Journal of Radiotherapy in Practice

cambridge.org/jrp

Quantification of intra-fraction motion in breast radiotherapy using cine EPID images

Behnaz Fouladinezhad[1], Mehdi Momennezhad[1,2], Parisa Farjami[3] and Shahrokh Naseri[1]

[1]Medical Physics Research Center, Mashhad University of Medical Sciences, Mashhad, Iran; [2]Nuclear Medicine Research Center, Mashhad University of Medical Sciences, Mashhad, Iran and [3]Department of Biology, Islamic Azad University, Mashhad, Iran

Original Article

Cite this article: Fouladinezhad B, Momennezhad M, Farjami P, and Naseri S. (2024) Quantification of intra-fraction motion in breast radiotherapy using cine EPID images. *Journal of Radiotherapy in Practice*. **23**(e10), 1–5. doi: 10.1017/S1460396924000049

Received: 17 September 2023
Revised: 28 January 2024
Accepted: 6 February 2024

Keywords:
Automated motion estimation algorithm; breast cancer; conformal radiation therapy; EPID

Corresponding author:
Shahrokh Naseri; Email: naserish@mums.ac.ir

Abstract

Background: The aim of this study was to develop a method for accurately measuring the intra-fraction motion in cine electronic portal imaging device (EPID) images of tangential breast irradiation.

Patients and methods: The cine EPID images were acquired for 18 breast cancer patients during medial tangential breast radiotherapy. The skin surface and the chest wall were segmented separately in each EPID image using an automated MATLAB algorithm to obtain the magnitude of intra-fraction motion.

Results: The patients had an average age of 55 years (range 43–69 years), with the highest observed displacement at 3·50 mm. The mean intra-fraction motion due to respiration for the skin surface and chest wall was 1·04 ± 0·24 mm and 1·10 ± 0·27 mm, respectively. The amount of intra-fraction motion showed no significant association with either the patient's age or the side of the breast receiving the treatment.

Conclusion: In this study, by utilising cine EPID technology and the automated MATLAB algorithm, the intra-fraction motion during breast radiotherapy treatment was accurately measured and analysed. Results indicate minimal skin surface and chest wall motion (approximately 1 mm), confirming negligible intra-fraction motions during conformal radiotherapy in breast cancer patients.

Introduction

In radiotherapy, intra-fraction motion occurs during treatment and causes instant geometrical changes. In addition, it directly impacts the precision of dose delivery.[1] Intra-fraction motion is the result of breathing or other physiological processes such as swallowing and the digestive system.[2,3] The breast intra-fraction motion can be investigated during radiotherapy via portal imaging in cine mode.[4–8] Other methods include monitoring the motion of the breast's surface using optical sensors or tracking the position of a radiopaque marker with fluoroscopic imaging.[9,10] The advantage of an electronic portal imaging device (EPID) over other methods is that it is a quick and easy technique to determine internal motions in the radiotherapy field. The technique acquired images from the region of interest without giving an additional dose to the patient during radiotherapy, and it mitigated concerns about the risk of infection due to the implantation of a marker.[7,11]

To quantify chest wall motion during irradiation, anatomical landmarks were manually marked on each cine EPID image. These landmarks included the central lung distance (CLD), central flash distance (CFD) and inferior central margin (ICM).[5] The range of motion measured based on changes in the position of each marker in all images.[4–6,12] Manual contouring of anatomical landmarks in EPID images suffers from several limitations. It is prone to interobserver variability, requiring substantial time and effort from clinicians, and introducing errors due to misidentification. Moreover, a nonautomated measurement system is not easily achievable for large datasets or low-contrast images. These drawbacks necessitate the development of automated motion analysis techniques based on computer vision and image processing algorithms to provide a more objective and efficient assessment of motion, enhancing patient positioning monitoring.[13]

Automatic motion estimation is a computer process in which two or more consecutive images are processed to determine motion vectors that describe the image transformation. One of the algorithms used for automatic motion estimation in consecutive images is the block-matching MATLAB algorithm.[14,15] While previous studies did not utilise block-matching algorithms to estimate motion in EPID images, this study presents a novel approach that employs this technique to automatically quantify intra-fraction motion in breast cancer patients.

CAMBRIDGE UNIVERSITY PRESS

https://doi.org/10.1017/S1460396924000049 Published online by Cambridge University Press

Patients and methods

Ethical approval has been received by our Institutional Ethics Committee. Eighteen cases of breast cancer patients who were treated at the clinical department (Department of Radiation Oncology, Imam Reza Hospital, Mashhad, Iran) were selected for this study. All patients included in the study had undergone mastectomy surgery. The mean age of patients was 55·11 years (ranging from 43 to 69 years), with nine right and nine left breasts treated.

The three-dimensional treatment planning by computed tomography (CT) scan was used. The patients were positioned supine on the breast board and breathed normally during the CT scan and treatment. Patients were treated with six megavolts on an Elekta Precise linear accelerator equipped with a multileaf collimator and megavoltage EPID.

During the medial tangential treatment field delivery, EPID images were acquired in cine mode. Each image was acquired after receiving 30 monitor units of radiation during treatment. Approximately three to six images were obtained in each treatment step, depending upon the monitor unit. These images were saved in Joint Photographic Experts Group format and transferred to a personal computer and MATLAB software for processing and calculations. The pixel size and the scale of the EPID images were 1024 × 1024 pixels and 0·25 mm/pixel, respectively.

Calculation

A three-dimensional array was created in the first step to store and process each sequence of EPID images, followed by smoothing with a 10 × 10 pixels median filter for noise reduction.[16] The filter size was chosen according to the noise of images and the edge detection process. Patients' skin surface and chest wall were segmented separately in all images using a Canny edge detector.[17]

For automated estimation of vector motion in cine images, the block-matching algorithm was applied to images.[18,19] In this algorithm, each image of the sequence was divided into macro-blocks. The range of some common block sizes is 4, 8, 16, 32 and 64 pixels.[20] The choice of block size is a trade-off between accuracy and computational complexity. Smaller blocks provide more accuracy but require more processing power. Larger blocks offer faster processing but may introduce more motion estimation errors.[21] In this study, the image size and the macroblock size were 1024 × 1024 and 16 × 16 pixels, respectively. To track motion, each block was compared to its corresponding block and neighbours in the next image. This comparison estimates the direction and distance each block has moved, creating 'motion vectors' for the entire image. Mean absolute difference (MAD) and mean square error (MSE) are two standard metrics for measuring the similarity of the blocks of images.[18]

In this study, four algorithms are as follows: (a) exhaustive search with MAD criterion, (b) exhaustive search with MSE criterion, (c) three-step search with MAD criterion and (d) three-step search with MSE criterion were applied to all images.[22]

The intra-fraction motion of the skin surface and the chest wall equalled the average of the estimated motion vectors. Furthermore, the total intra-fraction motion of each patient was equal to the mean displacement of the skin surface and the chest wall.

Validation of calculations

Standard images with specified motion vectors were used to determine the accuracy of these four methods. An EPID image was initially selected as the primary standard, which was substituted by a geometric translation algorithm with a specified motion vector. This translated image was considered the next image of our sequence. The calculation process was conducted on these two images to estimate motion vectors. The error of estimation was calculated by the difference of the applied displacement vector from the average size of the calculated vectors:

$$\sigma = \left| d_{tr} - \overline{d_{es}} \right| \tag{1}$$

In the formula, σ, d_{tr} and d_{es} are the error of estimation, translation displacement and mean estimation displacements. The average of σ was calculated as the mean error of these four methods. The method with the lowest error was selected for the intra-fraction motion estimation of patients.

Table 1. Patients' clinical features and mean intra-fraction motion estimation

Patient	Age (year)	Tumour location	Mean motion (mm)
1	47	left	0·94
2	43	right	0·75
3	61	right	0·90
4	65	right	0·95
5	59	left	1·27
6	48	right	0·93
7	53	left	1·32
8	69	left	1·03
9	55	left	1·59
10	62	right	1·57
11	50	right	1·02
12	57	left	0·89
13	60	left	0·94
14	66	right	1·13
15	48	left	1·04
16	51	left	0·97
17	53	right	1·09
18	45	right	0·92
Mean	55·11		1·06
Standard deviation	7·67		0·23

Statistical analysis

The correlation between the intra-fraction motion of the surface skin and chest wall was analysed by the Pearson correlation test. Descriptive statistics were calculated for individual patient motion and its correlation with age using Pearson correlation. Independent *t*-tests compared motion based on the side of the breast receiving radiation.[23] All statistical analyses were performed at the significance level of 95%. Version 20 of Statistical Package for the Social Sciences software was used for these analyses.

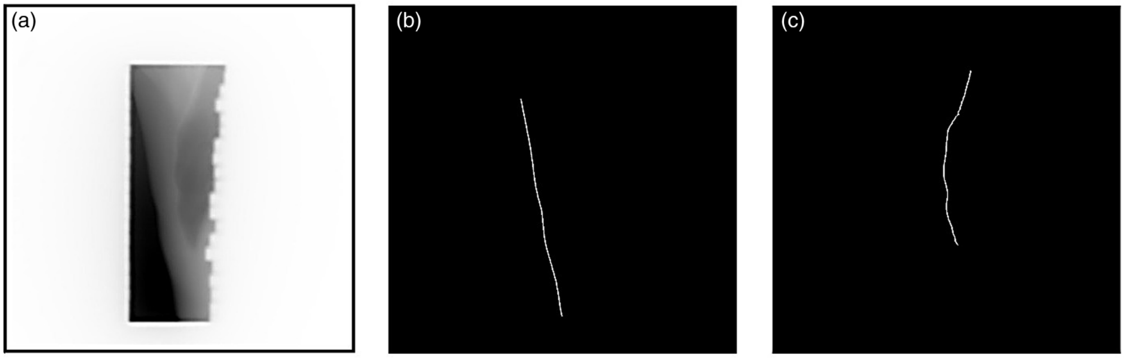

Figure 1. A sample of edge detection step. (a) Main EPID image obtained from a patient; (b) Result of the skin surface detection; (c) Result of the chest wall detection.

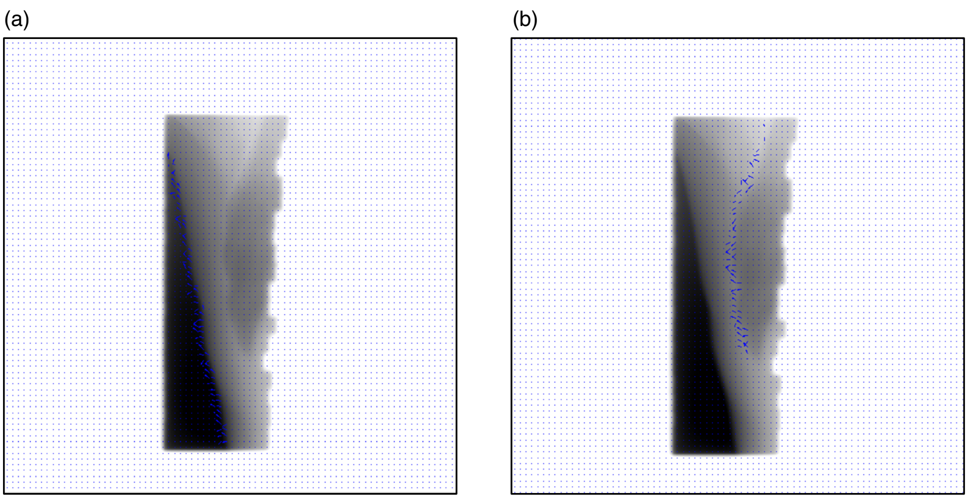

Figure 2. A sample of motion vector estimation step. (a) Result of the skin surface motion vector; (b) Result of the chest wall motion vector.

Results

Table 1 summarises the clinical characteristics of eighteen breast cancer patients, including their tumour side, age and mean movement.

A total of 168 images were obtained. The main EPID image was greyscale and noisy. In the first step, the skin surface and the chest wall were detected separately (Figure 1).

Figure 2 shows the motion vectors for the skin surface and chest wall. The motion vectors are represented as arrows, with the length and direction of the arrow indicating the magnitude and direction of the motion.

The mean error of estimation was computed to validate four methods of this algorithm (Table 2). The least error was obtained from the exhaustive search with the MSE criterion method ($\sigma = 0{\cdot}07 \pm 0{\cdot}04\ mm$). This method was employed to estimate the displacement vectors and statistical descriptions of parameters.

The mean intra-fraction displacements of the skin surface and the chest wall were 1·04 ± 0·24 and 1·10 ± 0·27 mm (Table 3). The maximum movement was calculated to be 3·5 mm. An analysis using Pearson's correlation coefficient reveals a statistically significant linear relationship between the mean displacement of the skin surface and the chest wall ($r = 0{\cdot}61$, $p = 0{\cdot}04$) (Figure 3).

The mean of the total intra-fraction motion of each patient was 1·04 ± 0·24 mm. Pearson's correlation coefficient showed no correlation between the intra-fraction motion of patients and age ($p = 0{\cdot}17$). The independent *t*-test revealed no relationship between the intra-fraction motions of patients and the side of the breast receiving radiation ($p = 0{\cdot}48$).

Table 2. Mean error of four motion estimation algorithms

Method	σ (mm)
Exhaustive search with MAD criterion	0·10 ± 0·02
Exhaustive search with MSE criterion	0·07 ± 0·04
Three-step search with MAD criterion	0·38 ± 0·25
Three-step search with MSE criterion	0·53 ± 0·32

Table 3. Mean and standard deviation of intra-fraction displacement of the skin surface and the chest wall, resulting from four methods of block-matching algorithms in the tangential radiation field (mm)

Method	Chest wall (mm)	Skin surface (mm)
Exhaustive search with MAD criterion	0·97 ± 0·31	0·88 ± 0·31
Exhaustive search with MSE criterion	1·10 ± 0·27	1·04 ± 0·24
Three-step search with MAD criterion	1·24 ± 0·35	1·20 ± 0·29
Three-step search with MSE criterion	1·32 ± 0·36	1·28 ± 0·28

Discussion

In the present study, we intended to quantify the mean chest motion during irradiation using an automated algorithm. The mean displacement of intra-fraction motion of the breast cancer patient's skin surface and chest wall during radiotherapy was

https://doi.org/10.1017/S1460396924000049 Published online by Cambridge University Press

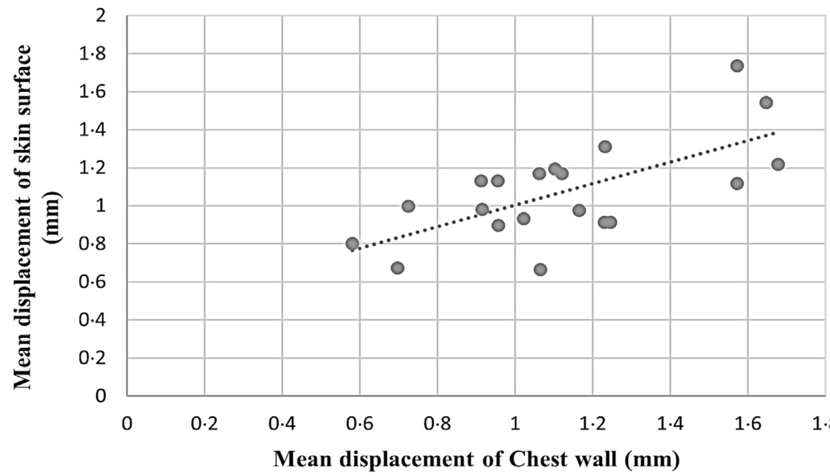

Figure 3. The linear relationship between the displacement of the skin surface and the chest wall.

estimated to be 1·04 ± 0·24 and 1·10 ± 0·27 mm, respectively. We exploited the block-matching algorithm to precisely determine the mean movement in our participants. Unlike previous continuous portal imaging studies,[4–8] the current study not only automatically contoured the chest wall and skin surface for all frames but also calculated the displacement for the entire edge instead of focusing on a single point-based metric like CLD. In the study by Krone et al.,[6] a single observer manually measured CLD, CFD and ICM for 20 breast patients. To ensure the accuracy of these measurements, two patients' images were evaluated by a separate observer. The average changes of these distances were reported as 1·06 ± 0·19, 0·98 ± 0·16 and 1·27 ± 0·45 mm, respectively. Jones et al.[4] measured the average CLD and CFD displacements of 2·5 and 3·5 mm, respectively. Two independent radiation therapists conducted these measurements. A limitation of this study was the inability to visualise the CLD in one of the ten breast cancer patients. The patient's chest wall was not clearly visible on the imaging scans, which prevented the CLD measurement.

Similar to the previously conducted investigations, the intra-fraction motion in our study was small (approximately 1 mm).[5,7,8] The reports of the American Association of Physicists in Medicine Task Group recommend using respiratory motion management techniques in breast cancer patients with tumour displacement of greater than 5 mm.[24] In our study, the maximum motion was less than 3·5 mm; therefore, the intra-fraction motions were negligible in conformal radiotherapy of breast cancer patients.

Although many studies reveal intra-fraction motion on portal images, few studies adopted automatic methods to estimate the quantity of these motions. In a study, Smith et al.[7] used software to apply a histogram equalisation and edge enhancement by the Sobel operator on all images. A physician manually contoured the lung, heart and breast in the first frame, and the software automatically determined the contours in subsequent frames. To track patient movement during radiotherapy, the CLD was calculated for each frame of the image in eight patients. These patients had a maximum CLD motion of 2·5 mm during their treatment course. Thomsen et al.[8] evaluated the residual positioning errors in breast cancer treatment after adjusting based on two orthogonal setup images taken during normal breathing. Through a 'semi-automatic registration' programme designed in MATLAB software, they determined the position of the chest wall on all EPID images. The registration process involved intra-fraction chest wall motion, with an average value of 2·0 ± 0·7 mm. The semi-automatic registration programme relies on user interaction to define landmarks or reference points, while the block-matching algorithm automatically compares image blocks to identify the best match. Both methods can effectively identify chest wall movement, but the semi-automatic approach offers greater flexibility and control over the registration process, while the block-matching algorithm is more efficient and less dependent on user input. Given the limitations of this algorithm in discovering each block size, it is recommended to evaluate and compare other motion estimation algorithms in future investigations.

Conclusion

We estimated the intra-fraction motion of the skin surface and the chest wall using cine EPID images during breast radiotherapy. A MATLAB algorithm was used to automatically identify the skin surface and chest wall, thereby reducing human error in the selection of anatomical landmarks. The steps are fully automatic, and due to the low contrast of the EPID images, there is no need for human intervention in drawing contours on consecutive frames. This is an automatic, repeatable and independent method. Our results showed that for breast cancer patients, both the range of intra-fraction motion of the skin surface and the chest wall was estimated to be approximately 1 mm.

Acknowledgements. All authors have approved the manuscript and agree with its submission.

The authors confirm that written informed consent has been obtained from the involved patients or if appropriate from the parent, guardian or power of attorney of the involved patients, and they have given approval for this information to be published in this case report.

References

1. George R, Keall PJ, Kini VR, et al. Quantifying the effect of intrafraction motion during breast IMRT planning and dose delivery. Med Phys 2003; 30 (4): 552–562.
2. Langen KM and Jones DT Organ motion and its management. Int J Radiat Oncol Biol Phys 2001; 50 (1): 265–278.
3. Watanabe M, Isobe K, Takisima H, et al. Intrafractional gastric motion and interfractional stomach deformity during radiation therapy. Radiother Oncol 2008; 87 (3): 425–431.
4. Jones S, Fitzgerald R, Owen R, et al. Quantifying intra-and inter-fractional motion in breast radiotherapy. J Med Radiat Sci 2015; 62 (1): 40–46.
5. Fein DA, McGee KP, Schultheiss TE, et al. Intra-and interfractional reproducibility of tangential breast fields: a prospective on-line portal imaging study. Int J Radiat Oncol Biol Phys 1996; 34 (3): 733–740.

6. Kron T, Lee C, Perera F, et al. Evaluation of intra-and inter-fraction motion in breast radiotherapy using electronic portal cine imaging. Technol Cancer Res Treat 2004; 3 (5): 443–449.
7. Smith RP, Bloch P, Harris EE, et al. Analysis of interfraction and intrafraction variation during tangential breast irradiation with an electronic portal imaging device. Int J Radiat Oncol Biol Phys 2005; 62 (2): 373–378.
8. Thomsen MS, Harrov U, Fledelius W, et al. Inter-and intra-fraction geometric errors in daily image-guided radiotherapy of free-breathing breast cancer patients measured with continuous portal imaging. Acta Oncologica 2014; 53 (6): 802–808.
9. Kinoshita R, Shimizu S, Taguchi H, et al. Three-dimensional intrafractional motion of breast during tangential breast irradiation monitored with high-sampling frequency using a real-time tumor-tracking radiotherapy system. Int J Radiat Oncol Biol Phys 2008; 70 (3): 931–934.
10. Price GJ, Sharrock PJ, Marchant TE, et al. An analysis of breast motion using high-frequency, dense surface points captured by an optical sensor during radiotherapy treatment delivery. Phys Med Biol 2009; 54 (21): 6515.
11. Kothary N, Heit JJ, Louie JD, et al. Safety and efficacy of percutaneous fiducial marker implantation for image-guided radiation therapy. J Vasc Interventional Radiol 2009; 20 (2): 235–239.
12. Michalski A, Atyeo J, Cox J, et al. Inter-and intra-fraction motion during radiation therapy to the whole breast in the supine position: a systematic review. J Med Imaging Radiat Oncol 2012; 56 (5): 499–509.
13. Mylonas A, Booth J and Nguyen DT A review of artificial intelligence applications for motion tracking in radiotherapy. J Med Imaging Radiat Oncol 2021; 65 (5): 596–611.
14. Jain J and Jain A Displacement measurement and its application in interframe image coding. IEE Trans Commun 1981; 29 (12): 1799–1808.
15. Puri A, Hang H-M and Schilling D, An efficient block-matching algorithm for motion-compensated coding. in ICASSP'87. IEEE International Conference on Acoustics, Speech, and Signal Processing. 1987. Vol. 12, pp. 1063–1066. IEEE.
16. Wang Z and Zhang D Progressive switching median filter for the removal of impulse noise from highly corrupted images. IEE Trans Circuits Syst II: Analog Digital Signal Processing 1999; 46 (1): 78–80.
17. Canny J A computational approach to edge detection. IEEE Trans Pattern Anal Mach Intell 1986 (6): 679–698.
18. Barjatya A Block matching algorithms for motion estimation. IEEE Trans Evol Comput 2004; 8 (3): 225–239.
19. Chen P-Y and Jou JM An efficient blocking-matching algorithm based on fuzzy reasoning. IEE Trans Syst Man Cybernetics, Part B (Cybernetics) 2001; 31 (2): 253–259.
20. Lu J and Liou ML A simple and efficient search algorithm for block-matching motion estimation. IEE Trans Circuits Syst Video Technol 1997; 7 (2): 429–433.
21. Yaakob R, Aryanfar A, Halin AA, et al. A comparison of different block matching algorithms for motion estimation. Procedia Technol 2013; 11: 199–205.
22. Chung K-L and Chang L-C A new predictive search area approach for fast block motion estimation. IEE Trans Image Process 2003; 12 (6): 648–652.
23. Sharma AK Text Book of Correlations and Regression. New Delhi: Discovery Publishing House, 2005.
24. Keall PJ, Mageras GS, Balter JM, et al. The management of respiratory motion in radiation oncology report of AAPM Task Group 76 a. Med Phys 2006; 33 (10): 3874–3900.