



Research article

Impact of abdominal compression on setup error and image matching during radical abdominal radiotherapy

Kwun-Ye Chu^{a,b,*}, Rosie Cooke^{a,b}, Frank Van den Heuvel^{a,b}, Somnath Mukherjee^{a,b}, Maria A. Hawkins^a^a CRUK/MRC Oxford Institute for Radiation Oncology, Department of Oncology, University of Oxford, Old Road Campus Research Building, Roosevelt Drive, Oxford OX3 7DQ, United Kingdom^b Oxford University Hospitals NHS FT, Churchill Hospital, Old Road, Oxford OX3 7LE, United Kingdom

ARTICLE INFO

Article history:

Received 1 July 2019

Received in revised form 31 October 2019

Accepted 11 November 2019

Keywords:

Abdominal compression

Image matching

Time

SBRT

IGRT

ABSTRACT

Purpose: To determine the impact of abdominal compression (AC) on setup error and image matching time.**Materials and methods:** This study included 72 liver, pancreas and abdominal node patients treated radically from 2016 to 2019 in a single centre. Patients received either SBRT or conventional radical fractionation (CRF). Compressed patients were supine, arms up with kneefix and AC equipment. Uncompressed patients were supine, arms up with kneefix. All patients received daily online-matched CBCTs before treatment. Initial setup error was determined for all patients. Registration error was assessed for 10 liver and 10 pancreas patients. Image matching times were determined using beam on times. Statistical tests conducted were an F-test to compare variances in setup error, Student's t-tests for setup error and average image analysis, and a Wilcoxon Mann Whitney test for imaging matching time analysis.**Results:** Initial setup displacement was similar between compressed and uncompressed patients. Displacements > 1 cm occurred more frequently in the longitudinal direction for most patients. SBRT patients required more additional manual positioning following imaging. Mean absolute registration error in the SI direction was 5.4 mm and 3.3 mm for uncompressed and compressed pancreas patients respectively and 1.7 mm and 0.8 mm for uncompressed and compressed liver patients respectively. Compressed patients required less time for image matching and fewer images per fraction on average. Repeat imaging occurred more frequently in SBRT and uncompressed patients.**Conclusions:** Although abdominal compression has no significant impact on setup error, it can reduce imaging matching times resulting in improved treatment accuracy.© 2019 The Authors. Published by Elsevier B.V. on behalf of European Society for Radiotherapy & Oncology. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Tumour motion can impact on target delineation, treatment accuracy and dose to organs at risk (OARs). Motion during imaging can result in blurring and double images thus making target delineation and image matching difficult. As well, greater tumour motion requires larger planning tumour volumes (PTVs) to ensure tumour coverage which can result in greater dose to adjacent OARs [1]. This can be especially important in stereotactic body radiotherapy (SBRT) patients where large daily doses are delivered in fewer fractions. Due to the location of abdominal tumours, motion management is imperative to delivering abdominal SBRT due to the

close proximity to dose-limiting OARs such as duodenum and stomach. Liver is the third most common SBRT site treated [2] while the role of SBRT in the pancreas is still up for debate [3].

Immobilisation with abdominal compression (AC) can be used to reduce tumour motion. It has been shown to be effective in minimizing tumour motion attributed to respiration in abdominal and lung patients [4,5]. The motion reduction attributed to AC can vary from patient to patient [6] as well as vary in magnitude depending on direction [7]. Gender and body mass index have also been shown to affect AC efficacy in liver patients [8]. While AC can benefit planning and imaging, it can involve large pieces of equipment that can be intimidating and/or uncomfortable to patients and cumbersome to staff. AC equipment can make the setting up procedure more complex resulting in longer treatment times. This may deter some from using this type of equipment for conventional fractionation and make it more readily accepted for SBRT

* Corresponding author at: CRUK/MRC Oxford Institute for Radiation Oncology, Department of Oncology, University of Oxford, Old Road Campus Research Building, Roosevelt Drive, Oxford OX3 7DQ, United Kingdom.

E-mail address: kwun-ye.chu@oncology.ox.ac.uk (K.-Y. Chu).

patients as they have fewer fractions. However, perhaps not all setups with bridge-type AC take longer to setup as evidenced by Han et al who found that their AC equipment is more comfortable and faster to set up than alternative SBRT immobilization [9].

While AC has been demonstrated to have sufficient reproducibility during treatment for liver patients [10], there are few studies that have shown how AC can impact on the image matching process during treatment delivery for abdominal patients [11,12]. This study aims to determine the benefits of AC and its impact on setup error and image matching time for patients receiving radical abdominal radiotherapy.

Materials and methods

Patient population

This retrospective study included all liver, pancreas and abdominal node patients treated radically from January 2016 to January 2019 in a single institution. Patients received either SBRT (node 27–36 Gy/3#; pancreas 40–50 Gy/5–10#; liver 42–60 Gy/5–10#) or conventional radical fractionation (CRF) (pancreas 50.4–60 Gy/28–30#). Only patients that had consented to information use were included. All data was anonymised prior to analysis. This study was conducted in accordance with the Declaration of Helsinki 1964 and its amendments.

Patient position

Patient position was determined prior to the planning CT acquisition. Patients with compression were supine, arms up in a ¼ length vacbag, with a kneefix (CIVCO Radiotherapy, Coralville, USA) and AC equipment: Stradivarius™ SBRT Overlay, bridge and compression paddle (Qfix, Avondale, USA). All patients that had AC attempted received a brief discussion beforehand explaining AC, and that there may be discomfort but no pain. Patients without compression were supine, arms up in a ¼ length vacbag supporting arms/head, and kneefix. All patients were given four setup tattoos: one anterior (near the xiphoid process), two laterals and one inferior alignment (approximately 20 cm inferior to the anterior tattoo). At planning, patients were nil by mouth 2 hours prior and this was repeated for all treatment fractions. Some patients had clinician-requested dilute oral contrast (8 mL Omnipaque™ (GE Healthcare, Chicago, USA) in 125 mL water) 10–15 minutes prior to imaging to facilitate gastrointestinal (GI) tract visualisation. These patients consumed the same volume of liquid at each fraction to ensure consistent GI tract filling.

Imaging

All patients received daily cone beam CTs (CBCTs) with online matching prior to treatment (Clinac® iX, Varian Medical Systems, Palo Alto, USA). A CBCT was taken after patient setup prior to treatment delivery each fraction and then radiation therapists (RTTs) matched the CBCT online. Following a soft-tissue match to the GTV, the displacement was assessed in relation to the imaging tolerance to determine if corrective action was required prior to treatment delivery. As per departmental policy, the imaging tolerance for patients receiving SBRT was 0.1 cm, 3° rotation and the tolerance for patients receiving CRF was 0.2 cm, 3° rotation. If displacement was within tolerance, no corrective action was taken prior to treatment. Any rotations outside of these tolerances were corrected for using additional manual positioning while any displacements outside of these tolerances were corrected either using automated couch corrections (for smaller displacements) or additional manual positioning by the treating RTTs (displace-

ments > 1 cm). For those fractions where additional manual positioning was required, another CBCT would be acquired thereafter with a subsequent online match before treatment delivery. For those that had automated couch corrections greater than 1 cm, an additional CBCT imaging was taken to confirm positioning prior to treatment delivery at the discretion of the treating RTTs.

Setup error measurements

Initial setup error was measured using the tumour displacement observed on initial CBCT following patient positioning and online matching. Registration error following online matching was determined by rematching CBCTs offline to assess any displacement remaining following the online match. This was done for the first 5 fractions for 10 liver and 10 pancreas patients; CBCTs taken immediately before daily treatment were rematched by an experienced RTT (12 + years CBCT matching experience). Any discrepancy between the online match and offline match was determined to be the registration error for that fraction. All match data was retrieved from Offline Review (ARIA® Oncology Information System, Varian Medical Systems, Palo Alto, USA).

Image matching time

Image matching time generally refers to the time required to assess an image to determine a course of action. For the purposes of this study, both the time required to assess an image and the time required to take corrective actions following image matching were included in the definition of image matching. Using the beam on times captured in the record and verify system (ARIA® Oncology Information System, Varian Medical Systems, Palo Alto, USA), the image matching time was calculated from the recorded time between CBCT acquisition beam on and the next beam on, whether this was for another CBCT acquisition or for treatment delivery.

Statistical analysis

Statistical analysis was performed using commercially available software (Excel 2016, Microsoft, Redmond, US; IBM SPSS Statistics 25, IBM, Armonk, US). An F-test was performed in Excel to assess differences in variances in registration error. SPSS was used to perform a Student's t-test for registration error and average image analysis, and a Wilcoxon Mann Whitney test for imaging matching time analysis. A p-value of <0.05 was considered to represent statistical significance.

Results

Patients

For the purposes of this paper, 72 of 73 consecutive patients were included with 54 receiving SBRT and 18 receiving CRF. 1 patient had not consented for their information to be used. There were 39 liver (39 SBRT: 0 CRF), 30 pancreas (12 SBRT: 18 CRF) and 3 abdominal node patients (3 SBRT: 0 CRF). The median age was 71 (range 41–84) with 31 female and 41 male patients.

AC was only attempted on those patients where it was requested by a clinician. Prior to March 2017, departmental protocol stipulated that a fluoroscopic session was arranged prior to planning to determine whether AC reduced breathing motion in the superior-inferior direction effectively to warrant AC for planning and treatment. If motion was reduced enough at the discretion of the planning RTT, then the patient proceeded to planning with AC. Following March 2017, a departmental protocol change was instated that if a clinician requested AC, then it would be

attempted during planning and only discarded if the patient could not tolerate compression. Breathing motion reduction was no longer assessed prior to planning. Of the 58 patients where AC was attempted, 8 patients did not proceed with AC either due to patient discomfort during the initial immobilisation setup when the compression settings were being determined (4 patients), or because these patients underwent fluoroscopy and the planning RTT deemed the breathing motion reduction to be insignificant (≤ 5 mm) (4 patients). In 14 cases (12 CRF pancreas and 2 SBRT node), the clinician did not request AC.

Of the 72 patients included, 50 were compressed and 21 were uncompressed for all fractions. A single pancreas CRF patient was initially planned without AC and treated for 14 fractions but then was replanned and treated for the remaining 14 fractions with AC. The doctor had requested a replan with AC due to image matching difficulties during the initial 14 treatment fractions. The appropriate fractions for this patient were separated into both CRF compressed and CRF uncompressed categories (Table 1). 839 total fractions were included in the analysis.

Setup error

The distribution of initial setup error for all groups were similar (Fig. 1). The mean absolute displacements ranged from 2.9–4.0 mm, 3.6–6.3 mm and 3.3–4.5 mm in the right-left (RL), superior-inferior (SI), and anterior-posterior (AP) directions respectively. Initial setup displacement ranges tend to be greater in the SI and AP directions. There was little difference between the ranges of initial setup displacement between compressed and uncompressed patients.

Displacements greater than 1 cm were infrequent for all types of patients (Table 2) except uncompressed SBRT patients. For the SBRT compressed, SBRT uncompressed and CRF uncompressed

Table 2

Proportion of patients with initial setup error greater than 1 cm.

% of fractions for that group where displacement > 1 cm (# of fractions)		AP	SI	RL
Compressed	SBRT (302)	2.6 (8)	7.0 (21)	0
	CRF (183)	3.8 (7)	1.6 (3)	2.2 (4)
Uncompressed	SBRT (49)	2.0 (1)	20.4 (10)	4.1 (2)
	CRF (305)	2.7 (8)	8.2 (24)	2.4 (7)

patients, larger displacements occurred more frequently in the SI direction and to a lesser extent the AP direction.

SBRT patients required more additional manual positioning than CRF patients. Uncompressed patients required more additional manual positioning than compressed (Table 3). Additional manual corrections were completed at the treating RTTs' discretion when rotation > 3°, displacement $\gg 1$ cm or when target or OAR positions on CBCT could not be aligned with planning.

The distribution of residual error in both pancreas and liver patients can be seen in Fig. 2. In the pancreas dataset, the mean absolute registration error is larger in the SI direction in uncompressed patients (mean \pm sd: 3.6 ± 2.4 mm RL, 5.4 ± 3.3 mm SI, 3.2 ± 1.3 mm AP) than in compressed (3.5 ± 2.1 mm RL, 3.3 ± 2.2 mm SI, 4.0 ± 2.2 mm AP). In the liver dataset, the mean absolute registration error was larger in the SI and AP directions for uncompressed patients (0.9 ± 0.7 mm RL, 1.7 ± 1.6 mm SI, 1.4 ± 1.4 mm AP) than compressed (0.6 ± 0.8 mm RL, 0.8 ± 1.2 mm SI, 0.4 ± 0.6 mm AP) (Fig. 2). Differences in mean registration error between compressed and uncompressed groups were not statistically significant for both pancreas and liver patients using the

Table 1
Patient demographics.

		# of patients	Total fractions
Compressed	SBRT	44	302
	CRF	7	183
Uncompressed	SBRT	10	49
	CRF	12	305

Table 3

Proportion of patients where additional manual positioning was required.

% of fractions for that group where additional manual positioning required (# of fractions)		Reason		
		Rotation	Displacement	Unable to match anatomy
Compressed	SBRT (302)	1.7 (5)	0.3 (1)	0
	CRF (183)	0.5 (1)	0.5 (1)	0.5 (1)
Uncompressed	SBRT (49)	10.2 (5)	6.1 (3)	2.0 (1)
	CRF (305)	5.8 (17)	1.0 (3)	1.4 (4)

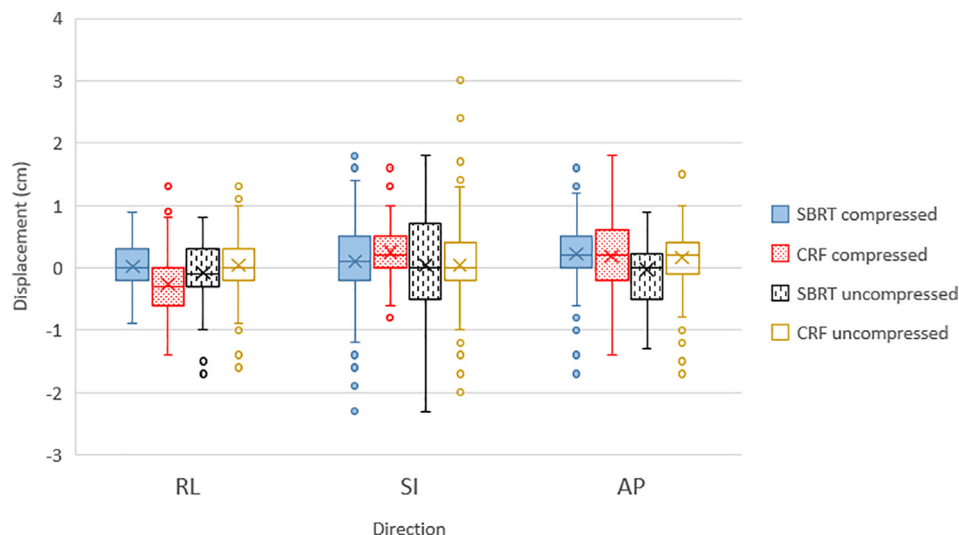


Fig. 1. Boxplots of initial setup error (cm) for all patients with outliers (o), median (-) and mean (x).

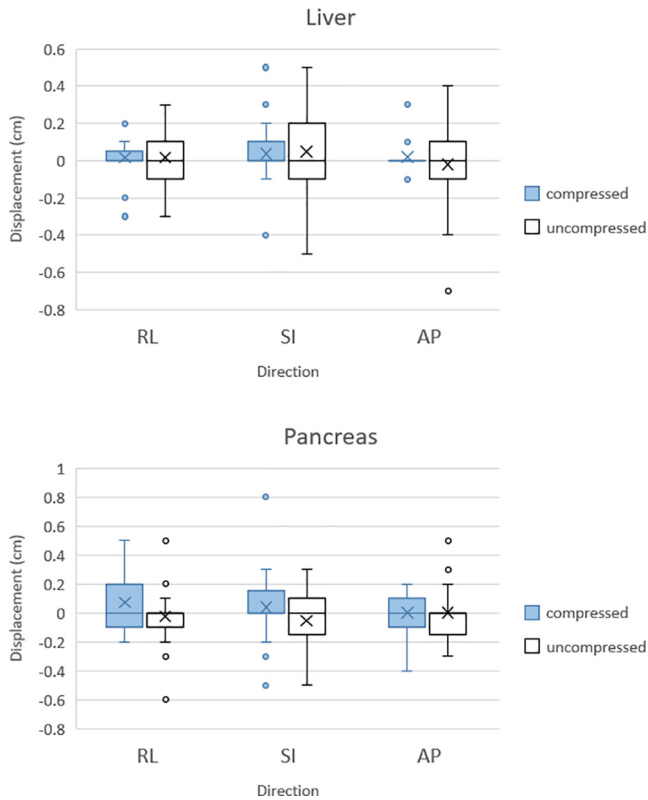


Fig. 2. Boxplots of registration error (cm) for ten liver and ten pancreas patients with outliers (o), median (–) and mean (x).

Student t-test. The F-test determined that the difference in variances of the compressed and uncompressed groups were not significant for pancreas patients ($F(74) = 1.13$, $p = 0.30$), while in liver patients the difference in variances between the two groups were significant ($F(74) = 2.96$, $p < 0.001$).

Image matching time

Compressed patients had smaller mean image matching times than uncompressed and had fewer images per fraction on average (Table 4). The differences in image matching time between compressed and uncompressed groups were not statistically significant.

Repeat imaging was performed if the treating RTT considered the matching time to be lengthy or if the patient may have moved during matching. For SBRT patients and for uncompressed patients, the average number of images taken per fraction was slightly greater though not statistically significant (Table 4).

Discussion

Abdominal compression is an effective and accepted method for reducing motion during radiotherapy. In this study, all patients who had AC at planning were able to tolerate this treatment position for all delivered fractions. No patients complained of pain while compressed during treatment delivery as treatment with compression would have been discontinued otherwise. There was no need to limit compression as others have suggested [13]. In the department where these patients were treated, a protocol change was introduced in March 2017 that if a clinician requested AC, it would be attempted during planning and only discarded if the patient could not tolerate compression. Significant reduction in breathing motion was no longer considered when rejecting AC

Table 4

Image matching times (minutes).

		Mean image matching time (range)	Average # of images/fraction
Compressed	SBRT	6:56 (1:44–44:54)	1.2
	CRF	5:34 (1:35–25:08)	1.1
Uncompressed	SBRT	9:09 (2:11–28:30)	1.4
	CRF	5:49 (1:19–36:58)	1.2

as the department considered any reduction in motion better than no reduction in motion.

In this study, mean initial setup error was less than 1 cm for all groups which corresponds with previous findings in radiotherapy for pancreas [14] and liver malignancies [15]. There was little difference in initial setup error when comparing compressed patients with uncompressed. Whether or not there was any difference in initial setup error between groups does not bear much clinical significance as any displacements at this point in the patient's daily treatment can be improved upon immediately with online image matching and positional corrections.

Although the imaging tolerance was 1–2 mm, there was still potential for additional displacement due to registration error. A contributing factor in registration error could be imprecision in image matching. There was little difference in registration error between compressed and uncompressed patients. While the difference in variance between compressed and uncompressed patients was statistically significant in liver, this was not so in pancreas. Registration error was less than 5 mm in each direction for the majority of patients. The RTTs were able to match accurately and consistently regardless of AC. This may be attributed to the level of competency attained by the RTTs prior to being permitted to online image match abdominal patients. In the radiotherapy department where these patients were treated, only RTTs who had demonstrated competency in abdominal image matching and been assessed by the department's imaging RTT could perform online image matching for radical abdominal patients. This local policy may have encouraged baseline knowledge and competency for abdominal image matching resulting in more consistent matching between RTTs. As previous research has found [16], appropriate training can help reduce inter-observer variability.

A possible reason that uncompressed patients take longer to image match than compressed patients may be due to time to interpret the poorer image quality attributed to breathing motion. Breathing motion can create motion artifacts on imaging. With reduced breathing motion from AC, presumably this would also reduce motion artifacts on imaging. In images from compressed patients, the anatomical structures can appear well defined while those from uncompressed patients' images can appear blurred (Fig. 3). This lack of image definition can make uncompressed images more difficult to assess and target identification difficult, especially in the superior-inferior aspect where breathing motion is most prominent [17], thus requiring additional time to perform and confirm an accurate image match.

Another reason that uncompressed patients had longer image matching times could be that they had more rotational errors ($>3^\circ$) and larger displacements (>1 cm) requiring additional manual positioning. Manual positioning requires the RTT to enter the treatment room to physically adjust the patient's position and this tends to be more time consuming than performing automated couch corrections. The need for additional manual positioning is likely due to the less comprehensive immobilisation utilised for the uncompressed patients. Compressed patients had longer vac-bags for comfort as AC can cause pressure on the patient's lower back due to placement of the compression bridge. The shorter vac-bags for uncompressed patients likely allowed for more rotational

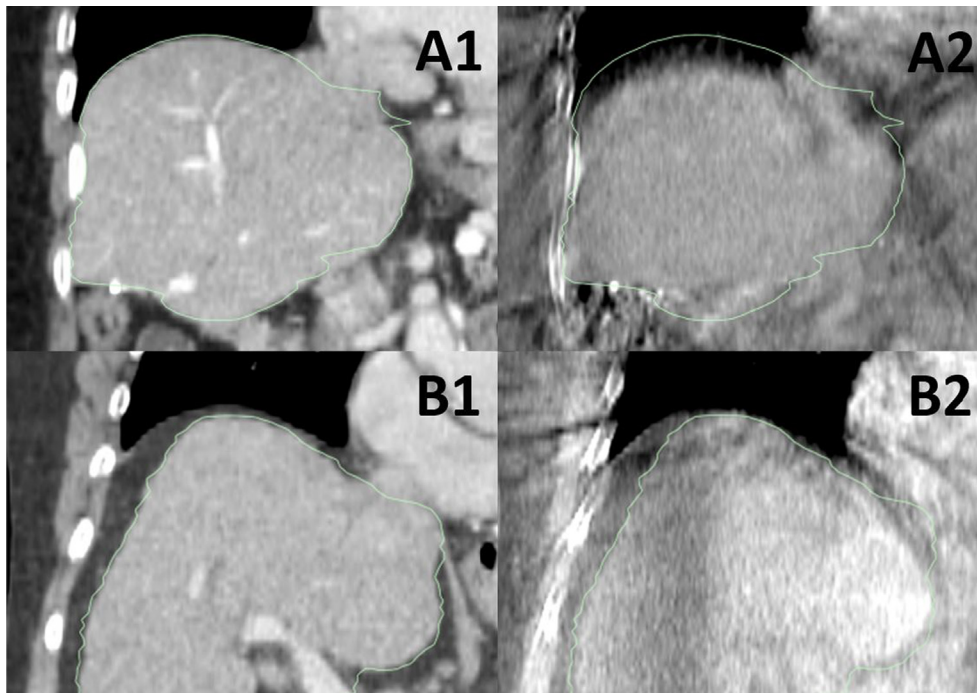


Fig. 3. Coronal views of (1) CTs and (2) CBCTs from two liver patients receiving SBRT. Liver contour (light green) from planning CT transposed to CBCT after matching: (A) Uncompressed – breathing motion artifact at dome of diaphragm; (B) Compressed – clear definition of dome of diaphragm.

discrepancies. Also, the design of the compression equipment makes it difficult for the patient to move once the compression paddle has been depressed. The rigid nature of the compression equipment makes it less likely that inadvertent patient movement between positioning and imaging has occurred. However, while manual positional corrections may be a factor in influencing longer image matching times, it may not be a large factor. If this was the case, we would have expected a statistically significant larger initial setup error for uncompressed than compressed and perhaps a greater number of fractions requiring additional manual positioning.

The mean matching times for the abdominal patients in this study were greater than those found for other anatomical sites by Robb et al. [18]. They found mean matching times ranging from ~2 to 6 minutes for chest, pelvis and head and neck patients while the mean matching times for the abdominal patients in our study ranged from ~5 to 9 minutes for all groups. The greater mean matching times for abdominal patients is likely due to the complex arrangement of anatomical organs, lack of soft tissue definition on CBCT, and breathing motion in the abdomen which can lead to greater difficulty with image matching. With compressed patients taking less time for imaging matching than uncompressed patients, this can potentially result in improved treatment accuracy for compressed patients due to decreased opportunity for intrafraction motion. Shorter image matching times can also have a beneficial impact on resource allocation with respect to treatment appointment times. While this study did not find the difference in image matching time to be statistically significant between compressed and uncompressed groups, this does not discount the potential benefit that AC can have on individual patients during the image matching process. The single pancreas CRF patient who was initially planned uncompressed had a mean image matching time of 11min42sec and an average of 1.6 images per fraction. After replanning with compression, the same patient had a mean image matching time of 4min31sec and an average of 1.2 images per fraction.

SBRT patients had slightly more images taken than CRF patients as SBRT patients had smaller imaging tolerances of 1 mm versus 2 mm. The maximum imaging matching times were greater than 20 minutes for all groups as patients sometimes needed to be removed from compression, given a short break and then setup again prior to the next set of images.

A limitation of this retrospective study is that the image matching times were deduced from beam on times and thus included both the time required for image assessment and the time required to take corrective action. These two components could not be parsed out from each other. The method used in this study to extract image matching times corresponds with that used in previous research also looking at image matching times [18]. Further prospective study could provide definitive information as to whether image assessment time is greater for uncompressed patients than for compressed patients although observations may have to be done surreptitiously to avoid undue influence on image matching time assessment. Additional studies may also benefit from testing out other forms of compression equipment such as pneumatic belts [6,19].

Another limitation of this study was the use of an older model of linear accelerator (linac) for treatment and the acquisition of 3D-CBCTs during free-breathing. With newer models of linacs currently on the market, it is possible to acquire gated CBCTs or take 4D-CBCTs. With more modern imaging capabilities, the impact of breathing motion on imaging can be minimised. Gated CBCTs have been shown to reduce image blurring caused by respiratory motion [20]. Better image quality has been observed in 4D-CBCTs over 3D-CBCTs resulting in improved image matching accuracy and reduced inter-observer variability [21]. It is possible that with newer linac models, the impact of AC on image quality and thus image matching time would be negligible. However, newer linacs may not decrease overall treatment appointment times as gated CBCTs and 4D-CBCTs are associated with longer image acquisition times [20,22]. Until the use of gated CBCTs and 4D-CBCTs become commonplace and more time efficient, AC can be used to aid image matching.

Conclusions

Although abdominal compression has no significant impact on setup error, it may reduce imaging matching times in addition to the well described reduction in radiation to normal tissues. This decrease in time from image acquisition to treatment can help improve treatment accuracy as it minimises the opportunity for intrafraction motion and increases the likelihood that the image represents the patient's position during treatment.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

Acknowledgements

We would like to acknowledge the funding support provided by Cancer Research UK and UK Medical Research Council. SM is part funded by NIHR Oxford Biomedical Research. MAH is funded by UK Medical Research Council grant MC_UU_00001/2.

References

- [1] Keall PJ, Mageras GS, Balter JM, Emery RS, Forster KM, Jiang SB, et al. The management of respiratory motion in radiation oncology report of AAPM Task Group 76. *Med Phys* 2006;33:3874–900. <https://doi.org/10.1118/1.2349696>.
- [2] Pan H, Simpson DR, Mell LK, Mundt AJ, Lawson JD. A survey of stereotactic body radiotherapy use in the United States. *Cancer* 2011;117:4566–72. <https://doi.org/10.1002/cncr.26067>.
- [3] Kim SK, Wu CC, Horowitz DP. Stereotactic body radiotherapy for the pancreas: a critical review for the medical oncologist. *J Gastrointest Oncol* 2016;7:479–86. <https://doi.org/10.21037/jgo.2015.10.01>.
- [4] Heinzerling JH, Anderson JF, Papiez L, Boike T, Chien S, Zhang G, et al. Four-dimensional computed tomography scan analysis of tumor and organ motion at varying levels of abdominal compression during stereotactic treatment of lung and liver. *Int J Radiat Oncol Biol Phys* 2008;70:1571–8. <https://doi.org/10.1016/j.ijrobp.2007.12.023>.
- [5] Stumpf PK, Jones B, Jain SK, Amini A, Thornton DA, Dzingle W, et al. Stereotactic body radiation therapy for pancreatic cancer: Assessing motion with and without abdominal compression. *J Clin Oncol* 2016;34:234–. https://doi.org/10.1200/jco.2016.34.4_suppl.234.
- [6] Van Gelder R, Wong S, Le A, Podreka A, Briggs A, Haddad C, et al. Experience with an abdominal compression band for radiotherapy of upper abdominal tumours. *J Med Radiat Sci* 2018;65:48–54. <https://doi.org/10.1002/jmrs.254>.
- [7] Campbell WG, Jones BL, Scheffer T, Goodman KA, Miften M. An evaluation of motion mitigation techniques for pancreatic SBRT. *Radiother Oncol* 2017;124:168–73. <https://doi.org/10.1016/j.radonc.2017.05.013>.
- [8] Hu Y, Zhou YK, Chen YX, Zeng ZC. Magnitude and influencing factors of respiration-induced liver motion during abdominal compression in patients with intrahepatic tumors. *Radiat Oncol* 2017;12:9. <https://doi.org/10.1186/s13014-016-0762-z>.
- [9] Han K, Cheung P, Basran PS, Poon I, Yeung L, Lochray F. A comparison of two immobilization systems for stereotactic body radiation therapy of lung tumors. *Radiother Oncol* 2010;95:103–8. <https://doi.org/10.1016/j.radonc.2010.01.025>.
- [10] Zwiers D, Koekoek S, Bouwhuis-Scholten A, Piersma H, Van Dieren E. OC-0196: Reproducibility of the liver in stereotactic radiotherapy using abdominal compression. *Radiother Oncol* 2018;127:S106. [https://doi.org/10.1016/S0167-8140\(18\)30506-1](https://doi.org/10.1016/S0167-8140(18)30506-1).
- [11] Dawson LA, Eccles C, Bissonnette JP, Brock KK. Accuracy of daily image guidance for hypofractionated liver radiotherapy with active breathing control. *Int J Radiat Oncol Biol Phys* 2005;62:1247–52. <https://doi.org/10.1016/j.ijrobp.2005.03.072>.
- [12] Hawkins MA, Brock KK, Eccles C, Moseley D, Jaffray D, Dawson LA. Assessment of residual error in liver position using kV cone-beam computed tomography for liver cancer high-precision radiation therapy. *Int J Radiat Oncol Biol Phys* 2006;66:610–9. <https://doi.org/10.1016/j.ijrobp.2006.03.026>.
- [13] Bouwhuis-Scholten AS, Van Dieren EB, Koch S, Piersma H, Woutersen D. EP-2097: Patient friendly compression-belt settings in liver stereotactic radiotherapy. *Radiother Oncol* 2016;119:S987. [https://doi.org/10.1016/S0167-8140\(16\)33348-5](https://doi.org/10.1016/S0167-8140(16)33348-5).
- [14] Fuss M, Wong A, Fuller CD, Salter BJ, Fuss C, Thomas CR. Image-guided intensity-modulated radiotherapy for pancreatic carcinoma. *Gastrointest Cancer Res* 2007;1:2–11.
- [15] Zhang T, Wang W, Li Y, Jin J, Wang S, Song Y, et al. Inter- and intrafractional setup errors and baseline shifts of fiducial markers in patients with liver tumors receiving free-breathing postoperative radiation analyzed by cone-beam computed tomography. *J Appl Clin Med Phys* 2014;15:4914. <https://doi.org/10.1120/jacmp.v15i6.4914>.
- [16] Lewis DG, Ryan KR, Smith CW. Observer variability when evaluating patient movement from electronic portal images of pelvic radiotherapy fields. *Radiother Oncol* 2005;74:275–81. <https://doi.org/10.1016/j.radonc.2004.11.009>.
- [17] Bussels B, Goethals L, Feron M, Bielen D, Dymarkowski S, Suetens P, et al. Respiration-induced movement of the upper abdominal organs: a pitfall for the three-dimensional conformal radiation treatment of pancreatic cancer. *Radiother Oncol* 2003;68:69–74. [https://doi.org/10.1016/S0167-8140\(03\)00133-6](https://doi.org/10.1016/S0167-8140(03)00133-6).
- [18] Robb D, Plank A, Middleton M. Assessing the efficiency and consistency of daily image-guided radiation therapy in a modern radiotherapy centre. *J Med Imaging Radiat Sci* 2014;45:72–8. <https://doi.org/10.1016/j.jmir.2013.10.005>.
- [19] Lovelock DM, Zatcky J, Goodman K, Yamada Y. The effectiveness of a pneumatic compression belt in reducing respiratory motion of abdominal tumors in patients undergoing stereotactic body radiotherapy. *Technol Cancer Res Treat* 2014;13:259–67. <https://doi.org/10.7785/tcrt.2012.500379>.
- [20] Kincaid Jr RE, Yorke ED, Goodman KA, Rimner A, Wu AJ, Mageras GS. Investigation of gated cone-beam CT to reduce respiratory motion blurring. *Med Phys* 2013;40:041717. <https://doi.org/10.1118/1.4795336>.
- [21] Sweeney RA, Seubert B, Stark S, Homann V, Muller G, Flentje M, et al. Accuracy and inter-observer variability of 3D versus 4D cone-beam CT based image-guidance in SBRT for lung tumors. *Radiat Oncol* 2012;7:81. <https://doi.org/10.1186/1748-717X-7-81>.
- [22] Li T, Xing L. Optimizing 4D cone-beam CT acquisition protocol for external beam radiotherapy. *Int J Radiat Oncol Biol Phys* 2007;67:1211–9. <https://doi.org/10.1016/j.ijrobp.2006.10.024>.