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Measurement of the photon and thermal neutron doses of contralateral breast surface in breast cancer radiotherapy

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Abstract

Introduction and purpose: During the radiation therapy of tumoral breast, the contralateral breast (CB) will receive scattered doses. In the present study, the photon and thermal neutron dose values received by CB surface during breast cancer radiation therapy were measured.
Materials and methods: The right breast region of RANDO phantom was considered as CB, and the measurements of photon and thermal neutron dose values were carried out on this region surface. The phantom was irradiated with 18 MV photon beams, and the dose values were measured with thermoluminescent dosimeter (TLD-600 and TLD-700) chips for 11 × 13, 11 × 17 and 11 × 21 cm^2 field sizes in the presence of physical and dynamic wedges.
Results: The total dose values (photon + thermal neutron) received by the CB surface in the presence of physical wedge were 12·06%, 15·75% and 33·40% of the prescribed dose, respectively, for 11 × 13, 11 × 17 and 11 × 21 cm^2 field sizes. The corresponding dose values for dynamic wedge were 9·18%, 12·92% and 29·26% of the prescribed dose, respectively. Moreover, the results showed that treatment field size and wedge type affect the received photon and thermal neutron doses at CB surface.
Conclusion: According to our results, the total dose values received at CB surface during breast cancer radiotherapy with high-energy photon beams are remarkable. In addition, the dose values received at CB surface when using a physical wedge were greater than when using a dynamic wedge, especially for medial tangential fields.

Introduction

Breast cancer is the most frequent malignancy among women worldwide.[1,2] Although this cancer has a higher incidence in developed countries, an estimated 60% of breast cancer deaths occur in developing countries.[3] Nowadays, due to effective screening and a combination of different treatment modalities such as surgery, radiation therapy and hormone therapy, the mortality of breast cancer has decreased in developed countries.[4] Radiation therapy plays a vital role in the multimodal treatment of breast cancer, as it has been reported in several literatures that this modality improves survival and reduces locoregional recurrence.[5–8] In some cases, high-energy beams (e.g., 18 MV) were used to treat patients with breast cancer.[9,10] Nevertheless, the interaction of high-energy beams (>8 MV) with various high-atomic-number (Z) nuclei of the materials in the components of the linear accelerator (linac) head would produce unavoidable neutrons.[11–13]

The areas away from the treatment field receive scatter radiation from different sources (such as the linac head, internal patient scatter radiation and unavoidable neutrons).[14,15] Compared to the inside-field dose, the out-of-field region would receive low dose values. However, these low doses can induce secondary malignancies with a long latency period, and the incidence of these cancers depends on several factors, including the size of irradiated volume, delivered dose, dose distribution, dose rate and patient-specific factors.[16,17]

During breast cancer radiation therapy, the contralateral breast (CB) surface will receive scattered doses.[18] Several studies have demonstrated the dependence of radiation with basal cell carcinoma and melanoma.[19,20] Nevertheless, there is little evidence for the dependence of radiation with squamous cell carcinoma at moderate doses.[20] Several studies have evaluated skin cancer risk as a second malignancy in cancer radiation therapy. In a study, Ghavami and Ghiasi estimated secondary skin cancer risk resulting from electron contamination in prostate radiation therapy. Their findings show that non-negligible doses (from contaminant electrons) are absorbed by the skin, which is associated with an excess risk of malignancy induction.[21] In another study, Goggins et al. reported a 42% increased risk of cutaneous melanoma among breast cancer patients who underwent radiation therapy. This increased risk of cutaneous melanoma was consistent with a large institutional case series of 1,884 patients who had undergone early-stage breast cancer radiation therapy.[19]

Therefore, the skin dose associated with radiation therapy may be of interest for clinically assessing or evaluating the risk of late effects. Although the received photon dose to CB surface of patients undergoing breast cancer radiation therapy has been investigated,[22–24] to the best of our knowledge, there is no measurement of received neutron dose to CB surface in the presence of physical and dynamic wedges and different field sizes. Hence, a study was conducted to measure the received photon and thermal neutron doses to CB surface in breast cancer radiation therapy for different treatment field sizes in the presence of dynamic and physical wedges.

Methods and Materials

In the current research, for the measurement of photon and thermal neutron dose values at CB surface, the right breast region of RANDO phantom was irradiated with 18-MV photon beams. Then, dose values were measured with thermoluminescent dosimeter (TLD) chips for different field sizes in the presence of physical and dynamic wedges.

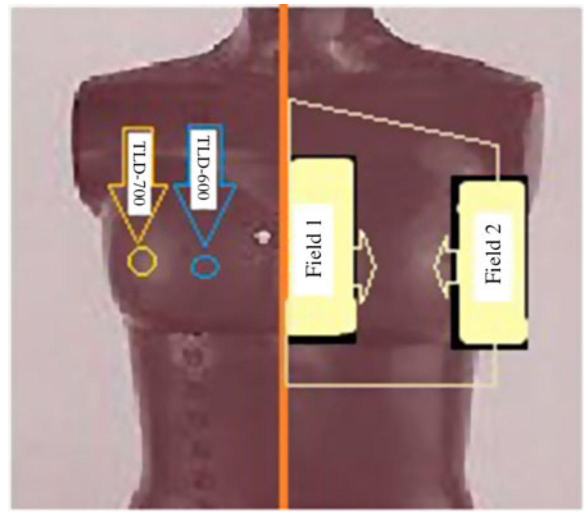

Figure 1. Tangential fields of breast radiation therapy and placement of TLD chips on the RANDO phantom.

TLD Dosimetry

The use of TLD chips in radiation dose measurement has been well established.[23] Due to the small size and appropriate spatial resolution, TLD chips have widespread application for point dosimetry in radiation therapy, especially in high-dose gradient regions. There are several literatures on how to use the TLD chips for the measurement the photon and neutron doses.[25–27]

In the current study, dose measurements were carried out with ^{600}TLD and ^{700}TLD chips. These TLD chips are produced by Harshaw Company and made of LiF, Mg and Ti with a thickness of 0·9 mm and size of 3 × 3 mm^2. Readout and analysis of TLD chips was performed at the National Medical Physics Research Center using a special protocol. More details on the calibration of ^{600}TLD and ^{700}TLD chips are available in our previous study.[12]

Furthermore, a pair of TLD chips was applied to measure background dose.

The relative biological effect of radiation depends on energy radiation, type radiation, etc. So, a radiation weighting factor was considered for each radiation beam, and these factors for neutron rays were 5–20 (depending on neutron energy).[28] In this study, the radiation weighting factor of 5 was applied for the conversion of physical dose to equivalent dose, because the absorbed dose by TLDs are thermal neutrons (<10 keV). Consequently, to obtain equivalent dose (Sv), the absorbed doses by TLDs were multiplied by the radiation weighting factor.

Finally, to increase the precision of dosimetry data, each measurement was repeated three times.

Treatment Planning and Phantom Irradiation

The RANDO phantom (Phantom Laboratory, NY, USA) was scanned with a computed tomography scanner and then the images were transferred to a radiotherapy treatment planning system (COREPLAN; Seoul C and J, South Korea). The left breast of the RANDO phantom was considered the target volume (tumoral breast), and the right breast was selected for the measurement of surface dose originating from the photons and thermal neutrons. Two tangential fields (medial and lateral) were planned. A 15° wedge angle (for both physical and dynamic wedges) was used to create a uniform dose distribution, and treatment field sizes were 11 × 13, 11 × 17 and 11 × 21 cm^2. Finally, a source axis distance technique was used to deliver 200 cGy based on the International Commission on Radiation Units and Measurements.[29] For a possible comparison of the results of the current study (doses received at CB surface) with that of our previous study (doses received to CB),[12] treatment planning in this study was similar to our previous study. Figure 1 shows the anterior view relating to the tangential fields of left breast region of the RANDO phantom.

To measure CB surface dose in each of the field sizes, one pair of TLD chips (one ^{600}TLD and one ^{700}TLD) was located on the surface of right breast region of the RANDO phantom (Figure 1). In other words, for dose measurements, three pairs of TLD chips were applied in the presence dynamic wedge and three pairs in the presence physical wedge. Irradiations on the RANDO phantom were done based on the treatment plan with 18-MV Varian 2100 C/D Linac (Varian Medical Systems, Palo Alto, CA, USA).

Finally, the CB surface dose was obtained from the average of three-time readings of TLD chips at each point for different field sizes in the presence of physical and dynamic wedges.

Results

Findings relating to the received photon and thermal neutron doses at CB surface in the presence of dynamic and physical wedges for different field sizes are summarised in Table 1. The received photon doses at CB surface ranged from 92·94 to 335·47 mSv, and also the received thermal neutron doses at CB surface ranged from 90·62 to 332·56 mSv. The maximum and minimum CB surface doses (both of photons and thermal neutrons) were related to using the physical wedge with 11 × 21 cm^2 field size (668·03 mSv) and the dynamic wedge with 11 × 13 cm^2 field size (183·56 mSv), respectively. The mean received dose at CB surface with physical wedge was 197·09 mSv higher than that with the dynamic wedge in the three field sizes.

Figure 2 illustrates variations in photon and thermal neutron dose values received at CB surface, as a function of treatment field size, for physical (a) and dynamic (b) wedges.

Figure 3 shows the effect of wedge type (dynamic and physical) on photon (a) and thermal neutron (b) dose values received at CB surface in different treatment field sizes.

Table 1. Photon and thermal neutron dose values received at contralateral breast (CB) surface relating to wedge types and different treatment field sizes

	Received dose at CB surface (physical wedge)		Received dose at CB surface (dynamic wedge)	
Field size (cm^2)	Photon dose (mSv)	Neutron dose (mSv)	Photon dose (mSv)	Neutron dose (mSv)
11 × 13	122·13 ± 12·31	119·03 ± 11·98	92·94 ± 9·31	90·62 ± 9·10
11 × 17	157·52 ± 15·76	157·50 ± 15·75	130·25 ± 13·10	128·09 ± 12·93
11 × 21	335·47 ± 33·57	332·56 ± 33·30	296·49 ± 29·65	288·73 ± 28·92

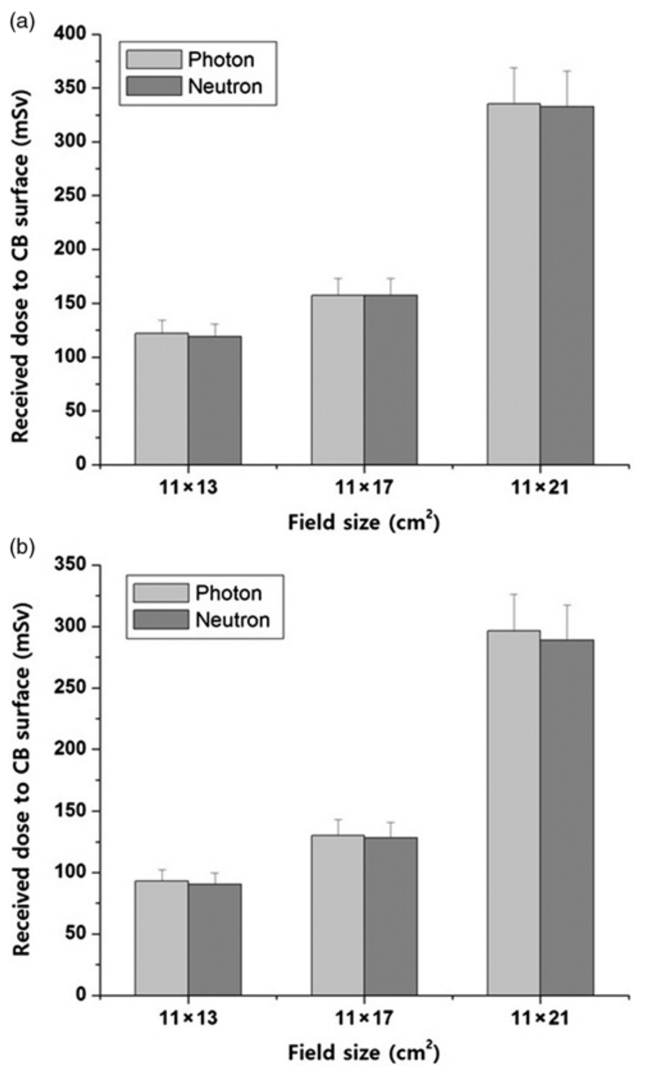

Figure 2. Photon and neutron dose values received at contralateral breast (CB) surface for different treatment field sizes with physical (a) and dynamic (b) wedges.

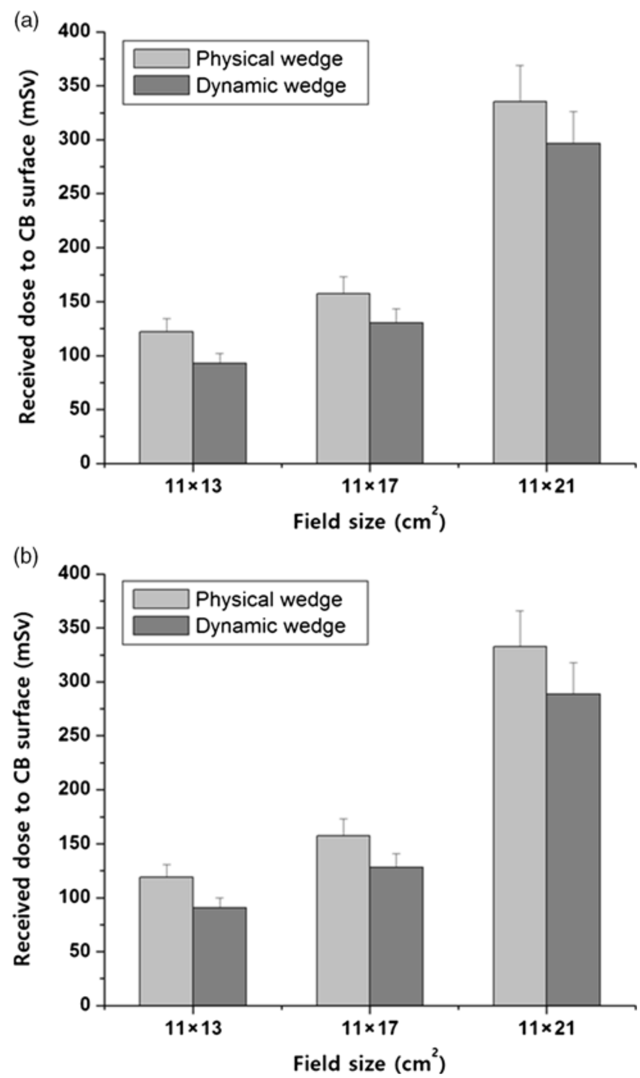

Figure 3. Effect of wedge types on the received photon (a) and neutron (b) dose values at contralateral breast (CB) surface for different field sizes.

Figure 4 demonstrates the effect of wedge type and treatment field size on photon and thermal neutron dose values received at CB surface.

Discussion

In the current study, the received photon and thermal neutron doses at CB surface in breast radiation therapy were measured in the presence of dynamic and physical wedges. Moreover, the effects of treatment field size and wedge type on photon and thermal neutron dose values received at CB surface were investigated.

Leakage and scattered radiation from linac head, treatment accessories and patient body were responsible for the received dose values at CB surface.[22] Skin is a radiosensitive structure and also dose values received at CB surface could lead to a secondary skin cancer during breast cancer radiation therapy. So, it is important to

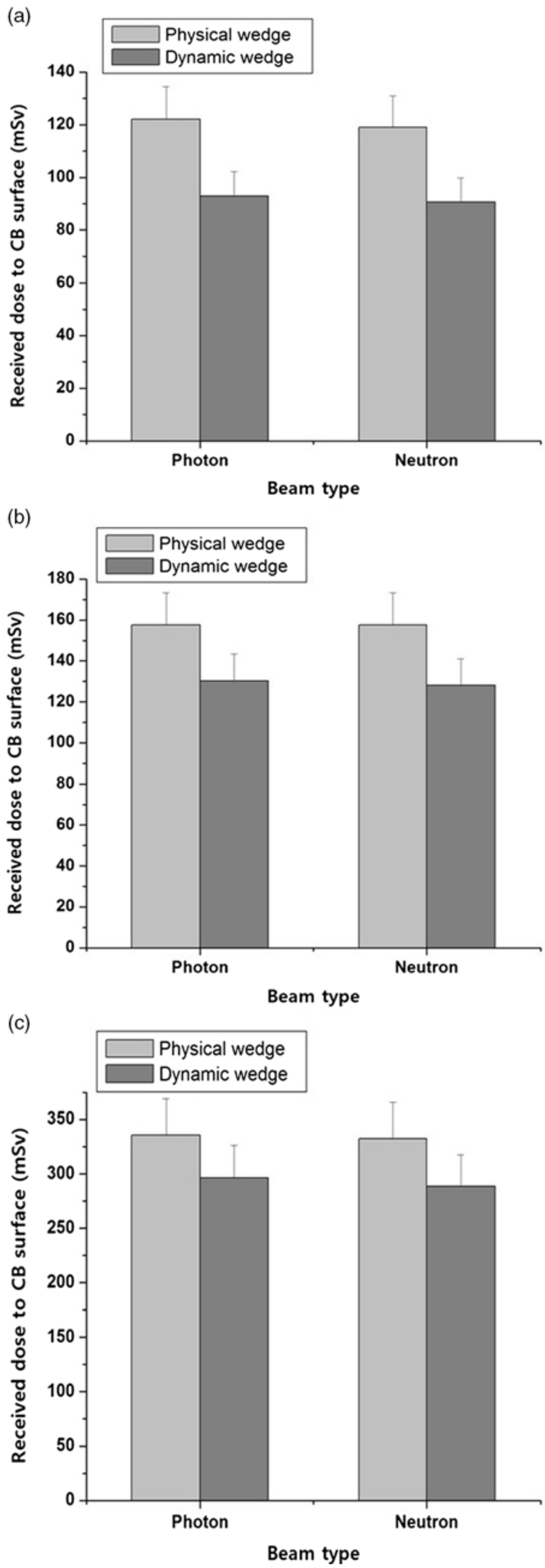

Figure 4. Effect of treatment field size and wedge type on photon and neutron dose values received at the contralateral breast (CB). (a), (b) and (c) relate to 11 × 13, 11 × 17 and 11 × 21 cm^2 treatment filed sizes, respectively.

measure and evaluate the superficial dose of CB and the parameters affecting this dose, including field size and wedge type. Recently, several studies have evaluated the effect of wedge filter on photoneutron contamination of photon beams and its spatial distribution around a linac head.[30–32] It was highlighted that using the high Z wedge in the pathway of high-energy photons would lead to an increase in the number of photoneutrons.[33] When using a wedge filter, photon fluence reaching the maximum dose depth (d_{max}) decreased by a rate which equals to the wedge factor. So, to compensate the attenuation effect of the wedge filter, the required monitor units may be increased to produce the same dose at d_{max} and this will increase photoneutron production for wedged beams.[30] Another effect could be an increase in backscattered photons and their interactions with linac head components, which might lead to further leakage of photon and neutron beams.[32]

In the current study, the total dose values (photon + thermal neutron) received at CB surface in the presence of physical wedge for 11 × 13, 11 × 17 and 11 × 21 cm^2 treatment filed sizes were 12·06%, 15·75% and 33·40% of the prescribed dose, respectively. The corresponding dose values for the dynamic wedge were 9·18%, 12·92% and 29·26% of the prescribed dose, respectively. In a previous study,[12] we measured photon and thermal neutron dose values received by CB in breast cancer radiation therapy. Table 2 compares the total dose values received at CB surface and CB[12] in the presence of physical and dynamic wedge for 11 × 13, 11 × 17 and 11 × 21 cm^2 filed sizes. By comparing the results of both studies (Table 2), it is evident that the received dose at CB surface was more than that of CB, especially for larger field sizes. Given that the total dose values received at CB surface during breast cancer radiotherapy with high-energy photon beams are remarkable, an attempt should be made to reduce the dose received at CB surface to the lowest value possible during breast cancer radiation therapy. There are several techniques to minimise the received radiation dose at CB surface/CB during breast cancer radiation therapy[34–42]: (1) the half beam technique with a wedge and block on the medial side should not be applied, unless breast shields are used,[34,35] (2) the use of intensity-modulated radiation therapy, in comparison with 3D conformal radiotherapy, can reduce the incidence of acute radiation dermatitis,[36,37] (3) the field-in-field technique, in comparison with conventional wedged fields, improves dose homogeneity and reduces the received dose to surrounding tissues,[39,42] (4) the use of proton therapy with a scanning method would generate lower photoneutron doses, compared with high-energy X-ray techniques, because it avoids the need for a scattering foil, flattening filter or compensating equipment, and in this technique, a pencil beam is magnetically scanned on the target volume.[43]

In addition, photon dose values received at CB surface in the presence of physical wedge for 11 × 13, 11 × 17 and 11 × 21 cm^2 filed sizes were 6·11%, 7·88% and 16·77% of the prescribed dose, respectively. The corresponding dose values for dynamic wedge were 4·65%, 6·51% and 14·82% of the prescribed dose, respectively. Prabhakar et al.[22] measured CB surface doses for different tangential field techniques. They stated that the skin dose measured at the nipple was 2·1–10·9% of the isocentre dose. Their results are consistent with the present study. In another study, Alzoubi et al. measured CB surface doses in chest wall and breast irradiations. Their results demonstrated that CB surface dose was 2·1–4·1% of the prescribed dose.[23] These dose values were lower than that reported by the present study, possibly due to differences in beam energies and treatment techniques.

Table 2. Comparison of dose values received at contralateral breast (CB) surface and CB relating to wedge types and different treatment filed sizes

	Received dose at CB surface(mSv) (current study)		Received dose at CB (mSv) (Bagheri et al.[12])	
Field size (cm^2)	Physical wedge	Dynamic wedge	Physical wedge	Dynamic wedge
11 × 13	241·16	183·56	118·38	58·49
11 × 17	315·02	258·34	127·23	92·51
11 × 21	668·03	585·22	135·40	111·94

As shown in Figure 2, photon and thermal neutron dose values received at CB surface increase with increasing treatment field sizes. It is expected that with increasing treatment field sizes, scattered photons – and consequently interactions of these photon beams with various high-Z nuclei of the materials inside the beams – also increase. Furthermore, our findings suggest that photon dose received at CB surface was a little more than thermal neutron dose across all field sizes. These findings are consistent with the study of Bagheri et al.[12]

Other results (Figure 3) demonstrate that photon and thermal neutron dose values received at CB surface were less in the presence of a dynamic wedge than a physical wedge. The physical wedge is made of metallic materials and inserted manually in the pathway of the beam, which might generate more scattering photons due to the interaction of primary photon beams with its materials. Several literatures have also stated that the use of a physical wedge can lead to a significantly higher dose at CB surface compared to an open field, especially for the medial tangential field.[22,24,44]

Figure 4 shows that the contribution of dose values received at CB surface in the presence of a dynamic wedge is approximately same as with a physical wedge for different treatment field sizes. These results are consistent with the study of Bagheri et al.[12]

Figure 5 illustrates variations in dose values received at CB surface and CB[12], as a function of treatment field size, for physical (a) and dynamic (b) wedges. As shown in this figure, with an increase in treatment field size, dose difference between CB surface and CB increases. For example, dose difference between CB surface and CB in the presence of a physical wedge was 34·15% for 11 × 13 cm^2 field size, while it was 66·29% for 11 × 21 cm^2 field size.

The effect of wedge type on dose values received at CB surface and CB[12] is shown in Figure 6 for 11 × 13 (a), 11 × 17 (b) and 11 × 21 cm^2 (c) field sizes. The figure shows that dose difference between CB surface and CB for a dynamic wedge was more than that for a physical wedge. For example, the dose difference between CB surface and CB was 34·15% in the presence of a physical wedge and 51·67% in the presence of a dynamic wedge for 11 × 13 cm^2 field size.

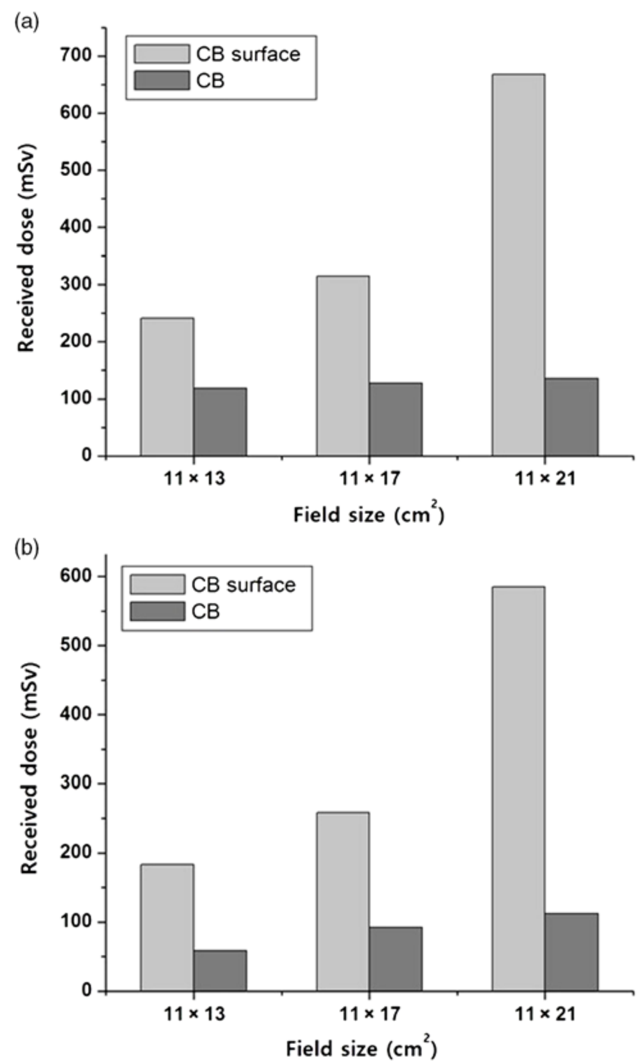

Figure 5. Comparison of dose values received at contralateral breast (CB) surface and CB in the presence of physical (a) and dynamic (b) wedges for different treatment field sizes.

Conclusion

With skin cancer risk as a second malignancy in breast cancer radiation therapy, the measurement of dose received at CB surface is essential. Our findings show that total dose values received at CB surface during breast cancer radiotherapy with high-energy photon beams were remarkable, especially for large treatment field sizes (33·40% of the prescribed dose); hence, it is important to reduce the dose received at CB surface to the least possible. Furthermore, the dose values received at CB surface when using a physical wedge were greater than when using a dynamic wedge, especially for medial tangential fields.

From a practical point of view, it is suggested to use a dynamic wedge or other techniques that can help reduce the dose to the CB during breast cancer radiation therapy.

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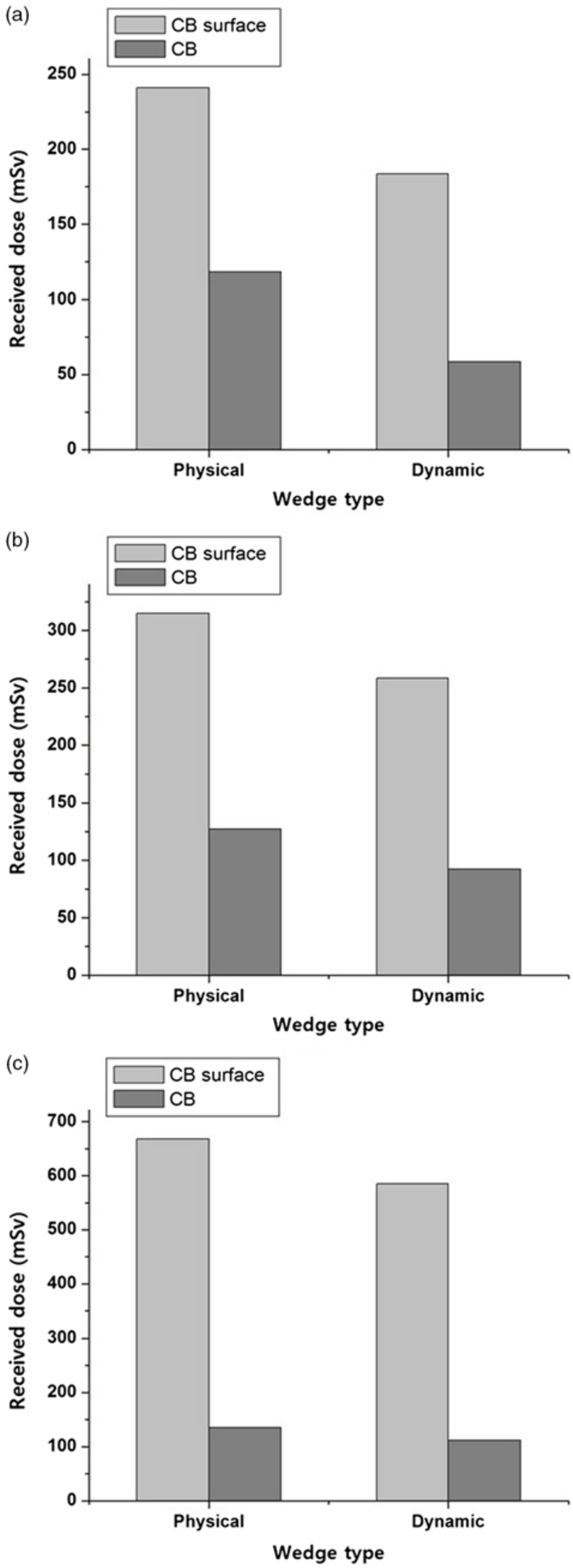

Figure 6. Comparison of dose values received at contralateral breast (CB) surface and CB in presence of wedge type for 11 × 13 (a), 11 × 17 (b) and 11 × 21 (c) cm^2 field sizes.

Conflicts of interest. None.

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