Cardiac Radiation Dose Reconstruction in the Study of Late Effects: A Comparison of Different Methods

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INTRODUCTION

Radiation-related cardiovascular disease can occur several decades after radiotherapy. Cardiac radiation dose information is not readily available for most historic patient cohorts. Therefore, to investigate radiation-related cardiac late effects, it is necessary to reconstruct the doses delivered to the heart retrospectively, often without individual CT planning scans. Several reconstruction methods have been published and their dose prediction accuracy has been questioned over time. Here we evaluate for the first time their performance estimating cardiac doses in Hodgkin lymphoma (HL) patients.

MATERIALS & METHODS

Fourteen patients treated with CT-based modern radiotherapy for mediastinal HL were selected for this study. Two-dimensional digitally reconstructed radiographs were reconstructed to mimic simulation films, which are available for patients treated in the past, during the 2D planning era. These were used to reconstruct cardiac doses using five reconstruction methods:

- a field superposition method which estimates the mean dose to organs at risk based on irradiated areas and as % of the prescribed dose. (**%Prescribed**) [1]
- a simple patient-specific approach, where the mean dose to the heart is estimated from the percentage cardiac area exposed within the 2D simulation fields (**%Heart**) [2]
- a method estimating dose to OAR based on an anthropomorphic phantom (**Phantom**) [3]
- a representative CT technique based on male and female anatomical data sets (**RepCT**) [4]
- a "2D to 3D" method using deformable image registration (**Navigator**) [5]

The reconstructed doses from all five methods were compared to the true doses derived from the patients' own CT scans. Paired t-test was used for the comparison with the True value and the standard error of prediction for each method was also estimated using linear regression. All statistical analysis was performed using Stata 14.2 (Stata Corp LLC).

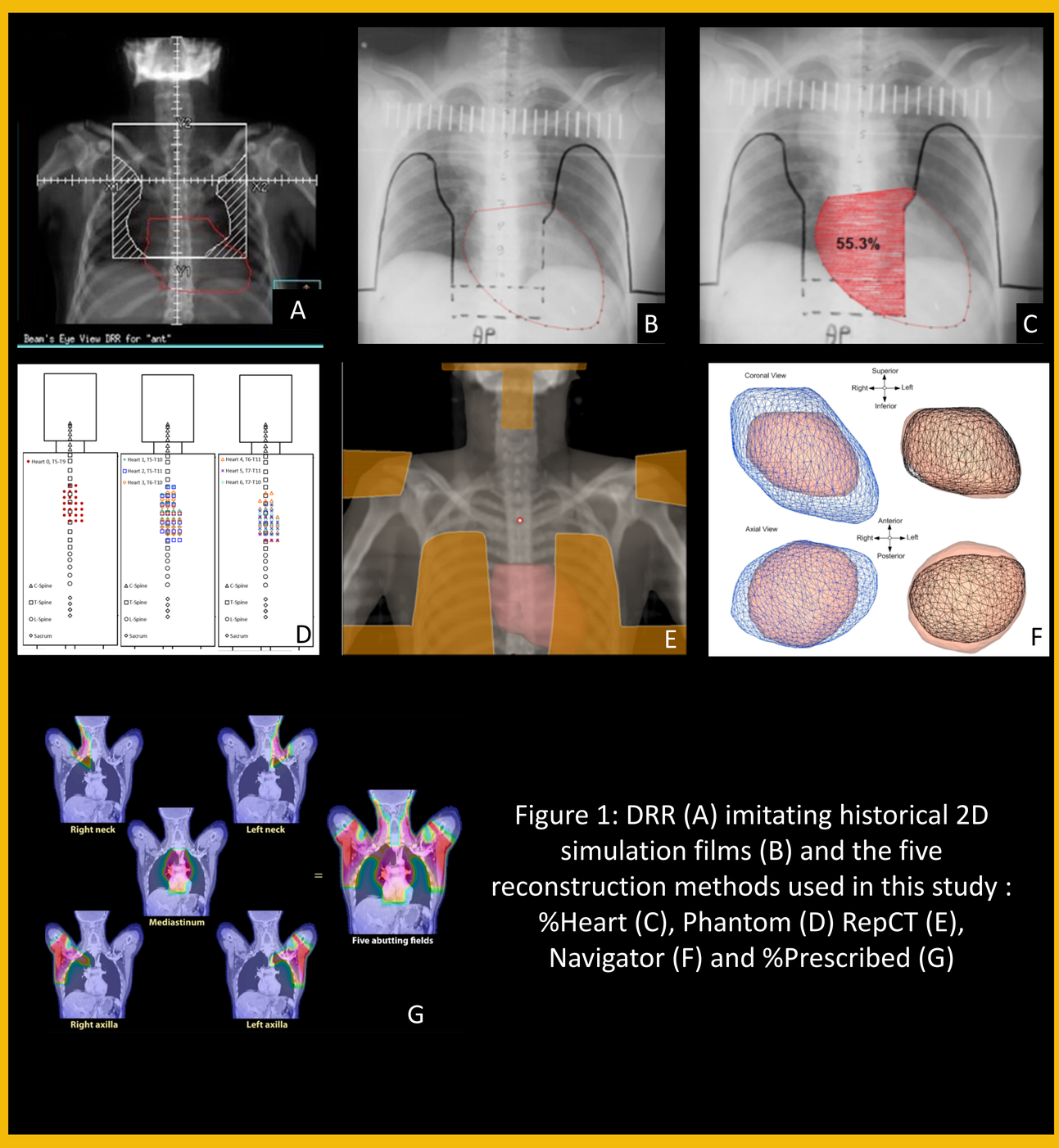

Figure 1: DRR (A) imitating historical 2D simulation films (B) and the five reconstruction methods used in this study : %Heart (C), Phantom (D) RepCT (E), Navigator (F) and %Prescribed (G)

Subject	sex	Prescribed dose/fractions	% Prescribed (Gy)	% Heart (Gy)	Phantom (Gy)	Rep CT (Gy)	Navigator (Gy)	True Value (Gy)
Patient 1	F	35Gy/20	13.0	13.1	10.2	15.9	12.4	13.3
Patient 2	F	20Gy/10	22.8	19.7	22.5	19.4	20.7	21.8
Patient 3	F	35Gy/20	19.9	23.0	18.1	19.7	22.6	23.2
Patient 4	F	30Gy/17	19.5	11.7	14.8	15.4	12.1	13.8
Patient 5	F	30Gy/20	13.7	6.6	7.6	7.3	7.0	7.2
Patient 6	F	21Gy/12	13.7	4.6	7.0	5.8	6.3	5.5
Patient 7	F	21Gy/14	19.5	12.8	16.5	13.8	16.7	15.5
Patient 8	F	30Gy/20	22.8	10.6	13.0	12.6	10.4	11.6
Patient 9	M	35Gy/20	13.0	7.3	7.0	8.0	7.4	6.5
Patient 10	M	20Gy/10	22.8	17.8	14.5	18.9	17.8	19.2
Patient 11	M	35Gy/20	19.5	22.3	27.5	27.2	23.0	23.9
Patient 12	M	30Gy/20	19.5	9.9	11.6	11.2	10.7	10.7
Patient 13	M	30Gy/20	22.8	17.0	22.7	21.1	22.4	19.4
Patient 14	M	35Gy/20	19.5	19.3	23.0	20.4	23.8	21.7
Patient 15	M	30Gy/20	13.0	13.1	10.2	15.9	12.4	13.3
Average MHD (Gy)			**18.7**	**14.0**	**15.4**	**15.5**	**15.2**	**15.2**
Standard Deviation of MHD (Gy)			**±3.8**	**±5.9**	**±6.6**	**±6.1**	**±6.5**	**±6.4**
SEP (Gy)			**5.8**	**1.6**	**2.5**	**1.9**	**1.3**	**-**

Table 1: Mean heart dose (MHD) as estimated by the five reconstruction methods, and from the individual CT-based plan ("True Value") , SEP= standard error of prediction based on linear regression.

RESULTS

The results can be seen on Table 1. The %Prescribed was the quickest method to use but it had the largest standard error of prediction (SEP) of 5.8 Gy. The Phantom is the most widely used method in the literature and with a SEP of 2.5 Gy. The %Heart method was simple to use and for the MHD it had a low SEP of 1.6 Gy. The RepCT and Navigator methods were the most labour intensive and the SEP was 1.9 and 1.3 Gy respectively.

CONCLUSIONS

Among the methods studied, there is a clear trade-off between accuracy and time consumption. The **%Prescribed** can provide less accurate MHD estimates but is the only method that can provide quick estimates when no simulation films are available. The **%Heart** method offers a good compromise and is the quickest way of estimating the MHD within 1.6 Gy when 2D simulation films are available. The **RepCT** and the **Navigator** methods are also accurate but more time consuming, therefore more appropriate for smaller patient cohorts. The **Phantom** method is arguably the most practical option for large patient cohorts (e.g. Childhood Cancer Survivor Study). The **Phantom** and **Navigator** methods, however, require in house software whilst the other three methods can be easily reproduced. Lastly, the **%Heart** is the only method that cannot estimate doses to cardiac substructures.

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