toxicity. This review examines whether an alternative prone patient positioning approach using a bellyboard device in conjunction with IMRT and VMAT treatment delivery can reduce small bowel doses further than using these technologies with the patient in a traditional supine position.

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1. Introduction

Rectal Cancer is the fifth most common malignancy occurring in New South Wales (NSW) Australia, accounting for 4.2% of all cancers in 2015. Gynaecological cancers accounted for 9.2% of all cancers in NSW females in 2015. Combined, rectal and gynaecological cancers were responsible for over 1200 deaths in NSW in 2015.[1] Radiotherapy is a common treatment option for these patient groups, often in conjunction with surgery and chemotherapy.

Delivering curative radiotherapy for rectal and gynaecological tumours has historically been complicated by the dose tolerances of organs including the bladder and small bowel. Small bowel dose is often the limiting factor in a patient successfully completing a course of radiotherapy.[2] Acute radiation-induced small bowel toxicity includes side effects such as abdominal pain, bloating, decreased appetite, nausea, diarrhoea and faecal urgency.[3] Late radiation-induced small bowel toxicity includes such side effects as bowel obstructions, ulceration, fistulae and bleeding.[4,5]

Baglan et al.[6] observed a toxicity threshold for the small bowel when a volume of 150cc of small bowel received 15Gy (V15). At this point the probability of a patient experiencing severe (grade 3) diarrhoea ("Common Terminology Criteria for Adverse Events (CTCAE) Version 5.0,")[7] increased from 0% to 50–60%. Kavanagh et al.[4] – in a Quantec Dose Volume Effect Review based on Baglan et al.[6] and later studies – suggested that the small bowel volume receiving 15 Gy (V15) should be kept beneath 120cc when individual bowel loops are contoured to avoid severe (Grade 3) acute toxicity.[4] Kavanagh et al. also stated that the volume receiving 45 Gy (V45) should be kept beneath 195 cc when possible to reduce late toxicity risk.[4] Baglan et al.'s study[6] reported on patients receiving chemotherapy plus radiotherapy which is routine for rectal and gynaecological cancer treatment. Chemotherapy is a radiosensitiser known to increase acute radiation toxicity, which further increases the need to minimise small bowel dose as much as possible for this patient group.[4] Jadon et al.[5] published a systematic review of dose volume predictors for late bowel toxicities. Six papers were reviewed that looked specifically at small bowel side effects for pelvic radiotherapy. Two of these studies (Chopra et al.[8] and Isohashi et al.[9]) concluded that there was a positive correlation between small bowel dose and late toxicities. Chopra et al.[8] recommended V15 < 275cc to keep late grade 3 toxicities below 5%; Isohashi et al.[9] recommended V40 < 340cc to avoid late grade 2 or higher toxicities.

Gynaecological radiotherapy (endometrium and cervix) and rectal radiotherapy typically utilise similar treatment volumes

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incorporating the majority of the pelvic cavity. This is to provide an adequate margin around the primary tumour site to cover microscopic disease and also to ensure critical pelvic lymph nodes such as the presacral and internal iliac nodal chains are adequately treated.[10] The superior borders of radiotherapy treatment fields for these sites generally encroach upon the small bowel.

With the advent of new treatment delivery modalities such as IMRT (Intensity Modulated Radiation Therapy) and VMAT (Volumetric Modulated Arc Therapy), there has been an expectation that small bowel doses can be better controlled with the use of these treatment delivery technologies. These modalities provide improved capability of modulating and shaping radiotherapy fields and can increase the number of angles from which treatment can be delivered. These capabilities enable the creation of treatment plans that can better avoid critical radiosensitive organs, such as the small bowel, and, hence, increase the patients' ability to complete their course of treatment.[11]

Patients receiving pelvic radiotherapy are traditionally treated in a supine position for optimal stability, but an alternative approach that may reduce small bowel doses involves a bellyboard device that requires the patient to lie in a prone position. This device results in a physical separation of the patient's small bowel loops away from the pelvic cavity.[12]

The purpose of this review is to look beyond advances in linear accelerator technology in seeking improvements to small bowel dose and toxicity. This review examines whether an alternative prone patient positioning approach using a bellyboard device in conjunction with IMRT and VMAT treatment delivery can reduce small bowel doses further than using these technologies with the patient in a traditional supine position. The review acknowledges that small bowel dose and toxicity are not the only considerations when deciding upon whether or not a bellyboard technique is superior for rectal and gynaecological treatments. Set-up accuracy and reproducibility must also be taken into consideration. This aspect will be investigated in the discussion section.

1.1. Problem statement

Radiotherapy for rectal and gynaecological malignancies is standardly treated with the patient lying in a supine position for optimal stabilisation. With modern radiotherapy delivery techniques, this can lead to acceptable small bowel doses; prone positioning on a belly board device is an alternative that physically separates the patient's small bowel from the primary treatment area, thereby further reducing small bowel doses and hence radiation side effects.

1.2. Research question

For patients receiving radiotherapy for rectal or gynaecological cancer, does prone positioning with a belly board device result in lower radiation doses received by the small bowel compared to standard supine positioning?

2. Method

The PICO format was used to structure the research question and guide the search:

Population- patients receiving rectal or gynaecological radiotherapy

Intervention- prone positioning using bellyboard

Comparison- supine positioning

Outcome- small bowel dose

2.1. Search strategy

PubMed, CINAHL, ProQuest, Scopus and Academic Search Premier electronic data bases were used to conduct systematic searches of the literature. These databases were chosen as they are recognised large databases of peer reviewed primary research literature in the medical and allied health fields. The research question is related to both medical and radiation therapy professions.

The following key search terms were selected and combined with Boolean operators: Rectum, Gynaecological, Cervical, Endometrial, Vaginal, Pelvis, Radiotherapy, Radiation Therapy, Prone, Bellyboard, Supine, Small Bowel Dose, Small Bowel Sparing. The delimiters used were similar for each database with only slight variations: Time period of 2004–2019, English language, peer reviewed journal articles. Some of the databases allowed the search to be focused solely on abstracts and keywords. Secondary and grey sources of literature were excluded from this review.

The search strategy, including the databases examined, key search terms and the number of articles found using this method, is shown in Table 1. The search was undertaken during April 2019; it was limited to articles published between 2004 and 2019. The reason for this time period was to select data that was gathered using modern radiotherapy techniques such as IMRT and VMAT. Older treatment methods, such as three dimensional conformal radiotherapy (3DCRT), are no longer suitable for dose comparisons and were excluded from the literature review.

The following inclusion criteria were applied during article selection:

- Study Designs can be historic/retrospective control group studies, quasi-experimental prospectively controlled studies, or randomised controlled studies.
- Retrospective or prospective studies
- Primary evidence from peer reviewed journals
- Patients receiving radiotherapy for primary pelvic cancers only (rectal or gynaecological)
- Studies with 10 or more patients
- English language.

The search yielded 111 articles in total: PubMed yielded 35 articles, CINAHL 8 articles, Academic Search Premier 23 articles, Scopus 25 articles and ProQuest 20 articles. Once duplicates (n = 58 articles) were removed, the abstracts of 53 articles were screened for inclusion in this review. After the abstracts were reviewed, additional articles were excluded (n = 34) as the research aims or methodologies did not align with the research question. Some articles reported on different pelvic treatment sites such as prostate and anal cancer; some reported on outcomes other than small bowel dose, such as side effects or treatment delivery accuracy; some compared two different bellyboard devices or did not look at supine setups at all, and instead compared prone treatments with and without a bellyboard. The remaining 19 full-text articles were screened for inclusion in this review. Nine were excluded for the following reasons:

- Two studies looked at prone vs. supine comparisons without the use of a bellyboard device. Bellyboard use as a theoretical benefit for treatment was included in the discussion sections of these two papers:
  - o The effect of treatment position, prone or supine, on dose-volume histograms for pelvic radiotherapy in patients with rectal cancer (Drzymala et al.)[13]
  - o A randomised study of the effect of patient positioning on setup reproducibility and dose distribution to organs at risk in radiotherapy of rectal cancer patients (Froseth et al.).[14]

Table 1
Study characteristics.

Study	Study design	Age range	Sample size	Country	Indication	Treatment	Method	Results
Beriwal et al.[27]	Retrospective quasi	42–84	n = 47 (21 prone, 26 supine)	U.S.A	Endometrial Ca.	45/25Fx–50.4/28FxGy	One CT pp	-No significant reduction of SB-V20/30/40/45 and V50 prone with a BB -No significant increase of SB-V10 prone position with a BB
	Experimental study					IMRT (plus brachytherapy 10 Gy)	Bladder filling not specified	
Stromberger et al.[26]	Prospective quasi	Not stated	n = 10	Germany	Cervical Ca.	50.4 Gy/28 Fx	Two CTs pp	-Significant decrease in SB at V20/30/40/45/50.4 prone with BB ($p < 0.05$)
	Experimental study					IMRT	No bladder filling instructions	-Mean dose of SB was 25.9 Gy vs 30.2 Gy prone with BB vs supine ($p = 0.049$)
Nijkamp et al.[24]	Prospective quasi	Radiotherapy students used	n = 11	Netherlands	Rectal Ca.	Chemotherapy 50 Gy/25 Fx	Four MRIs pp	-With BB 2 – significant improvement in SB dose up to V35 over supine.
	Experimental study					IMRT	Supine, prone and prone with 2 different bellyboards Full Bladder	-With BB 1– significant improvement in SB dose up to V30 over supine.
Joye et al.[23]	Prospective quasi	Not stated	n = 11	Belgium	Rectal Ca.	45 Gy/25 Fx	Two CTs pp	-Significant reduction of SB-V15 prone with a BB ($p = 0.008$) -Minor non significant reduction of SB-V45/mean prone with a BB -Prone with BB leads to significant reduction in SB dose
	Experimental study					VMAT	No bladder filling instructions	
Estabrook et al.[22]	Prospective quasi experimental study	40–75	n = 11	U.S.A.	Rectal Ca.	Chemotherapy Dose not Specified normalisation/ratios used.	Two CTs pp	−30.3% reduction in mean SB dose for prone IMRT vs Supine IMRT ($p = 0.002$)
						IMRT	No specific bladder filling instructions	-Also a 3DCRT vs IMRT study -Prone with IMRT leads to lowest SB dose
Kim et al.[28]	Retrospective quasi experimental study	40–86	n = 17 (8 prone, 9 supine)	Canada	Rectal Ca.	50.4 Gy/28Fx	One CT pp	-Minor increase SB-V45/50.4 prone with a BB
						VMAT	Comfortably full bladder	-Minor reduction of SB-V15,20,30,mean prone with a BB -No statistical significance either option. -Reproducibility metrics also collected. Supine recommended due to reproducibility and higher comfort. -SB prone and supine: comparison between different patients.

Table 1 (*Continued*)

Study	Study design	Age range	Sample size	Country	Indication	Treatment	Method	Results
Koeck et al.[30]	Retrospective quasi experimental study	Not stated – ex prostate cancer patients volumed as rectal cases	n = 10	Germany	Rectal Ca.	45 Gy/25Fx	Two CTs pp	-Volumed on ex-prostate Ca. patient scans
						IMRT	Full Bladder Protocol	-V15 to V45+, and mean and median SB dose significantly lower with prone and BB patients ($p < 0.01$) -Prone with BB leads to significant reduction in SB dose therefore prone recommended.
Li et al.[29]	Retrospective quasi experimental study	19–74	n = 13	China	Cervical + Endometrial Ca.	45 Gy/25Fx	Two CTs pp	-SB Dose lower at V20 to V50 when prone with BB. Lower with supine at V5 to V15 and V55+ with supine.
						IMRT – 2 different plans	Bladder filling not specified	-p values not used to compare supine and prone – only in same positions but with different plans. BB Good to decrease side effects.
Lin et al.[31]	Retrospective quasi experimental study	40–78	n = 20 (5 prone, 15 supine)	Taiwan	Rectal Ca.	50.4 Gy/28Fx	One CT pp	-No significant difference in either position with SB dose.
						VMAT, IMRT and TOMO	No specific bladder filling instructions	-SB prone and supine: comparison between different patients
						Chemotherapy		-Also Compared all 3 techniques – IMRT, TOMO and VMAT
Scobioala et al.[25]	Prospective quasi experimental study	45–63	n = 20	Germany	Rectal Ca.	50.4 Gy/28Fx	Two CTs pp	-Significant reduction of SB-V45 Gy + V75% prone with a BB ($p = 0.03$) - Significant reduction of SB-V10 to V30 prone with a BB -Also compared 3DCRT in prone and supine positions -Rotational therapy in prone with BB leads to superior SB sparing
						VMAT, IMRT and TOMO	No specific bladder filling instructions	

Abbreviations: BB, belly board; Ca, cancer; CT, computed tomography; Gy, Gray; Fx, fractions; MRI, magnetic resonance imaging; pp, per person; SB, small bowel.

- Two studies measured outcomes other than small bowel dose. One measured bowel volume, and one reviewed resulting tumour volume margins.
  - o The impact of patient positioning and use of belly board on small bowel toxicity in patients receiving pelvic radiotherapy for gynaecological malignancies. (Anjanappa et al.)[15]
  - o Optimal patient positioning (prone versus supine) for VMAT in gynaecologic cancer: a dosimetric study on the effect of different margins (Heijkoop et al.).[16]
- Three studies either focused on older 3D Conformal treatments and did not consider IMRT or VMAT, or had a mixed methodology comparing IMRT Supine with 3D Conformal Prone:
  - o Reduced dose to small bowel with the prone position and a belly board versus the supine position in neoadjuvant 3D conformal radiotherapy for rectal adenocarcinoma (White et al.)[17]
  - o Treatment with a belly-board device significantly reduces the volume of small bowel irradiated and results in low acute toxicity in adjuvant radiotherapy for gynaecologic cancer: results of a prospective study (Martin et al.)[18]
  - o Influence of position and radiation technique on organs at risk in radiotherapy of rectal cancer (Wang et al.).[19]
- One study looked at prone with and without a bellyboard, but not supine positioning:
  - o Intensity modulated radiation therapy (IMRT): differences in target volumes and improvement in clinically relevant doses to small bowel in rectal carcinoma (Mok et al.).[20]
- One study contained only 8 rectal and gynaecological cases in the comparison:
  - o Impact of prone versus supine positioning on small bowel dose with pelvic intensity modulated radiation therapy (Gonzalez et al.).[21]

The remaining 10 articles contained five quasi experimental prospective studies and five retrospective control group studies.

The five prospective quasi experimental studies are:

- o Role of belly board device in the age of intensity modulated radiotherapy for pelvic irradiation (Estabrook et al.)[22]
- o Implementation of volumetric modulated arc therapy for rectal cancer: pitfalls and challenges (Joye et al.)[23]
- o Bowel exposure in rectal cancer IMRT using prone, supine, or a belly board (Nijkamp et al.)[24]
- o A treatment planning study of prone vs. supine positions for locally advanced rectal carcinoma (Scobioala et al.)[25]
- o Intensity-modulated radiotherapy in patients with cervical cancer. An intra-individual comparison of prone and supine positioning (Stromberger et al.).[26]

The five retrospective quasi experimental studies are:

- o Dosimetric and toxicity comparison between prone and supine position IMRT for endometrial cancer (Beriwal et al.)[27]
- o The effect of prone and supine treatment positions for the preoperative treatment of rectal cancer on organ-at-risk sparing and setup reproducibility using volumetric modulated arc therapy (Kim et al.)[28]
- o Combination of prone position and intensity-modulated radiation therapy (IMRT) reduces small bowel doses in radiation therapy for gynaecologic malignancies (Li et al.)[29]
- o Small bowel protection in IMRT for rectal cancer (Koeck et al.)[30]
- o Compared planning dosimetry of TOMO, VMAT and IMRT in rectal cancer with different simulated positions (Lin et al.).[31]

The modified PRISMA flow diagram of article screening and selection is summarised in Fig. 1.

3. Results

3.1. Included studies

Ten articles (n = 10) met the inclusion criteria for this review; all were quasi experimental studies. Five studies (n = 5) used prospectively gathered data[22–26] and five used retrospective data.[27–31] The earliest study was published in 2006,[29] whilst the most recent study was published in 2018.[25] All studies had at least 10 cases within the study group, the largest of which contained 47 patients.[27] Table 1 shows a summary of the 10 included articles.

Seven (n = 7) of the studies scanned the same patients in both supine and prone with bellyboard positions, whilst three (n = 3) studies looked at different patients in each of the two patient positions being investigated. These three studies[25,28,31] did not assign patients randomly to each cohort, but the studies either explicitly state it was the clinicians' decision for each case, or this information was not included.

3.2. Demographics and diagnoses

Three studies (n = 3) reviewed data from gynaecological cases; one each for cervix and endometrial cancer, and one a combination of the two sites. Seven studies (n = 7) reviewed data from rectal cancer cases. Eight studies (n = 8) included real clinical data, whereas the remaining two studies used alternate methods to gather datasets which were volumed and planned as rectal cancer cases. One of these studies used previous prostate cancer data sets that had scans of patients in both prone and supine positions.[30] The second of these studies used healthy radiotherapy students scanned with an MRI scanner to ensure no radiation dose was received.[24] These two papers were included as the data gathered is clinically equivalent to real cases. Six of the studies (n = 6) included the patient age range of the patient cohort, with an overall age range of 19–86 across all published articles.

3.3. Interventions

External beam radiation prescriptions did not vary markedly between the ten studies reviewed, with prescriptions ranging from 45 Gy in 25 fractions, up to 50.4 Gy in 28 fractions. One study did not include the prescribed dose, but instead provided a dose ratio received by the small bowel in the two treatment positions.[22] This single study only provided a mean dose comparison for the small bowel.

All included studies used what are considered modern modulated radiotherapy treatment technologies. Studies using older 3DCRT were excluded unless IMRT or VMAT data gathered in both treatment positions were included for dosimetric comparisons. Six studies (n = 6) looked at fixed angle IMRT, two studies (n = 2) looked at VMAT. The remaining two studies (n = 2) looked at both IMRT and VMAT as well as tomotherapy plans in both supine and prone positions.[25,31] Tomotherapy requires a different type of specialised treatment unit, so tomotherapy data was not deemed relevant to this review and was excluded.

3.4. Quantitative results and study outcomes

All the included studies contained measurements of small bowel radiation dose in both supine position and prone position with a bellyboard. The studies were not consistent in the dose levels that were measured. The most detailed study recorded small bowel volumes at every 5 Gy dose level, measuring the volume receiving each dose up to 60 Gy (V60).[29] This study, however, did not provide measures of significance (p values) for small bowel volumes receiving each dose level between the prone and supine cases it reviewed.

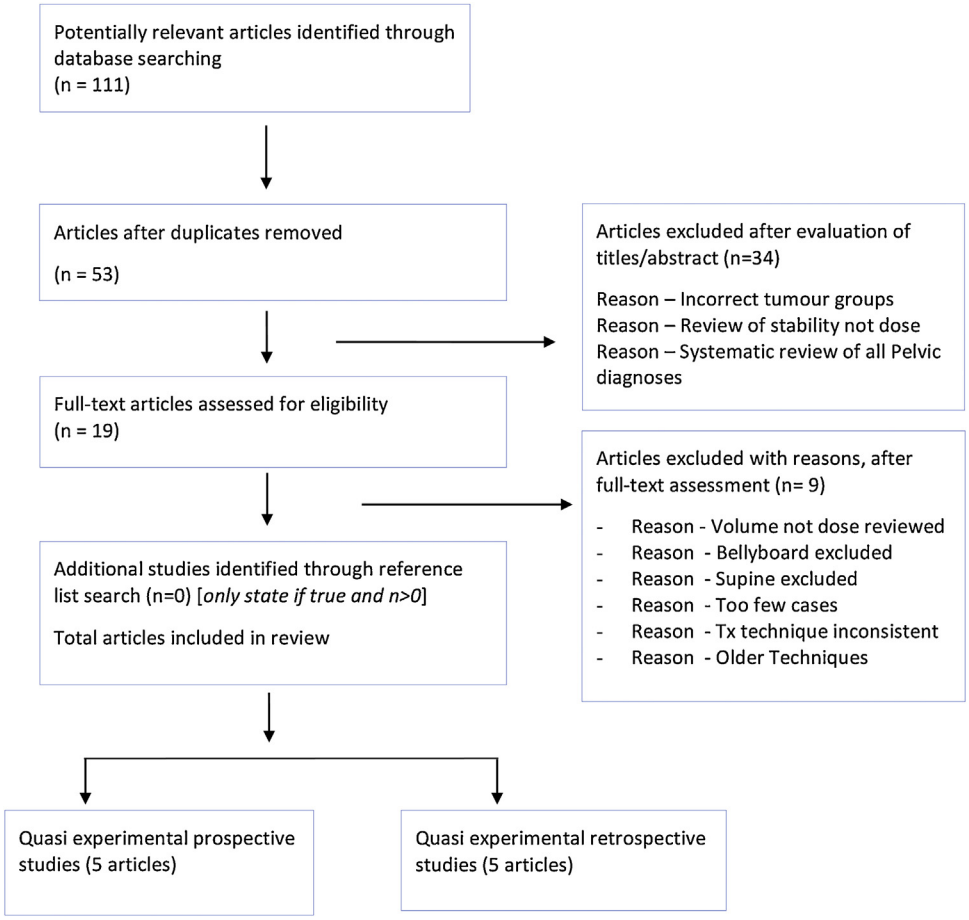

Fig. 1. Modified PRISMA flow diagram of article screening and selection.

Instead, the study focussed on different IMRT plans in each position, and hence was more a study of IMRT technique than prone versus supine positioning. The most basic comparisons between the two positions looked at only the maximum dose received by the small bowel[31] or mean dose.[22] The other seven studies contained various combinations between these extremes in the quantity and quality of data provided regarding small bowel dose.

Three studies (n = 3) concluded that treating pelvic patients in the prone position with a bellyboard does not lead to any statistically significant reduction in small bowel dose.[27,28,31] These three studies did not scan the same patients in both positions but, instead, scanned different patient cohorts and then compared the results. One of these three studies explicitly stated that supine was the preferred option as there was no advantage in small bowel dose, but there was an advantage in treatment accuracy and reproducibility.[28]

Six (n = 6) of the studies concluded that there is a statistically significant dosimetric advantage for the small bowel by positioning patients prone with a bellyboard device over supine positioning. The advantages were noted at different dose levels in the different studies. Estabrook et al.[22] simply found a significant mean dose advantage, and this was the only level measured in this study. Joye et al.[23] and Nijkamp et al.[24] both recorded advantages at the low dose levels: Joye et al. noted the largest advantage at the V15Gy level, while Nijkamp et al. noted that at all dose levels up to the V35Gy were favourable using the prone position with bellyboard.[23,24]

The three German studies reported lower volumes of small bowel receiving dose at the higher range, with Scobioala et al.[25] reporting advantages at the V45 Gy level, Stromberger et al.[26] at V20Gy to V50.4 Gy and Koeck et al.[30] in the V15Gy to V45 Gy and higher range.

The final paper by Li et al.[31] reported improvements for small bowel dose in the range of V20Gy to V50Gy but did not provide p values or comments on statistical significance.

4. Discussion

Radiotherapy for rectal and gynaecological malignancies is inadvertently associated with the risk of acute small bowel toxicities such as pain, nausea and diarrhoea,[3] and late toxicities such as bowel obstruction, fistulae and bleeding.[4,5] Baglan et al.[6] reported that if a 150cc volume of small bowel receives as little as 15 Gy the probability of patient's experiencing grade three acute bowel toxicity leaps from 0% to 50–60%. Kavanagh et al.[6] recommended an even lower small bowel volume of 120cc as the threshold for grade 3 acute toxicities. Clearly, limiting radiation dose to the small bowel is critical. Treating patients in a supine position is often considered optimal for the purposes of stabilisation and treatment reproducibility, and with modern radiotherapy treatment technology involving modulated beams small bowel doses can be controlled to a certain extent in the supine position. This review looks at the question of whether a bellyboard device that separates the patient's small bowel from the primary treatment area has the capability to reduce bowel doses and patient toxicity even further.

Seven of the ten eligible studies in this review provided a positive indication that prone positioning with a bellyboard device leads to an overall reduction in small bowel dose over supine positioning when using modern modulated treatment techniques such

as IMRT and VMAT. Six of the seven studies supported this improvement with a degree of statistical certainty ($p < 0.05$). The remaining three studies were inconclusive, not finding an advantage or disadvantage in terms of small bowel dose for supine versus prone treatment with a bellyboard.

Small bowel dose was measured at different dose levels in every one of the ten studies, so drawing comparisons between the results of each study is difficult. Two of the included studies[23,30] reported improvements at the low 15 Gy dose level which was described as significant by Baglan et al.[6] and Kavanagh et al.[4] Other studies described significant improvements at intermediate or high dose levels, up to and including the prescribed tumour dose.

The review found ten relevant and eligible studies that were suitable for assessment. The sample size was small in all publications, ranging from 10 to 47 patients, meaning that the results should be considered with a degree of caution. However, dose regimens between the studies were similar, ranging from 45 Gy to 50.4 Gy, and all studies included static angle IMRT and/or VMAT, making comparisons between the studies valid.

The three studies that reported no benefit for patients in a prone position were the only studies that did not compare the same patients in the two positions but, instead, included mixed results of different patients. This adds more weight to the seven studies that compared the same patients in both positions. The three studies not showing an advantage to prone positioning also were biased by the oncologist's choice in selecting the patient position in each case. These three studies were not randomised to select patient position but, instead, directed by the radiation oncologist for each patient. No large randomised study has been published on this topic at this time.

Other limitations of the review include the use of at least four different brands of bellyboard across the studies. One study reviewed two different bellyboards and concluded one was superior to the other.[24] Any department looking to implement the prone technique would need to consider the equipment purchased, as the quality of products and outcomes achieved can vary. Two studies showed that the quality and complexity of the treatment plan even between two IMRT plans on the same patient can have marked effects on the small bowel dose.[29],[30] In all the studies, the departments used varying numbers of beams and different beam angles to create treatment plans. This means that the use of a bellyboard is not the only factor in decreasing small bowel dose, but staff training, planning skills of the staff group, and departmental norms and protocols also can affect whether a bellyboard is advantageous or not, and to what extent. The review also revealed that dynamic VMAT could provide further advantages over static beam IMRT due to the increased number of angles dose can be delivered though.

The decision to implement a change to prone positioning must take other considerations into account. Patient stability and reproducibility was a common theme discussed throughout the studies reviewed, though only one of the included papers analysed stability data.[28] Kim et al.[28] concluded that supine positioning offered a big enough advantage over prone with a bellyboard in terms of treatment reproducibility, that it should be the treatment position of choice. Kim showed that the pitch rotational error was 2.5x greater for prone bellyboard patients, and the roll rotational errors, 3x greater compared to the supine position. No statistical difference for the two positions was found for yaw rotational errors. Other studies have reviewed set-up accuracy with a bellyboard; outcomes and conclusions vary. Allal et al.[32] stated that a bellyboard does lead to statistically significant reproducibility errors in all 3 planes, though there was no supine control group. Siddiqui et al.[33] completed a study incorporating 829 images from 30 patients and concluded that although systematic errors were larger with prone patients on a bellyboard, supine cases presented with more random errors. Stromberger et al.[26] agreed with Siddiqui's conclusion. In modern radiotherapy, No Action Level (NAL) pretreatment IGRT protocols mean that both systematic and random errors can be largely removed from the equation.[34] Six degrees of freedom radiotherapy treatment couches further enhance the ability to correct errors daily. Staff training in the use of the bellyboard has been identified as an area of key importance to improve setup repducibility.[35] When staff are provided with a task specific training package on the use of the bellyboard, systematic and random errors were both reduced due to increased quality of setup.[35]

Nijkamp et al.[24] theorised that the potential reduction in stability in the prone position could require larger margins on the tumour volume to ensure it is covered, thereby increasing proximity of the treatment fields to the small bowel and compromising any benefits gained by the bellyboard device.

Four of the studies included in the review did question patient comfort on the bellyboard device, quoting issues such as difficulties for patients with stomas, shortness of breath and frailty associated with age.[22–24,28] Kim et al.[28] even went as far as to say the bellyboard was a safety risk with one patient being injured after falling off the device during their study.

Variation in patient bladder filling is another consideration when examining study results. It is recognised that a full bladder displaces the small bowel superiorly from the pelvic cavity and away from the treatment area. The different studies used inconsistent bladder filling protocols. Some did not use, or did not report using a protocol at all, whilst some did attempt to keep bladder size consistently full throughout planning and treatment. Two studies acknowledged that bladder filling would improve small bowel doses[24,25] but at the cost of reproducibility due to patient discomfort[25] and increased day to day variations in bladder size without a strict protocol.

5. Conclusion and recommendations

This critical review of the literature has demonstrated that there is an advantage for prone patient positioning using a bellyboard device over supine patient positioning when the key metric of measuring improvement is the reduction of small bowel dose. Seven out of the ten included studies supported this conclusion, and the three that did not support this outcome concluded that both treatment positions were equivalent. As demonstrated in the review, the three studies that did not support prone positioning used non-randomised grouping of patients based on doctor preference, with no analysis of the same patient in both treatment positions. The review did however reveal that small bowel dose is not the only metric that needs to be considered. Patient stability in each position is also a vital component, and most studies reviewed acknowledged that prone positioning increases patient discomfort, adds more interfractional variation in setup, and may require larger tumour margins to ensure the tumour volume is adequately encompassed on each day of treatment. All these factors mean the theoretical advantages gained for small bowel dose from prone positioning with a bellyboard are potentially reduced.

The recommendation is that a department looking to implement prone positioning with a bellyboard for pelvic malignancies must do its own due diligence in assessing the department's ability to deliver accurate, reproducible treatments. The overall evidence demonstrates an advantage for prone positioning with a bellyboard when small bowel dose is the prime concern. Departmental factors, such as equipment (bellyboard, radiotherapy planning system, linear accelerator capabilities), departmental protocols for bladder preparation, and staff skill and training in the use of the bellyboard and radiotherapy planning system, are all variables that need to be assessed. An in-house study demonstrating acceptable set-up reproducibility with a bellyboard would

be the starting point for any department considering this technique. If set-up reproducibility can be achieved with confidence in the prone position with a bellyboard, then the evidence suggests that this is the optimal position to reduce small bowel dose and toxicity.

Conflict of interest

None declared.

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References

1. *Cancer statistics NSW.*; 2019. Retrieved from https://www.cancer.nsw.gov.au/cancer-statistics-nsw.
2. Xu B, Guo Y, Chen Y, et al. Is the irradiated small bowel volume still a predictor for acute lower gastrointestinal toxicity during preoperative concurrent chemo-radiotherapy for rectal cancer when using intensity-modulated radiation therapy? *Radiat Oncol*. 2015;10:257, http://dx.doi.org/10.1186/s13014-015-0566-6.
3. Stacey R, Green JT. Radiation-induced small bowel disease: latest developments and clinical guidance. *Ther Adv Prev Chronic Dis*. 2014;5:15–29, http://dx.doi.org/10.1177/2040622313510730.
4. Kavanagh BD, Pan CC, Dawson LA, et al. Radiation dose–volume effects in the stomach and small bowel. *Int J Radiat Oncol Biol Phys*. 2010;76:S101–S107, http://dx.doi.org/10.1016/j.ijrobp.2009.05.071.
5. Jadon R, Higgins E, Hanna L, Evans M, Coles B, Staffurth J. A systematic review of dose-volume predictors and constraints for late bowel toxicity following pelvic radiotherapy. *Radiat Oncol*. 2019;14:57, http://dx.doi.org/10.1186/s13014-019-1262-8.
6. Baglan KL, Frazier RC, Yan D, Huang RR, Martinez AA, Robertson JM. The dose–volume relationship of acute small bowel toxicity from concurrent 5-FU-based chemotherapy and radiation therapy for rectal cancer. *Int J Radiat Oncol Biol Phys*. 2002;52:176–183, http://dx.doi.org/10.1016/s0360-3016(01)01820-x.
7. *Common terminology criteria for adverse events (CTCAE) version 5.0.*; 2017. Retrieved from https://ctep.cancer.gov/protocolDevelopment/electronic_applications/docs/CTCAE_v5_Quick_Reference_5x7.pdf.
8. Chopra S, Dora T, Chinnachamy AN, et al. Predictors of grade 3 or higher late bowel toxicity in patients undergoing pelvic radiation for cervical cancer: results from a prospective study. *Int J Radiat Oncol Biol Phys*. 2014;88:630–635, http://dx.doi.org/10.1016/j.ijrobp.2013.11.214.
9. Isohashi F, Yoshioka Y, Mabuchi S, et al. Dose–volume histogram predictors of chronic gastrointestinal complications after radical hysterectomy and postoperative concurrent nedaplatin-based chemoradiation therapy for early-stage cervical cancer. *Int J Radiat Oncol Biol Phys*. 2013;85:728–734, http://dx.doi.org/10.1016/j.ijrobp.2012.05.021.
10. Kye B-H, Cho H-M. Overview of radiation therapy for treating rectal cancer. *Ann Coloproctol*. 2014;30:165–174, http://dx.doi.org/10.3393/ac.2014.30.4.165.
11. Simson DK, Mitra S, Ahlawat P, Sharma MK, Yadav G, Mishra MB. Dosimetric comparison between intensity modulated radiotherapy and 3 dimensional conformal radiotherapy in the treatment of rectal cancer. *Asian Pac J Cancer Prev*. 2016;17:4935–4937, http://dx.doi.org/10.22034/APJCP.2016.17.11.4935.
12. Gaya A, Brulinski P, Morris SL, et al. Evaluation of a Belly Board immobilisation device for rectal cancer patients receiving pre-operative chemoradiation. *J Radiother Pract*. 2014;13:403–409, http://dx.doi.org/10.1017/S1460396914000247.
13. Drzymala M, Hawkins MA, Henrys AJ, Bedford J, Norman A, Tait DM. The effect of treatment position, prone or supine, on dose–volume histograms for pelvic radiotherapy in patients with rectal cancer. *Br J Radiol*. 2009;82:321–327, http://dx.doi.org/10.1259/bjr/57848689.
14. Froseth TC, Strickert T, Solli KS, Salvesen O, Frykholm G, Reidunsdatter RJ. A randomized study of the effect of patient positioning on setup reproducibility and dose distribution to organs at risk in radiotherapy of rectal cancer patients. *Radiat Oncol*. 2015;10:217, http://dx.doi.org/10.1186/s13014-015-0524-3.
15. Anjanappa M, Raghavan R, James F, et al. The impact of patient positioning and use of belly board on small bowel toxicity in patients receiving pelvic radiotherapy for gynecological malignancies. *J Cancer Res Ther*. 2017;13:519–523, http://dx.doi.org/10.4103/0973-1482.179519.
16. Heijkoop St, Westerveld H, Bijker N, et al. Optimal patient positioning (prone versus supine) for VMAT in gynecologic cancer: a dosimetric study on the effect of different margins. *Int J Radiat Oncol Biol Phys*. 2016;96:432–439, http://dx.doi.org/10.1016/j.ijrobp.2016.05.025.
17. White R, Foroudi F, Sia J, Marr MA, Lim Joon D. Reduced dose to small bowel with the prone position and a belly board versus the supine position in neoadjuvant 3D conformal radiotherapy for rectal adenocarcinoma. *J Med Radiat Sci*. 2017;64:120–124, http://dx.doi.org/10.1002/jmrs.187.
18. Martin J, Fitzpatrick K, Horan G, et al. Treatment with a belly-board device significantly reduces the volume of small bowel irradiated and results in low acute toxicity in adjuvant radiotherapy for gynecologic cancer: results of a prospective study. *Radiother Oncol*. 2015;74:267–274, http://dx.doi.org/10.1016/j.radonc.2004.11.010.
19. Wang JF, Li H, Xiong H, Huang H, Zou YM. Influence of position and radiation technique on organs at risk in radiotherapy of rectal cancer. *J Huazhong Univ Sci Technol Med Sci*. 2016;36:741–746, http://dx.doi.org/10.1007/s11596-016-1655-y.
20. Mok H, Crane CH, Palmer MB, et al. Intensity modulated radiation therapy (IMRT): differences in target volumes and improvement in clinically relevant doses to small bowel in rectal carcinoma. *Radiat Oncol*. 2011;6:63, http://dx.doi.org/10.1186/1748-717x-6-63.
21. Gonzalez VJ, Hullett CR, Burt L, et al. Impact of prone versus supine positioning on small bowel dose with pelvic intensity modulated radiation therapy. *Adv Radiat Oncol*. 2017;2:235–243, http://dx.doi.org/10.1016/j.adro.2017.01.005.
22. Estabrook NC, Bartlett GK, Compton JJ, Cardenes HR, Das IJ. Role of belly board device in the age of intensity modulated radiotherapy for pelvic irradiation. *Med Dosim*. 2016;41:300–304, http://dx.doi.org/10.1016/j.meddos.2016.07.002.
23. Joye I, Verstraete J, Bertoncini C, Depuydt T, Haustermans K. Implementation of volumetric modulated arc therapy for rectal cancer: pitfalls and challenges. *Acta Oncol*. 2015;54:1677–1681, http://dx.doi.org/10.3109/0284186x.2015.1064159.
24. Nijkamp J, Doodeman B, Marijnen C, Vincent A, Van Vliet-Vroegindeweij C. Bowel exposure in rectal cancer IMRT using prone, supine, or a belly board. *Radiother Oncol*. 2012;102:22–29, http://dx.doi.org/10.1016/j.radonc.2011.05.076.
25. Scobioala S, Kittel C, Niermann P, et al. A treatment planning study of prone vs. Supine positions for locally advanced rectal carcinoma: comparison of 3-dimensional conformal radiotherapy, tomotherapy, volumetric modulated arc therapy, and intensity-modulated radiotherapy. *Strahlenther Onkol*. 2018;194:975–984, http://dx.doi.org/10.1007/s00066-018-1324-0.
26. Stromberger C, Kom Y, Kawgan-Kagan M, et al. Intensity-modulated radiotherapy in patients with cervical cancer. An intra-individual comparison of prone and supine positioning. *Radiat Oncol*. 2010;5:63, http://dx.doi.org/10.1186/1748-717x-5-63.
27. Beriwal S, Jain SK, Heron DE, de Andrade RS, Lin CJ, Kim H. Dosimetric and toxicity comparison between prone and supine position IMRT for endometrial cancer. *Int J Radiat Oncol Biol Phys*. 2007;67:485–489, http://dx.doi.org/10.1016/j.ijrobp.2006.08.067.
28. Kim A, Karotki A, Presutti J, et al. The effect of prone and supine treatment positions for the pre-operative treatment of rectal cancer on organ-at-risk sparing and setup reproducibility using volumetric modulated arc therapy. *Radiat Oncol*. 2017;12:1–7, http://dx.doi.org/10.1186/s13014-017-0918-5.
29. Li WB, Li MH, Le WJ, Mayr NA. Combination of prone position and intensity-modulated radiation therapy (IMRT) reduces small bowel doses in radiation therapy for gynecologic malignancies. *Chin J Cancer Res*. 2006;18:51–56, http://dx.doi.org/10.1007/s11670-006-0051-8.
30. Koeck J, Kromer K, Lohr F, et al. Small bowel protection in IMRT for rectal cancer: a dosimetric study on supine vs. prone position. *Strahlenther Onkol*. 2017;193:578–588, http://dx.doi.org/10.1007/s00066-017-1107-z.
31. Lin JC, Tsai JT, Chen LJ, Li MH, Liu WH. Compared planning dosimetry of TOMO, VMAT and IMRT in rectal cancer with different simulated positions. *Oncotarget*. 2017;8:42020–42029, http://dx.doi.org/10.18632/oncotarget.14923.
32. Allal AS, Bischof S, Nouet P. Impact of the "belly board" device on treatment reproducibility in preoperative radiotherapy for rectal cancer. *Strahlenther Onkol*. 2002;178:259–262.
33. Siddiqui F, Shi C, Papanikolaou N, Fuss M. Image guidance protocol comparison: supine and prone set-up accuracy for pelvic radiation therapy. *Acta Oncol*. 2008;47:1344–1350, http://dx.doi.org/10.1080/02841860802304564.
34. Goyal S, Kataria T. Image guidance in radiation therapy: techniques and applications. *Radiol Res Pract*. 2014:705604, http://dx.doi.org/10.1155/2014/705604.
35. Goldsworthy S, McGrail S. Prone belly board device training improves geometric setup accuracy in lower GI radiotherapy. *J Radiother Pract*. 2014;13:302–309, http://dx.doi.org/10.1017/S1460396913000393.