Radiobiological Evaluation of Three Common Clinical Radiotherapy Techniques Including Combined Photon-Electron, Tangential Beams and Electron Therapy in Left-Sided Mastectomy Patients

Abstract

Background: The aim of this study was radiobiological evaluation of different radiotherapy (RT) techniques, namely, combined photon-electron, two tangential photon beams, and electron therapy which are commonly used for treatment of mastectomy patients. **Materials and Methods:** The mentioned techniques were planned on the computed tomography (CT) images of a chest phantom, using TiGRT treatment planning system (TPS). The TPS dose calculations were verified using Thermo Luminescence dosimeters (TLD) measurements. Dose-volume histogram (DVH) of the plans was generated in the TPS, and also tumor control probability (TCP) and normal tissue complication probability (NTCP) values were calculated using DVH data for each technique. For TCP and NTCP modeling, Poisson Linear-Quadatric (PLQ) and Lyman-Kutcher-Burman (LKB) models were used, respectively. **Results:** The TCPs for the chest wall, internal mammary nodes, supraclavicular nodes, and axilla for the combined photon-electron was 90%, 90%, 90%, and 65%, respectively, which was higher compared to tangential beams (up to 11%, 11%, 5%, and 5%, respectively) and the electron therapy (up to 11%, 11%, 33%, and 23%, respectively) Whereas the NTCPs of the tangential beams for ipsilateral and contralateral lungs, heart, and chest wall–lung interface was 4%, 1%, 3%, and 5.6%, respectively. These NTCP values were considerably lower than electron therapy (up to 42%, 66%, and 40% and 30%, respectively) and combined photon-electron (up to 55%, 75%, 50%, and 20%, respectively) methods. **Conclusion:** Tangential beam is suggested for treating mastectomy patients, due to sufficient value of TCP, and also lower NTCP compared to the other techniques such as electron therapy and combined photon-electron.

Keywords: *Breast cancer, mastectomy, normal tissue complication probability, radiobiological evaluation, tumor control probability*

Hossein Taheri, Mohammad Bagher Tavakoli, Ali Akhavan[1]

From the Department of Medical Physics, School of Medicine, [1]Department of Radiotherapy and Oncology, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran

Introduction

For patients with high-risk breast cancer, mastectomy and postoperative radiotherapy (RT) of the chest wall and lymph nodes is considered as the most common treatment choices.[1-3] In the US, about 120,000 breast cancer females per year have been treated with RT,[4-6] and the number of these patients has been risen significantly during the recent decades.[7-9]

There are different RT techniques such as combined photon-electron, two tangential photon beams, and also one direct electron beam which are widely used to treat mastectomy patients. The purpose of all these RT techniques is not only to escalate the maximum possible radiation dose to the tumoral tissues but also to protect the normal tissues from adverse effects of the radiation beams.[10] However, using dose distribution data of different RT plans is not enough to evaluate the efficiency of different RT techniques.

Radiobiological evaluation of RT plans has opened new horizons on the prediction of treatment outcomes for target volume and organ at risks (OARs). In the breast RT, OARs include ipsilateral and contralateral lungs, heart, and chest wall–lung interface. A number of studies have been shown that RT of the chest wall and lymph nodes of the mastectomy patients may increase the normal tissue complications such as ipsilateral lung secondary cancers, cardiovascular disease, and also heart morbidity and mortality.[11-19] Therefore, some radiobiological evaluation tools, namely tumor control probability (TCP) and normal tissue complications probability (NTCP) are existed which estimate the radiobiological efficiency of a RT methods.[20-23]

Address for correspondence:
Prof. Mohammad Bagher Tavakoli,
Department of Medical Physics, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran.
E-mail: mbtavakoli@mui.ac.ir

Access this article online

Website: www.advbiores.net

DOI: 10.4103/abr.abr_198_17

Quick Response Code:

This study aimed to evaluate the radiobiological competence of different breast RT techniques including combined photon-electron, two tangential photon beams, and also one direct electron using TCP and NTCP models.

Materials and Methods

Irradiation and dosimetry

A chest wall phantom (designed and produced at Medical Physics Department, School of Medicine, Isfahan University of Medical Sciences, Isfahan, Iran) with 30 transversal slabs was used. The phantom was made of tissue-equivalent Plexiglas and also cork and Teflon which were used instead of lungs and ribs. The chest wall thickness of the phantom was chosen 2 cm. CT simulation images of the used phantom was performed with 1 mm slice spacing. The planning CT images of the phantom were imported to the treatment planning system (TPS) (TiGRT, LinaTech, China). OARs including ipsilateral lung, contralateral lung, and heart were defined and contoured by the stated TPS. The surface of the chest wall, three levels of axilla, supraclavicular, and internal mammary lymph nodes were drawn for the clinical target volume (CTV). The CTV contour was expanded for 1 cm in all direction, as planning target volume (PTV). The Siemens Primus linac measured data were used for commissioning the TPS. In this study, a Siemens Primus linac system with 6 MV photon and 10 MeV electron beams and also 51-pair leaf were used. Treatment planning of the techniques was done according to clinical standards at our department (Seyed Al-Shohada hospital, Isfahan, Iran). The image of the used techniques is illustrated in Figure 1.

According to Figure 1a, in the first method, the whole of the chest wall and also supraclavicular and internal mammary nodes was irradiated by 10 MeV electrons. In the second plan, the chest wall and internal mammary nodes were exposed with tangential beams, and also a single AP photon beam was used to treat supraclavicular nodes [Figure 1b]. A 15° wedge was used for this plan. In the combined photon-electron plan, the supraclavicular and internal mammary nodes were irradiated directionally by 6 MV photon beam, and the chest wall was exposed by 10 MeV electrons [Figure 1c]. The prescribed dose to PTV was 2 Gy per fraction which resulted to a total dose of 50 Gy.
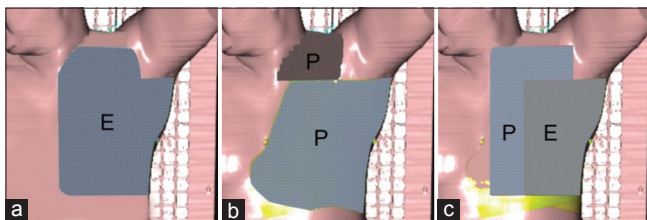

Figure 1: Images of different methods with electron (E) and photon (P) beams, including electron therapy (a), tangential beams (b), and combined photon-electron (c)

Verification of the TPS calculations was also performed using LiF Thermo Luminescence dosimeters, LiF (TLD-100), which were placed inside the phantom. Dose measurements were repeated for 3 independent experiments, and the TLDs were readout with a SOLARO-2A TLD reader (NEC Technology).

Radiobiological modeling

The dose-volume histograms (DVHs) of the mentioned techniques were generated, and also TCP and NTC*P* values were calculated using DVH data for each technique. In this study, the Poisson Linear-Quadatric (PLQ) and Lyman-Kutcher-Burman (LKB) models were used for estimating TCP and NTCP, respectively.

The PLQ model estimates the TCP according to following formula (equation 1)[24]:

$$TCP = \exp(-N\, p_s(D)) \tag{1}$$

Where, N is the initial number of tumoral cells, and $p_s(D)$ is the cell survival fraction after a dose D.

The LKB model estimates the NTCP according to following equation 2[20,22,24]:

$$NTCP = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} \exp\left(-\frac{u^2}{2}\right) du \tag{2}$$

Where, t is given from the below equitation 3:

$$t = \frac{EUD_a - D_{50}}{D_{50}.m} \tag{3}$$

In this equation, ""m" is the maximum inverse slope of dose-response curve, EUD is the equivalent uniform dose of the organ, and D_{50} is the total imposed dose to the normal tissues that may lead to force 50% complication to the organ.

Results

Comparison of the TPS dose calculations with TLD measurements showed up to 4.9% discrepancy.

Figure 2 illustrates the generated DVHs of the mentioned RT methods. Figures 3 and 4 compare the TCPs and NTCPs for target volume and normal tissues, respectively, among the techniques.

According to Figures 3 and 4, the TC*P* values for the chest wall, internal mammary nodes, supraclavicular nodes, and axilla of the combined photon-electron was 90%, 90%, 90%, and 65%, respectively. The TCPs for the chest wall, internal mammary nodes, supraclavicular nodes, and axilla of the tangential beams was 80%, 80%, 85%, and 60%, respectively [Figures 3 and 4]. These Figures also illustrate that the TC*P* values of the chest wall, internal mammary nodes, supraclavicular nodes, and axilla for the electron therapy was 80%, 80%, 60%, and 50%, respectively.

Whereas, for the NTCP, the values of ipsilateral lung, contralateral lung, heart, and chest wall–lung interface
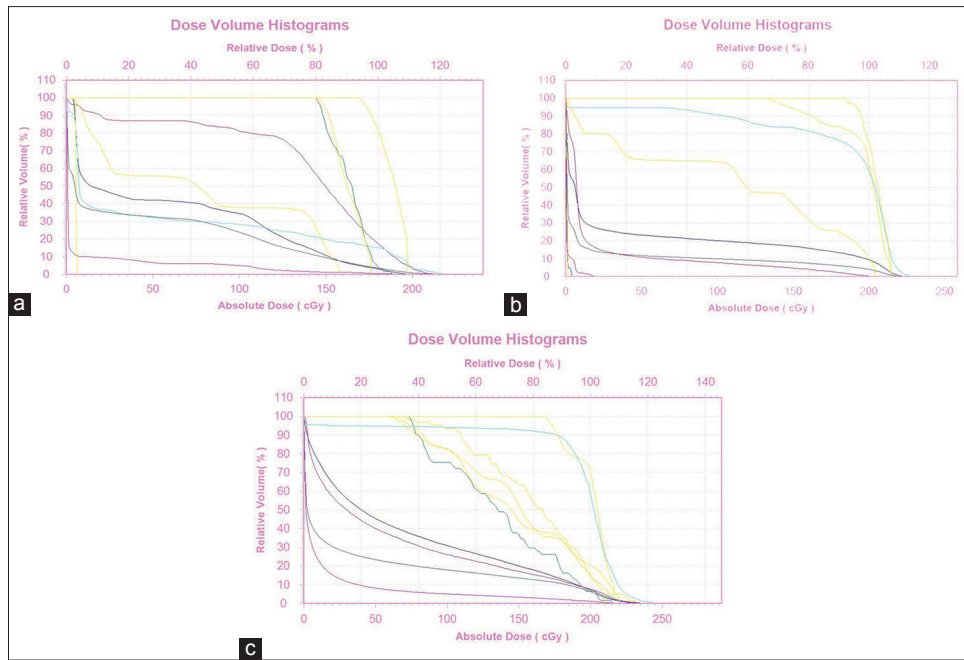
Figure 2: Dose volume histograms of combined photon-electron (a), tangential beams (b), and electron therapy (c) plans. Colors indicate the organs as follows: chest wall (red line), supraclavicular nodes (pink line), internal mammary nodes (lower blue line), three levels of axilla (three upper blue lines), ipsilateral lung (green line), contralateral lung (yellow line), heart (purple line), and chest wall–lung interface (white line) volumes
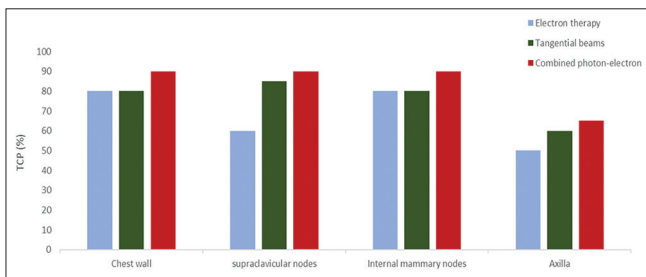

Figure 3: The tumor control probability (in percentage) among three techniques

for combined photon-electron was 9%, 4%, 6%, and 7%, respectively [Figures 3 and 4]. According to the Figures, the NTCPs of the tangential method for ipsilateral and contralateral lung, heart, and chest wall–lung interface was 4%, 1%, 3%, and 5.6%, respectively. It was found that the NTCPs of ipsilateral and contralateral lung, heart, and chest wall–lung interface for electron therapy was 7%, 3%, 5%, and 8%, respectively [Figures 3 and 4].

Discussion

This study was performed on radiobiological evaluation, including TCP and NTCP, of two different RT techniques such as combined photon-electron, two tangential photon beams, and electron therapy which are widely used for the treatment of mastectomy patients.

Figures 3 and 4 give the comparison of TCPs and NTCPs between the mentioned techniques. Our data showed that the TCPs and NTCPs were different among the studied methods [Figures 3 and 4].

Based on the results, TCP of the combined photon-electron for the chest wall was higher than tangential and electron irradiation (up to 11%). In addition, The TCPs of internal mammary nodes, supraclavicular nodes, and axilla for combined photon-electron was different compared to tangential beams (up to 11%, 5%, and 5%, respectively) and electron therapy (up to 11%, 33%, and 23%, respectively). Our data showed that the NTCPs of the ipsilateral and contralateral lung and also heart for the combined photon-electron was higher than tangential beams (up to 55%, 75%, and 50%, respectively) and electron therapy (up to 22%, 25%, and 16%, respectively). These results were mainly due to lateral scattering of electrons. In the combined photon-electron, this spread may create high-dose regions under the photon fields.[10,25] Furthermore, the divergence of the electron and photon beams can overlap the isodose curves, which produces high-dose regions in the depth of ipsilateral lung and heart.[10] The NTCP of tangential beams for chest wall–lung interface was lower compared to combined photon-electron method (up to 20%); in contrast, the NTCP of electron irradiation for chest wall–lung interface was higher than combined photon-electron (up to 12%) and tangential methods (up to 30%). It is mostly depended to a "high dose region that is, to some extent, before a rapid drop-off dose in electron beam."[10,25,26]

According to Figures 3 and 4, the TCP values of the chest wall and internal mammary nodes for the tangential photon beams and electron therapy was same while the TCP value for supraclavicular nodes of the tangential beams was different compared to electron
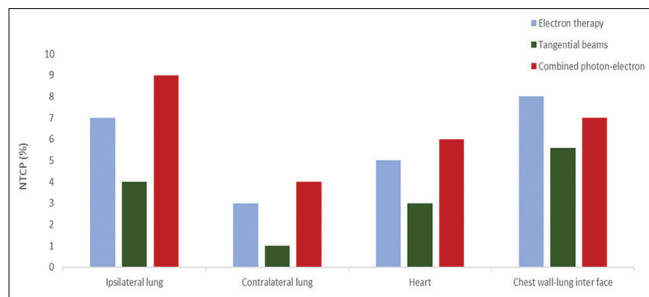
Figure 4: The normal tissue complication probability (in percentage) among three techniques

therapy (up to 29%). The NTCPs of the OARs for the tangential was different compared to electron therapy [Figures 3 and 4]. The NTCPs of the ipsilateral and contralateral lung and heart was lower than electron therapy (up to 42%, 66%, and 40%, respectively). This was seen as a result of the high-dose region before sharp dose drop-off of the electron beam beyond the build-up region compared to photon,[24,25] and it may impose higher radiobiological effects on chest wall–lung interface. Moreover, it is known that inhomogeneities including lungs and ribs can significantly affect the electron beam.[10,25-27] Also, electron beam has x-ray contamination at the end of its path.[10,25-27] Another point is the lateral scattering of electrons, which is higher than photons.[10] Therefore, the reasons may lead to increase NTCPs of electron therapy than tangential beams.

Similar results have been reported in other studies. Muran *et al*. have compared the NTCPs for two different tangential methods including conformal tangential and standard tangential irradiation.[28] In the study, the dosimetric data of twenty-six breast cancer patients were extracted from their DVHs, and NTCPs were estimated according to relative seriality model. In their study, they concluded that the conformal tangential method may impose lower complications to normal tissues such as lungs and heart compared to the other studied method.[27]

Alizadeh *et al*. have reported that the NTC*P* values of heart and lung were smaller in conformal tangential technique compared to conventional tangential one,[20] which is in line with our finding. The results of our study are in an agreement with Hurkmans *et al*. who stated that using conformal tangential technique may decrease NTCP compared to using rectangular fields.[29]

According to results of our study, tangential beams not only may lead to lower NTCPs, but also provide sufficient control over the tumor than other techniques such as combined photon-electron and electron therapy.

Conclusion

In this paper, the radiobiological efficiency of different RT techniques including combined photon-electron, two tangential photon beams and electron therapy was evaluated using TCP and NTCP models. Tangential beams could be a good choice to treat mastectomy patients, due to lower NTCPs compared to other techniques such as direct electron and combined direct photon-electron.

Acknowledgment

Financial support and sponsorship

Conflicts of interest

There are no conflicts of interest.

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