Pan Arab Journal of Oncology

Original Article ISSN 2070-254X

# Stereotactic Radiotherapy for Localized Prostate cancer, which is better Cyberknife or Rapid Arc?

*M. W. Hegazy[1, 2], R Mahmood[1], A. Nobah[3], B. Moftah[3], F. Alzorkany[3]*

1. *Department of Radiation Oncology, King Faisal Specialist Hospital & Research Centre, Riyadh, Saudi Arabia.*
2. *Department of Clinical Oncology &Nuclear Medicine, Zagazig Faculty of Medicine, Egypt.*
3. *Department of Biomedical Physics, King Faisal Specialist Hospital and Research Centre, Riyadh, Saudi Arabia*

*Corresponding Author:*
*M. W. Hegazy*
*Department of Radiation Oncology,*
*King Faisal Specialist Hospital & Research Centre,*
*Riyadh, Saudi Arabia*
*Tel +966550742859*
*Email: mohamed_wahba_1@yahoo.com*

Keywords: Stereotactic Radiotherapy RapidArc CyberKnife

## Abstract

**Aim**: We aim to compare two different stereotactic body radiation therapy (SBRT) techniques, non-isocentric Cyberknife (CK) with isocentric Rapidarc (RA), a more widely available treatment technique for the treatment of localized prostate cancer.
**Methods**: The study included six patients treated with CK then re-planned with the new version of flattening filter free (FFF) RA and CK. The prescription dose was 36.25 Gy in five fractions. The two SBRT techniques were compared by target coverage, normal tissue sparing, dose distribution parameters and delivery time.
**Results**: The RA technique exhibited comparable PTV coverage and better bladder and rectum sparing at high doses. The conformity and homogeneity indices of the RA were better and statistically significant than the CK plans. Additionally, the RA resulted in statistically significant lower dose regions and faster delivery times than the CK.
**Conclusions**: The good dosimetric distribution and shorter delivery time make the new version of RA an attractive and reasonable alternative SBRT technique for the treatment of localized prostate cancer; however no intrafractional (real-time) target tracking is possible on the RA, which is available on the CK platform.

## Background

Over recent years, stereotactic body radiotherapy (SBRT) has been increasing in the management of low- and intermediate-risk prostate adenocarcinoma [1]. SBRT is the delivery of either a single dose or a small number of fractions of high-dose, precisely targeted, highly conformal radiation therapy [2]. SBRT improved outcomes may be due to the dose escalation alone, which is widely accepted in prostate adenocarcinoma [3, 4]; or as a result of the increased dose per fraction, due to the apparent low $\alpha/\beta$ ratio of prostatic adenocarcinoma[5, 6].
The SBRT, including the CyberKnife technique (CK), has achieved promising clinical results in the treatment of prostate cancer [7-10]. The CK stereotactic radiotherapy system is an accurate image-guided method with intrafractional (real-time) target tracking for delivering radiation to a precisely targeted area using multiple non-isocentric beams with steep surrounding-dose gradients[11]. RapidArc (RA) is volumetric-modulated arc radiotherapy (VMAT) technique that can deliver highly conformal, intensity-modulated radiation doses by a single or multiple rotations of the gantry of the linear accelerator[12].

One of the potential benefits of SBRT is reduced patient visits (4-5 fractions) rather than the standard 35-40 fractions. A number of small studies and single-centre series have been published showing comparable outcomes with conventional fractionation schedules[13-19]. Most of these studies have used CK treatment. These preliminary studies and case series have led to the development of the PACE study, an international, randomized, phase III study comparing SBRT with both surgery and conventionally fractionated intensity-modulated radiotherapy in two parallel arms[20].

Our study may present an alternative to the CK platform, with the additional benefits of increased availability of gantry-based volumetric systems and possibly shorter delivery times.

## Materials and Methods

*Patients and imaging*
Six patients with localized low risk (T1-2 NoMo, Gleason score ≤6 and PSA ≤10) prostate cancer who had recently received hypofractionated radical radiotherapy by CK were included in the study. Gold seeds are implanted to prostate by radiologists

under transrectal ultrasound guidance (TRUS), and then one week after 1mm slice thickness CT simulation in a supine position with alpha cradle with bladder and bowel preparation protocol and MR images are acquired. CT scans from the fifth lumbar vertebrae level to below the ischial tuberosities. CT and MR images were transferred to treatment planning system for image registration and to delineate regions of interest (ROIs).

*Contouring and SBRT treatment plan requirements*

The same radiation oncologist delineated the target and the critical structures using CT and MR fusion. The following ROIs were defined: Clinical Tumor Volume (CTV) consisted of the prostate without margin; The CTV was increased by 5 mm to create the planning target volume (PTV) for the Rapid Arc and by 3 mm for PTV for the Cyberknife. Organs at risk (OARs) that were delineated included the entire rectum; the whole bladder; penile bulb and femoral heads. A treatment plan that delivered 36.25 Gy to the PTVs was attempted in both treatment planning systems. Both modalities were required to achieve these criteria as per a combination of studies[7, 9, 20-25]. Required planning constraints are detailed in Table 1.

Table1 Dose planning constraints

| | | |
|---|---|---|
| **PTV** | Minimum dose received by PTV | ≥34.4 Gy of prescription dose |
| **Rectum** | V18 < 50%<br>V28 < 20%<br>V36 < 1 $cm^3$ | |
| **Bladder** | V18 < 40%<br>V36 < 10$cm^3$ | |
| **Femoral heads** | Maximum point dose | 30 Gy |
| **Penile bulb** | Maximum point dose | No more than 100% of prescription dose |

*Treatment Planning*

Rapidarc

Eclipse treatment planning system (Varian Medical Systems, Inc., Palo Alto, CA) was used along with the analytical anisotropic algorithm (AAA, Version 11.031) dose calculation algorithm. For RA optimization; progressive resolution optimizer (PRO) Version11.031 was used. All plans generated using True Beam linacs with 120 leaf millennium multileaf collimator and kV imaging, 2 full arcs one clockwise & the other counterclockwise, with collimator angles ± 20° from 0 and a couch angle of 0, SRS Arc mode, 6MV Flattening Free Filter (FFF) beam energy, and maximum dose rate of 1400 MU/min. Both arcs had the same isocenter, located at the center of the PTV.

Cyberknife

Inverse planning was carried out using the sequential optimization algorithm using MULTIPLAN v. 5.1 for delivery on a Cyberknife G4 v10.1 (only the IRIS collimators was used, 3 collimators of different sizes ranging from 7.5mm to 60mm) which is capable of delivering 800 MUs/Min. The planning approach was to use a Prostate-path (allows 114 Nodes and 5 of pitch correction), 2 shells (i.e. 2 mm to control the conformity to the PTV and 40 mm to control the dose spillage), and the range of MUs per beam per fraction was 50-150. The PTV was prescribed to an isodose line of (78% - 80%) and a maximum of conformity index (CI) 1.24 was achieved. The PTV was at least covered by 99.2% of dose or more. The range of beam numbers was 100-150.

*Plan evaluation statistics*

Target volume coverage

The percentages of the PTV that received 95% of the prescription dose, PTV mean, median and maximum were compared between the CK and RA plans.

Dosimetric parameters

The normalized conformity index (nCI) [26] was calculated as:

CI = VRI/TV but homogeneity index equation as follows[26]:
HI = Imax/RI

Where VRI is the volume of prescribed dose for PTV, TV is the total volume of PTV, Imax is the maximum dose and RI is the prescribed dose of PTV.

The percentages of the rectum and urinary bladder that received 18 Gy (V18), 28 Gy and the volume ($cm^3$) that received 36 Gy (V36) of the prescription dose were compared. The dose regions (V10, V20, V30 & V36) were evaluated based on the body volume received 10, 20, 30 and 36 Gy of the prescription dose for each group.

*Treatment time*

The on-couch time for the patient will be added to the overall beam-on time for the RapidArc treatments, in our hospital the imaging and registration time is on average 3-4 minutes (CBCT 1 min., reconstruction and registration in three planes 2-3 min.).

*Statistical analysis*

The dosimetric endpoints of the target volumes, normal organs, CI, HI and delivery time were analyzed using the non-parametric (small sample size) Wilcoxon signed rank test (SPSS, V19, USA), a probability value of <0.05 considered to be statistically significant (two tailed).

## Results

*Target volume coverage*

All dose constraints regarding PTV coverage were similarly achieved by both plans except the maximal doses generated by the RA plans were statistically significant lower than those of the CK plans (p value 0.028) table 2, 4.

*Comparison of dosimetric parameters*

The median of Conformity and homogeneity indices of RA plans had a statistically significant higher degree of conformity than the CK plans (p values 0.027 & 0.026) table 2, 4.

CK cyberknife, RA Rapid Arc, PTV planning target volume, PTVmax maximum dose to PTV
nCI normalized conformity index, HI homogeneity index.

*Normal tissue sparing*

We analyzed the volume dose parameters of the rectum and bladder (Table 3, 4). All requirements were comparable in both groups; however, the CK plans achieved a superior sparing of the rectum and bladder in the low dose region (V18&28 for rectum and V18 for bladder) but statistically insignificant (p values 0.3, 0.2 & 0.4), while the RA plans exhibited a lower percentage of rectal and bladder volumes that received 100% of the prescription dose compared with the CK plans but statistically insignificant (p values 0.17& 0.11). The femoral heads and penile bulb received lower doses with RA. The body V35 was the same for both groups, whereas body V10, V20, V30 was all lower with RA in all cases with p values of 0.04, 0.03 & 0.06 respectively.

*Treatment time*

Across all five fractions of radiation treatment, the estimated delivery time of the RA (beam on 2.4 min., CBCT 1 min., reconstruction and registration in three planes 2 min.) is faster than the CK (Mean & Median 5.4, 5.4 vs 34.3, 34.5 minutes) with significance (p value 0.028). The details are shown in Table 2, 4.

## Discussion

Stereotactic body radiotherapy (SBRT) using CK has recently emerged as an alternative technique to deliver hypofractionated radiotherapy to the prostate, comparable in many respects to high dose rate (HDR) brachytherapy, but with a noninvasive approach [7, 13, 15, 17, 27-29].

Almost all the literature on prostate SBRT delivers these treatments on Cyberknife but there is increasing interest in using conventional linacs to deliver SBRT[38]. In our study we tried to find out a reasonable alternative to CK especially with the new versions of RA. We compared the two methods of

Table 2: Target dose results

| | Patient 1 | | Patient 2 | | Patient 3 | | Patient 4 | | Patient 5 | | Patient 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RA | CK | RA | CK | RA | CK | RA | CK | RA | CK | RA | CK |
| **Rectum** | | | | | | | | | | | | |
| V18Gy (%) | 41.3 | 46.8 | 45.9 | 35.8 | 39.5 | 43.1 | 46.1 | 31.6 | 37.9 | 41.4 | 47.6 | 41.2 |
| V28Gy (%) | 18.5 | 17.9 | 16.3 | 15.4 | 14.8 | 20.8 | 17.2 | 16.8 | 16.5 | 11.3 | 22.6 | 15.5 |
| V36Gy($cm^3$)(%) | 1.4 | 0 .70 | 0.01 | 0.30 | 0.05 | 1.7 | 0.01 | 0.81 | 0.01 | 0.34 | 0.03 | 0.40 |
| **Bladder** | | | | | | | | | | | | |
| V18Gy (%) | 37.7 | 35.4 | 37.3 | 36 | 10.6 | 13.3 | 33.6 | 36 | 33.7 | 36 | 25.2 | 27.2 |
| V36Gy($cm^3$)(%) | 7.2 | 7.3 | 0.3 | 5.2 | 1.5 | 6.88 | 0.8 | 1.37 | 0.01 | 3.6 | 1.05 | 0.20 |
| **Penile bulb** | | | | | | | | | | | | |
| Max dose (Gy) | 30.6 | 30.5 | 36.7 | 34.9 | 38.4 | 38.6 | 39.3 | 31.7 | 38 | 37.2 | 36.5 | 36.7 |
| Max dose(%) | 84.4 | 84.1 | 101.2 | 96.3 | 106 | 106.5 | 108.4 | 87.5 | 105 | 102.6 | 100.7 | 101 |
| **RFH** | | | | | | | | | | | | |
| Max (Gy) | 18.6 | 25 | 12.6 | 20 | 14.9 | 11.6 | 10.9 | 19.3 | 16.8 | 25.7 | 11.3 | 17.7 |
| **LFH** | | | | | | | | | | | | |
| Max (Gy) | 18.5 | 26.7 | 11.7 | 18.6 | 13.5 | 12.5 | 18.9 | 15.1 | 17.2 | 22 | 10 | 14.5 |
| **Body** | | | | | | | | | | | | |
| volume($cm^3$) | 23469 | | 46767 | | 29441 | | 32226 | | 21826 | | 24312 | |
| V10Gy (%) | 10.6 | 11.9 | 4.3 | 7.4 | 3.9 | 4.3 | 5.7 | 6 | 7.4 | 9.7 | 5.5 | 5.3 |
| V20Gy (%) | 3 | 3 | 1.2 | 1.9 | 1 | 1.1 | 1.3 | 1.4 | 2 | 2.7 | 1.3 | 1.4 |
| V30Gy (%) | 1.5 | 1.4 | 0.5 | 0.9 | 0.5 | 0.5 | 0.7 | 0.6 | 1.1 | 1.3 | 0.7 | 0.6 |
| V35Gy (%) | 1.1 | 1 | 0.4 | 0.6 | 0.3 | 0.3 | 0.5 | 0.4 | 0.8 | 0.9 | 0.5 | 0.3 |
| **Time (min)** | 5.4 | 33 | 5.4 | 34 | 5.4 | 35 | 5.4 | 35 | 5.4 | 38 | 5.4 | 31 |

Table 3: Organs at risk dose and treatment time results

| | Patient 1 | | Patient 2 | | Patient 3 | | Patient 4 | | Patient 5 | | Patient 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RA | CK | RA | CK | RA | CK | RA | CK | RA | CK | RA | CK |
| **Rectum** | | | | | | | | | | | | |
| V18Gy (%) | 41.3 | 46.8 | 45.9 | 35.8 | 39.5 | 43.1 | 46.1 | 31.6 | 37.9 | 41.4 | 47.6 | 41.2 |
| V28Gy (%) | 18.5 | 17.9 | 16.3 | 15.4 | 14.8 | 20.8 | 17.2 | 16.8 | 16.5 | 11.3 | 22.6 | 15.5 |
| V36Gy ($cm^3$)(%) | 1.4 | 0 .70 | 0.01 | 0.30 | 0.05 | 1.7 | 0.01 | 0.81 | 0.01 | 0.34 | 0.03 | 0.40 |
| **Bladder** | | | | | | | | | | | | |
| V18Gy (%) | 37.7 | 35.4 | 37.3 | 36 | 10.6 | 13.3 | 33.6 | 36 | 33.7 | 36 | 25.2 | 27.2 |
| V36Gy ($cm^3$)(%) | 7.2 | 7.3 | 0.3 | 5.2 | 1.5 | 6.88 | 0.8 | 1.37 | 0.01 | 3.6 | 1.05 | 0.20 |
| **Penile bulb** | | | | | | | | | | | | |
| Max dose (Gy) | 30.6 | 30.5 | 36.7 | 34.9 | 38.4 | 38.6 | 39.3 | 31.7 | 38 | 37.2 | 36.5 | 36.7 |
| Max dose(%) | 84.4 | 84.1 | 101.2 | 96.3 | 106 | 106.5 | 108.4 | 87.5 | 105 | 102.6 | 100.7 | 101 |
| **RFH** Max (Gy) | 18.6 | 25 | 12.6 | 20 | 14.9 | 11.6 | 10.9 | 19.3 | 16.8 | 25.7 | 11.3 | 17.7 |
| **LFH** Max (Gy) | 18.5 | 26.7 | 11.7 | 18.6 | 13.5 | 12.5 | 18.9 | 15.1 | 17.2 | 22 | 10 | 14.5 |
| **Body volume($cm^3$)** | 23469 | | 46767 | | 29441 | | 32226 | | 21826 | | 24312 | |
| V10Gy (%) | 10.6 | 11.9 | 4.3 | 7.4 | 3.9 | 4.3 | 5.7 | 6 | 7.4 | 9.7 | 5.5 | 5.3 |
| V20Gy (%) | 3 | 3 | 1.2 | 1.9 | 1 | 1.1 | 1.3 | 1.4 | 2 | 2.7 | 1.3 | 1.4 |
| V30Gy (%) | 1.5 | 1.4 | 0.5 | 0.9 | 0.5 | 0.5 | 0.7 | 0.6 | 1.1 | 1.3 | 0.7 | 0.6 |
| V35Gy (%) | 1.1 | 1 | 0.4 | 0.6 | 0.3 | 0.3 | 0.5 | 0.4 | 0.8 | 0.9 | 0.5 | 0.3 |
| **Time (min)** | 5.4 | 33 | 5.4 | 34 | 5.4 | 35 | 5.4 | 35 | 5.4 | 38 | 5.4 | 31 |

Table 4: Statistical results of both plans

| | RA | | CK | | P value |
|---|---|---|---|---|---|
| | Mean | Median | Mean | Median | |
| **PTV95%** | 99.4 | 99.4 | 99.4 | 99.5 | 0.49 |
| **PTV max** | 107 | 106.7 | 127 | 126.6 | 0.028 |
| **PTV mean** | 100 | 100 | 105 | 110 | 0.34 |
| **nCI** | 1.05 | 1.06 | 1.2 | 1.21 | 0.027 |
| **HI** | 1.1 | 1.07 | 1.27 | 1.27 | 0.026 |
| **Rectum** | | | | | |
| V18Gy (%) | 43.1 | 43.6 | 40 | 41.3 | 0.35 |
| V28Gy (%) | 17.7 | 16.9 | 16.3 | 16.5 | 0.25 |
| V36Gy ($CM^3$)(%) | 0.25 | 0.02 | 0.71 | 0.54 | 0.173 |
| **Bladder** | | | | | |
| V18Gy (%) | 39.7 | 35.5 | 27.3 | 30.8 | 0.46 |
| V36Gy ($CM^3$) (%) | 1.8 | 0.93 | 4.1 | 4.4 | 0.116 |
| **Penile bulb max Gy (%)** | 101 | 103 | 96.3 | 99 | 0.173 |
| **Femur head max Gy (%)** | | | | | |
| Right | 14.2 | 13.8 | 20 | 19.6 | 0.046 |
| Left | 15 | 15.4 | 18.2 | 16.9 | 0.116 |
| **Body** | | | | | |
| V10 (%) | 6.23 | 5.6 | 7.4 | 6.7 | 0.046 |
| V20 (%) | 1.63 | 1.3 | 1.9 | 1.65 | 0.038 |
| V30 (%) | 0.83 | 0.7 | 0.9 | 0.75 | 0.68 |
| V36 (%) | 0.6 | 0.5 | 0.6 | 0.5 | 0.78 |
| **Time** | 5.4 | 5.4 | 34.3 | 34.5 | 0.028 |

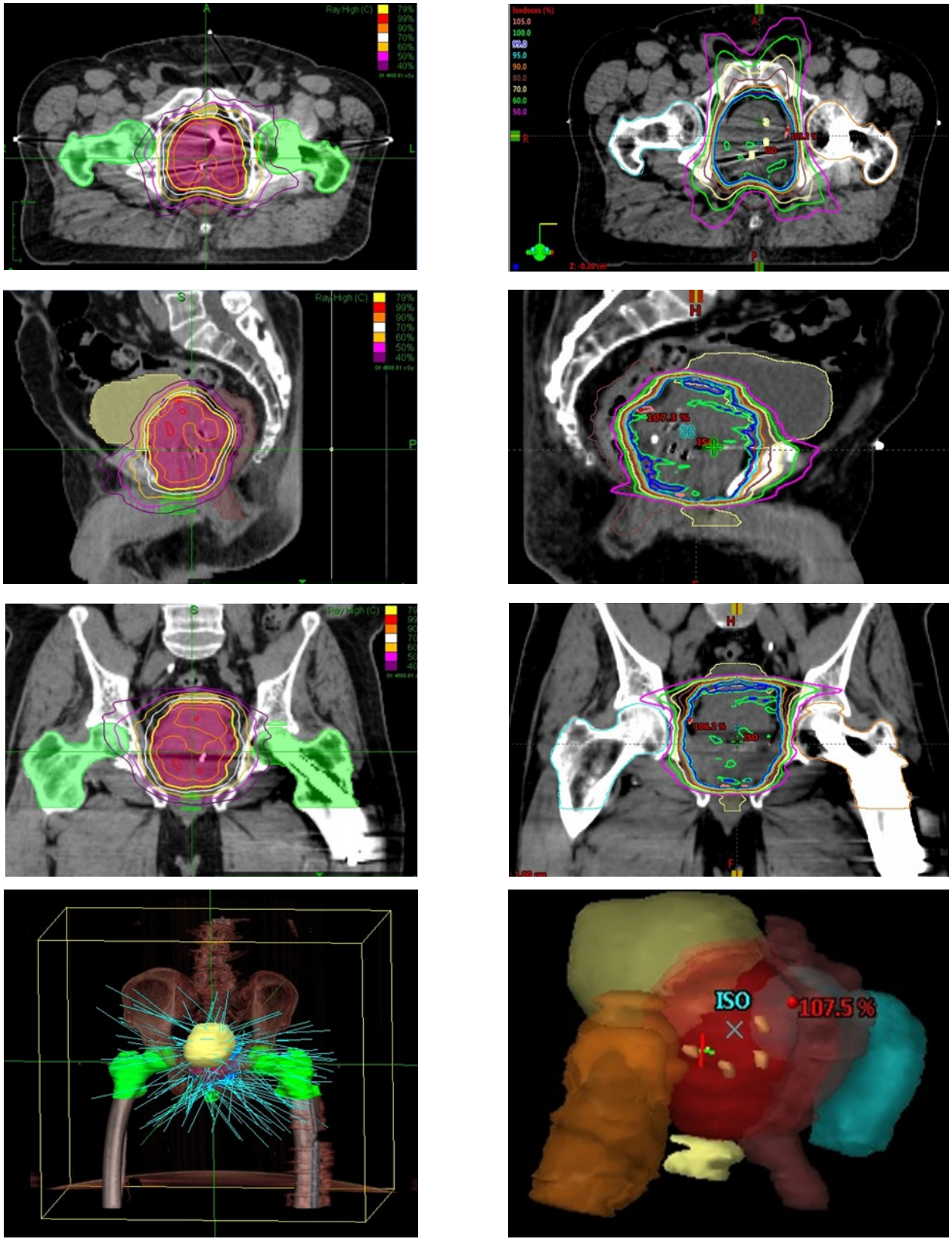


**Figure 1: displayed the CK & RA isodose lines of one patient (axial, sagittal, coronal & 3D view)**

SBRT delivery available to us at our institution – Cyberknife (using Multiplan planning software) and RapidArc (arc therapy using Varian linacs).We used the criteria regarding to the prescription dose, dose constraints and CTV to PTV margin depending on many studies[7,9,17,20-33].

Cyberknife system incorporates near real-time tracking of the prostate which allows smaller margins to be used, as it tracks and corrects for intra-fraction motion so if intra-fraction motion could be tracked and corrected during arc-therapy on a conventional linac, then the dosimetry is likely to be at least as good as Ck However, without intra-fraction motion control, a margin of 2–3 mm is likely to be needed to account for intrafraction motion after initial set-up to gold markers[34]. Alternatively, if new flattening filter free (FFF) linacs can deliver these plans in much shorter times, then intra-fraction motion may be less important, although transient, significant excursions of prostate position are still possible [35] and this was implicated in our study, by using RA with FFF.

In our study, the dose constraints regarding PTV coverage were achieved by both planning techniques. The conformity and homogeneity indices of the RA plans were better than the CK plans and statistically significant (p values 0.027 & 0.026). The constraints on the rectum and bladder were well achieved by both planning techniques. Additionally, the RA plans resulted in lower body dose regions (V10, V20, V30 were all lower with RA in all cases with p values of 0.04, 0.03 & 0.06 respectively but V35 was the same for both groups), lower statistically significant monitor units, and faster statistically significant delivery times (mean 2.4 minutes) than the CK plans (34.3 mean minutes).

Tree et al. have shown that RA and CK can produce clinically acceptable plans where comparing the new versions of CK and RA treatments, the results showed a higher conformity and a lesser low-dose region of the RA when compared to the CK, with a similar target coverage and normal tissue sparing, even under different PTV margins. The mean estimated delivery time for treatments was 39 min for CK and 3 min for RA. These differences were the result of the different nature of the CK and RA systems[36].

MacDougall et al. have shown that there is no discernible dosimetric advantage to choosing Cyberknife over Rapidarc for SBRT delivery in prostate cancer. All dose constraints regarding PTV coverage were achieved by both planning platforms. The nCI was consistently better with Rapidarc. The constraints on the rectum and bladder were well achieved by both planning platforms. The body V35 was consistently lower with Cyberknife, whereas body V10, V20, V30were all lower with Rapidarc in all cases. The mean estimated delivery time for treatments was 39 min for Cyberknife and 3 min for Rapidarc[37].

Lin et al have shown that RA plans were shown to have a greater potential than CK plans in creating conformal dose distributions and in reducing treatment times. The RA plans consistently exhibited superior PTV coverage and better rectum sparing at low doses in the both groups. The conformity and homogeneity indices of the RA plans were better than the CK plans. Additionally, the RA plans resulted in fewer low-dose regions, lower MUs, and faster delivery times than the CK plans. Currently, RA has become one of the SBRT options for localized prostate cancer treatments at their institution[38].

## Conclusions

There is no dosimetric advantage for choosing CK over RA for SBRT delivery in prostate cancer. Given the significant benefits of RA in terms of availability and delivery time, make the new version of RA reasonable alternative SBRT technique for the treatment of localized prostate cancer; however no intrafractional (real-time) target tracking is possible on the RA, which is available on the CK platform.

## References


1. Boyyounouski MK, Price RA, Harris EER, et al. Stereotactic body radiotherapy for primary management of early-stage, low- to intermediate-risk prostate cancer: report of the American Society for Therapeutic Radiology and Oncology emerging technology committee. Int J Radiat Oncol Biol Phys 2010; 76:1297-1304.
2. Martin A, Gaya A. Stereotactic body radiotherapy: a review. Clin Oncol 2010; 22:157-172.
3. Peeters STH, Heemsbergen WD, Koper PCM, et al. Dose response in radiotherapy for localized prostate cancer: results of the Dutch multi-center randomized phase III trial comparing 68Gy of radiotherapy with 78Gy. J Clin Oncol 2006; 24:1990-1996.
4. Pollack A, Zagars GK, Starkschall G, et al. Prostate cancer radiation dose response: results of the M.D. Anderson phase III randomised trial. Int J Radiat Oncol Biol Phys 2002; 53:1097-1105.
5. Proust-Lima C, Taylor JMG, Secher S, et al. Confirmation of a low a/b ratio for prostate cancer treated by external beam radiation therapy alone using a post-treatment repeated measures model for PSA dynamics. Int J Radiat Oncol Biol Phys 2010; 79:195-201.
6. Williams SG, Taylor JMG, Liu N, et al. Use of individual fraction size data from 3756 patients to directly determine the a/b ratio of prostate cancer. Int J Radiat Oncol Biol Phys 2007; 68:24-33.
7. King CR, Brooks JD, Gill H, Pawlicki T, Cotrutz C, Presti Jr JC. Stereotactic body radiotherapy for localized prostate cancer: interim results of a prospective phase II clinical trial. Int J Radiat Oncol Biol Phys 2009; 73:1043-8.
8. Katz AJ. CyberKnife radiosurgery for prostate cancer. Technol Cancer Res Treat 2010; 9:463-72.
9. Freeman DE, King CR. Stereotactic body radiotherapy for low-risk prostate cancer: five-year outcomes. Radiat Oncol 2011; 6:3.
10. King CR, Freeman D, Kaplan I, Fuller D, Bolzicco G, Collins S, et al. Stereotactic body radiotherapy for localized prostate cancer: pooled analysis from a multiinstitutional consortium of prospective phase II trials. Radiother Oncol 2013; 109:217-21.
11. King CR, Lehmann J, Adler JR, Hai J. CyberKnife radiotherapy for localized prostate cancer: rationale and technical feasibility. Technol Cancer Res Treat 2003; 2:25-30.

12. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys 2008; 35:310-7.
13. Madsen BL, His RA, Pham HT, Fowler JF, Esagui L, Corman J. Stereotactic hypofractionated accurate radiotherapy of the prostate (sharp). 33.5Gy in five fractions for localised disease: first clinical trial results. Int J Radiat Oncol Biol Phys 2007; 67:1099-1105.
14. Tang CI, Loblaw DA, Cheung P, et al. Phase I/II study of a five fraction hypofractionated accelerated radiotherapy treatment for low-risk localized prostate cancer: early results of pHART3. Clin Oncol 2008; 20:729-737.
15. Friedland JL, Freeman DE, Masterson-McGary ME, Spellberg DM. Stereotactic body radiotherapy: an emerging treatment approach for localized prostate cancer. Technol Cancer Res Treat 2009; 8:387-392.
16. Bolzicco G, Favretto MS, Scremin E, Tambone C, Tasca A, Guglielmi R. Image-guided stereotactic body radiation therapy for clinically localized prostate cancer: preliminary clinical results. Technol Cancer Res Treat 2010; 9:473-477.
17. Katz AJ, Santoro M, Ashley R, Diblasio F, Witten M. Stereotactic body radiotherapy for organ-confined prostate cancer. BMC Urol 2010; 10:1.
18. King CR, Brooks JE, Gill H, Presti JC. Long-term outcomes from a prospective trial of stereotactic body radiotherapy for low-risk prostate cancer. Int J Radiat Oncol Biol Phys 2012; 82:877-882.
19. Jabbari S, Weinberg VK, Kaprealian T, et al. Stereotactic body radiotherapy as monotherapy or post-external beam radiotherapy boost for prostate cancer: technique, early toxicity and PSA response. Int J Radiat Oncol Biol Phys 2012; 82:228-234.
20. The PACE trial. 2013. http://www.clinicaltrials.gov/ct2/show/NCT01584258.
21. A Randomized Phase II Trial of Hypofractionated Radiotherapy for Favorable Risk Prostate Cancer (ongoing) RTOG 0938 ClinicalTrials.gov Identifier: NCT01434290.
22. Anwar RP, Vincent SK, John S, Janet EH, Martin OL, David PD. Evaluating the effect of rectal distension and rectal movement on prostate gland position using cine MRI. Int J Radiat Oncol Biol Phys 1999; 44:525e33.
23. Xie Y, Djajaputra D, King CR, Hossain S, Ma L, Xing L. Intrafractional motion of the prostate during hypofractionated radiotherapy. Int J Radiat Oncol Biol Phys 2008; 72:236e46.
24. Cheung P, Sixel K, Morton G, Loblaw DA, Tirona R, Pang G, et al. Individualized planning target volumes for intrafraction motion during hypofractionated intensity-modulated radiotherapy boost for prostate cancer. Int J Radiat Oncol Biol Phys 2005; 62:418e25.
25. Madsen BL, Hsi RA, Pham HT, Presser J, Esagui L, Corman J, et al. Intrafractional stability of the prostate using a stereotactic radiotherapy technique. Int J Radiat Oncol Biol Phys 2003; 57:1285e91.
26. Cemile Ceylan, N Kucuk, et al, Dosimetric and physical comparison of IMRT and CyberKnife plans in the treatment of localized prostate cancer: reports of practical oncology and radiotherapy 1 5 ( 2 0 1 0 ) 181–189.
27. Aluwini S, van Rooij P, Hoogeman M, Bangma C, Kirkels WJ, Incrocci L, Kolkman-Deurloo IK: CyberKnife stereotactic radiotherapy as monotherapy for low- to intermediate-stage prostate cancer: early experience, feasibility, and tolerance. J Endourol 2010, 24:865-869.
28. Fuller DB, Naitoh J, Lee C, Hardy S, Jin H: Virtual HDR (SM) CyberKnife Treatment for Localized Prostatic Carcinoma: Dosimetry Comparison With HDR Brachytherapy and Preliminary Clinical Observations. Int J Radiat Oncol Biol Phys 2008, 70:1588-1597.
29. Townsend NC, Huth BJ, Ding W, Garber B, Mooreville M, Arrigo S, Lamond J, Brady LW: Acute toxicity after CyberKnife-delivered hypofractionated radiotherapy for treatment of prostate cancer. Am J Clin Oncol 2010.
30. Davis BJ, et al: The radial distance of extraprostatic extension of prostate carcinoma: implications for prostate brachytherapy. Cancer 1999, 85(12):2630–7.
31. Chao KK, et al: Clinicopathologic analysis of extracapsular extension in prostate cancer: should the clinical target volume be expanded posterolaterally to account for microscopic extension? Int J Radiat Oncol Biol Phys 2006, 65(4):999–1007.
32. McNair HA, et al: A comparison of the use of bony anatomy and internal markers for offline verification and an evaluation of the potential benefit of online and offline verification protocols for prostate radiotherapy. Int J Radiat Oncol Biol Phys 2008, 71(1):41–50.
33. Kupelian P, et al: Multi-institutional clinical experience with the Calypso System in localization and continuous, real-time monitoring of the prostate gland during external radiotherapy. Int J Radiat Oncol Biol Phys 2007, 67 (4):1088–98.
34. Litzenberg DW, et al: Influence of intrafraction motion on margins for prostate radiotherapy. Int J Radiat Oncol Biol Phys 2006, 65(2):548–53.
35. Langen KM, et al: Observations on real-time prostate gland motion using electromagnetic tracking. Int J Radiat Oncol Biol Phys 2008, 71(4):1084–90.
36. Tree A, Jones C, Sohaib A, Khoo V, van As N. Prostate stereotactic body radiotherapy with simultaneous integrated boost: which is the best planning method? Radiat Oncol 2013; 8:228.
37. N.D. MacDougall, C. Dean, R. Muirhead Stereotactic Body Radiotherapy in Prostate Cancer: Is Rapidarc a Better Solution than Cyberknife? Clin onco 26 (2014): 4 -9.
38. Yu-Wei Lin, Kuei-Hua Lin, Hsiu-Wen Ho, Hsiu-Man Lin, Li-Ching Lin, Steve P. Lee, Chen-Shou Chui Treatment plan comparison between stereotactic body radiation therapy techniques for prostate cancer: Non-isocentric CyberKnife versus isocentric RapidArc Physica medica 30 (2014) :654-661.