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Cardiac risk and MCNP/SISCODES doses in RT of the left internal mammary chain with photon and electron portals

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ABSTRACT

Aim: The present study evaluated the increment of cardiac risk (CR) and absorbed dose in radiotherapy of the internal mammary chain (IMC), in particular with photon portals of 4 6 MV, and cobalt therapy (Co60); and, electron portals of 8, 12 and 16 MeV applied in the left breast, considering the adoption of a combined photon (16 Gy) and electron (30 Gy) protocols.

Materials and methods: The modified ICRP-reference female model of 60 kg, 163 cm and 43 years of age, coil RCP-AF, was modelled. The MCNP6/SICODES codes were employed, where the spatial dose distributions and dose-volume histograms were generated. Toxicity limits and a CR model were considered.

Results: CR associated with the 6 MV, 4 MV and Co60 portals increased 41.1; 40.6 and 34.5%, respectively; while, in 8, 12 and 16 MeV portals, they were 5.0, 32.5 and 49.2%, respectively. High anomalous scatter radiation from electron portals was found in the left lung providing an average dose of 3.3–5.0 Gy.

Conclusions: To RCP-AF, the Co60 portal for IMC-RT presented more attractive dose distribution, whose 16 Gy for photon-component produced less CR increase, 5% lower than the other photon portals. Considering electron portals, the smallest CR increase was produced by 8 MeV portal while 12–16 MeV made the risk higher. There is a call for a less hardened energetic spectrum in order to reduce CR; however, holding suitable IMC penetration. A combined Co60/8–12 MeV may bring benefits, reducing CR. The lowest risk was found to 46 Gy electron portals exclusively.

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1. Background

After mastectomy or breast-conserving surgery for breast cancer (CA), radiation therapy (RT) in the lymph nodes (RT-LN) of the internal mammary chain (IMC), of the supraclavicular medial and fossa (SCF) and of the axillary chains (AXL) definitely increases the rate of disease free survival (DFS), metastases free survival (MFS) and the overall survival rate (OS) in patients with breast cancer in stage I to III. Three recent randomized clinical trials, identified by: (i) NCIC Clinical Trials Group MA.20, reported by Whelan et al., 2011, in the period of 2000–2007 with 1,832 patients[1]; (ii) EORT22922-10925 (EORT-European Organization for Research and Treatment of Cancer) in 1996–2004 with 4004 patients[2]; and, (iii) reported by Hennequim et al, 2013, coil FR, from 1991 to 1997 with 1334 patients (based on meta-analysis),[3] confirmed these findings. Such findings may point to the RT-LN application in breast CA in stages I–III.

RT-LN including SCF and IMC, in MA20, FR and EORTC studies, resulted in an increase in OS. In summary, the general benefit of RT-LN in OS was 1.6% at 5 years with MA20, 1.6% at 10 years with EORTC and 3.3% at 10 years with FR. RT-LN has also determined a 3% additional time in DFS and MFS.[4,5]

Past and current recommendations to RT-LN with IMC, SCF and AXL portals are still not clear. In the past, Lacour et al., 1983, showed no evidence of prognostic change with RT-IMC complements to breast RT.[6] There was no indication of benefit in RT-IMC in cases with T < 5 cm, unless the tumor was present in the internal or central quadrant (IQ/CQ) with LN+. At that time, no significant benefits were identified in comparison with the risk of cardiac toxicity present in RT-LN in IMC in the case of T in IQ with LN−.[6,7]

Currently, in AXL committed to at least three LN+, it is prudent to irradiate the lymphatic drainage pathways, including SCF portals and IMC.[8] Then, AXL, IMC and SCF portals may be needed when occur lymphatic chains compromised, AX+ with axillary lymphatic complete drain or missing. It is expected that the IMC and SCF portals promote the reduction of loco regional recurrence (RLR).[8–11]

The MA20 studies, FR and EORT brought new important information that confirms the need for RT-LN in patients with 1 to 3 LN+. Poortmans et al., 2015, suggests the reintroduction of RT-LN in IMC with LN+ or when T is medial or central at breast.[2] Reintroduction of RT-LN means the dosimetry and risk reassessment associated with photon beams for megavoltage accelerators or Co60; and, with electron beams, in the light of robust planning tools, such as provided by the Monte Carlo technique, where the reliable anatomical representation, equivalence in mass density and chemical composition of the region under study can be reproduced. Thus, one can have the knowledge of the absorbed dose produced by the direct and scatter radiation in the organs, incorporating the anatomical and morphological heterogeneity of the tissues.

Toxicology Working Group defined a maximum tolerated dose that provides a risk of incidence of a clinical effect in a group of patients at *n* years in a specific organ.[12] The organs with the greatest potential for risks of developing complications in breast RT are the lungs and heart. The main damage in the lungs is acute and chronic pneumonia, and in the heart, pericarditis and pancarditis.[12]

Portals involving the heart lead to an increase in the rate of cardiac ischemia post-radiation. The rate of occurrence of heart disease is proportional to the average absorbed dose in the heart, starting 5 years post-exposure and continuing until 20 years later. Woman irradiated to the left breast has a higher rate of coronary events than the one irradiated to the right breast. There is no risk alteration associated with the size and location of the tumor, or radiation treatment.[13–15]

In agreement with Peres, 2003, T1 and T2 breast CA can receive the IMC portal with doses of 16 Gy of photons complemented with 30 Gy of 12 to 16 MeV electrons, with the aim of reduction of absorbed dose in the lung. In turn, the investigation of the dosimetry of the IMC portal holding 4 MV, 6 MV and Co60, complemented to high energy electrons, becomes relevant considering the possible reintroduction of the RT-LN, whose indications were pointed out in the MA20, FR and EORT studies.[1–3] The Monte Carlo technique coupled with the ICRP/ICRU reference computational phantoms is a robust tool for investigating particle transport especially for dealing with the heterogeneity of the IMC region.

2. Aim

The present study aims to assess the increase in cardiac risk and the absorbed dose distribution provided by the electron and photon portals in IMC, in particularal with 4 and 6 MV megavoltage RT or Co-60, and electron beams of 8, 12 and 16 MeV, applied in the left breast due to the higher proportion of the heart exposure. The dosimetry, based on Monte Carlo, will cover the internal volume of the thorax, head and neck, the primary and scatter radiation, both into and outside the radiation field generated by the electron and photon portals.

3. Methods

3.1. *Computational model*

The ICRP and ICRU provided reference phantoms for masculine and feminine adults.[16,17] The female model, named RCP-AF, represents a woman of 60 kg and 163 cm. The patient whose images raise the phantom was 43 years old. The model had the dimensions of $137 \times 348 \times 299$ voxels of $1.775 \times 4.84 \times 1.775\ mm^3$. The number of tissues was 138 and 53 materials were defined. The chemical composition and density of these materials have been described in the ICRP110.[17] A computational routine made *in-house* was elaborated for rotation and adjustment of the upper limbs of the RCP-AF. This routine was used to hyperextend the phantom left arm to 90 degrees with correction of the anatomy of the axilla.

3.2. *Definitions of clinical structures and IMC field*

The organs at risk (OARs) were the heart-wall, right lung, left lung, left and right breast with glandular breast tissue and fat tissues. The prescribed target volume (PTV) was outlined in the model RCP-AF as a set of voxels in the region occupied by