


Atlas Sampling for Prone Breast Automatic Segmentation of Organs at Risk: The Importance of Patients' Body Mass Index and Breast Cup Size for an Optimized Contouring of the Heart and the Coronary Vessels

Technology in Cancer Research & Treatment
Volume 19: 1-8
© The Author(s) 2020
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1533033820920624
journals.sagepub.com/home/tct


Xinzhao Wang, MD^{1,2}, Raymond Miralbell, MD^{2,3},
Odile Fargier-Bochaton, MD², Shelley Bulling, MS⁴,
Jean Paul Vallée, MD⁵, and Giovanna Dipasquale, MS²

Abstract

Objective: Delineation of organs at risk is a time-consuming task. This study evaluates the benefits of using single-subject atlas-based automatic segmentation of organs at risk in patients with breast cancer treated in prone position, with 2 different criteria for choosing the atlas subject. Together with laterality (left/right), the criteria used were either (1) breast volume or (2) body mass index and breast cup size. **Methods:** An atlas supporting different selection criteria for automatic segmentation was generated from contours drawn by a senior radiation oncologist (RO_A). Atlas organs at risk included heart, left anterior descending artery, and right coronary artery. Manual contours drawn by RO_A and automatic segmentation contours of organs at risk and breast clinical target volume were created for 27 nonatlas patients. A second radiation oncologist (RO_B) manually contoured (M_B) the breast clinical target volume and the heart. Contouring times were recorded and the reliability of the automatic segmentation was assessed in the context of 3-D planning. **Results:** Accounting for body mass index and breast cup size improved automatic segmentation results compared to breast volume-based sampling, especially for the heart (mean similarity indexes >0.9 for automatic segmentation organs at risk and clinical target volume after RO_A editing). Mean similarity indexes for the left anterior descending artery and the right coronary artery edited by RO_A expanded by 1 cm were ≥ 0.8 . Using automatic segmentation reduced contouring time by 40%. For each parameter analyzed (eg, $D_{2\%}$), the difference in dose, averaged over all patients, between automatic segmentation structures edited by RO_A and the same structure manually drawn by RO_A was <1.5% of the prescribed dose. The mean heart dose was reliable for the unedited heart segmentation, and for right-sided treatments, automatic segmentation was adequate for treatment planning with 3-D conformal tangential fields. **Conclusions:** Automatic segmentation for prone breast radiotherapy stratified by body mass index and breast cup size improved segmentation accuracy for the heart and coronary vessels compared to breast volume sampling. A significant reduction in contouring time can be achieved by using automatic segmentation.

Keywords

breast cancer, prone, automatic segmentation, heart, LAD, RCA, contouring time

¹ Division of Radiation Oncology, Tianjin Union Medicine Center, China

² Division of Radiation Oncology, Geneva University Hospital, Switzerland

³ Institut Oncològic Teknon, Barcelona, Spain

⁴ Centre d'Oncologie des Eaux-Vives, Geneva, Switzerland

⁵ Radiology division, Diagnostic department, Geneva University Hospital and University of Geneva, Geneva, Switzerland

Corresponding Author:

Giovanna Dipasquale, Division of Radiation Oncology, Geneva University Hospital, CH-1211 Geneva 14, Switzerland.

Email: giovanna.dipasquale@hcuge.ch



Abbreviations

AS, automatic segmentation; BCS, breast cup size; BH, breath-hold; BMI, body mass index; CT, computed tomography; CTV, clinical target volume; LADA, left anterior descending artery; M, manual; OARs, organs at risk; PTV, planning target volume; RCA, right coronary artery; SD, standard deviation.

Received: June 19, 2019; Revised: March 10, 2020; Accepted: March 24, 2020.

Introduction

Treatment planning for breast radiotherapy requires contouring of several organs at risk (OARs) in order to optimize the dose distribution and prevent potential treatment-related complications. Manual organ contouring is a complex and time-consuming task. Several automatic segmentation (AS) programs have been developed and used to reduce contouring time and improve inter- and intraobserver reproducibility.¹⁻⁶ Atlas-based AS software can adopt different strategies. The approach adopted by the one used in this study allows the selection of only one representative subject from the atlas library. This approach is different from a multiple subject approach, which is generally considered more performing.

In a previous study, the Smart Segmentation knowledge-based contouring tool (Varian Medical Systems, Palo Alto, California) showed that AS was useful for contouring the clinical target volume (CTV).² For autosegmentation of the CTV to work well, breast volume was used to sample the atlas library. It was not clear, however, whether organs with dimensions unrelated to the breast volume—such as the heart—could be automatically contoured to satisfaction without introducing other anatomic parameters to the atlas algorithm. Ideally, AS should be able to contour both the breast CTV and the heart and give results for the similarity index of the heart of >0.9 .

The purpose of this study was to test the hypothesis that using body mass index (BMI) and breast cup size (BCS) could improve the performance of AS of OARs for breast radiotherapy in prone position. We were particularly interested in AS results for the heart and the main coronary vessels.

Material and Methods

Thirty-six subjects (18 left breast and 18 right breast) were selected from our institution database to constitute an atlas for contouring of CTV and OARs for breast radiotherapy, including the heart, the left anterior descending artery (LADA), and the right coronary artery (RCA), see Table 1. For validation, manual (M) and AS contours of OAR and breast CTV were created for 27 additional “nonatlas” subjects, Table 1. Two different criteria were tested for selecting the subject from the atlas to be used for AS. Together with laterality (left/right), one criteria (AS1_AS) sampled for breast volume, while the other (AS2_AS) sampled for BMI and BCS. The same group of 40 patients (13 atlas cases and 27 test cases) that has been previously described,² extended with additional patients for the atlas, was used in this study. All patients gave written informed consent and were

representative of a population of different breast shapes and sizes. Breast volume sampled for 3 volume sizes, ($<600\text{ cm}^3$, $600\text{-}1100\text{ cm}^3$, and $>1100\text{ cm}^3$).² Published data correlating BMI with heart volume⁷ for a group of female patients receiving radiotherapy was used to sample BMI into 3 levels ($<24\text{ kg/m}^2$, $24\text{ to }28\text{ kg/m}^2$, and $>28\text{ kg/m}^2$). For a complete atlas library, stratifying patients according to BCS A to F, and 3 distinct BMI levels, 36 atlas patients were needed, that is, 2 sets of 18 atlas cases (for laterality).

In order to validate the segmentation tool, the selection criteria, and the atlas library, the 27 test subjects were contoured manually by the senior radiation oncologist (RO_A, M_A contours) and automatically contoured with the 2 different subject selection criteria (AS1 and AS2 structures). After that, AS contours were edited by the senior radiation oncologist RO_A (producing AS1_EA and AS2_EA contours). A second radiation oncologist (RO_B) independently manually contoured (M_B) the CTV and heart to evaluate interobserver variability. RO_B edited only AS2 CTV and heart contours (AS2_EB).

The CTV and OARs of the atlas library were manually segmented on noncontrast computed tomography (CT) axial slices of 3-mm thickness.² The contouring of the heart and coronary arteries was reviewed and validated by an experienced cardiovascular radiologist. The contouring of the heart, the LADA—for left-sided breast treatments—and the RCA—for right-sided breast treatments—was performed according to the recommendations of Feng *et al.*⁸ In particular, the delineation of the heart included the heart muscles, chambers, and the outermost fibrous layer of the pericardium. The coronary arteries crossing the epicardial fat were included in the heart contour. A 1-cm margin was added around the LADA and RCA, manually drawn or automatically segmented (LADA + 1 cm and RCA + 1 cm) as described by Kirby *et al.*⁹ As in clinical practice, lung contouring was done automatically with the Eclipse version 11 treatment planning system, with manual correction of the trachea and bronchus.

Table 1. Number of Subject Used for Atlas Sampling and Number of Test Patients.

	Atlas for AS1_AS and AS2_AS	Test Patients
No. of subjects: left side	18	11
No. of subjects: right side	18	16

Abbreviations: AS1_AS, automatic segmentation sampling by breast volume; AS2_AS, automatic segmentation sampling by body mass index and breast cup size.

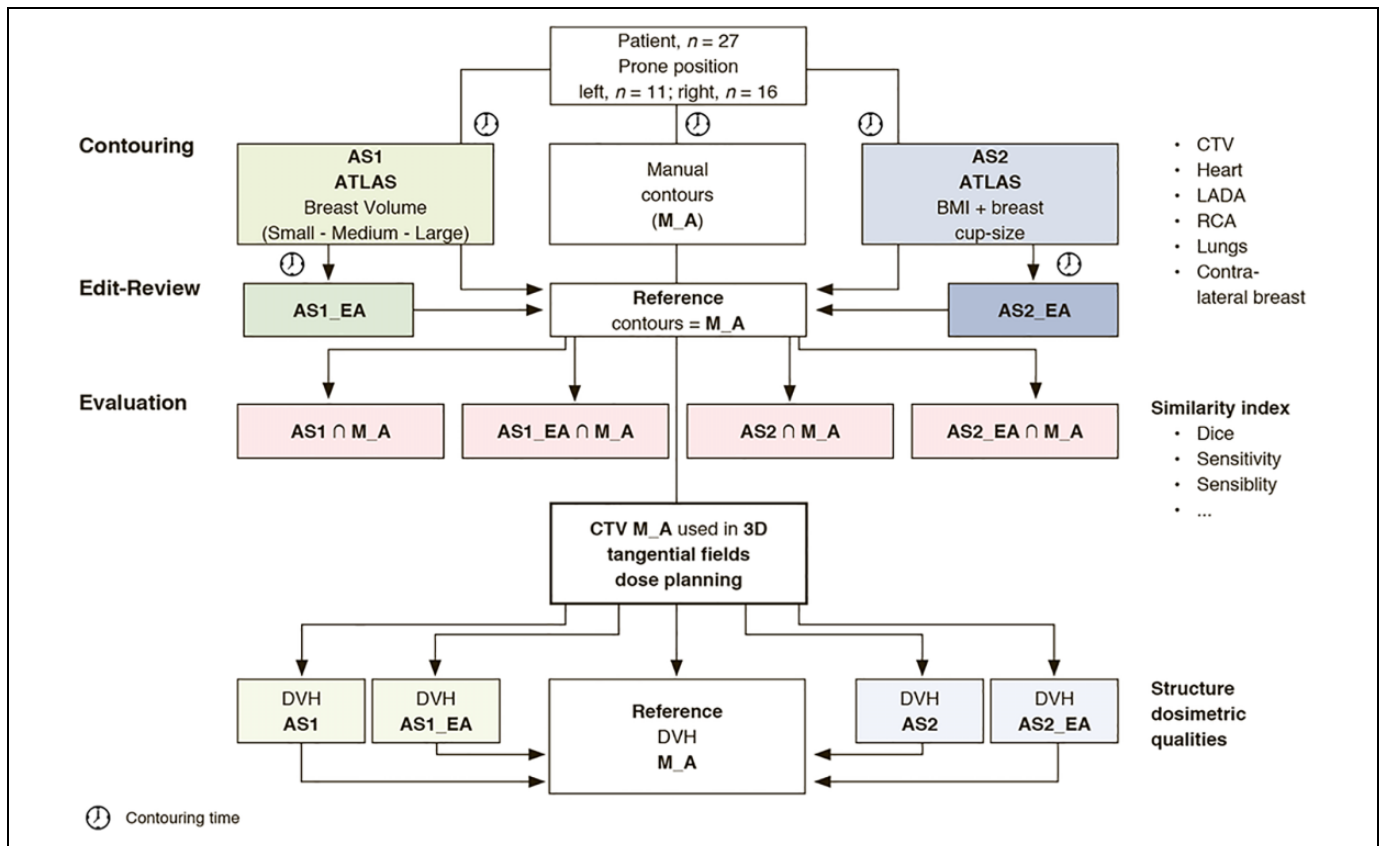


Figure 1. Study workflow.

Manually segmented organs, contoured by the same senior radiation oncologist (M_A), were compared to structures obtained via AS, with and without editing, in order to evaluate the reliability of the atlas-based AS algorithm and the criteria of atlas cases selection being tested. The similarity indexes between the reference manual structures M_A and the independently drawn structures of the second radiation oncologist M_B, as well as AS1, AS2, AS2_EA, and AS2_EB, were calculated and analyzed. The center of mass shifts and percentage volume differences were also reported.

For the CTV, as well as for each OAR, the similarity indexes ($DICE = 2(V_A \cap V_B) / (V_A + V_B)$), that measures the spatial overlap between two volumes, A structure (reference) and B structure, sensibility = $V_A \cap V_B / V_A$ and inclusiveness = $V_A \cap V_B / V_B$ indexes, percentage of volume difference, and absolute center of mass shifts) were calculated using VODCA (MSS GmbH, Hagendorf, Switzerland) software.² Figure 1 shows the general study workflow for comparing AS1_AS and AS2_AS.

3-D treatment plans using conformal tangential fields were generated on CTV manually contoured by RO_A. Dose-volume parameters were calculated for automatically segmented OARs with and without editing (AS1, AS2, AS1_EA, AS2_EA; Figure 1). Treatment plans were prepared using Eclipse and calculated using the *Analytical Anisotropic Algorithm*.¹⁰ The planning target volume (PTV) was obtained by expanding the CTV with a 5-mm margin, while cropping

5 mm inside the breast skin surface. To avoid interfering with the AS process being investigated, the dose to the heart was not optimized (compared to our actual clinical practice where the multileaf collimator is used to shield the heart). Dose prescription to the PTV (50 Gy in 25 fractions) required at least 95% of the PTV to receive 95% of the prescribed dose, with no more than 2% of the PTV exceeding 107% of the prescribed dose. Dose-volume histograms were used to get dose-volume information such as the mean dose and the dose to 2%, 5%, and 10% of the organ ($D_{2\%}$, $D_{5\%}$, and $D_{10\%}$, respectively) for all OARs and segmentation type. Finally, we measured contouring times to determine whether AS plus manual editing was faster than manual contouring alone. The *Wilcoxon signed rank test* was used to evaluate the similarity indexes, dosimetric parameters, and contouring times for the different contouring methods and OARs.

Results

A selection of atlas subjects based on BMI and BCS gave the best AS results for the heart and coronary arteries. Figure 2 presents 3 patients with left-sided breast targets, where the heart and the LADA, in addition to being manually contoured (M_A), were automatically segmented either by selecting atlas samples stratified by breast volume only (AS1 structures) or by selecting atlas samples stratified by BMI and BCS (AS2

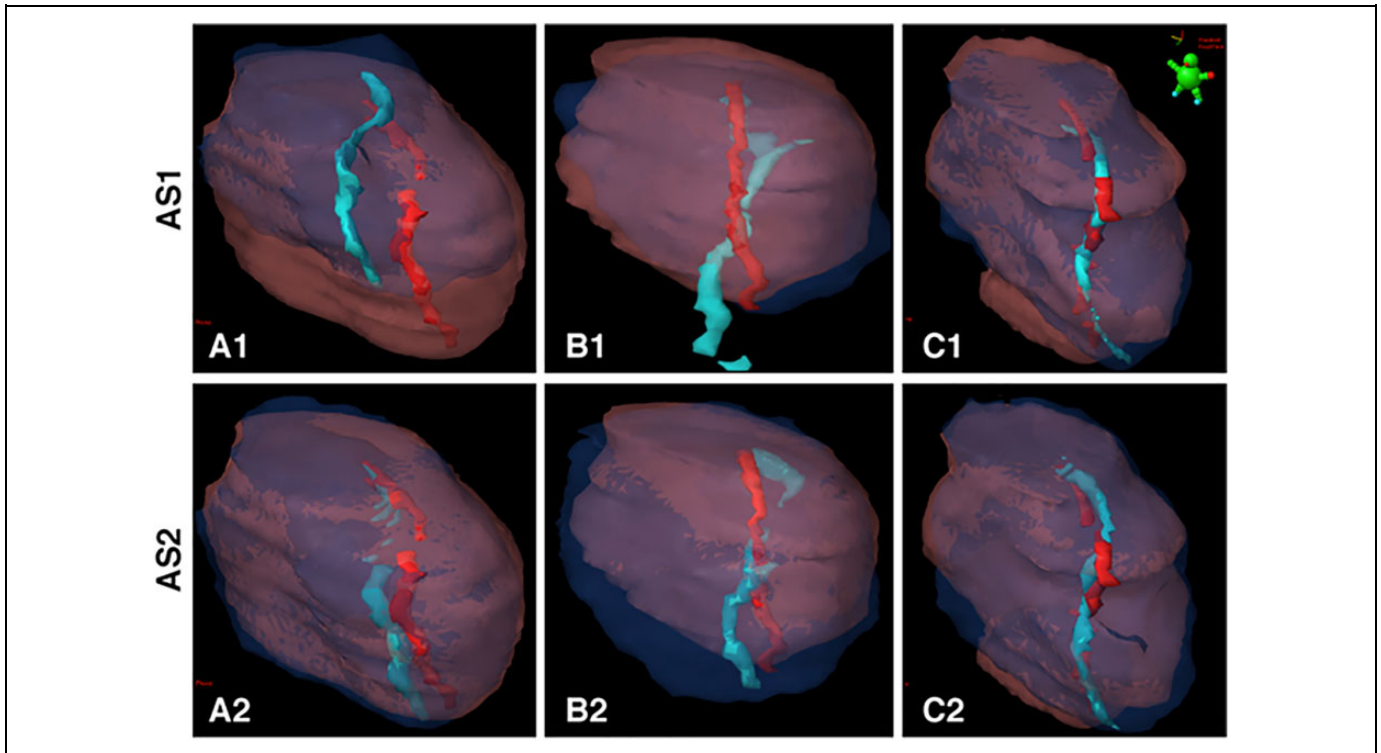


Figure 2. Heart and left anterior descending artery (LADA) contours segmented on computed tomography images for 3 different patients (left to right) A, B, and C. The heart (dark blue) and LADA (cyan) contours after automatic segmentation 1 (AS1) are shown for the three patients, in A1, B1 and C1 figures (top row) and after automatic segmentation 2 (AS2) in A2, B2 and C2 figures (bottom row). Manually segmented organs are also shown for the 3 patients (pink for the heart and red for the LADA).

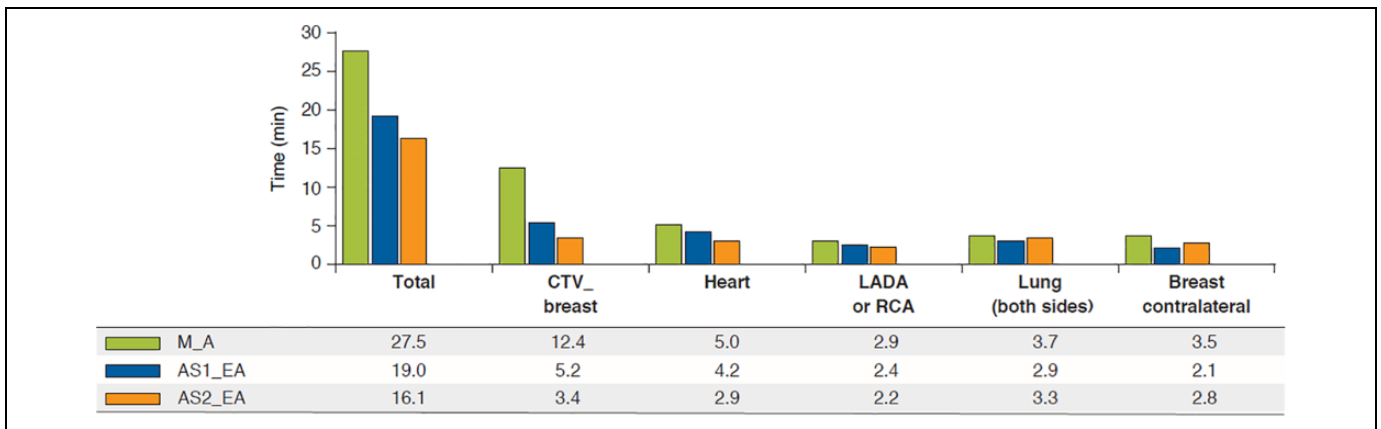


Figure 3. Contouring times of manual versus automatic segmentation with editing.

structures). Manual segmentation by RO_A, that is, M_A, was the reference for comparison of both AS algorithms.

The mean DICE and sensibility values for the heart increased from 0.89 and 0.88 for AS1 structures to 0.91 and 0.92 for AS2 structures, respectively ($P < .05$) and an optimal inclusiveness index of 0.91. Unlike for the heart, similarity index mean values were low for the LADA and the RCA (ie, 0.1-0.2), regardless of the AS atlas that was used. However, when the LADA and the RCA were expanded by 1 cm, the similarity index improved for both AS algorithms, approaching

values of 0.5 for the RCA + 1 cm and 0.7 for the LADA + 1 cm. For the LADA, the improvement in the similarity index was more marked when using AS2_AS compared to AS1_AS. For example, the minimum DICE of LADA + 1 cm after AS1_AS increased compared to AS2_AS from 0.25 to 0.55. A significant improvement in the similarity indexes mean value using AS2_AS, compared to AS1_AS, was not observed after editing the AS2 LADA and RCA and adding 1-cm margin expansion to the contours. Similarity index values after editing by RO_A increased from 0.5 and 0.7 to ≥ 0.8 . Concerning

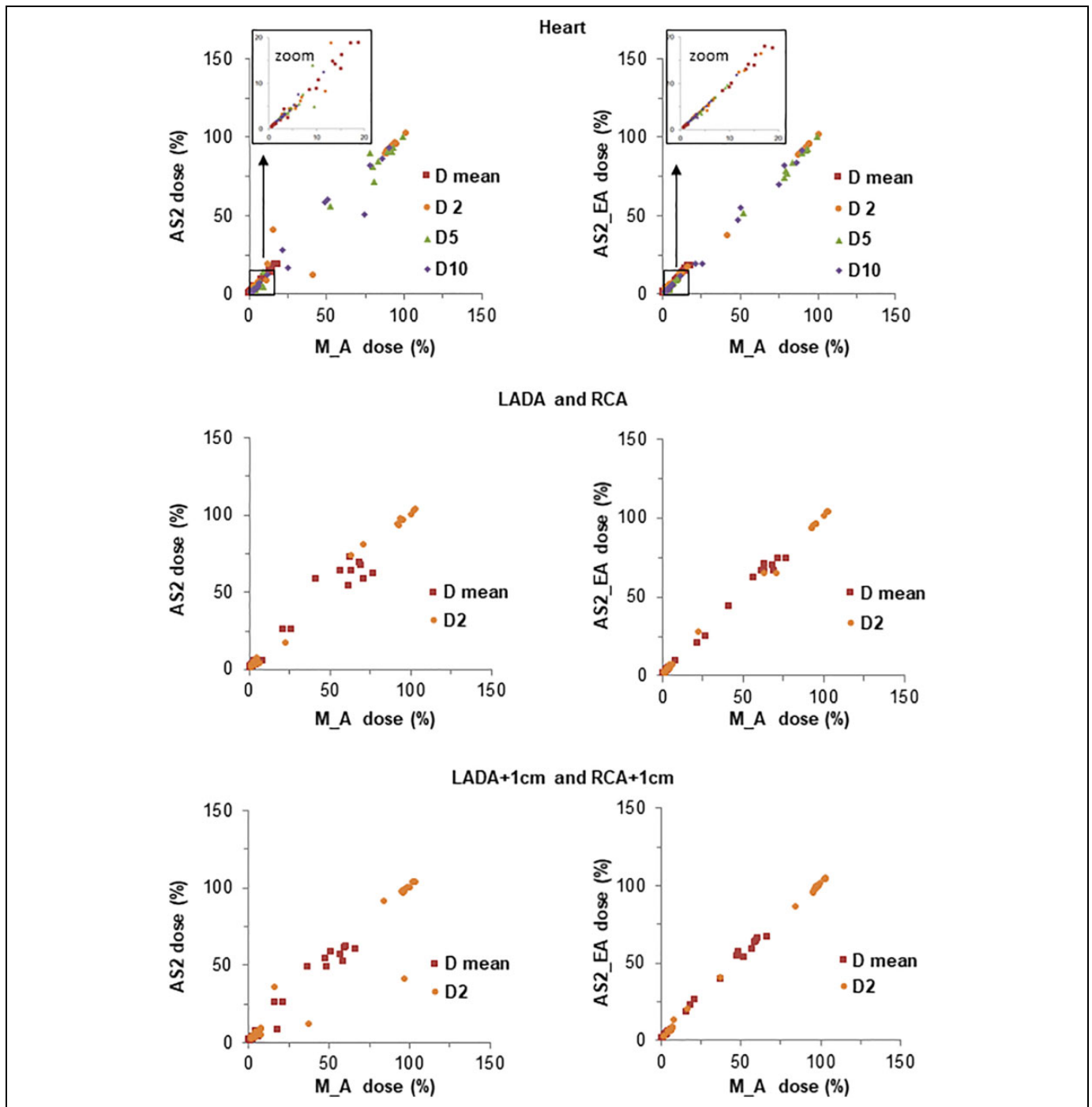


Figure 4. Dose–volume parameters for the heart, the left anterior descending artery (LADA), the LADA + 1 cm, the right coronary artery (RCA), and the RCA + 1 cm after automatic segmentation (AS2) and after editing by RO_A, AS2_EA, plotted against the same values obtained for manually contoured structures, M_A.

center of mass shifts, the largest difference was in the LADA's lateral coordinate and in the RCA's cranial–caudal one, with shifts remaining after editing by RO_A.

The time taken for complete AS of the breast CTV and the OARs was $2.1 (\pm 1.3)$ and $1.5 (\pm 1.5)$ minutes (mean \pm standard deviation [SD]) for AS1_AS and AS2_AS, respectively. Figure 3 shows the average times required for contouring and

for AS with editing/reviewing by RO_A. The segmentation/review/editing of all structures contoured with AS2_AS was faster than the segmentation/review/editing with AS1_AS. A mean (\pm SD) time gain of $8.5 (\pm 3.3)$ minutes and $11.4 (\pm 2.4)$ minutes was observed for contouring the CTV and the OARs with AS1_AS and AS2_AS, respectively, compared with manual contouring ($P < .01$).

Table 2. CTV and Heart Similarity Indexes Comparing the 2 Radiation Oncologist Contours: The Senior Radiation Oncologist (RO_A), With Its Reference Contours (M_A), Versus the Second Radiation Oncologist (RO_B), Whose Manual Contours Are Tagged as M_B.

Groups	1	2	1 vs 2	3	4	3 vs 4
	M_B vs M_A Mean (SD)	AS2 vs M_A Mean (SD)	P Value	M_B_EA vs M_A Mean (SD)	AS2_EA vs M_A Mean (SD)	P Value
CTV						
DICE	0.93 (0.03)	0.91 (0.02)	.933	0.96 (0.02)	0.95 (0.01)	.002
Sensibility	0.95 (0.04)	0.92 (0.04)	.614	0.96 (0.03)	0.96 (0.02)	.073
Inclusiveness	0.92 (0.05)	0.91 (0.04)	.572	0.95 (0.03)	0.95 (0.02)	.103
Center of mass shifts						
X = R-L (mm)	3.5 (4.6)	4.2 (3.5)	.706	2.6 (3.4)	2.0 (1.8)	.239
Y = A-P (mm)	3.7 (3.3)	3.2 (2.2)	.141	2.3 (2.7)	1.9 (1.5)	.501
Z = C-C (mm)	8.9 (6.5)	7.3 (5.0)	.511	4.7 (4.1)	5.5 (5.1)	.017
Volume difference (%)	2.0 (8.6)	-3.6 (6.1)	.011	0.9 (4.4)	-1.7 (3.5)	.349
Heart						
DICE	0.93 (0.03)	0.91 (0.02)	.002	0.95 (0.01)	0.94 (0.01)	.001
Sensibility	0.94 (0.03)	0.92 (0.04)	.553	0.95 (0.01)	0.96 (0.02)	.866
Inclusiveness	0.92 (0.04)	0.91 (0.04)	.001	0.95 (0.02)	0.93 (0.02)	.001
Center of mass shifts						
X = R-L (mm)	0.5 (0.4)	1.7 (1.5)	.782	0.7 (0.6)	0.7 (0.6)	.034
Y = A-P (mm)	1.6 (1.3)	1.9 (1.9)	.004	1.1 (1.0)	1.1 (0.7)	.181
Z = C-C (mm)	2.3 (2.3)	3.3 (2.7)	.030	1.0 (1.4)	2.3 (1.8)	.014
Volume difference (%)	2.4 (6.5)	3.4 (7.0)	.407	0.2 (2.8)	-1.1 (4.3)	.656

Abbreviations: A-P, anterior–posterior; AS2, automatically segmented structures obtained when sampling by body mass index and breast cup size; AS2_EA, automatically segmented structures obtained when sampling by body mass index and breast cup size and edited by RO_A; C-C, cranial–caudal; CTV, clinical target volume; M_A, manual structures contoured by RO_A; M_B, manual structures contoured by RO_B; M_B_EA, manual structures contoured by RO_B and edited by RO_A; R-L, right–left; RO_A, senior radiation oncologist; RO_B, second radiation oncologist; SD, standard deviation.

For specific dose parameters (eg, $D_{2\%}$), the difference in dose between AS1_EA (or AS2_EA) structures and manually contoured structures (M_A) was calculated and the value was averaged over all patients. Averaged over all patients, the difference was less than 1.5% of the prescribed dose for any organ and dose parameter analyzed. No significant difference in dose was observed between AS1_EA contours and AS2_EA contour. Nevertheless, editing AS2 structures was faster than editing AS1 contours, implying that structure quality was superior, as described by the similarity indexes.

Dose–volume parameters for the heart, the LADA, and the RCA for AS2 and AS2_EA structures are plotted against values obtained for the corresponding M_A structures in Figure 4. The plots show good agreement between AS2 and M_A contours regarding dose to the heart. Furthermore, no differences were observed between mean values of the dose parameters analyzed comparing AS2 and AS2_EA. For right-sided treatments, unedited AS2 heart structures could reliably be used for planning 3D conformal tangential fields. For left-sided treatments, however, the heart $D_{2\%}$ was different for AS2 compared to M_A with a mean (\pm SD) dose difference of 3.2% (\pm 7.3%). Editing the AS2 heart structures for left-sided treatments resulted in a heart $D_{2\%}$ similar to that calculated from manual contours with a mean (\pm SD) dose difference of -0.5% (\pm 0.8%; $P = .02$).

For the LADA and the RCA, dose–volume parameters after AS1 and AS2 were different from the reference contours. Even editing the autosegmented LADA and RCA contours after AS did not result in the same dose distribution parameters as for the reference contours.

Lung AS performed to satisfaction in terms of overlap and dose parameters, except for the segmentation of lung tissue adjacent to the diaphragm, where AS was less reliable. However, in the context of prone treatment position, this limitation contributed weakly to the variation in the estimated mean dose to the lungs.

Contralateral, nontarget, breast contouring was not optimal after either AS1_AS or AS2_AS with similarity indexes as low as 0.84 compared to edited structures, AS1_EA and AS2_EA, with similarity indexes ≥ 0.87 . There was no marked difference between AS1_EA and AS2_EA structures.

Concerning interobserver variability for the CTV, there is little difference between automatic, AS2, and M_B. For the heart, there is more variability in the results with manual M_B contours comparing better to M_A structures with respect to AS2 (see Table 2). Editing automatically segmented structures, CTV and heart, improved similarity indexes and other parameters, but editing manual structures (M_B_EA) could have superior result for some indexes. AS2_EA heart structures ≥ 0.93 and equal to 0.95 for M_B_EA. Concerning the center of mass, the differences in mean values were in the order of 1 mm.

Discussion

To optimally plan breast cancer treatments with radiotherapy, it is important to reliably contour the CTV and OARs, especially the heart, the LADA, and potentially also the RCA. In this study, including BMI and BCS in the AS atlas library resulted in a better sampling method for more reliable contouring of the heart and coronary vessels—much better than by sampling

patients stratified by breast volume alone, as is usually performed for AS of the breast CTV. The CTV continued to be correctly segmented when using BMI and BCS to sample the atlas (see Table 2), in comparison to our previous data.²

Automatic segmentation of the heart in prone position may be as reliable as data reported in the literature for patients treated in supine position.¹¹ Indeed, in the present study, after heart editing (AS2), mean DICE (SD) values improved from 0.91 (0.02) to 0.94 (0.01), which compares favorably with data from Lorenzen *et al*¹² and Kaderka *et al*.¹³ Lorenzen *et al* reported a mean (range) interobserver DICE value of 0.93 (0.91-0.95), the same DICE value we obtained using data from the second radiation oncologist (Table 2), while Kaderka *et al* reported a mean (SD) DICE of 0.93 (0.02). Automatically segmented/edited CTV and heart structures compared well with manually segmented structures of the second radiation oncologist, with similarity indexes ≥ 0.95 for CTV and ≥ 0.93 for the heart. In another study, Lorenzen *et al* tested an atlas-based AS algorithm for heart contouring on the same group of patients and analyzed the result in terms of dose and clinical significance.³ To obtain good results, they needed 8 to 9 atlas cases to reach an acceptable mean dose compared to manual contouring, but the heart AS time was approximately 30 minutes. Their mean heart dose difference between “unedited” automatic and manual segmentation was 0.1%, which is similar to our prone AS2 (ie, 0.1%), notwithstanding the anatomical differences of the heart in relation to the anterior chest wall when lying in either prone or supine position.

For left-sided breast cancers, unlike right-sided ones, the heart, in contact with the chest wall and exposed to high doses, needed further editing, considering that the heart $D_{2\%}$ differed significantly for manual contours (M_A) and AS2-based contours.

Concerning the mean difference in dose of the order of 1.5% for the OARs, it is difficult to evaluate its clinical impact. Nevertheless, for the heart, it could translate into an increased/decreased risk of ischemic heart disease.¹⁴ For a dose prescription of 50 Gy, it would correspond to a dose of 0.75 Gy and a predicted percent increase/decrease in rate of a major coronary event of 5.5% according to Darby *et al*.¹⁴ To reduce the risk of coronary events, supine treatments in breath-hold (BH) are often preferred to prone for left breast treatments.¹⁵ Nevertheless, Mulliez *et al*^{16,17} have shown that prone treatment in deep inspiration BH can be superior to supine. Therefore, atlas-based segmentation for prone, and prone BH position, should also be investigated and contouring guidelines developed for prone breast radiotherapy as this technique has the potential to reduce cardiac risks.

The LADA and the RCA contours drawn with either AS1 or AS2 overlapped poorly with the manually drawn structures, though with some improvement after editing. The poor spatial overlap was partly due to the LADA and the RCA anatomical characteristics, that is, small volume, slender, and twisted, with motion artifacts, and challenging to identify on CT images. We observed that the RCA was even more difficult to contour than the LADA (lower conformity index), as also reported by Feng

et al, when analyzing supine BH images from breast treatments.⁸ The LADA contouring has always been challenging, even among experienced observers,¹² and the use of dynamic CT imaging may not improve the LADA’s identification.¹⁸

Contouring of the contralateral, non-target breast, with the prone technique presented in this report, was not optimal after either AS1 or AS2. Editing, however, improved DICE values to 0.9 and above in both cases. So far, the prone breast irradiation technique has focused mostly on improving the target breast repositioning reliability and has been less concerned with the repositioning reproducibility of the contralateral non-target breast, often randomly compressed against the treatment board. This is not a major constraint when 3-D conformal treatment techniques with tangential fields are used, but it may present a problem if volumetric modulated arc techniques are used to treat patients lying in prone position. In this case, the contralateral breast may receive a fraction of low to intermediate dose that has to be accounted for if the contralateral breast has already been irradiated or to allow for an eventual future radiotherapy.

Editing after AS in order to contour the CTV and OARs in patients treated in prone position was 30% to 40% faster than manual contouring (time reduction to <15 minutes). This achievement has been possible as a result of enlarging the library with additional atlas cases. Sampling patients according to BCS A to F, and 3 distinct BMI levels, resulted in 2 sets of 18 atlas patients (right and left). This number may look large, but we have to underline that it includes almost all BCS. To optimize AS results, it may be of primary importance to feed the algorithm with the right parameters that optimally define the atlas. Furthermore, a multiatlas approach containing multiple images available for coregistration with the test image may further help to obtain the best segmentation result for each organ.¹⁹ Whichever the best choice of AS tool, it is clear that in the era of “big data,” AS will become an important element in data analysis because it will help contour in a systematic way thousands of images to better estimate radiation doses. Kaderka *et al*¹³ have stressed this point in their study on geometric and dosimetric evaluation of atlas-based autosegmentation of cardiac structures in patients with breast cancer. Our data on the possible use of unedited AS heart structures, to evaluate mean heart doses, and the results from the study of Kaderka *et al*¹³ should encourage further research in this direction.

There are several limitations to this retrospective study. Among these, the most significant may be that the dosimetric analysis is only valid for 3-D tangential conformal planning. We also did not evaluate any possible improvement in inter-observer variability when using AS. This should be assessed in a future study with multiple observers.

Conclusions

Selecting samples stratified by BMI and BCS helped to improve an AS atlas in order to optimally define the heart, the LADA, and the RCA when planning breast radiotherapy in prone position. A significant contouring time reduction was

observed between AS and manual segmentation. In the future, contouring guidelines should be developed for prone breast radiotherapy to help construct atlas libraries to share for research and clinical purposes.

Authors' Note

No ethical approval was obtained because this study did not involve a prospective evaluation, did not involve laboratory animals, and is noninvasive. All patients gave written informed consensus on the use of their data for studies.

Acknowledgments

Dr Wang wishes to thank the National Natural Science foundation of China (grant no: 81573089) as well as the Fundació Privada CELLEX for their funding of the study. The authors also wish to thank Prof. J. H. D. Fasel and Dr. B. Stimec of the Clinical Anatomy Research Group, Department of Cell Physiology and Metabolism, University Medical Centre, Geneva, Switzerland, for their expert advice.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Funded by the National Natural Science foundation of China (grant no: 81573089) as well as the Fundació Privada CELLEX.

References

- Eldesoky AR, Yates ES, Nyeng TB, et al. Internal and external validation of an ESTRO delineation guideline-dependent automated segmentation tool for loco-regional radiation therapy of early breast cancer. *Radiother Oncol*. 2016;121(3):424-430.
- Dipasquale G, Wang X, Chatelain-Fontanella V, Vinh-Hung V, Miralbell R. Automatic segmentation of breast in prone position: Correlation of similarity indexes and breast pendulousness with dose/volume parameters. *Radiother Oncol*. 2016;120(1):124-127.
- Lorenzen EL, Ewertz M, Brink C. Automatic segmentation of the heart in radiotherapy for breast cancer. *Acta Oncol*. 2014;53(10):1366-1372.
- Anders LC, Stieler F, Siebenlist K, Schäfer J, Lohr F, Wenz F. Performance of an atlas-based autosegmentation software for delineation of target volumes for radiotherapy of breast and anorectal cancer. *Radiother Oncol*. 2012;102(1):68-73.
- Reed VK, Woodward WA, Zhang L, et al. Automatic segmentation of whole breast using atlas approach and deformable image registration. *Int J Radiat Oncol Biol Phys*. 2009;73(5):1493-1500.
- Li XA, Tai A, Arthur DW, et al. Variability of target and normal structure delineation for breast cancer radiotherapy: an RTOG multi-institutional and multiobserver study. *Int J Radiat Oncol Biol Phys*. 2009;73(3):944-951.
- Badouna ANI, Veres C, Haddy N, et al. Total heart volume as a function of clinical and anthropometric parameters in a population of external beam radiation therapy patients. *Phys Med Biol*. 2012;57(2):473.
- Feng M, Moran JM, Koelling T, et al. Development and validation of a heart atlas to study cardiac exposure to radiation following treatment for breast cancer. *Int J Radiat Oncol Biol Phys*. 2011;79(1):10-18.
- Kirby AM, Evans PM, Donovan EM, Convery HM, Haviland JS, Yarnold JR. Prone versus supine positioning for whole and partial-breast radiotherapy: a comparison of non-target tissue dosimetry. *Radiother Oncol*. 2010;96(2):178-184.
- Ulmer W, Pyyry J, Kaissl W. A 3D photon superposition/convolution algorithm and its foundation on results of Monte Carlo calculations. *Phys Med Biol*. 2005;50(8):1767-1790.
- La Macchia M, Fellin F, Amichetti M, et al. Systematic evaluation of three different commercial software solutions for automatic segmentation for adaptive therapy in head-and-neck, prostate and pleural cancer. *Radiat Oncol*. 2012;7:160.
- Lorenzen EL, Taylor CW, Maraldo M, et al. Inter-observer variation in delineation of the heart and left anterior descending coronary artery in radiotherapy for breast cancer: a multi-centre study from Denmark and the UK. *Radiother Oncol*. 2013;108(2):254-258.
- Kaderka R, Gillespie EF, Mundt RC, et al. Geometric and dosimetric evaluation of atlas based auto-segmentation of cardiac structures in breast cancer patients. *Radiother Oncol*. 2019;131:215-220.
- Darby SC, Ewertz M, McGale P, et al. Risk of ischemic heart disease in women after radiotherapy for breast cancer. *N Engl J Med*. 2013;368(11):987-998.
- Bartlett FR, Colgan RM, Donovan EM, et al. The UK Heartspare Study (Stage IB): randomised comparison of a voluntary breath-hold technique and prone radiotherapy after breast conserving surgery. *Radiother Oncol*. 2015;114(1):66-72.
- Mulliez T, Van de Velde J, Veldeman L, et al. Deep inspiration breath hold in the prone position retracts the heart from the breast and internal mammary lymph node region. *Radiother Oncol*. 2015;117(3):473-476.
- Mulliez T, Veldeman L, Speleers B, et al. Heart dose reduction by prone deep inspiration breath hold in left-sided breast irradiation. *Radiother Oncol*. 2015;114(1):79-84.
- Vennarini S, Bidoz NF, Aristei C, et al. Visualisation of the left anterior descending coronary artery on CT images used for breast radiotherapy planning. *B J Radiol*. 2013;86(1025):20120643.
- Sharp G, Fritscher KD, Pekar V, et al. Vision 20/20: perspectives on automated image segmentation for radiotherapy. *Med Phys*. 2014;41(5):050902.