Is stereotactic CyberKnife radiotherapy or multicatheter HDR brachytherapy the better option for accelerated partial breast irradiation?

Georgina Fröhlich, Ph.D.[a,b], Norbert Mészáros, M.D.[a,c], Viktor Smanykó, M.D.[a], Gábor Stelczer[a], András Herein[a], Csaba Polgár, D.Sc.[a,c] , Tibor Major, D.Sc.[a,c]

a. National Institute of Oncology, Centre of Radiotherapy, Ráth György Street 7-9, H-1122 Budapest, Hungary

b. Eötvös Loránd University, Faculty of Science, Pázmány Péter mall 1/A, H-1117 Budapest, Hungary

c. Semmelweis University, Faculty of Medicine, Department of Oncology, Ráth György Street 7-9, H-1122 Budapest, Hungary

Corresponding author: Georgina Fröhlich, National Institute of Oncology, Centre of Radiotherapy, Ráth György Street 7-9, H-1122 Budapest, Tel: +36-1-224-8600, Fax: +36-1-224-8620, E-mail: frohlich.georgina@gmail.com

Dosimetric comparison of CyberKnife and HDR BT in APBI

Declaration of Interest statement:

This study was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and the ÚNKP-18-4 New National Excellence Program of the Ministry of Human Capacities and by the 2019 Thematic Excellence Program (TUDFO/51757/2019-ITM).

Abstract

Objective: To compare dosimetrically the stereotactic CyberKnife (CK) therapy and multicatheter high-dose-rate (HDR) brachytherapy (BT) for accelerated partial breast irradiation (APBI).

Methods: Treatment plans of twenty-five patients treated with CK were selected and additional plans using multicatheter HDR BT were created on the same CT images. The prescribed dose was 6.25/25 Gy in both plans to the target volume (PTV). The dose-volume parameters were calculated for both techniques and compared.

Results: The D90 total dose of the PTV was significantly lower with CK than with HDR BT, D90 was 25.7 Gy and 27.0 Gy ($p<0.001$). However, CK plans were more conformal than BT, COIN was 0.87 and 0.81 ($p=0.0030$). The V50 of the non-target breast was higher with CK than with BT: 10.5% and 3.3% ($p=0.0010$), while there was no difference in the dose of the contralateral breast and contralateral lung. Dose to skin, ipsilateral lung and ribs were higher with CK than with BT: D_1 was 20.6 Gy vs. 11.5 Gy ($p=0.0018$) to skin, 11.4 Gy vs. 9.6 Gy ($p=0.0272$) to ipsilateral lung and 18.5 Gy vs. 12.3 Gy ($p=0.0013$) to ribs, while $D_{0.1}$ to heart was lower, 3.0 Gy vs. 3.2 Gy ($p=0.0476$), respectively.

Conclusions: Multicatheter HDR BT yields more advantageous plans than stereotactic CyberKnife treatment in accelerated partial breast irradiation, except in terms of dose conformality and the dose to the heart. There was no difference in the dose of the contralateral breast and -lung.

Keywords: breast cancer; CyberKnife therapy; multicatheter high-dose-rate brachytherapy; accelerated partial breast irradiation

Introduction

Over the last decades, breast-conserving surgery followed by postoperative radiotherapy became the standard of care for the treatment of early-stage breast carcinoma [1-2]. Nowadays, accelerated partial breast irradiation (APBI) is an attractive alternative to conventional whole breast radiotherapy for selected group of patients [3]. Moreover, it has been demonstrated that higher doses to the tumour bed significantly reduce the local recurrence rate [4-7]. The number of techniques and devices used to deliver APBI has increased dramatically in recent decades in an attempt to create more conformal, homogenous, and reproducible dose distributions as well as to provide shorter, more convenient treatment schedules. Such as EBRT using 3D conformal (3D-CRT), intensity-modulated (IMRT) technique or arc-therapy (IMAT) [8], helical tomotherapy (HT) [9], stereotactic radiotherapy with CyberKnife (CK) [10-14], protontherapy (PT) [15], as well as high-dose-rate (HDR) or pulsed-dose-rate (PDR) balloon [16] or multicatheter BT [17] or using Strut Adjusted Volume Implant (SAVI) [18]. All of these techniques offer equal convenience but differ substantially in dose distribution and treatment delivery [19].

While the dosimetric parameters which affect toxicity have been thoroughly investigated for BT techniques [20-21], and the use of interstitial BT is supported by over ten years of follow-up data demonstrating excellent local control and minimal long-term toxicity when established dosimetric guidelines are used for planning [22-26], EBRT is associated with less available follow-up data, and currently no standardized, evidence-based treatment planning guidelines exist for this technique. Therefore, a detailed dosimetric analysis comparing the rapidly developing EBRT techniques to the pivotal BT modality is essential.

In our previous study we compared the dose distributions of 3D-CRT and three different intensity-modulated APBI technique: step and shoot and sliding window IMRT and IMAT in 40 patients [8]. Goggin et al. [27] compared 3D-CRT and CK with circular (Iris) and multi-leaf collimators in case of 9 patients. Xu et al. [28] and Rault et al. [29] compared the dosimetry of CK, 3D-CRT and IMRT plans, while Bonfantini et al. [30] made a dosimetric comparison of CK, 3D-CRT and IMAT plans.

Khan et al. [31] investigated the dosimetric differences among MammoSite balloon BT, 3D-CRT and IMRT for 15 cases. Previously, we examined the dosimetry of organs at risks (OARs) in multicatheter HDR BT against IMRT for 34 cases [32]. Hoekstra et al. studied the long-term risk of secondary cancer calculating Lifetime Attributable Risks using a Rando breast

phantom in multicatheter HDR BT, 3D-CRT, CK, IMAT and whole breast irradiation (WBI) [33].

Recently, stereotactic CyberKnife therapy and interstitial multicatheter high-dose-rate brachytherapy are considered as the most advantageous APBI techniques in early-stage breast cancer, at the same time their dosimetric comparison is not available in the literature. At our institute, both state-of-the art techniques are available. To take the advantage of this situation, the aim of the present study is a detailed dosimetric comparison of CK treatment and HDR multicatheter BT for APBI.

Materials and methods

Stereotactic CyberKnife radiotherapy

Twenty-five CK plans of patients with early-stage breast cancer treated at our institute were included in this study. Selection criteria for treatment were the following: unifocal tumour; primary tumour size by final pathology <30 mm (pT1); microscopically negative surgical margins (>2 mm); histologic grade 1–2; pN0 axillary status, age over 50 years, without extensive intraductalis component or lymph vessel invasion [34].

CK treatments were performed with non-coplanar fields using CyberKnife M6 linear accelerator (Accuray, Sunnyvale, CA, USA). Titanium surgical clips were implanted into the tumour bed during the surgery to help contouring the lumpectomy cavity and defining the clinical target volume (CTV), and additional 4 fiducial gold markers were placed around the cavity with US guidance for tracking purpose. The CTV was extended by an isotropic 2 mm margin to create the planning target volume (PTV), and the fractional prescribed dose was 6.25 Gy. A total of 4 fractions (total dose 25 Gy) were given every consecutive day. For treatment planning Accuray Precision 1.1 treatment planning system (TPS) (Accuray, Sunnyvale, CA, USA) was used. The dose was prescribed to the 80−85% isodoses *(Fig 1.a)*. The relative volume of the PTV receiving at least the prescribed dose (V100) had to be at least 95%. The detailed description of our treatment method can be found in our previous publication [14].

Multicatheter brachytherapy

On the CT series made for CK treatment planning, additional plans using virtual interstitial catheters were created using the same contour set. The CTV was identical to the PTV, and the prescribed dose was also the same as in CK, 25 Gy in 4 treatment fractions giving 6.25 Gy two times a day using an HDR Ir-192 radioactive source. HIPO (Hybrid Inverse Planning

Optimization) optimisation method was used to achieve the optimal dose distribution, where the target volume coverage by the reference dose is at least 90%, while keeping the dose non-uniformity ratio (DNR) less than 0.35 *(Fig 1.b)*. For planning the Oncentra Prostate v3.1 TPS (Elekta Brachytherapy, Veendendaal, The Netherlands) was used. The detailed description of our treatment method can be found in our previous publications [17,22-25].

Dosimetric comparison

The absolute and the relative () total dose were calculated for both techniques. The following dose-volume parameters were used for quantitative evaluation of plans:

D90: the minimum dose delivered to 90% of the PTV;

COIN: conformal index [35];

V50(non-target breast): the relative volume in percentage of non-target breast receiving at least the 50% of the prescribed dose;

D_1(x), $D_{0.1}$(x): the minimal dose of the most exposed 1 and 0.1 cm^3 of *the critical organ x,*

where x: *contralateral breast (contralat breast), skin, ipsilateral lung (ipsilat lung), contralateral lung (contralat lung), heart and ribs.*

Wilcoxon Matched Pairs Test was used (Statistica 12.5, StatSoft, Tulsa, OK, USA) to compare dose-volume parameters of CK and HDR BT techniques.

Results

The mean volume of the CTV and PTV was 51.1 cm^3 (27.0-81.5 cm^3) and 71.6 cm^3 (41.1-105.6 cm^3). The ratio of the CTV to the whole breast volume was 0.09 (0.05-0.19). Eleven patients had tumour in her left breast and fourteen in the right one.

We found that D90 total dose of the PTV was significantly lower with CK than with HDR BT, it was 25.7 Gy and 27.0 Gy ($p<0.001$). However, CK plans were more conformal than BT, the COIN was 0.87 and 0.81 ($p=0.0030$), respectively.

In our comparison, the V50 of the non-target breast was higher with CK than with BT: 10.5% and 3.3% ($p=0.0010$), while there was no statistical difference in the doses of the contralateral breast (D_1: 0.5 vs. 0.4 Gy, $P=0.3112$) and contralateral lung, (D_1: 0.7 vs. 0.7 Gy, $p=0.5345$).

In terms of the other OARs, dose to skin, ipsilateral lung and ribs were higher with CK than with BT: D_1 was 20.6 Gy vs. 11.5 Gy ($p=0.0018$) to skin, 11.4 Gy vs. 9.6 Gy ($p=0.0272$) to ipsilateral lung and 18.5 Gy vs. 12.3 Gy ($p=0.0013$) to ribs, while $D_{0.1}$ to heart for left sided

lesions was lower, 3.0 Gy vs. 3.2 Gy (p=0.0476), respectively. The detailed results can be found in Table 1.

Discussion

The debate on the advantages and disadvantages of different treatment techniques of APBI seems to be ongoing and refreshing when a new treatment modality appears. In spite of that several dosimetric and clinical comparative studies exist in the literature, no detailed analysis of the two most technologically advanced techniques, stereotactic CK and multicatheter HDR BT was performed yet.

In our previous study we have pointed out that the 3D-CRT provides the best heart protection compared to step and shoot and sliding window IMRT and IMAT [8]. However, the sliding window IMRT technique achieved the best plan quality index and should be recommended for APBI. Goggin et al. [27] found that CK and 3D-CRT plans resulted in similar tumour coverage and dose to critical structures, with the exception of the lung V5%, which was significantly smaller for 3D-CRT than CK-Iris and CK-multi-leaf: 6.2% vs. 39.4% and 17.9%. Both CK plans demonstrated lower ipsilateral breast V50% (25.5% and 24.2%, respectively) than the 3D-CRT (56.2%). The CK plans were more conformal but less homogeneous. In the comparison of Xu et al [28] the PTV coverage from CK plans was the highest and the ratio of V20% to V100% of the breast was the smallest. The heart and lung doses were similar in CK, IMRT and 3D-CRT plans, except for the V5% of the lung and the heart, which was higher in CK plans. Rault et al. [29] found insignificant dosimetric differences between CK, 3D-CRT and IMRT plans regarding the PTV coverage and sparing the lung and heart. However, CK reduced high doses of the non-target breast. Bonfantini et al. [30] concluded that CK and IMAT provided higher conformity than 3D-CRT plans, although reduced the dose to the OARs. CK resulted in longer treatment times, but with it the delivery accuracy is expected to be better than with IMAT and 3D-CRT techniques.

Khan et al. [31] stated that the dose coverage of the PTV was the highest with MammoSite balloon BT and the lowest using the 3D-CRT technique. Regarding sparing the ipsilateral breast, there were the same order between the studied techniques, but the mean dose of the ipsilateral lung was the lowest for IMRT and the highest for 3D-CRT, while in regard to volume of the heart irradiated by 5 Gy, IMRT yielded the lowest and MammoSite balloon resulted the highest value. The conflicting results published by different institutions most likely can be explained by differences in planning methods and the lack of standardized dosimetric parameters.

In our previous study it was shown that multicatheter HDR BT provided better sparing of normal tissue and OARs compared to IMRT [32]. Ipsilateral lung was spared better with BT, the mean lung dose was 5.1% vs. 7.1%, D1 was 39.0% vs. 54.3% and V5 was 32.9% vs. 41.7% in favour of BT. For left sided lesions the heart was generally irradiated by larger doses with BT. Mean heart dose was 4.5% vs. 2.0% and D2 was 18.3% vs. 19.7%, correspondingly. Volumetric maximal skin doses were similar, but regarding dose to 0.1 cm^3 and 1 cm^3 of most exposed volume, BT provided significantly less doses (76.6% vs. 94.4% and 60.2% vs. 87.8%, respectively). Ribs received less dose with BT with values of 45.6% vs. 69.3% for D1 and 1.4 cm^3 vs. 4.2 cm^3 for V50. Dose to contralateral breast and lung was low with both techniques. No significant differences were observed in maximal doses, but dose to volumes of 0.1 cm^3 and 1 cm^3 were less with BT for both organs. D1 was 3.2% vs. 6.7% for contralateral breast and 3.7% vs. 5.6% for lung with BT and IMRT, respectively. In current study, we concluded the same result in term of stereotactic CK and HDR BT. However, the EQD2 total dose of the PTV was significantly lower with CK than with BT, D90 was 44.7 Gy and 49.0 Gy, BT yielded better sparing of OARs, except for the heart. V50 of the non-target breast was 10.5% and 3.3%, D_1 to skin, ipsilateral lung and ribs were 35.2 Gy vs. 13.7 Gy, 14.0 Gy vs. 10.4 Gy and 28.7 Gy vs. 15.7 Gy, while $D_{0.1}$ to heart was 2.4 Gy vs. 3.6 Gy for left-sided lesions in our CK and BT plans. Only, between doses of the contralateral breast and contralateral lung for the two techniques there was no significant difference, D_1 was 0.3 Gy and 0.2 Gy to the contralateral breast and 0.5 Gy and 0.5 Gy to contralateral lung, respectively.

Based on the radiobiological evaluation of Hoekstra et al. [33] about multicatheter HDR BT, 3D-CRT, CK, IMAT and WBI, WBI resulted in the highest risk with 4.3% excess risk of secondary cancer for patients at age 50 years. Lung cancers accounted for 75-97% of secondary malignancies. For a typical early stage patient irradiated at 50 years, the excess risks of secondary lung cancer were 1.1% for HDR BT, between 2.2% and 2.5% for 3D-CRT or CK, 3.5% for IMAT APBI and 3.8% for WBI. This is in good agreement with our dosimetric results, where BT resulted in lower dose to lung than CK therapy.

It has to be mentioned, that in our study BT plans were made on the planning CT of the CK without template and real catheters, and the breast was not compressed. So this anatomy was disadvantageous for BT. On the other hand, the virtual needles were not parallel but we tried to mimic their real trajectories. In the light of our results multicatheter HDR BT proved to be the optimal choice in APBI in the aspects of sparing most of the OARs beside dose coverage of the PTV. Stereotactic CK therapy resulted in higher dose to the OARs at the equivalent

prescribed dose to the PTV. And even, our study comparing the dosimetrical parameters of plans treated by CK and HDR BT using two separate patient cohorts is in progress.

Conclusions

Using interstitial multicatheter HDR brachytherapy, D90 dose of the PTV is higher than with stereotactic CyberKnife radiotherapy, however CK technique results more conformal dose distributions. Dose to skin, ipsilateral lung and ribs is higher, while dose to heart is lower with CK than with HDR BT technique. There is no difference in the dose of the contralateral breast and -lung. Overall, multicatheter HDR brachytherapy yields more advantageous treatment plans in accelerated partial breast irradiation, except for the dose conformality and the dose to heart, where CK plans are more optimal.

Contributions:

GF: worked out the concept, did the analysis and wrote this paper.

NM: made the contouring and discussed the details of this study.

VS: made the contouring and discussed the details of this study.

GS: performed the treatment plans of the CK and discussed the details of this study.

AH: discussed the details.

CsP: supported the study, revised the manuscript.

TM: supported the study, discussed the details and helped composing the manuscript.

References

1. Effects of radiotherapy and surgery in early breast cancer. An overview of the randomized trials. Early Breast Cancer Trialists' Collaborative Group. N Engl J Med, 1995;333:1444-1455.
2. NIH Consensus Conference: Treatment of early-stage breast cancer. JAMA, 1991; 265: 391-5
3. Polgár C, Major T: Current status and perspectives of brachytherapy for breast cancer. Int J Clin Oncol 2009; 14: 7-24
4. Polgar C, Fodor J, Orosz Z, et al. Electron and high-dose-rate brachytherapy boost in the conservative treatment of stage I-II breast cancer first results of the randomized Budapest boost trial. Strahlenther Onkol 2002;178:615-623.
5. Bartelink H, Horiot JC, Poortmans H, et al: Impact of a higher radiation dose on local control and survival in breast-conserving therapy of early breast cancer: 10-year results of the randomized boost versus no boost EORTC 22881-10882 trial. J Clin Oncol, 2007; 25: 3259-65
6. Polgár C, Fodor J, Major T, et al: The role of boost irradiation in the conservative treatment of stage I-II breast cancer. Pathol Oncol Res, 2001; 7: 241-50
7. Romestaing P, Lehingue Y, Carrie C, et al: Role of a 10-Gy boost in the conservative treatment of early breast cancer: Results of a randomized clinical trial in Lyon, France. J Clin Oncol, 1997; 15: 963-8
8. Stelczer G, Major T, Mészáros N et al. External beam accelerated partial breast irradiation: dosimetric assessment of conformal and three different intensity modulated techniques. Radiol Oncol, 2019;53(1):123-130. doi: 10.2478/raon-2019-0001
9. Hui SK, Das RK, Kapatoes J et al. Helical tomotherapy as a means of delivering accelerated partial breast irradiation. Technol Cancer Res Treat. 2004,3(6):639-46.
10. Won HL, Jee SC, Min JK et al. First Experience in Korea of Stereotactic Partial Breast Irradiation for Low-Risk Early-Stage Breast Cancer. Frontiers in Oncology. 2020,10:672. doi: 10.3389/fonc.2020.00672

11. Lozza L, Fariselli L, Sandri M et al. Partial breast irradiation with CyberKnife after breast conserving surgery: a pilot study in early breast cancer. Rad Onc. 2018;13:49. https://doi.org/10.1186/s13014-018-0991-4

12. Obayomi-Davies O, Kole TP, Oppong B et al. Stereotactic Accelerated Partial Breast Irradiation for Early-Stage Breast Cancer: Rationale, Feasibility, and Early Experience Using the CyberKnife Radiosurgery Delivery Platform. Frontiers in Oncology. 2016; 6:129

13. Vermeulen SS, Haas JA. CyberKnife stereotactic body radiotherapy and CyberKnife accelerated partial breast irradiation for the treatment of early breast cancer. Transl Cancer Res. 2014;3(4):295-302. doi: 10.3978/j.issn.2218-676X.2014.07.06

14. Mészáros N, Smanykó V, Major T et al. Implementation of Stereotactic Accelerated Partial Breast Irradiation Using Cyber-Knife – Technical Considerations and Early Experiences of a Phase II Clinical Study. Pathology & Oncology Research, in press.

15. Cuaron JJ, MacDonald SM, Cahlon O. Novel applications of proton therapy in breast carcinoma. Chin Clin Oncol. 2016;5(4):52. doi: 10.21037/cco.2016.06.04

16. Dickler A, Seif N, Kirk MC et al: A dosimetric comparison of MammoSite and ClearPath high-dose-rate breast brachytherapy devices. Brachytherapy, 2009;8(1):14-8. doi:10.1016/j.brachy.2008.07.006

17. Major T, Fröhlich G, Lövey K et al. Dosimetric experience with accelerated partial breast irradiation using image-guided interstitial brachytherapy. Radiother Oncol, 2009;90:48–55.

18. Zhang Z, Dou K. SU-E-T-229: Monte Carlo Dosimetric Study of SAVI HDR Applicator for Partial Breast Irradiation. Med Phys. 2012;39(6):37-56. doi: 10.1118/1.4735292

19. Dorin T, Stewart B. Brachytherapy is better than external beam therapy for partial breast irradiation? Med Phys. 2013,40(8)

20. Wazer DE, Kramer B, Schmid C, et al: Factors determining outcome in patients treated with interstitial implantation as a radiation boost for breast conservation therapy. Int J Radiat Oncol Biol Phys, 1997; 39: 381-93

21. Fröhlich G, Major T, Polgár Cs. Evaluation of the dosimetric parameters and the late side effects in CT-guided partial breast brachytherapy. Magy Onkol 2011;55(2):132. (in Hungarian)

22. Major T, Polgár Cs, Fröhlich G. Dosimetric characteristics of accelerated partial breast irradiation with CT image-based multi-catheter interstitial brachytherapy: A single institution's experience. Brachytherapy, 2011;10(5):421-426.

23. Major T, Polgár Cs, Fröhlich G. Assessment of dose homogeneity in conformal interstitial breast brachytherapy with special respect to ICRU recommendations. J Contemp Brachyther, 2011;3(3):150-155.

24. Fröhlich G, Geszti Gy, Vízkeleti J et al. Dosimetric comparison of inverse optimisation methods versus forward optimisation in HDR brachytherapy of breast, cervix and prostate cancer. Strahlenther Onkol, 2019;195(11):991-1000. DOI: 10.1007/s00066-019-01513-x.

25. Major T, Fröhlich G, Mészáros N et al. Does the inverse planning improve the plan quality in interstitial high dose rate breast brachytherapy? J Contemp Brachyther, 2020;12(2):166–174. DOI: 10.5114/jcb.2020.94584.

26. Kauer-Dorner D, Berger D. The Role of Brachytherapy in the Treatment of Breast Cancer. Breast Care. 2018;13(3):157-161. doi: 10.1159/000489638.

27. Goggin LM, Descovich M, McGuinness C et al. Dosimetric Comparison Between 3-Dimensional Conformal and Robotic SBRT Treatment Plans for Accelerated Partial Breast Radiotherapy. Technology in Cancer Research & Treatment. 2016;15(3):437–445. DOI: 10.1177/1533034615601280

28. Xu Q, Chen Y, Grimm J et al. Dosimetric investigation of accelerated partial breast irradiation (APBI) using CyberKnife. Med Phys. 2012;39:6621. doi: 10.1118/1.4757616

29. Rault E, Lacornerie T, Dang HP et al. Accelerated partial breast irradiation using robotic radiotherapy: a dosimetric comparison with tomotherapy and threedimensional conformal radiotherapy. Radiation Oncology. 2016;11:29. DOI 10.1186/s13014-016-0607-9

30. Bonfantini F, De Martin E, Giandini T et al. A Dosimetric Comparison between Three Different External Photon Beam Techniques for Accelerated Partial Breast Irradiation. Clin Oncol. 2018;3:1501

31. Khan AJ, Kirk MC, Mehta PS et al. A dosimetric comparison of three-dimensional conformal, intensity-modulated radiation therapy, and MammoSite partial-breast irradiation. Brachytherapy, 2006;5:183-188

32. Major T, Stelczer G, Pesznyák C et al. Multicatheter interstitial brachytherapy versus intensity modulated external beam therapy for accelerated partial breast irradiation: A comparative treatment planning study with respect to dosimetry of organs at risk. Radiother Oncol, 2017;122(1):17-23. doi:10.1016/j.radonc.2016.08.003

33. Hoekstra N, Fleury E, Merino Lara TR et al. Long-term risks of secondary cancer for various whole and partial breast irradiation techniques. Radiother Oncol, 2018;128(3):428-433. doi: 10.1016/j.radonc.2018.05.032

34. Polgár Cs, Major T, Fodor J et al. Accelerated partial-breast irradiation using high-dose-rate interstitial brachytherapy: 12-year update of a prospective clinical study. Radiother Oncol, 2010; 94(3):274-9. doi:10.1016/j.radonc.2010.01.019

35. Baltas D, Kolotas C, Geramani K, Mould RF, Ioannidis G, Kekchidi M, Zamboglou N. (1998) A conformal index (COIN) to evaluate implant quality and dose specification in brachytherapy. Int J Radiat Oncol Biol Phys, 40(2): 515-524.

Tables:

	CK	BT	p*
D90	25.7 Gy (25.3-26.0) *102.7% (101.3-105.2)*	27.0 Gy (26.7-27.9) *108.1% (107.0-111.6)*	**<0.001**
COIN	0.87 (0.77-0.92)	0.81 (0.77-0.85)	**0.0030**
V50(non-target breast)	10.5% (5.0-17.0)	3.3% (0.9-8.1)	**0.0010**
D_1(contralat breast)	0.5 Gy (0.1-1.5) *2.2% (0.4-6.1)*	0.4 Gy (0.0-2.3) *1.6% (0.0-9.3)*	0.3112
$D_{0.1}$(contralat breast)	0.9 Gy (0.1-3.9) *3.8% (0.3-15.5)*	0.6 Gy (0.0-2.9) *2.5% (0.0-11.6)*	0.1205
D_1(skin)	20.6 Gy (9.0-26.5) *86.1% (52.4-106.0)*	11.5 Gy (5.2-21.5) *46.1% (20.9-86.0)*	**0.0018**
$D_{0.1}$(skin)	23.7 Gy (9.8-28.7) *99.6% (70.2-114.6)*	15.2 Gy (8.4-27.3) *60.9% (33.6-109.3)*	**0.0203**
D_1(ipsilat lung)	11.4 Gy (0.9-16.9) *45.0% (3.6-67.6)*	9.6 Gy (6.4-12.8) *38.4% (25.6-51.2)*	**0.0272**
$D_{0.1}$(ipsilat lung)	14.4 Gy (8.6-20.0) *57.5% (34.2-80.0)*	10.9 Gy (7.6-14.5) *43.8% (30.2-58.1)*	**0.0008**
D_1(contralat lung)	0.7 Gy (0.1-2.5) *2.9% (0.5-10.0)*	0.7 Gy (0.2-1.7) *2.9% (0.8-6.8)*	0.5345
$D_{0.1}$(contralat lung)	0.9 Gy (0.3-2.8) *3.7% (1.3-11.2)*	1.0 Gy (0.4-2.1) *4.0% (1.6-8.4)*	0.4671
D_1(heart)	2.7 Gy (0.8-8.0) *10.5% (3.2-32.0)*	2.8 Gy (0.1-5.7) *11.2% (0.4-22.8)*	0.0534
$D_{0.1}$(heart)	3.0 Gy (1.6-8.2) *12.1% (6.4-32.8)*	3.2 Gy (0.1-8.5) *12.8% (0.4-34.0)*	**0.0476**
D_1(ribs)	18.5 Gy (10.9-24.7) *73.6% (43.5-98.8)*	12.3 Gy (8.7-16.3) *49.0% (34.9-65.1)*	**0.0013**
$D_{0.1}$(ribs)	23.3 Gy (14.8-27.7) *93.2% (59.3-110.6)*	15.3 Gy (9.9-20.3) *61.2% (39.5-81.4)*	**0.0012**

Table 1. Mean total doses of CyberKnife (CK) and high-dose-rate brachytherapy (BT) of breast cancer. D90: the minimum dose delivered to 90% of the planning target volume, COIN: conformal index, V50(non-target breast): the relative volume of non-target breast receiving at least the 50% of the prescribed dose, $D_1(x)$ and $D_{0.1}(x)$: the minimal dose of the most exposed 1 and 0.1 cm^3 of 'x' organ at risk, where x are contralateral breast (contralat breast), skin, ipsilateral lung (ipsilat lung), contralateral lung (contralat lung), heart and ribs. *Wilcoxon Matched Pairs Test.

Figures:

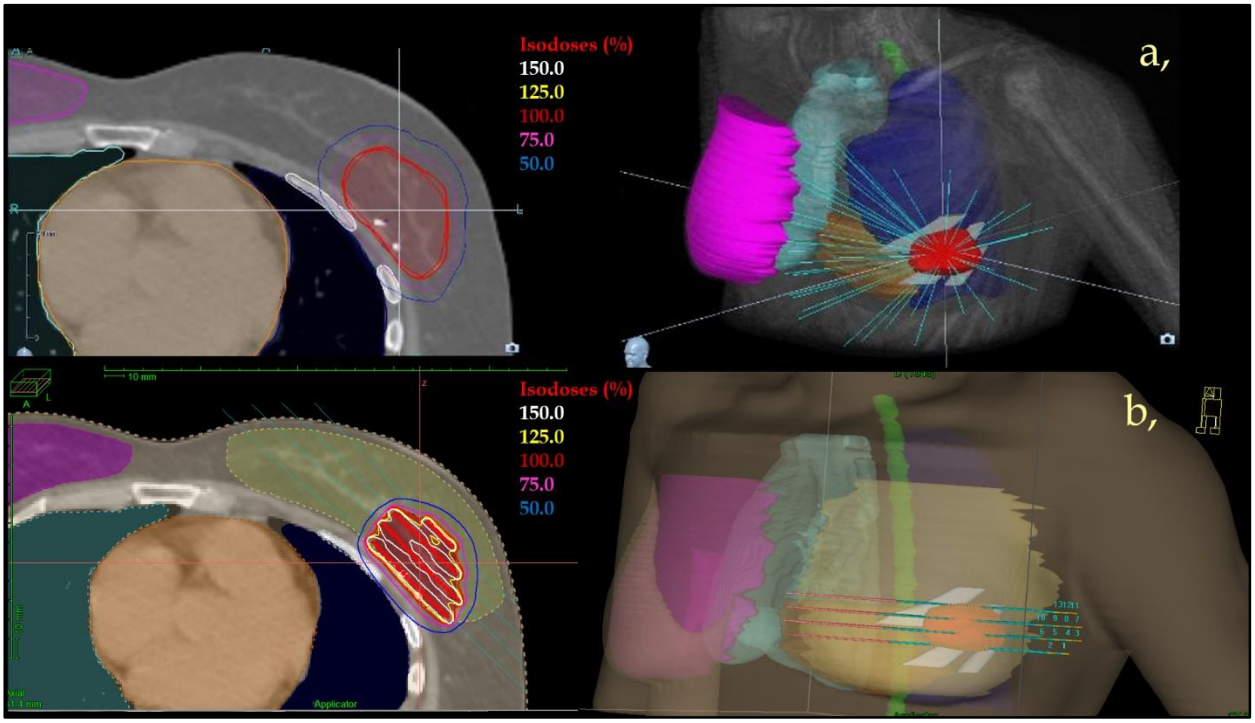

Figure 1. Axial CT slide (left) and 3D reconstruction (right) of a stereotactic CyberKnife breast radiotherapy (a,) and a multicatheter interstitial high-dose-rate breast brachytherapy (b,) plan. PTV: red, ipsilateral breast: yellow, contralateral breast: pink, spinal cord: green, ribs: white, heart: orange, ipsilateral lung: dark blue, contralateral lung: light blue.