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Field-In-Field Plan Versus Tangential Wedged Beam Plan in Chest Wall Radiotherapy of Post-Mastectomy Patients: Treatment Planning Study

Mehran Yarahmadi[1], Bahar Faramarzi[2], Abbas Haghparast[2]*, Zeinab Saalehi[3]

[1] Department of Medical Physics, Kurdistan University of Medical Sciences, Sanandaj, Iran.
[2] Department of Medical Physics, School of medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran.
[3] Tohid Hospital, Department of Radiotherapy, Kurdistan University of Medical Sciences, Sanandaj, Iran.

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ABSTRACT

Introduction: In this study, dose distribution of the chest wall in post-mastectomy breast cancer patients was evaluated and compared in the tangential wedged beam (TWB) and field-in-field (FIF) plans.

Materials and Methods: Thirty-six patients with left-sided breast cancer were enrolled in this study. The FIF and TWB plans were generated for each patient to compare dosimetric parameters of the chest wall. The maximum dose (D_{max}), homogeneity index (HI), conformity index (CI), and uniformity index (UI) were defined and used for comparison of the dosimetric parameters of the planning target volume (PTV) in both FIF and TWB plans. The percentage of volumes receiving at least 10, 20, 30, and 40 Gy of the left lung and 5, 10, 20, 25 and 30 Gy of the heart were used to compare the dosimetric results of the organs at risk. Statistical analysis was performed using SPSS, version 20.

Results: The FIF plan had significantly lower HI (P=0.000) than the TWB plan, indicating that the FIF plan was better than the TWB plan in PTV. The V_{40lung} (15.36±4.35 vs. 18.37±4.42) and $V_{30heart}$ (8.15±3.75 vs. 10.94±3.94; P=0.000) were significantly lower in the FIF plan than in the TWB plan. In addition, the monitor unit (MU) was significantly lower in the FIF plan than in the TWB plan (227.76 vs. 323.59; P=0.000).

Conclusion: The FIF plan significantly reduced the dose volume of the left lung and heart in post-mastectomy radiotherapy compared to the TWB plan. Therefore, the FIF plan is recommended for this purpose.

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Introduction

Globally, breast cancer is the most common type of among women, and annually, millions of new cases of breast cancer are reported [1]. Treatment methods for this disease include surgery, chemotherapy, radiotherapy, and hormone therapy. The choice of treatment depends on the disease stage at the time of diagnosis [2]. In Europe and the United States, the most regular treatment for breast cancer is adjuvant radiation therapy after breast-conserving surgery [3]. However, in the Middle East, because of late diagnosis and disease progression, mastectomy is the most common treatment. Post-mastectomy radiotherapy is necessary in some cases including inflammatory breast cancer, locally advanced breast cancer, and patients with T > 5 cm [4].

As a standard treatment method, radiotherapy plays an important role in the treatment of breast cancer after mastectomy. It also lowers the probability of local recurrence and increases patient survival [5-7]. Post-mastectomy radiotherapy reduces the probability of breast cancer recurrence up to 66% and increases 15-year survival up to 9% [8]. The purpose of radiotherapy is delivering the maximum radiation dose to the planning target volume (PTV) and minimizing radiation dose to the organs at risk (OARs). The approach to the reduction of the absorbed dose in the critical structures is beam shaping. By using the conventional collimators, only a rectangular field will be created, but treatment volume is not commonly rectangular; therefore, additional shaping is required [9].

Attention to dose homogeneity in the target volume is mandatory in various radiotherapy techniques. The uniformity of dose distribution in the target volume depends on the applied method of radiotherapy. Lack of uniformity of dose distribution in the target tissue gives rise to hot and cold spots in

**Corresponding Author:* Department of Medical Physics, School of medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran, Tel:+98 9183334998, Fax: +98 83 34276477, Email: a.haghparast@kums.ac.ir

PTV [10]. In radiotherapy of breast cancer, sensitive organs such as the heart and lungs are irradiated because they are behind the breast tissue. Former studies on breast cancer patients showed that radiotherapy of the chest wall elevates the risk of pneumonitis and cardiovascular diseases [11, 12]. Thus, the use of appropriate techniques in breast cancer radiotherapy diminishes the received doses to the OARs and their complications.

Radiotherapy centers use various techniques for the treatment of breast cancer. Tangential beam technique is the standard technique for the treatment of this type of cancer. Tangential beams are matched with the supraclavicular field in some cases [13]. In three-dimensional conformal radiotherapy (3D-CRT), treatment planning system (TPS) uses computed tomography (CT) images to evaluate the dose distribution in PTV and OARs. Optimal dose distribution and dose reduction in the adjacent healthy tissues is the main purpose of 3D-CRT [14]. Target volume usually has an irregular shape; hence, obtaining a homogeneous dose distribution is challenging. Therefore, wedge filters are adopted to improve dose distribution in the conformal radiotherapy techniques. However, homogeneous dose distribution in the chest wall is hard to achieve. Although in tangential wedge beam (TWB) technique homogeneous dose distribution is obtained at the center of PTV, high-dose areas are observed at the inferior and superior regions of the PTV. Other radiotherapy techniques such as intensity modulated radiation therapy (IMRT) and field-in-field (FIF) are employed to achieve the optimum dose distribution in the treatment of breast cancer [15-19]. The FIF technique (also known as forward-IMRT technique) is a simple method introduced by the development of multi-leaf collimators (MLC). This technique is performed by machines equipped with MLC [20].

In this study, the dosimetric parameters of the FIF plan were evaluated and compared with those of the TWB plan in post-mastectomy chest wall radiotherapy and OARs.

Materials and Methods

Patients

This study was carried out on 36 patients with left-sided breast cancer, who were treated in Tohid hospital radiotherapy center. All the patients had undergone mastectomy and were treated with postoperative radiotherapy. Each patient had pathologic T3 or T4 tumors with positive lymph nodes. All the patients were scanned with CT simulation (model GE). A breast board (Aktina Medical, New York, USA) was used to prevent patient movement. The patients were positioned supine with the left arm located behind the head at a 90-120 angle. The patient's head was slightly turned to the right. CT slices were taken with 5 mm thickness, and the CT data were transferred to the TPS (DOSIsoft ISOgray Version 4.1) with DICOM network connection. The clinical characteristics of the patients are provided in Table 1.

Table 1. Clinical characteristics of the patient population

Number of patients (n)	36
Median age (years) (min-max)	48 (31-70)
Median weight (kg)	62.5 (45-100)
Median height (cm)	157 (150-170)
BMI	25.35
Median PTV(cm^3)	601
Pathologic stage	
Stage Ш	20
Stage IV	16

BMI= body mass index; PTV= planning target volume.

Contouring Target Volume and Organs at Risk (OARs)

The body and lungs were contoured by using anatomic figures in the TPS by a physicist. Also, the PTV and the heart were contoured by an oncologist. The PTV for the chest and OARs, including the heart and lungs, were contoured using ISOgray TPS based on Radiation therapy Oncology Group (RTOG) breast cancer contouring atlas [21]. The PTV included the chest wall with pectoral muscles, the chest wall muscles, and the ribs [22]. The PTV excluded 5 mm from the skin surface because of build-up effect. OARs, such as the heart and left lung, were excluded from the treatment fields as far as possible. Afterward, the TWB and FIF plans were generated in the TPS for each patient.

Treatment Planning

Elekta Synergy Platform medical linear accelerator was used in this study. In the TWB plan, the conformal fields according to the PTV were created by MLC blocks in both the medial and lateral tangential gantry angles. Appropriate wedges were added to both fields to achieve the best plan and dose distribution. The utilized angle wedges were between 4 and 35 degrees. For the FIF plan, two open tangential beams were generated with the same gantry angle as the TWB plan. The initial calculations were carried out without any beam modifiers. Then, 2-3 additional subfields (segments) were used for shielding the hot spots. Hot spots were defined as the points receiving the doses higher than 103% of the prescribed dose [23]. The isodoses 109%, 107%, and 105% were employed for creating adequate block and making suitable subfields. The plan was improved by using these suitable subfields. The weights of the subfields were up to 12% of the prescription dose (PD).

Main fields and subfields were merged into a portal that included several MLC segments for sequence radiation. Voxel size of 2 mm^3 was selected and dosimetric parameters of all the plans were calculated by pencil beam convolution algorithm in the TPS. Dose-volume histogram (DVH) was calculated for the PTV, lungs, and heart. The doses were prescribed according to quality criteria (QC) recommended in the International Commission on Radiation Units and Measurements reports 50 and 62 (at least 95% of the PTV must be receiving 95% of the prescription dose). Due to removal of the whole breast tissue and rugged surface of PTV, appropriate dose distribution was not obtained in this work. Therefore, in this study 95% of the PTV received at least 45 Gy dose, that it was the acceptable dose distribution. The total dose was 50 Gy in 25 fractions (2 Gy per fraction). The 6 MV photon beams was used for both plans. These plans did not have any impact on patient treatment and plans were evaluated and compared by computer only for this study.

Dosimetric Parameters, Target Volumes, and The Organs at Risk

The homogeneity index (HI), conformity index (CI), and uniformity index (UI) in the PTV were compared between the two plans. Also, $V_{95\%}$, $V_{105\%}$ (the volumes of PTV that received at least 95% and 105% of the PD, respectively), D_{max}, and D_{mean} were determined for the PTV. V_5, V_{10}, V_{20}, V_{25}, and V_{30} (percentage of the heart volume receiving at least 5, 10, 20, 25 and 30 Gy, respectively), D_{max}, and D_{mean} were defined for the heart. V_{10}, V_{20}, V_{30}, V_{40} (percentage of the left lung volume receiving at least 10, 20, 30, and 40 Gy, respectively), D_{max}, and D_{mean} were determined for the left lung. Also, D_{max} and D_{mean} were determined for the right lung. All of these parameters were calculated for both plans and were compared with each other. Moreover, the monitor unit (MU) was calculated for both plans.

Homogeneity index (HI)

HI is used to evaluate dose homogeneity in the target volume and is obtained by the following formula [23]:

$$HI = \frac{D_{max}}{PD} \quad (1)$$

Conformity index (CI)

CI was used to evaluate dose conformity in the PTV. It is presented as the relationship between TV (treated volume: volume enclosed by a given isodose surface, 95%) and PTV and is calculated by the following formula [24]:

$$CI = \frac{TV}{\mathrm{PTV}} \quad (2)$$

Uniformity index (UI)

UI was defined as the percentage of the PTV that received doses between 97% and 103% of the prescribed dose. This index is applied to evaluate and improve dose distribution in the PTV. UI is defined as the following formula [23]:

$$UI = \frac{V_{97\%} - V_{103\%}}{V_{PTV}} \quad (3)$$

Statistical Analysis

The planning results of the PTV and OARs calculated in the FIF and TWB plans were compared with each other. Paired samples t-test was run for comparison of indices, doses, and volumes in both plans. P-value less than 0.05 were considered statistically significant. For P-values less than 0.001, the software rounded them off and showed P=0.000. Also, MU was measured and evaluated for the two plans. All the statistical analyses were performed using SPSS, version 20.

Results

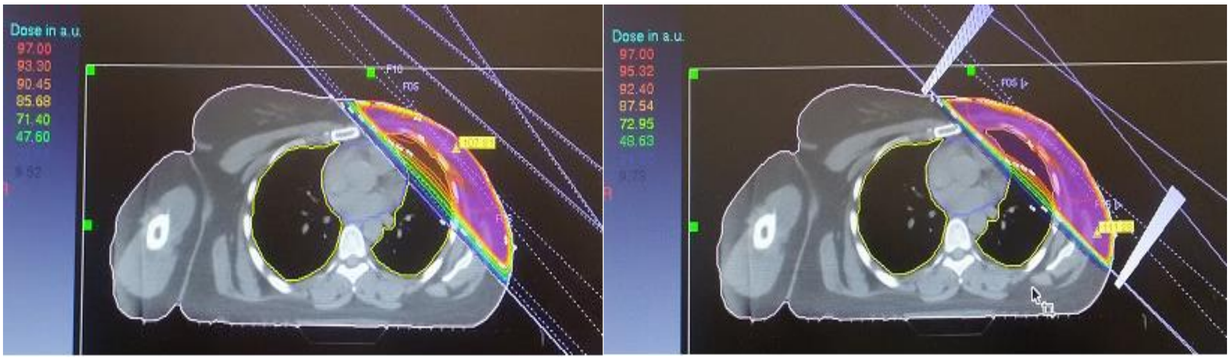
Dosimetric parameters, PTV volumes, and doses are shown in Table 2.

The HIs for the FIF and TWB plans were 1.085 and 1.098, respectively. A significant difference in HI was found between the two plans (P=0.000). HI was lower in the FIF plan than in the TWB plan. HIs closer to 1 were indicative of a better technique. HI in the FIF plan was closer to 1 than the TWB plan; therefore, it is the better plan and dose homogeneity in the PTV was higher in this plan. Nevertheless, CI in the TWB plan was higher than in the FIF plan. Also, there was not a significant difference between UIs of the two plans.

Table 2. Dosimetric parameters of the field-in-field and tangential wedged beam plans

Parameters	Field-in-field plans	Tangential wedged beam plans	p-value
	Mean±S.D	Mean±S.D	
Homogeneity index (HI)	1.085±0.023	1.098±0.022	0.000
Conformity index (CI)	0.912±0.015	0.918±0.019	0.027
Uniformity index (UI)	53.84±12.40	52.36±19.03	0.434
D_{max}	54.29±1.15	54.94±1.10	0.000
D_{mean}	49.81±0.57	50.01±0.63	0.051
$D_{95\%}$	45.63±0.755	45.93±0.965	0.027
$V_{95\%}$	86.01±5.192	87.39±5.198	0.114
$V_{100\%}$	53.42±12.736	55.54±13.586	.0.387
$V_{105\%}$	8.55±8.825	11.63±7.989	0.040
Total MU	227.76±8.36	323.59±78.91	0.000

Abbreviations: D_{mean} = mean dose (Gy); D_{max} = maximum dose (Gy); V_x = volume (%) receiving x dose (Gy) or higher; FIF= field-in-field, TWB: tangential wedge beam, S.D= standard deviation; MU= monitor unit.



(a) FIF (b) TWB

Figure 1. Axial view of a computed tomography-based breast radiation treatment plan; isodose distributions for a typical patient field-in-field (a) and tangential wedge beam (b) plan

Table 3. Dosimetric parameters of the organs at risk for the field-in-field and tangential wedged beam plans

Organ at risk	Parameters	Field-in-field plans Mean±S.D	Tangential wedged beam plans Mean±S.D	P-value
Left Lung	D_{mean}	10.50±2.51	11.70±2.69	0.000
	D_{max}	51.30±1.05	52.38±1.08	0.000
	V_{10Gy}	25.28±5.91	27.19±6.22	0.000
	V_{20Gy}	21.67±5.32	23.63±5.71	0.000
	V_{30Gy}	19.22±4.92	21.50±5.38	0.000
	V_{40Gy}	15.36±4.35	18.37±4.82	0.000
Heart	D_{mean}	5.08±1.84	6.39±1.95	0.000
	D_{max}	50.42±1.24	50.85±1.10	0.049
	V_{5Gy}	4.87±14.88	5.13±16.95	0.000
	V_{10Gy}	4.40±11.34	4.31±14.06	0.000
	V_{20Gy}	4.01±9.43	4.24±12.28	0.000
	V_{25Gy}	3.88±8.77	4.07±11.58	0.000
	V_{30Gy}	3.75±8.15	3.94±10.94	0.000
Right Lung	D_{max}	0.81±0.399	1.22±0.81	0.000
	D_{mean}	0.005±0.005	0.007±0.006	0.088

Abbreviations: Dmean = mean dose (Gy); V_x = volume (%) receiving x dose (Gy) or higher; FIF= Field-in-Field, TWB= tangential Wedge beam, S.D= standard deviation

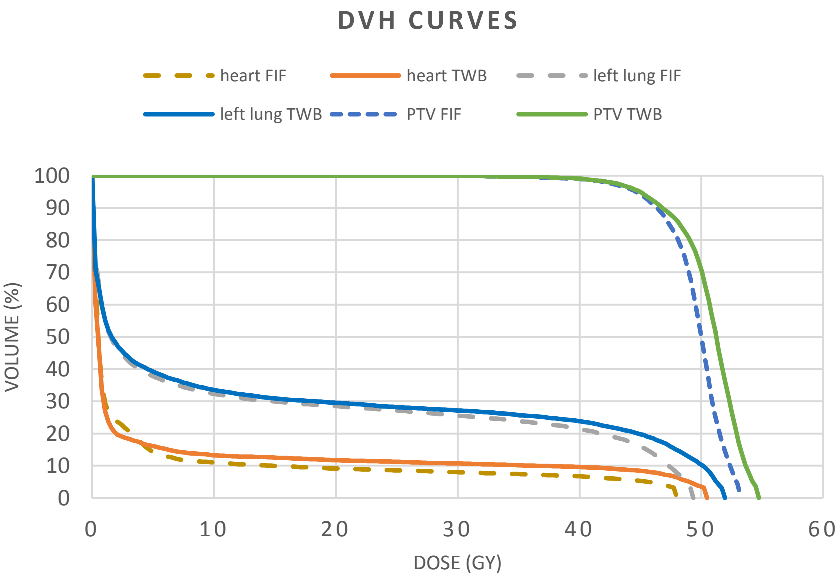


Figure 2. An example of dose volume histogram curves for planning target volume and organs at risk of a patient; comparison of the field-in-field and tangential wedge beam plans

The maximum doses for the FIF and TWB plans were 54.29 Gy and 54.94 Gy, respectively. The maximum dose was lower in the FIF plan than in the TWB plan (P=0.000). There was no significant difference in the mean dose between the two plans. A significant difference was observed in $V_{105\%}$ between the FIF and TWB plans (8.55% vs. 11.63%; P=0.040). MU in the FIF plan was significantly lower than in the TWB plan (227.76 vs. 323.59; P=0.000). Accordingly, treatment by the FIF plan imposes less workload on the machine.

Figure 1 demonstrates dose distributions of the FIF and TWB plans for the same patient. The areas receiving more than 97% of the PD are shown in purple. Dosimetric parameters of the OARs are exhibited in Table 3. A significant difference was observed between the FIF and TWB plans in the mean (10.50 Gy vs. 11.70 Gy) and maximum doses (51.30±1.05 vs. 52.38±1.08) of the left lung. The V_{10lung} in the FIF was significantly lower than in the TWB plan (25.28±5.91 and 27.19±6.22; P=0.000). Also, V_{20lung}, V_{30lung}, and V_{40lung} in the FIF plan were less than in the TWB plan. The FIF plan reduced the mean (5.08±3.69 Gy vs. 6.39±3.91 Gy) and maximum doses (50.42±1.24 vs. 50.85±1.10) of the heart. The V_{5heart}, $V_{10heart}$, $V_{20heart}$, $V_{25heart}$, and $V_{30heart}$ were significantly lower in the FIF plan than in the TWB plan (P=0.000).

The comparison of the dose-volume histogram (DVH) curves for the PTV and OARs of a patient for FIF and TWB plans are shown in Figure 2.

Discussion

In previous studies, an improvement in dose distribution was reported using the FIF plan rather than the TWB plan for the whole breast in early-stage breast cancer patients [23, 25-28]. Dosimetric comparison of the TWB and FIF plans has been rarely discussed for post-mastectomy chest wall radiotherapy in previous studies. These studies have compared the IMRT plan with the FIF and TWB plans separately [22, 29]. The positive effects of post-operative radiotherapy were proven, but it causes a few complications in the OARs. These complications include arteriosclerosis and pericarditis in the heart, pneumonia in the lungs, and rib fracture [11, 12]. In recent years, state-of-the-art techniques such as FIF have been adopted by linear accelerators equipped with MLC in the treatment of breast cancer. In the FIF technique, less time is spent compared to the IMRT technique, and MU in the FIF technique is less than in the IMRT and TWB techniques; thus, FIF plan decreases machine workload [29, 30]. Moreover, total MU was lower in the FIF plan than in the TWB plan in our study. Several studies compared the FIF and TWB plans for breast cancer irradiation [25, 31, 32]. In a whole breast radiotherapy planning study with 30 patients, Kim et al. showed that the FIF plan had a lower HI and higher UI than the TWB plan. The received doses of the heart and lungs were reduced and the maximum dose was less in the FIF plan, as well [23]. In our study, which was for post-mastectomy radiotherapy patients, the FIF plan had a lower HI than in the TWB plan, but there was no significant difference between the two plans in terms of UI.

The maximum dose in the FIF plan was less than in the TWB plan. In dosimetric comparison of the three radiotherapy techniques, Ma et al. indicated that the MUs and received doses of OARs were lower in the FIF plan than in the than IMRT and VMAT plans in post-mastectomy breast cancer [29]. Also, Ruder et al. reported that the received doses of the OARs significantly reduced by using IMRT plan rather than the TWB plan for post-mastectomy breast cancers [22]. Ercan et al. compared the FIF and TWB plans for 20 breast cancer patients in terms of dosimetric parameters. They proposed that the received dose of the heart and lungs were less in the FIF plan compared to the TWB plan. In addition, $V_{105\%}$ in the FIF plan was lower than in the TWB plan [31]. This finding was in agreement with our results regarding the reduction in the maximum dose (D_{max}) and $V_{105\%}$ using the FIF plan. Likewise, the calculated received dose by the OARs such as the heart and left lung was lower in the FIF plan in our study. Gursel et al. compared the dosimetric results of the TWB and FIF plans for whole breast radiotherapy. They evaluated the received doses of the OARs and reported less received dose in the FIF plan than in the TWB plan [30], which was in agreement with our study for post-mastectomy radiotherapy.

In meta-analysis, mean dose ≥ 14Gy, $V_5 \geq 40\%$, $V_{10} \geq 34\%$, $V_{20} \geq 25\%$, and $V_{30} \geq 18\%$ to 22% for the lungs were identified as the significant risk factors for pneumonitis [33, 34]. In our study, the received doses of the OARs were determined by V_{10}, V_{20}, V_{30}, and V_{40} for the lungs and V_5, V_{10}, V_{20}, V_{25}, and V_{30} for the heart. The D_{mean} of the left lung, V_{10lung}, V_{20lung}, and V_{30lung} in both plans were lower than the constraints for pneumonitis in this study; these values were lower in the FIF plan compared to the TWB plan.

Many studies reported that left breast irradiation could be a risk factor for the development of ischemic heart disease. Cardiac complications are a specific problem with radiotherapy to the mediastinum and breast, particularly in cases more than 65% of the heart volume is irradiated. The number of ischemic heart diseases does not increase rapidly until 10 years after radiotherapy [35]. Doses higher than 35 Gy caused pericarditis, myocardial, and coronary artery disease. Also, doses higher than 25 and 40 Gy gave rise to myocardial, pericarditis, coronary artery disease, and vascular disease, respectively [36]. Darby et al. reported that the rate of ischemic heart disease increased linearly with the mean received dose of the heart by 7.4% per gray, without any threshold [28]. Therefore, any dose level can enhance the risk of this cardiovascular complication. D_{mean}, V_5, V_{10}, V_{20}, V_{25}, and V_{30} of the heart were lower in the FIF plan than in the TWB plan. Accordingly, the rate of cardiovascular diseases can be reduced using the FIF plan.

Moreover, Patt et al. reported that with up to 15 years of follow-up there were no significant differences in cardiac morbidity after radiation for left- versus right-sided breast cancer [37]. Post-mastectomy radiotherapy does not increase the actuarial risk of ischemic heart disease after 12 years [38]. Therefore, post-mastectomy radiotherapy does not cause any complications for the heart such as pericardium or long-term cardiac mortality.

Conclusion

According to our findings, the FIF plan had better HI in comparison with the TWB plan, but CI in the TWB plan was higher than in the FIF plan. There was no significant difference between UIs of the two plans. The D_{max} in the PTV was lower than in the FIF plan. Further, the received radiation doses of the lungs and heart were diminished using the FIF plan. Utilizing updated radiotherapy equipment and techniques decreases cardiac complications. MU in the FIF plan was lower than in the TWB plan leading to reduced machine workload. MU increases using the TWB technique because of attenuation of some photons in the wedge and more photons should be produced to deliver same doses to the PTV. Therefore, use of the FIF plan is recommended for post-mastectomy radiotherapy instead of the TWB plan when the linear accelerators equipped with the MLC are employed. The evaluation and comparison of the received doses by PTV and OARs using the FIF and common techniques for other tumors is suggested for future studies.

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