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### A comparison of coordinate systems for use in determining a radiotherapy delineation margin for whole breast

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# A comparison of coordinate systems for use in determining a radiotherapy delineation margin for whole breast

## Abstract

Cartesian co-ordinates, traditionally used for radiotherapy margins, calculated at 6 points, may not adequately represent changes in inter-observer contour variation as necessary to define a delineation margin. As a first step, this study compared the standard deviation (SD) in contour delineation using Polar and Cartesian co-ordinates for whole breast. Whole breast Clinical Target Volumes (CTV) were delineated by eight observers for 9 patients. The SD of contour position was determined for Polar co-ordinates at 1 degree increments for 5 slices and averaged across all patients. The mean centre of mass (COM) was used as the origin for the right breast, for the left the COM was shifted 1cm superiorly to avoid clipping. The SD was determined for Cartesian co-ordinates for medial-lateral and anterior-posterior positions. At slice Z=0cm considering Polar co-ordinates, the SD peaked medially reaching 3.55cm at 15 degrees for the right breast, and 1.44 cm at 171 degrees for the left. The SD of the remaining slices maintained a similar distribution, with variation in the peak occurring within 10 degrees of the Z=0cm positions. By comparison, for Cartesian co-ordinates at slice Z=0cm, the largest SD in the medial-lateral and anterior-posterior directions was 0.54/0.57cm and 1.03/0.67 cm respectively for right/left breasts. The SD for inter-observer variation for whole breast varies with anatomical position. The maximum SD determined with Polar co-ordinates was greater than with Cartesian co-ordinates. A delineation margin may thus need to vary with angle over the entire structure and Cartesian co-ordinates may not be the best approach for margin determination for whole breast.

## Keywords

coordinate, comparison, radiotherapy, determining, delineation, systems, margin, whole, breast

## Disciplines

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## A comparison of coordinate systems for use in determining a radiotherapy delineation margin for whole breast

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**Abstract.** Cartesian co-ordinates, traditionally used for radiotherapy margins, calculated at 6 points, may not adequately represent changes in inter-observer contour variation as necessary to define a delineation margin. As a first step, this study compared the standard deviation (SD) in contour delineation using Polar and Cartesian co-ordinates for whole breast. Whole breast Clinical Target Volumes (CTV) were delineated by eight observers for 9 patients. The SD of contour position was determined for Polar co-ordinates at 1° increments for 5 slices and averaged across all patients. The mean centre of mass (COM) was used as the origin for the right breast, for the left the COM was shifted 1cm superiorly to avoid clipping. The SD was determined for Cartesian co-ordinates for medial-lateral and anterior-posterior positions. At slice Z=0cm considering Polar co-ordinates, the SD peaked medially reaching 3.55cm at 15° for the right breast, and 1.44cm at 171° for the left. The SD of the remaining slices maintained a similar distribution, with variation in the peak occurring within 10° of the Z=0cm positions. By comparison, for Cartesian co-ordinates at slice Z=0cm, the largest SD in the medial-lateral and anterior-posterior directions was 0.54/0.57cm and 1.03/0.67cm respectively for right/left breasts. The SD for inter-observer variation for whole breast varies with anatomical position. The maximum SD determined with Polar co-ordinates was greater than with Cartesian co-ordinates. A delineation margin may thus need to vary with angle over the entire structure and Cartesian co-ordinates may not be the best approach for margin determination for whole breast.

### 1. Introduction and Background

Radiotherapy treatment techniques have improved significantly with the implementation of; Intensity Modulated Radiotherapy (IMRT), Volumetric Modulated Arc Therapy (VMAT) and Image Guided Radiotherapy (IGRT). Further improvements in radiotherapy are achieved by setting clear delineation protocols, minimising set-up errors and imaging errors, and imaging for internal motion management (1). Delineation uncertainty arising from inter-observer variability has traditionally been ignored as larger systematic errors dominate. Inter-observer variability is still a significant uncertainty, even with clear delineation protocols and uncertainties from delineation, may now play a significant role in influencing the success of these improved techniques.



Although the inclusion of delineation margins in PTV margin recipes is well acknowledged in the literature as necessary, particularly with the introduction of more conformal delivery techniques calculation of these margins is rarely attempted. Studies have been performed for cancer sites such as the Prostate (2, 3) and the Brain (4) to optimise set-up and motion margins ignoring the inter-observer delineation uncertainties. These have shown that margins are necessary to reduce the likelihood of geographical misses, reduce effects from systematic errors (under-dosage) and reduce effects from random errors (blurring) (1). Margin formulae using the combined preparation/systematic  $\Sigma$  standard deviation and execution/random  $\sigma$  standard deviation such as  $2.5\Sigma + 0.7\sigma - 3mm$  (5), incorporate inter-observer variability within the preparation errors  $\Sigma$ . However this is performed with one value over the whole structure equally or with 3 values in 3 planes. As the inter-observer variation may be accurately determined over the whole structure (multiple angles and points), perhaps this adaptation should be performed before the other margin formula is applied. The appropriate amount or weight that this should have compared to the whole margin formula needs to be investigated further. Introduction of an additional margin, or ensuring PTV margins include the inter-observer variability margin, to account for breast delineation uncertainties would reduce the clinical impact of inter- and intra- observer variation. This has previously been performed using Cartesian co-ordinates for sites such as the prostate and seminal vesicles (6), partial breast (7), whole breast (8) and performed using spherical co-ordinates for sites such prostate (9) and bladder (10). Shape of the target will play a significant role in what co-ordinate system should be used.

## 2. Method

Datasets from 9 patients from a previous study were utilised (11). Volumes of the CTV were contoured by four breast cancer radiation oncologists (with experience ranging from 6 to over 20 years in oncology) and four radiation therapists (with experience ranging from 3 to 13 years). One sided whole breast Clinical Target Volumes (CTV) were outlined on transverse slices with a standard window level (0) and width (500). Radio-opaque wire was used to aid delineation. Each observer was allocated a unique letter to de-identify their contours. Observers were blind to other observer contours.

The standard deviation (SD) in delineation uncertainty using Polar co-ordinates for 360 degrees in 1 degree increments and in Cartesian co-ordinates (the maximum in each X and Y direction) for whole breast was compared. As the CTV structure may be easily elongated many papers calculate the deviation in the cardinal directions (from the geometric center co-ordinates in 6 directions) and perform this adaption enabling some change over the entire volume. This has been generally undertaken to account for tumour motion, however for interobserver error a more detailed expansion at many directions may be necessary. For this study 360 interpolated points were calculated for each slice Z in Cylindrical coordinates and compared to the Cartesian cardinal points and extensions. The interpolation at 1 degree increments were compared with the original structures to ensure the shape of the structures remained constant.

The standard deviation (SD) of this was calculated for slices as in equation (1) for Cylindrical co-ordinates and equation (4) for Cartesian co-ordinates.

### 2.1. Cylindrical Co-ordinates

The contours were input into CERR as DICOM RT structure sets and associated Cartesian co-ordinates (X,Y,Z) were determined for each patient and observer at the selected slices. The Cartesian co-ordinates were then converted into Cylindrical co-ordinates for analysis. The SD of contour positions were determined for cylindrical co-ordinates at  $\theta=1^\circ$  increments for 5 slices ( $Z=-2cm, -1cm, 0cm, 1cm$  and  $2cm$  from the origin) for each patient using equation (1).

$$SD = \sum_{interobserver, radial}^j(\theta, Z) = \sqrt{\frac{\sum_{i=1}^N (r_i^j(\theta, Z) - \bar{r}_{obs}^j(\theta, Z))^2}{N-1}} \quad (1)$$

Where N is the total number of observers per patient and  $\bar{r}$  is the radius averaged over all observations, Z is the slice or Height of the structure in cm, j is the inter-observer and  $\theta$  is the Polar

angle ranging from 0-360 degrees. The mean center of mass (COM) was used as the origin for the right breast, for the left the COM was shifted 1cm superiorly to avoid clipping of the structure.

If an observer did not have a contour on a distal slice e.g.  $Z=2\text{cm}$  the number of observers was reduced to those present. A margin to account for margin delineation uncertainty (MDU) was then calculated as in equation (2). This is not recommended and is simply a preliminary study into the validity of including inter-observer margins in multiple directions in PTV margin recipes.

$$MDU_{\theta,Z}^i = 4 \times SD_{\theta,Z}^i \quad (2)$$

Where SD is the standard deviation,  $i$  the patient number and  $\theta, Z$  indicate the direction. This margin was selected such that 95% of the contoured union volume would be included for any of the initial contours assuming a gaussian distribution of contour variation. The margin to be used on a new patient would be calculated using all 9 previous patient datasets as outlined in equation (3). Where  $P$  is the total number of patients.

$$MDU_{\theta,Z}^{general} = \frac{\sum_{j=0}^P MDU_{\theta,Z}^j}{P} \quad (3)$$

## 2.2. Cartesian Co-ordinates

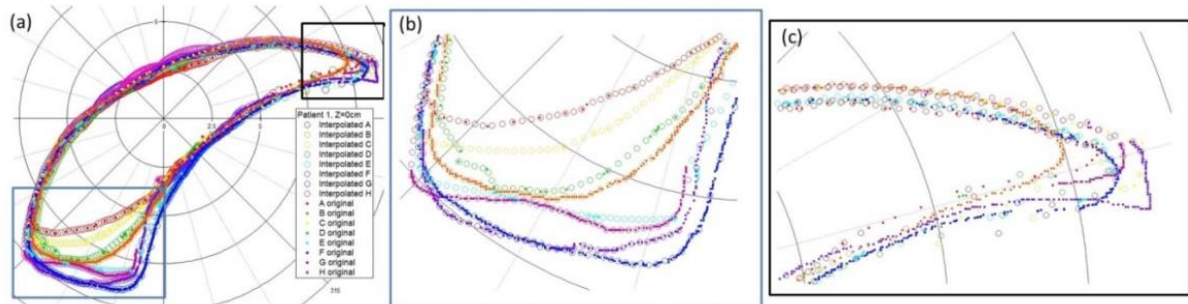
The SD and MDU were determined for Cartesian co-ordinates for medial-lateral and anterior-posterior positions, following previously published methodology (8). If inter-observer variability is considered in studies the SD is calculated usually in only 6 directions as treatment planning systems typically allow extension only in the anterior (A), posterior (P), superior (S), inferior (I), lateral (L) and medial (M) directions by one value for all points (from the average COM). The SD is outlined in equation (4). Where  $x_d$  is the pixel position, in cm, at the edge of the contour in the appropriate direction ( $d=A, P, S, I, M$ , or  $L$ ). And  $x_{com}$  is the average centre of mass co-ordinate also in that direction ( $d$ ).

$$SD = \sqrt{\frac{\sum_{i=1}^N [(x_{i,d} - x_{i,d,com}) - (x_{i,d} - x_{i,com})]^2}{N-1}} \quad (4)$$

The MDU is found as in equation (2-3), where  $d$  is the directions replacing  $\theta$  and  $Z$  (A, P, S, I, L or M). The MDU was added onto the observer contour in all 6 directions to generate a CTV with a margin to account for inter-observer errors. For all methodologies the MDU would be clipped to the Skin, Lung, Heart, Muscle interface and the Medial border if necessary.

## 3. Results

Figure 1 displays the interpolation points and original points of eight contours on one patient at slice  $Z=0$  for Polar interpolation at 1 degree increments, indicating consistency through the interpolation without clipping or diverging.



**Figure 1. (a) Interpolated data points in Polar co-ordinates for patient 1 at slice  $Z=0$ . The interpolated points are shown as circles and the original data-points are shown as dots. The same colour has been used for each observer. Parts (b) and (c) are zoomed in pictures of the whole structure as indicated on part (a) using a blue and black box respectively.**

The interpolation used linear interpolation at 1 degree increments. The over-all uncertainty for  $Z=0$  is plotted for patient 1 in Figure 2.



Figure 2. The contours at  $Z=0$  for patient one, with the overall uncertainty for all patients at  $Z=0$  overlaid in red.

Figure 2 highlights the anatomical borders that are most affected by the uncertainty.

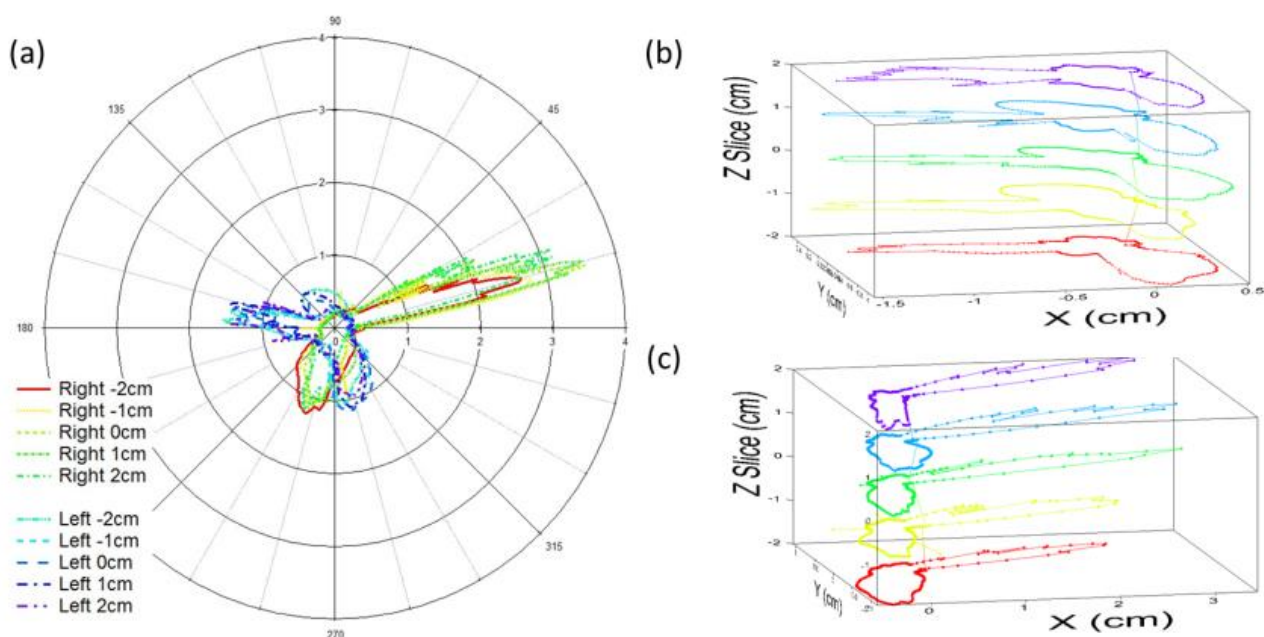


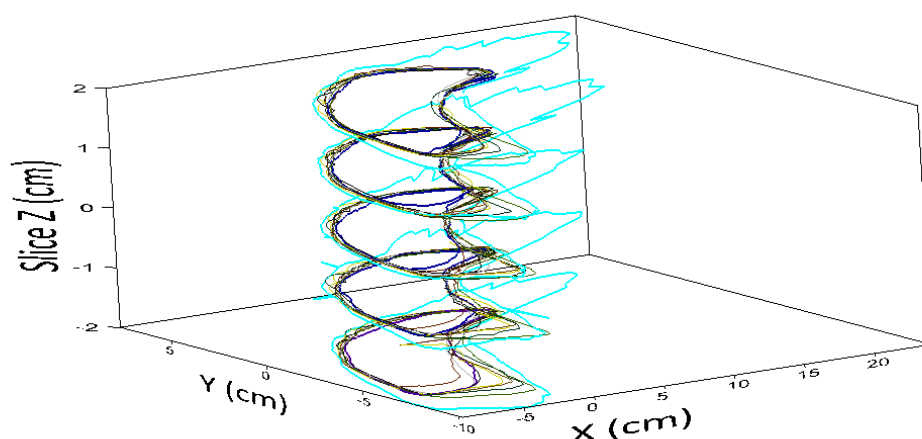
Figure 3. (a) The uncertainty (one standard deviation) derived from 9 patients (5 patients with right breast cancer and 4 with left breast cancer) utilising 8 observers calculated in Polar co-ordinates for  $Z=-2,-1,0,1,2$ cm. The R axis is displayed here in cm. This is shown in three dimensions in (b) and (c) for the left and right breast respectively.

At slice  $Z=0$ cm considering Polar co-ordinates (lateral= $0^\circ$ ), the SD peaked medially reaching 3.55cm at  $15^\circ$  for the right breast, and 1.44cm at  $171^\circ$  for the left (see Figure 3.). The SD of the remaining slices maintained a similar distribution, with variation in the peak occurring within  $10^\circ$  of the  $Z=0$ cm positions. In comparison, for Cartesian co-ordinates at slice  $Z=0$ cm, the largest SD in the medial-lateral and anterior-posterior directions was 0.54/0.57cm and 1.03/0.67cm respectively for right/left breasts. The average MDU for the cardinal directions in Cartesian co-ordinates is displayed in Table 1 (8).

**Table 1. Standard Deviation and Margin to account for delineation uncertainty in Cartesian co-ordinates.**

Direction	Anterior	Posterior	Medial	Lateral	Superior	Inferior
Right SD (cm)	0.40	0.22	1.15	1.48	0.52	0.79
Left SD (cm)	0.32	0.46	1.70	1.13	0.46	0.64
Left MDU (cm)	1.28	1.82	1.13	1.70	1.83	2.57
Right MDU (cm)	1.61	0.87	1.15	1.48	2.07	3.17

It may be seen in Figure 4 that for every contour the additional margin of 4 SD is in line with the statistical account of 95% for any observers contour. This was also the case for  $Z=-2\text{cm}$ ,  $-1\text{cm}$ ,  $1\text{cm}$  and  $2\text{cm}$  as shown in Figure 4 for Patient 1.



**Figure 4. Patient 1 (Right breast) contours are all within the minimum MDU calculated from Cylindrical co-ordinates. All 8 observers lie within the minimum observers contour with the addition of the MDU. The thin lines are observers 1-7, observer 8 contour (minimum contour) is the thick dark blue line. The light blue thick line is the MDU of observer 8. Each observers contour is of a different colour consistent through all slices.**

This is the case for all the patients, only one patient is shown as an example for clarity. The average standard deviation was calculated separately for left and right breast patients.

#### 4. Conclusion

It has been shown that there is more accuracy in calculating a standard deviation at multiple points (1 degree increments) to extend the CTV to account for inter-observer error, rather than extending X, Y and Z by their cardinal variances. Margins are larger in some directions using Cylindrical co-ordinates than if the contour was extended by these cardinal variances. This highlights the regions where inter-observer variation is high such as both edges of the contours for both left and right breast patients. At slice  $Z=0\text{cm}$  considering Polar co-ordinates (lateral= $0^\circ$ ), the SD peaked medially reaching  $3.55\text{cm}$  at  $15^\circ$  for the right breast, and  $1.44\text{cm}$  at  $171^\circ$  for the left. The SD of the remaining slices maintained a similar distribution, with variation in the peak occurring within  $10^\circ$  of the  $Z=0\text{cm}$  positions. By comparison, for Cartesian co-ordinates at  $Z=0\text{cm}$ , the largest SD in the medial-lateral and anterior-posterior directions was  $0.54/0.57\text{cm}$  and  $1.03/0.67\text{cm}$  respectively for right/left breasts. Future work will calculate and compare Cartesian co-ordinates at every point to Cylindrical co-ordinate calculations. Sensitivity to COM variations and a spherical co-ordinate analysis method is also being investigated. Incorporation into a margin recipe that includes organ motion, set-up errors and random errors should be investigated for clinical implementation. A method of extending contours outside six directions (e.g. 360 directions) used in treatment planning systems also requires investigation.

## 5. Acknowledgement

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