

Comparison of Virtual Wedge versus Physical Wedge Affecting on Dose Distribution of Treated Breast and Adjacent Normal Tissue for Tangential Breast Irradiation

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Purpose: The ideal breast irradiation method should provide an optimal dose distribution in the treated breast volume and a minimum scatter dose to the nearby normal tissue. Physical wedges have been used to improve the dose distribution in the treated breast, but unfortunately introduce an increased scatter dose outside the treatment field, particularly to the contralateral breast. The typical physical wedge (PW) was compared with the virtual wedge (VW) to determine the difference in the dose distribution affecting on the treated breast and the contralateral breast, lung, heart and surrounding peripheral soft tissue.

Method and Materials: The data collected consisted of a measurement taken with solid water, a Humanoid Alderson Rando phantom and patients. The radiation doses at the ipsilateral breast and skin, contralateral breast and skin, surrounding peripheral soft tissue, and ipsilateral lung and heart were compared using the physical wedge and virtual wedge and the radiation dose distribution and DVH of the treated breast were compared. The beam-on time of each treatment technique was also compared. Furthermore, the doses at treated breast skin, contralateral breast skin and skin 1.5 cm away from the field margin were also measured using TLD in 7 patients of tangential breast irradiation and compared the results with phantom measurements.

Results: The virtual wedge showed a decreased peripheral dose than those of a typical physical wedge at 15°, 30°, 45°, and 60°. According to the TLD measurements with 15° and 30° virtual wedge, the irradiation dose decreased by 1.35% and 2.55% in the contralateral breast and by 0.87% and 1.9% in the skin of the contralateral breast respectively. Furthermore, the irradiation dose decreased by 2.7% and 6.0% in the ipsilateral lung and by 0.96% and 2.5% in the heart. The VW fields had lower peripheral doses than those of the PW fields by 1.8% and 2.33%. However the skin dose increased by 2.4% and 4.58% in the ipsilateral breast. VW fields, in general, use less monitor units than PW fields and shortened beam-on time about half of PW. The DVH analysis showed that each delivery technique results in comparable dose distribution in treated breast.

Conclusions: A modest dose reduction to the surrounding normal tissue and uniform target homogeneity were observed using the VW technique compare to the PW beam in tangential breast irradiation. The VW field is dosimetrically superior to the PW beam and can be an efficient method for minimizing acute, late radiation morbidity and reduce the linear accelerator loading by decreasing the radiation delivery time.

Key Words: Breast cancer, Virtual wedge, Physical wedge, Dose distribution

Submitted May 12, 2004 accepted August 24, 2004
This study was supported by a grant from the Catholic Cancer Center.
Presented at 2001 RSNA Annual Meeting, Chicago, Illinois, November 25-30, 2001.
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Introduction

Breast of women having a three dimensional cone shape structure, homogenous dose distribution is difficult to obtain in the target volume.¹⁾ Wedge filters have been commonly used as missing tissue compensators and as a wedge pair to alter the shape of isodose curves so that they improve the dose

uniformity in the target volume.²⁾ Although the typically used physical wedge can improve the dose distribution within the treated breast, they pose the risk of radiation induced carcinogenesis in young women by prolonging radiation delivery time and then increasing the radiation dose in the contralateral breast and the surrounding area of radiation field. Recently, virtual wedge or dynamic wedge system were implemented in digital linear accelerator which made it possible to create wedge-like dose distribution by computer controlled motion of one of the collimator jaws across the field during irradiation.²⁾ The speed of the jaw motion is constant for a given field but the dose rate changes. Due to different mechanisms used to generate wedged dose distribution as well as their relative positions to the linear accelerator target, the two wedge systems, physical wedge and virtual wedge are expected to have some different dosimetric characteristics.³⁾ The ideal breast irradiation method should be provided an optimal dose distribution in the treated breast volume and a minimum scatter dose to the nearby normal tissue. Because of the combined effects of the distance to the patients and shielding by treatment head, scattered radiation to contralateral breast and to nearby normal tissue in virtual wedge is expected to be less than that of conventional physical wedge. We compared treatment techniques using virtual wedge and physical wedge for tangential breast irradiation with special attention to dosimetric improvements in the treated breast volume, contralateral breast, skin, lung, heart, peripheral soft tissue and treatment irradiation time. There are lots of studies on physical wedge and virtual wedge,

but in this paper we compared dosimetric difference of PW and VW with radiation oncologist's clinical view point.

Materials and Methods

1. Measurement of peripheral dose

We compared the peripheral dose outside the field using a regular physical wedge, virtual wedge and open field. Measurement of peripheral dose of 6 MV x-ray were performed using Markus chamber (PTW) in the depth of d_{max} (1.5 cm, 6 MV) with collimator setting of $10 \times 10 \text{ cm}^2$ and $20 \times 20 \text{ cm}^2$ for 15° , 30° , 45° and 60° wedge in both PW and VW. Measurement points are 5 cm outside the field in both heel and toe side of the wedge (Fig. 1).

2. CT simulation

An anthropomorphic (Alderson Rando) phantom were used for the study. CT images were acquired at 5 mm spacing from CT simulator (Picker, Phillips, U.K.). Field size, beam direction, isocenter were determined using virtual simulation (ACQSIM, Phillips, U.K.), taking into account breast tissue distribution and lung volume within radiation field. Standard wedged tangential beams were generated. Virtual wedged technique used same treatment parameter for comparison with PW plan. We used a 6 MV photon (Siemens, Concord, U.S.A.) and prescription point was to mid breast in the central axis plan.

3. DVH analysis

3-D planning system (Helax 5.0, MDS Nordon, Sweden) was used to calculate dose of tangential breast irradiation. We compared dose distribution of physical wedge with virtual wedge and DVH analysis at the treated breast volume.

4. Dose measurement using TLD in the anthropomorphic (Alderson Rando) phantom

Furthermore, we compared the radiation doses at the treated breast and skin, contralateral breast and skin, surrounding peripheral soft tissue, and ipsilateral lung and heart using TLD (Harshaw TLD-100 LiF TLD, Harshaw Chemicals, Solon, OH, U.S.A). TLD chips were embedded in 12 different locations for dose measurement. Fig. 2. shows the points of dose measurements. TLD chips were wrapped with plastic

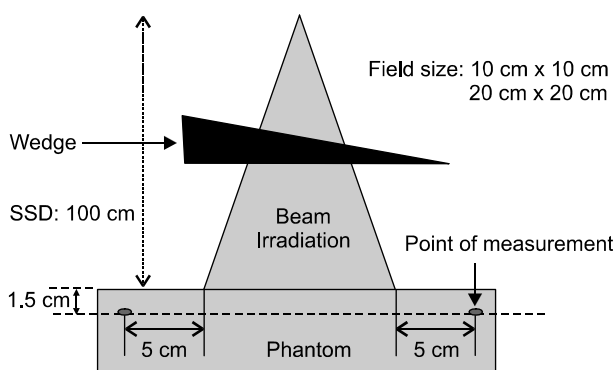


Fig. 1. Measurement of peripheral dose for the 6 MV x-ray at the depth of d_{max} and 5 cm away from the field edge in the solid water phantom.

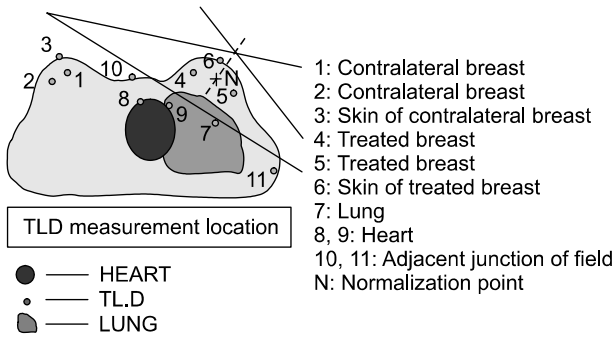


Fig. 2. Schematic diagram representing the transverse contour of anthropomorphic phantom. TLD chips were embedded in 12 different location in contralateral and treated breast and surrounding normal tissue.

sheet before being inserted into measurement location. Three measurements were made and average reading of TLD chips was used as dose determination. To increase the measurement precision, calibration of TLD chips was performed before each measurement, and all TLD chips from same study were read at the same time. The accuracy of TLD dose measurement was estimated to be $\pm 5.0\%$. If TLD reading out of this range, we repeated measurement.

5. Irradiation time

We also measured beam-on time of each treatment technique. Irradiation time means the sum of time elapsed between the initiation of radiation (pushing the rad ON button) and the completion of the irradiation ports. We didn't include the time required for patient and beam set-up.

6. In vivo dosimetry in 7 tangential breast irradiated patients

After selecting nine points on the treated breast skin, contralateral breast skin, and skin 1.5 cm away from the field margin, we measured doses at each point using TLD according to physical wedged and virtual wedged technique in 7 patients of breast cancer. And then we compared the results with data of phantom measurements. Each points of same breast were located 5 cm away from the same Y line. Fig. 3 shows the points of dose measurements.

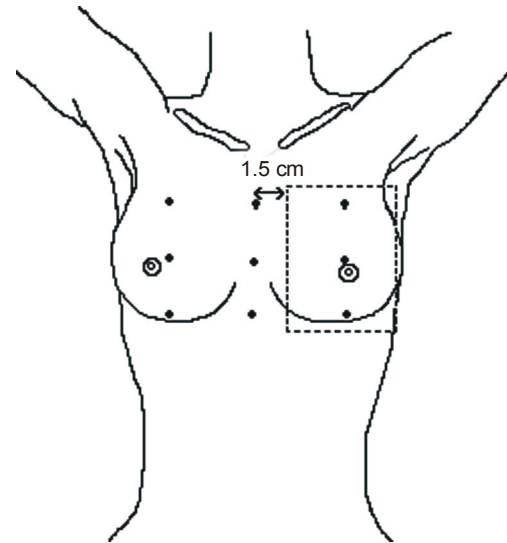


Fig. 3. TLD chips were attached at 9 different location for skin dose measurement in 7 tangential irradiated breast cancer patients. The dotted area on the skin indicate the treatment field.

and virtual wedge systems are shown in Fig. 4. The open field peripheral dose are included for comparison. All wedge systems produce increased peripheral doses relative to the open field except virtual wedge in 20x20 cm heel side field. However, the virtual wedge produced less increase in peripheral doses, while physical wedge exhibited greater increases, representing a increase about by a factor 2 or 3 times than open field. In summary virtual wedge showed decreased surrounding peripheral doses compared with those of physical wedge at each of 15°, 30°, 45°, and 60°.

2. Dose measurement using TLD in the anthropomorphic (Alderson Rando) phantom

Fig. 5, Table 1 compared the dose at each point using PW vs VW. All of doses are expressed as percentages of the dose measured at the prescription point in treated breast. In virtual wedged field, the measured dose to contralateral breast tissue reduced from 3.18% to 1.83% and from 4.1% to 1.55% with the use of 15° and 30° VW, respectively. Dose to skin of contralateral breast also decreased by 0.87% with 15° and 1.9% with 30° VW compare to PW. Furthermore, it decreased by 2.7% and 6.0% in the ipsilateral lung and decreased by 0.96% and 2.5% in the heart. PW fields have higher peripheral doses than VW fields by 1.8% and 2.33%.

Results

1. Peripheral doses

The peripheral dose at dmax depths produced by physical

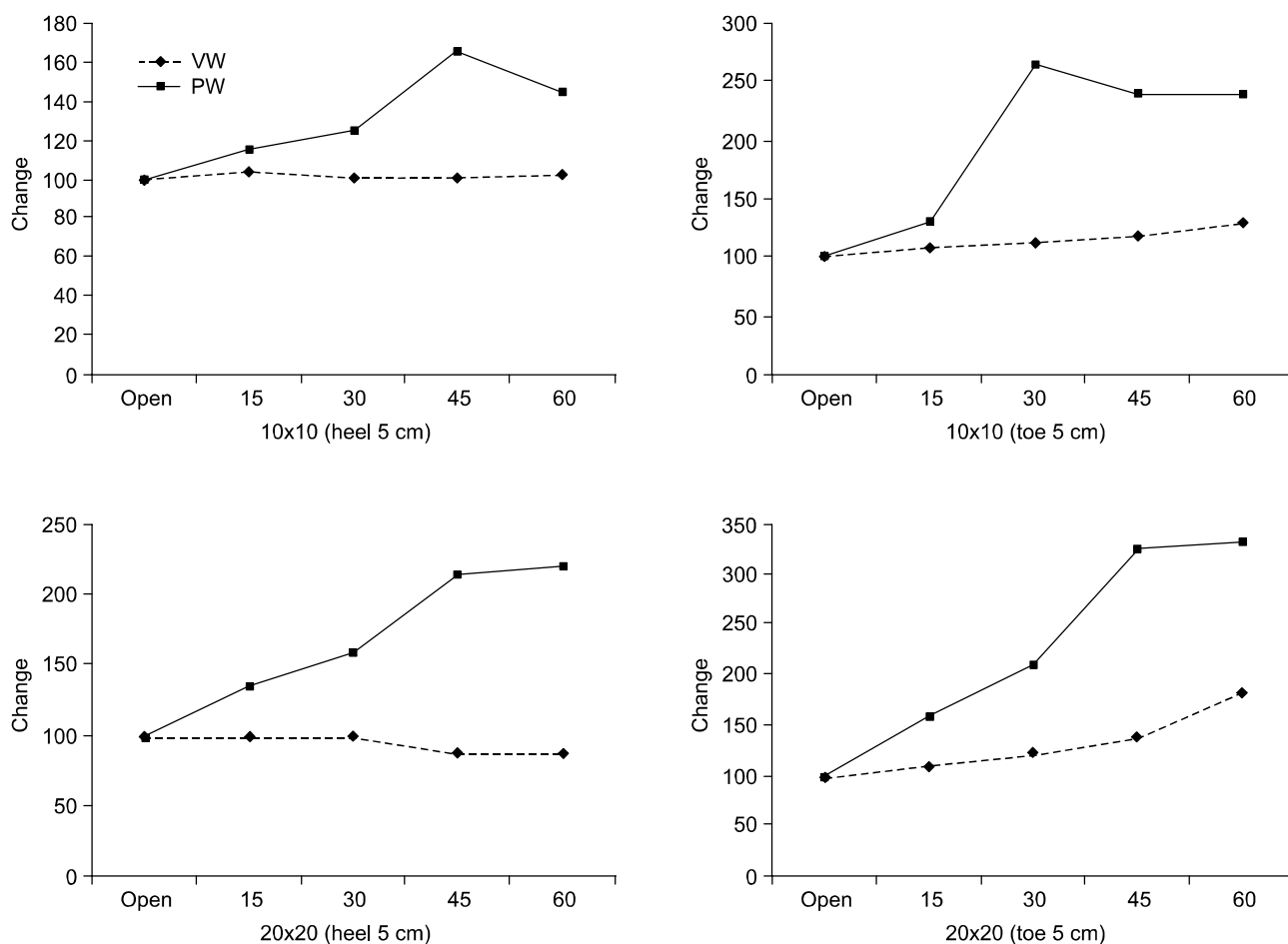


Fig. 4. Capital comparison of peripheral doses for 15°, 30°, 45°, 60° physical wedge and virtual wedge with field size 10x10 cm² and 20x20 cm² for 6 MV x-ray.

Table 1. Summary of Doses Measured within Humanoid Phantom (Anderson Rando Phantom). All of Doses Are Expressed as Percentages of the Prescription Dose

Measurement site	VW* 15	PW† 15	Changes‡	VW 30	PW 30	Changes*
Treated breast	95.5±1.2	96.5±1.9	-1.0	98.5±2.4	94.3±2.2	+4.2
Contralateral breast	1.83±0.04	3.18±0.06	-1.35	1.55±0.03	4.1±0.07	-2.55
Treated breast skin	76.5±2.1	74.1±1.8	+2.4	76.4±1.6	71.8±1.4	+4.58
Contralateral breast skin	3.03±0.06	3.9±0.07	-0.87	3.0±0.05	4.9±0.06	-1.9
Lung	100.5±2.4	103.2±1.6	-2.7	105.3±1.9	111.3±1.8	-6.0
Heart	4.12±0.07	5.08±0.09	-0.96	4.55±0.08	7.05±0.12	-2.5
Adjacent field junction	8.5±0.17	10.3±0.13	-1.8	7.6±0.11	9.93±0.19	-2.33

*Virtual wedge, † Physical wedge, ‡ Percent change compare virtual wedge with physical wedge

However VW fields tend to have higher surface doses of treated breast than PW by the increase of 2.4% in 15° and 4.58%, in 30° wedge.

3. In vivo dosimetry in actual patients treated with tangential breast irradiation

Although a significant variation existed in each patient of the measured doses at the treated breast skin, contralateral

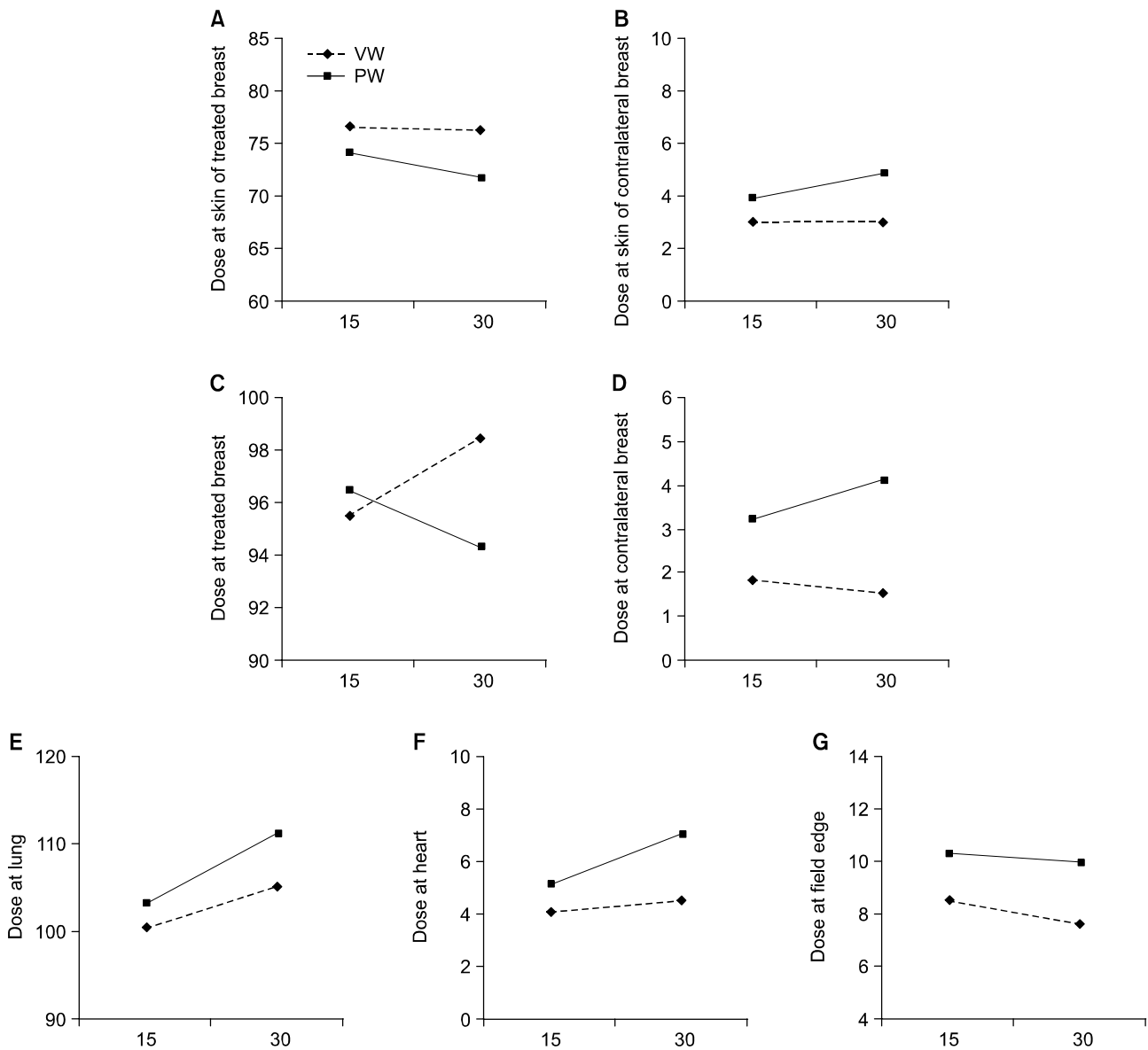


Fig 5. The average of doses measured at skin of treated breast (A), skin of contralateral breast (B), treated breast (C), contralateral breast (D), lung (E), heart (F) and adjacent tissue apart from field edge (G) in phantom. All of doses are expressed as percentages of the dose measured at the prescription point in treated breast.

breast skin, and skin of peripheral tissue using a 30° wedge, the tendency was similar as found in phantom measurement (Table 2). All 7 patients showed decreased dose at contralateral breast skin and skin of 1.5 cm from field margin.

4. DVH Analysis

The dose homogeneity within the treated breast was similar with no remarkable difference between using the physical wedge and virtual wedge according to DVH analysis using Helax 5.0 RTP system (Fig. 6). Mean dose to treated breast

was 97.2% of prescription point in 15° PW compared to 97.5% in 15° VW and 99.6% in 30° PW compared to 100.3% in 30° VW.

5. Irradiation duration

The virtual wedge decreased the irradiation duration by 53~55% compared with the physical wedge, showing a clinical cost effectiveness (Fig. 7).

Table 2. The Summary of Doses Measured at Skin of Treated Breast, Contralateral Breast, and Skin of 1.5 cm from Field Edge in 7 Patients. All of Doses Are Expressed as Percentages of the Prescription Dose

Patients	Treated breast			Contralateral breast			1.5 cm from field edge		
	VW 30	PW 30	Change*	VW 30	PW 30	Changes	VW 30	PW 30	Changes*
A	64.6	60.0	+4.6	2.6	3.3	-0.7	6.1	8.4	-2.3
B	66.9	60.0	+6.9	2.3	3.3	-1.0	5.2	8.4	-3.2
C	69.5	70.9	-1.4	5.4	7.3	-1.9	9.3	14.3	-6.4
D	72.6	69.4	+3.2	5.3	6.8	-1.5	10.3	16.7	-6.4
E	69.3	68.5	+0.8	2.8	4.5	-1.7	7.3	9.2	-1.9
F	65.9	63.6	+2.3	2.1	4.8	-2.7	7.9	8.4	-0.5
G	77.8	74.5	+3.3	9.3	9.3	0	3.9	4.6	-0.7

*: Percent change compare virtual wedge with physical wedge

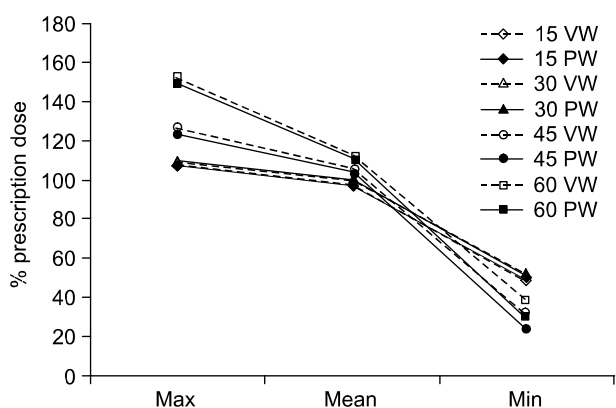


Fig. 6. Comparison of DVH of treated breast between PW and VW.

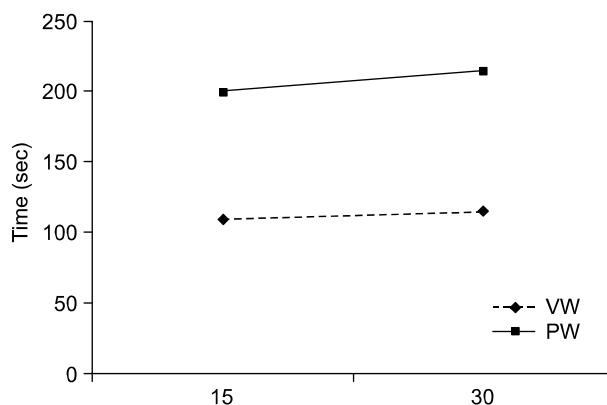


Fig. 7. Comparison of radiation delivery time between PW and VW.

Discussion

We have presented a direct comparison of dosimetric characteristics of siemens VW and PW in phantom and patients. The evaluation includes the measured dose to adjacent normal tissue including contralateral breast tissue, the calculated dose uniformity in the treated breast volume, and the measured irradiation time of each treatment technique. With the widespread use of radiation treatments in younger women the concern of secondary malignancy related to the initial treatment has been a subject of interest in recent years.^{4,5)}

So efforts have been made to develop new techniques that limit the possible exposure to the contralateral breast and near by normal tissue. Virtual wedge is a computer controlled

moving collimator jaw system that move across the treatment field, thereby recreating any wedge angle by having a ratio of open field to partially treated field, so the virtual wedge can modify the dose profiles without generating unwanted scatter.²⁾ This study is designed to assess the practical benefit of virtual wedge eg, reducing the scatter dose. Recent large scaled studies have shown that the scatter radiation to the contralateral breast may play a large part in the induction of second breast cancer.^{6,7)}

Radiation carcinogenesis is a stochastic phenomenon with no proven safe dose limit, consequently, reducing dose to the contralateral breast or other organs is worthwhile.⁸⁾ Detailed knowledge of the contralateral breast dose is necessary not only to assess whatever potential risk may exist for the induction of secondary cancer, but also to determine ways of reducing the magnitude of this dose so as to minimize further

any possible risk. We compared the peripheral dose outside the field using a regular physical wedge, virtual wedge and open field. Our measurement show that the peripheral dose outside the field using a virtual wedge is close to that of open field, and significant lower than that of physical wedge.

Zuofeng and Klein compared the peripheral doses at 5 cm outside the field at d_{max} depths produced by the three different wedge systems. All wedge systems produce increased peripheral doses relative to the open field. However, the dynamic wedge produced the least increase in peripheral doses, while the upper and lower wedges exhibited greater increases.⁹⁾ These results are similar to those reported by Leavitt¹⁰⁾, McFarland³⁾ and ours. Leavitt et al.¹⁰⁾ pointed out that this difference in peripheral dose increase can be minimized the contralateral breast dose.

VW and open fields have similar peripheral doses, as shown in Fig. 4. PW, on the other hand, may have a significantly higher peripheral dose, especially for large wedge angles. This is due to scattered radiation in the wedge filter contributing to doses outside the field.

Peripheral dose for PW presented in Fig. 4, the toe side are larger than that on the heel side.

These observations suggest that increased fluence on the toe side of a wedge field, especially for a large field size and a large wedge angle.²⁾ For a typical wedge orientation, heel anterior in a tangential breast treatment, the peripheral dose on the toe side of the medial tangent field is more directly relevant to doses to the contralateral breast.

Our data clearly demonstrate that VW produces significant lower peripheral doses on the toe side of the wedge. Therefore, lower doses to the contralateral breast in medial tangential breast treatments are expected. This has been recently confirmed by Chang et al and Zhu et al for VW in their phantom study.¹¹⁾ Fraass et al demonstrated, through various technique to reduce the radiation peripheral dose during treatment. One of these technique is removing the wedge from the medial tangential field.⁴⁾ The isodose distribution, with only the lateral wedge, may give an acceptable treatment plan most of the time, but sometimes medial wedge would improve the isodose distribution through out the treatment volume. So we need to determine way of reducing the magnitude of peripheral dose with both medial and lateral wedge.

Zuofeng and Klein⁹⁾ demonstrated virtual wedge produced slightly higher surface dose than physical wedge approximately 5%. These values are close to open field surface dose for an identical measurement geometry. But the high skin dose in the virtual wedge than physical wedge has less dramatic clinical effect in this region. Scattered low energy electrons generated from the accelerator primarily contribute to the surface dose. The electrons are absorbed in the epithelial tissue of the skin and deliver only a minimal dose to the underlying breast tissue. The major component of dose at depth is the scattered photons from the metal wedge.⁵⁾ Breast tissue dose rather than surface dose was important because the primary concern with dose to the contralateral breast is the development of a tumor within the breast tissue.¹²⁾ Otherwise Ochran et al pointed out, higher surface doses produced by virtual wedges may actually be beneficial when treating the breast with isocentric tangential beam.

It was found that the contralateral breast dose decrease with the perpendicular distance from the posterior edge of the medial tangent to dose measurement point and increase with effective wedge angle. Comparisons with data in the literature show that the contralateral breast dose increase by a dynamic wedge is typically only about half of that reported for a conventional physical wedge for the same wedge angle and distance from the beam.¹³⁾ With conventional physical wedged technique, Chang et al¹¹⁾ showed that the measured contralateral breast dose ranged from 3% to 6% of the treated breast dose. This observation is consistent with Kelly's study.¹²⁾ Oh's study demonstrated contralateral breast dose is 1~5.5% of treated breast and dynamic wedge reduced it 0.5~1% range¹⁴⁾ Our data also show contralateral breast dose 1.55~4.1% of treated breast and further demonstrate that contralateral breast dose reduced 1.35~2.55% using virtual wedge techniques. But limitation of our data is number of measurement point. The dose gradient across the entire breast is probably large, but we measured only 12 points in central axis plane of phantom. Chang et al¹¹⁾ evaluated 8 different intensity modulation technique using physical wedge and virtual wedge, MLC and compensator. They suggested that intensity modulation treatment via virtual wedge and MLC can offer the least dose to contralateral breast.

We used anthropomorphic (Alderson Rando) phantom which allowed the use of TLD chips in a very reproducible manner.

However the phantom is so rigid thus does not represent the typical breast that we see in our patients. So we measured skin dose of treated breast, contralateral breast, and 1.5 cm away from field edge in 7 patients. Measurement of the actual opposite breast dose and peripheral dose in patients showed a wide variation, but the results of phantom measurement are generally good agreement with the patients data (Table 1, 2). The general behavior of the dose outside of a radiation field (the "peripheral dose") is exponential with distance from the field edge.⁴⁾ The wide variation in opposite breast dose in our patients even for same treatment technique may be related different distance from field edge and gantry angle.

The ideal treatment method should provide an optimal dose distribution in the treated breast volume and a minimum scatter dose outside the treatment field. Furthermore, the ideal treatment method should require the least amount of cost (treatment time). The time analysis was performed for a commonly used daily treatment dose of 200 cGy for each wedged technique. The automation of virtual wedge eliminates the physical handling of the wedge and save the time needed to manually exchange the wedge between treatment ports. Even we didn't included this set up time saving in the irradiation time analysis, VW can shortened the irradiation duration about 50%. In addition to time saving, use of virtual wedge has another advantages, that include no need to manipulate a physical wedge and it obviates potential mistake with the wrong insertion of physical wedge.⁵⁾

Conclusion

Complete knowledge of the dosimetric characteristic, including surface and peripheral doses is important for proper choice of particular wedge system in clinical use. Virtual wedge has practically clinical benefit which improves the dose distribution in patients undergoing breast conservation while at the same time minimizing dose to the contralateral breast and nearby normal tissue, thereby reducing potential side effects.

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유방암의 방사선치료에서 Virtual Wedge와 Physical Wedge사용에 따른 유방선량 및 주변조직선량의 차이

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목적: 유방의 방사선조사 시 결손조직을 보상하고 방사선 균질선량 분포를 얻기 위해 통상적으로 physical wedge를 사용하여 왔다. Physical wedge 사용 시 주변의 폐, 심장, 반대편 유방, 피부에 조사되는 방사선량의 증가에 따른 급성, 만성 부작용의 증가가 문제시 된다. 본 연구에서는 일반적인 Physical wedge와 virtual wedge를 비교하여 동측 유방, 반대편 유방, 폐, 심장, 주변연부조직에 미치는 선량분포의 개선점을 알아보고자 하였다.

재료 및 방법: Solid water phantom을 이용하여 Dmax와 10 cm 깊이에서 physical wedge와 virtual wedge 사용 시 조사야 주변선량을 비교하였다. Humanoid Phantom (Anderson Rando Phantom)을 사용하여 Lt. breast의 tangential irradiation 시 physical wedge와 virtual wedge 사용에 따른 동측 유방선량과 피부선량, 반대편 유방 선량과 반대편 유방의 피부선량, 주변 연부조직선량, 동측 폐선량 및 심장에 조사되는 선량을 TLD를 이용하여 비교하였으며 Helax 5.0 RTP system을 이용한 computer planning으로 선량분포 및 관심부의 DVH를 비교하였다. 이때 virtual wedge와 physical wedge의 사용에 따른 총조사 시간을 측정하였다. 또한 7명의 유방암 환자에서 virtual wedge, physical wedge 사용에 따른 동측 유방 피부선량, 반대편 유방 피부선량, 조사야에서 1.5 cm 떨어진 주변 선량을 측정하여 비교하였다.

결과: Virtual wedge는 15°, 30°, 45°, 60° 모두에서 physical wedge에 비해 주변선량이 감소하였으며 방사선조사 시간을 53~55% 감소시켜 유용한 결과를 나타냈다. 15°, 30° wedge를 사용한 Humanoid Phantom의 TLD 측정에서도 virtual wedge에서 반대편 유방선량은 1.35%, 2.55% 감소하였고, 반대편 유방 피부선량은 0.87%, 1.9% 감소하였다. 또한 동측 폐선량은 2.7%, 6.0%, 심장선량은 0.96%, 2.5% 감소하였다. 또한 조사야 경계부위의 선량은 1.8%, 2.33% 감소하였으며 동측 유방의 피부선량은 2.4%, 4.58% 증가하였다. Helax 5.0 RTP system을 이용한 DVH analysis에서 동측 유방내 선량균질정도는 physical wedge와 virtual wedge에서 차이가 유사하였다.

결론: 유방암치료에서 virtual wedge는 통상 사용하는 physical wedge에 비하여 주변 연부조직선량, 반대편 유방선량, 동측 폐선량 및 심장선량을 감소시켜 급, 만성 방사선 부작용의 위험을 감소시킬 수 있는 임상적으로 매우 유용한 방법이며 또한 방사선조사시간을 단축시킴으로써 선형가속기의 부하를 줄일 수 있다.

핵심용어: 유방암, Physical wedge, Virtual wedge, 선량분포