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Tumor Bed after Segmental Mastectomy

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13. ABSTRACT (Maximum 200 Words) This trial tests a regimen of prone conformal hypo-fractionated radiotherapy directed to the original tumor bed with margins in a selected subset of post-menopausal women with breast cancer with a very low risk for local recurrence elsewhere in the breast. After planning CT is conducted in the prone position, the breast tissue and tumor bed are contoured on a 3D planning system and a 2 cm margin added to determine the planning treatment volume (PTV). A plan is generated to treat the PTV with six Gy per fraction are delivered to the 95% isodose surface in 5 fractions over ten days weeks to a total dose of 30 Gy. Fifty-three of the 99 patients planned to accrue to the study have completed treatment and the results have been reported at the ASTRO 2003 meeting and 2004 American Radium Society meeting. All patients tolerated treatment very well. DVH varied based on the position of the original tumor bed and the size of the breast. In most cases it was possible to successfully plan and treat a quadrant of the breast without exceeding 50% of the dose to 50% of the breast volume. Longer follow up is necessary to assess efficacy and cosmetic results.				
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Introduction

Since in a selected subset of post-menopausal women with breast cancer there is a very low risk for local recurrence elsewhere in the breast^{1,2}, a regimen of conformal hypo-fractionated radiotherapy (5 fractions in 2 weeks) directed to the original tumor bed with margins, could generate local control rates and cosmetic results equivalent to those achieved by conventional post-operative radiotherapy (30 fractions over 6 weeks³) while being much more convenient and economical^{4,5}.

The specific aims of this IDEA grant were:

1. To determine the feasibility of a regimen of hypo-fractionated conformal radiotherapy to the tumor bed as part of breast preservation in selected post-menopausal women with T1 breast cancers.
2. To explore the efficacy of this approach when compared to historical local control rates achieved by standard post-operative radiation.
3. To prospectively assess the role of circulating TGF- β pre-treatment as a marker for post-treatment fibrosis.
4. To pilot-test the use of ultrasound for localizing the radiation therapy target (tumor bed) and for daily positioning of the target with respect to the linear accelerator's radiation beams.

Body

An NYU-IRB approved protocol testing the research hypothesis of this study has been actively recruiting patients since October 2000, with independent funding from those allocated by the current award.

The study is designed to accrue a total of 99 patients in 4 years. The first 29 patients were accrued according to the original NYU IRB-approved protocol and consent. Since the modifications to the protocol and the consent required by the DOD-IRB were minor (mainly confined to phrasing within the informed consent) and did not modify the research component of the trial, these patients were maintained within the same cohort when the data was analyzed and reported.

Currently, 54 patients were treated in this trial and while the grant support period from the Award is terminated, we are requesting a no cost extension to continue the study to complete the planned accrual of 99 patients.

With regard to Task 1 and 2 of the approved statement of work: (year 1-4)

“To determine the feasibility of a regimen of hypo-fractionated conformal radiotherapy to the tumor bed as part of breast preservation in selected post-menopausal women with T1 breast cancers, and to explore the efficacy of this approach when compared to historical local control rates achieved by standard post-operative radiation.”

A copy of the accepted manuscript reporting the experience on the first 47 patients in attached (appendix, page 13).

At the time of the current report 54 patients have accrued (median age 67.5 years, range: 51 to 88). The median tumor diameter is 1 cm (range 0.2-1.9). Fifty-three of the 54 patients completed treatment and are available for follow-up. One patient refused further treatment after 2 fractions for personal reasons, as previously reported. This patient remains in communication with her primary doctor and she is reported to be NED three years later.

All 53 patients tolerated treatment very well with only mild discomfort reported when lying prone for planning and treatment.

The most common acute toxicity is grade 1-2 erythema (45%) occurring in the treatment portal and fatigue (20%), usually manifesting in the second week of treatment. Two patients reported Grade 1-2 nausea. Two patients developed Grade 1 dry desquamation and one patient grade 1 breast edema. Six patients had induration at the surgical scar, pre-dating radiation therapy.

There are 33 patients who have ≥ 6 months follow-up. Preliminary assessment of late toxicity, included 12 patients who developed 17 events, including grade 1-2 induration (5 patients), fibrosis (1 patient), breast edema (2 patients), teleangectasia (5 patients), hyper-pigmentation (4 patients).

With a median follow-up of 17 months, preliminary cosmetic grading by the treating physician was "good to excellent" in 24 of 26 patients, "fair" in 2 patients at baseline, which was not changed by the addition or radiation therapy.

Among the 53 patients who have completed treatment no recurrence have occurred: median follow up is 17 months.

During this first phase of the trial we have focused on two tasks:

- 1) designing a more comfortable and reliable treatment table that can enable geriatric breast cancer patients to comfortably withstand the treatment in prone position.

As a result of a partnership with one of our breast cancer survivor/advocate who is an architect, a new, much more comfortable table for prone imaging and treating was designed (designing and engineering was generously donated by our partner-advocate) and built, as per the attached digital photo (see appendix). The table has been used since and its design has influenced a new generation of prone treatment tables, with more ergonomic features, currently under development (2).

- 2) developing preliminary **physics data about dose volume histogram (DVH) analysis** in the studied population.

Much of our initial research effort has been spent in studying geometric and anatomic issues of the tested technique and their dosimetric implications.

As described in the original proposal the breast tissue and tumor bed, identified at CT as the post-surgical cavity, are contoured on a 3D planning system (Varian Somavision/CadPlan) and a 2 cm margin added to determine the PTV. A plan was generated in the attempt to treat the entire PTV to 90% of the prescription dose. Six Gy per fraction are delivered to the 95 % isodose surface in 5 fractions over ten days weeks. to a total dose of 30 Gy.

Planning in the prone position was feasible in 50 patients. Four patients were treated in the supine position (as accepted protocol deviations), 2 patients were unable to tolerate lying in the prone position secondary to paraplegia and 2 patients, the position of the tumor bed was located very lateral and better treated supine. The predominant technique for treatment was a pair of parallel-opposed mini-tangents. This arrangement assured good coverage given the constraints imposed by the PTV and its relationship to the table.

For the entire group the volume of breast receiving 30 Gy ranged from 10% to 45%. We found heterogeneity of DVH based on the position of the original tumor bed and the size of the breast. In 12 of the 46 patients, in order to successfully treat the PTV, greater than 50% of the ipsilateral breast volume received >50% of the prescription dose. This was largely dependent on the size of the tumor bed and its location in comparison to the index breast. Doses to the heart and lungs were clinically insignificant.

In conclusion, these preliminary data confirm in that in most cases (35/46) it is possible to successfully plan and treat the PTV with parallel opposed tangent fields without exceeding 50% of the dose to 50% of the breast volume.

Task 3: (year 1-4)

To prospectively assess the role of circulating TGF- β pre-treatment as a marker for post-treatment fibrosis.

As planned, patients were seen once/week during treatment and once two weeks after. Thereafter they will be seen in follow up every 3 months for the first year and every six months for the following five years. At each visit, physical exam to detect clinical recurrence was performed and mammography films (once/year) were reviewed. The data has been regularly collected in the Oracle forms specifically developed for data collection and submitted with the previous annual report.

Task 4: (year 1-2)

To pilot-test the use of ultrasound for localizing the radiation therapy target (tumor bed) and for daily positioning of the target with respect to the linear accelerator's radiation beams.

We had planned to establish the accuracy in target definition by ultrasound (US) imaging and to compare it to CT imaging. Since the US device was acquired only one year ago, only CT imaging was used for the first 47 patients accrued to the trial. The subsequent seven patients had both US and CT imaging. Currently, parallel US evaluation of target volume remains under investigation: preliminary data on consecutive 20 patients are expected to be available in the Fall.

Key Research Accomplishments

- 1. feasibility is demonstrated in the first 54 patients**
- 2. dosimetric findings obtained in the first 54 patients appear to confirm our predictions.**
- 3. optimal patient accrual, with an acceptance rate of 94 % among patients who refused the initial recommendation for conventional six weeks of post-segmental mastectomy fractionated radiotherapy**

Reportable Outcomes

Since the award was received the study has been presented by the P.I. at three international and three national conferences (all CME approved):

- IV Madrid Breast Cancer Conference: changes in the treatment of breast cancer.
Madrid, June 7-9, 2001
- Mayo Clinic Amelia Island Oncology Review Course
August 15-18, 2001
- Manhattan Breast Cancer Society
January 17, 2002
- V Madrid Breast Cancer Conference: changes in the treatment of breast cancer.
Madrid June 11-13, 2003
- American Society for Therapeutic Radiology and Oncology (ASTRO) 45th Annual Meeting, Salt Lake City, Utah, October 19-23, 2003
- Emerging Trends in Adjuvant Therapy of Breast Cancer: 2003 Symposium in New York, October 24-26, 2003
- American Radium Society (ARS) 86th Annual Meeting May 1-5, 2004

Conclusions

The current trial has shown to be feasible and well tolerated. The encountered acceptance rate is 94% (53/55 patients) in the studied population and the accrual is close to the approved final target (53/99).

Preliminary dosimetric findings encourage us to continue, especially in view of the excellent tolerability of this approach. In addition, outstanding sparing of normal tissue was achieved by prone positioning.

Longer follow-up is required for efficacy, cosmesis and to assess the role of circulating TGF- β 1 pre-treatment as a marker for post-treatment fibrosis.

While the grant support has terminated, the study continues as planned to complete accrual of 99 patients. TGF- β 1 measurements will be conducted at the end of accrual and associations with post-treatment fibrosis will be explored.

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Appendix

Copies of 1 published manuscript, and three in press.

Truong MT, Hirsch AE, Formenti SC.

Novel approaches to postoperative radiation therapy as part of breast-conserving therapy for early-stage breast cancer.

Clin Breast Cancer. 2003 Oct;4(4):253-63. Review.

Formenti SC, Truong MT, Rosenstein B, Goldberg J, Cho C, DeWyngaert KJ,

Hypo-fractionated partial breast radiation after breast-conserving surgery: preliminary clinical results and dose volume histogram (DVH) analysis.

Int J Radiat Oncol Biol Phys. 2004 Oct (in press)

Rosenstein, B.S., † Lymberis, S.C. † and Formenti, S.C.

Biological comparison of partial breast irradiation protocols

Int J Radiat Oncol Biol Phys. 2004 Oct (in press)

Formenti SC:

External-beam partial breast irradiation

Seminars in radiation oncology January 2005 (in press)

Novel Approaches to Postoperative Radiation Therapy as Part of Breast-Conserving Therapy for Early-Stage Breast Cancer

Minh Tam Truong, Ariel E. Hirsch, Silvia C. Formenti

Abstract

Breast-conserving therapy (BCT) consists of segmental mastectomy followed by postoperative radiation therapy (RT) to the whole breast. At least 6 prospective randomized trials have proven the equivalence of BCT to mastectomy. However, BCT remains underused and, most importantly, a sizable proportion of patients with invasive breast cancer fail to complete the recommended protocol of breast preservation by omitting postoperative RT. The inconvenience of complying with the standard 6-week radiation regimen, which includes approximately 30 daily visits, at least partially explains this lack of adherence. New clinical studies have generated preliminary evidence that more convenient, shorter radiation regimens might reveal equivalence to the current standard. Moreover, the availability of modern technology to deliver and target ionizing radiation by improving homogeneity of radiation dose has made it possible to safely explore the use of greater radiation doses per fraction. Finally, currently ongoing research trials will enable the identification of specific subsets of patients who are likely to be safely treated by partial-breast radiation (instead of radiation to the whole breast) with more accelerated regimens. This article reviews the available data and the current ongoing research on novel RT techniques and fractionation schedules in BCT for early-stage breast cancer.

Clinical Breast Cancer, Vol. 4, No. 4, 253-263, 2003

Key words: Accelerated external-beam radiation therapy, Brachytherapy, Cosmesis, Fibrosis, Partial-breast radiation therapy, Radiation genomics, Telangiectasia

Breast-Conserving Therapy

At least 6 prospective, randomized controlled trials have demonstrated the equivalence of breast-conserving therapy (BCT) to mastectomy.¹⁻⁶ Despite level 1 evidence of comparable efficacy to that of mastectomy, BCT remains underused in the United States.⁷⁻¹² In 1990, the National Institutes of Health (NIH) Consensus Development Conference concluded that BCT was the appropriate method of treatment for the majority of women with early stage I or II breast cancer.¹³ However, this subsequently translated to only a moderate increase in the use of BCT, from 34% to 60% for stage I breast cancer and from 19% to 39% for stage II breast cancer.¹⁴ There appear to be multiple causes for the underuse. The demands of the standard radiation schedule and its perception by referring surgeons and patients probably play a role.

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Generally, radiation therapy (RT) after lumpectomy consists of 4-5 weeks of whole-breast radiation of a total dose of 45-50 Gy in 23-25 fractions, usually followed by a boost of 10-16 Gy in 5-8 fractions to the tumor bed area (Figure 1). The total length of treatment is 5-7 weeks, commonly 6 weeks. Thus, women who choose BCT automatically commit to a regimen of approximately 6 weeks of daily radiation treatments (Monday through Friday) to complete the local management of their breast cancer. For many women, concerns about this commitment are likely to influence the choice for mastectomy instead of breast preservation: only 40%-60% of women who meet criteria for BCT actually undergo the procedure.¹⁴ Studies that have addressed the components of the decision-making choices in women choosing mastectomy suggest that the inconvenience of RT is a factor influencing their decision; concerns arise about the inconvenience, duration of treatment, and travel restrictions associated with the radiation component of breast preservation. The surgeon or primary health care provider also appears to be influential in the process.¹⁵ As a consequence, some surgeons use more stringent criteria than those in published guidelines and recommend mastectomy to their patients based on the perceived difficulties of adhering to a 6-week postoperative regimen.⁷ An example of BCT underuse comes from the Arimidex, Tamoxifen, Alone or in Combination trial, in which higher rates

of mastectomy for women who would have otherwise been eligible for BCT had occurred in the United States than in other countries.¹⁶

In addition to the effect of possible biases of the primary health care provider, distance from RT treatment facilities has also been shown to correlate with patient choice to undergo mastectomy instead of BCT.¹⁷⁻²¹ Most importantly, 15%-30% of patients who have actually selected BCT, particularly older patients and those with ≥ 2 comorbid conditions, do not receive postoperative RT.^{17,18,22-26} These facts warrant a critical assessment of standard RT and justify the exploration of new radiation regimens.

Radiation Therapy in Breast-Conserving Therapy

Several multivariate analyses have found no patient subgroup with sufficiently low risk of in-breast recurrence (IBR) to avoid treatment with whole-breast external-beam RT as part of the breast-conserving management of breast cancer.²⁷⁻²⁹ As a consequence, the last NIH Consensus Statement on this subject (2000) maintained the standard of care for BCT as breast-conserving surgery followed by whole-breast external-beam RT.³⁰

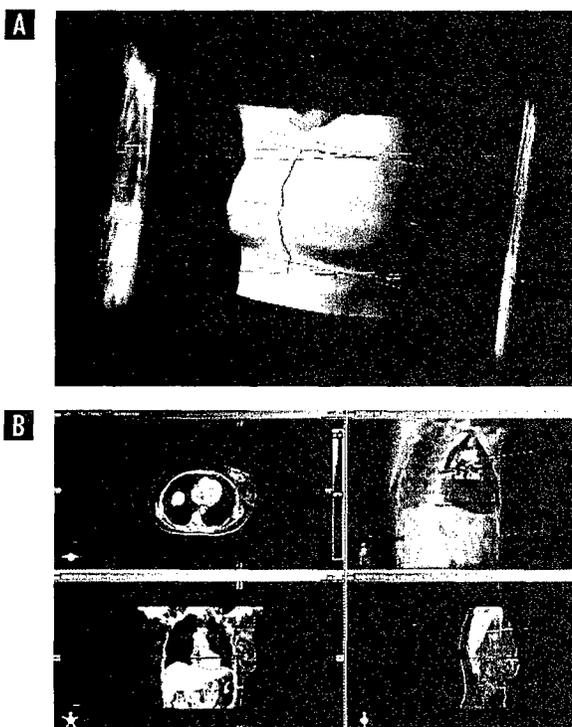
Data from pathologic studies justify this recommendation. For instance, in a study of 135 mastectomy specimens of breast cancer from patients theoretically eligible for conservative treatment (≤ 4 cm in size, all pathologic types except invasive lobular carcinoma), it was found that, even with ≥ 1 cm free of tumor beyond the dominant mass, in 11% of cases, tumor was found in the breast beyond 2 cm of distance, thus arguing that surgery alone may not be sufficient.³¹

Similar clinical data are available to demonstrate unacceptable risk of recurrence if radiation is omitted. Illustrating this is the experience of the Joint Center for Radiation Therapy in a study that omitted the use of adjuvant radiation after wide excision alone in T1 tumors (median tumor size, 0.9 cm).³² Eligibility criteria limited study inclusion to carriers of unicentric T1 infiltrating ductal, mucinous, or tubular cancers without extensive intraductal component (EIC) or lymphatic vessel invasion; negative margins of excision measuring ≥ 1 cm; and negative axillary nodes. Despite the stringent eligibility criteria and the fact that 75% of the lesions were mammographically detected (nonpalpable), the study was discontinued prematurely because of unacceptable local recurrence rate: 16% at 56 months of follow-up, or a 3.6% annual rate of local recurrence. The authors concluded that, even in a stringently selected group of patients with early-stage breast cancer, a considerable risk of local recurrence persists after conservative surgery without radiation. Interestingly, most recurrences were at the original tumor site, confirming that the original tumor bed remains the area at the highest risk for recurrence after surgery.

Omission of Radiation Therapy After Quadrantectomy

Recent evidence has emerged that performance of quadrantectomy—a more generous surgical excision than segmental mastectomy, equivalent to a quadrant of the breast—may allow omission of radiation in a selected subset of patients. In

Figure 1 Digital Reconstruction and Computed Tomography Planning for External-Beam Radiation



(A) Digital reconstruction of a patient's body and projection of tangent beams on the skin surface. (B) CT planning for external-beam radiation of a patient in supine position. The normal tissue structures including lung and heart, and tumor and the tangent field are outlined on the digital reconstructed radiograph (top right), axial plane of tangent fields (top left), coronal plane (bottom left), and sagittal plane (bottom right).

Abbreviation: CT = computed tomography

a retrospective study of 356 patients > 60 years of age with stage I or II breast cancer treated by quadrantectomy and axillary dissection, the subset of patients with negative lymph nodes and positive receptor status had a locoregional recurrence rate of 3% (median follow-up of 60 months) with or without adjuvant radiation.³³ These findings were confirmed by the results of the Milan III trial, a randomized trial testing the effect of radiation after quadrantectomy.³⁴ This trial demonstrated that, for women treated by quadrantectomy, as the age of the patient increased, the risk of local recurrence decreased. The difference in the risk for ipsilateral breast recurrence appeared to be particularly high in women ≤ 45 years of age and then tended to decrease with increasing age, with no apparent difference in women > 65 years of age.

In fact, for women ≥ 66 years of age, the local recurrence rate was 4% with or without RT, whereas women < 45 years of age had local recurrence rates of 43% with surgery alone and 9% with surgery and RT. In the group aged 46-55 years, the local recurrence rates were 20.2% without RT versus 5% with RT. In the subset of women aged 56-65 years, the risk was 12.1% without RT versus 2.4% with RT. The authors concluded that women ≤ 55 years of age derive a significant benefit from whole-breast postoperative radiation when quadrantectomy is performed. For women > 65 years of age, quadrantectomy alone is probably adequate.³⁴

Table 1 Actuarial Results of NSABP B-21 Trial

Treatment	Median Follow-up (Months)	Number of Patients	5-Year IBR	8-Year IBR
Surgery + Tamoxifen + Radiation	87	334	2%	2.8%
Surgery + Placebo + Radiation	86	332	4%	9.3%
Surgery + Tamoxifen	89	334	10.5%	16.5%

Abbreviations: IBR = in-breast recurrence; NSABP = National Surgical Adjuvant Breast and Bowel Project

In North America, quadrantectomy is not commonly performed, and according to a retrospective study of McCready et al, may translate to patients treated with segmental mastectomy or lumpectomy.³⁵ Local failure rate was 9% at 10 years after lumpectomy alone among patients who were \geq 65 years of age and had favorable pathologic features including negative nodes, no comedo features, no lymphovascular invasion, and estrogen receptor-positive tumors.

Omission of Radiation Therapy After Segmental Mastectomy

The identification of a distinct subset of women who could be safely treated by segmental mastectomy without the addition of RT was the motivation for 2 prospective randomized trials in older women that further addressed the issue of omitting RT in elderly patients. A Canadian randomized trial of women > 50 years of age with T1 or T2 node-negative breast cancer compared tamoxifen alone to tamoxifen and RT.³⁶ With a median follow-up of 3.4 years among 769 patients (83% with T1 breast cancer), the relapse-free rate in the ipsilateral breast was 94% in the tamoxifen-alone arm, compared with 99.7% in the tamoxifen/RT arm ($P = 0.0009$).

An Intergroup trial conducted by Cancer and Leukemia Group B randomized 647 postmenopausal women \geq 70 years of age with stage I estrogen receptor-positive breast cancer to tamoxifen versus tamoxifen and RT. With a short follow-up of 28 months, the rate of locoregional failure was very low, 0.9% annually (6 of 319 recurrences in the tamoxifen-

alone arm and none in the tamoxifen/RT arm; P value not significant). This study suggests that the benefit derived from RT in this elderly group of patients is very limited as a result of the high incidence of death from other causes. The rate of breast recurrence in the index breast was actually similar to the rate in the contralateral breast.³⁷

Could an original tumor size of \leq 1 cm justify the avoidance of postoperative RT? This was investigated by the National Surgical Adjuvant Breast and Bowel Project (NSABP) B-21 trial, which was limited to women with invasive breast tumors \leq 1 cm in largest dimension, who had undergone lumpectomy with tumor-free margins at pathology, and who had axillary dissection with negative lymph nodes. Approximately 80% of the women in the NSABP 21 trial were \geq 50 years of age and 76% of women were postmenopausal.³⁸ The cumulative incidence of IBR at 8 years was 16.5% with tamoxifen alone, 9.3% with RT and placebo, and 2.8% with the combination of tamoxifen and RT. Distant treatment failures were infrequent and not significantly different among groups ($P = 0.28$). Survival rates in the 3 groups were 93%, 94%, and 93%, respectively ($P = 0.93$). Although NSABP B-21 trial showed that whole-breast external-beam RT significantly reduced the actuarial estimate of incidence of IBR at 8 years, it also demonstrated that IBR continued to occur with time, as demonstrated by the gradual increases at 5 and 8 years of follow-up (Table 1). Protracted observation time to assess IBR is warranted, even in a population of patients with very small primary breast cancers.

Patterns of Local Recurrence After Breast-Conserving Therapy

Results from 5 prospective randomized trials of breast-preserving surgery with or without adjuvant RT have elucidated the geographic patterns of local recurrence after lumpectomy alone and thereby provide the foundation to justify the exploration of partial-breast irradiation (PBI).^{2,28,29,38-40} (Table 2). In each of these trials, most failures occurred in the tumor bed, raising questions as to the necessity of irradiating the whole breast. For instance, in the NSABP B-06 trial, all recurrences were reported to be within or close to the quadrant of the original tumor.⁴¹ In the study of Liljegren et al, in a more select group than patients from NSABP B-06, 381 patients with unifocal T1 breast cancers (premenopausal and postmenopausal women) were randomized to

sector resection with or without radiation.^{29,42} Predictably, at 10-year follow-up, significantly higher rates of local recurrences occurred in the arm of patients who underwent segmental mastectomy alone compared with the arm of patients who underwent segmental mastectomy and postoperative RT (24% vs. 8.5% at 10 years). Noticeably, 67% of the recurrences in the surgery-alone arm occurred within the initial tumor bed. A similar geographic pattern of local recurrence has also been demonstrated in other studies.^{43,44} The study of Veronesi

Table 2 Prospective Randomized Trials of Breast-Preserving Surgery with or Without Adjuvant RT

Study	Number of Patients	Cancer Size (cm)	Type of Surgery	Local Recurrence with Surgery Alone	Local Recurrence with Surgery + RT	Follow-up (Years)
Fisher et al ¹	1362	4	WE	39%	14%	20
Veronesi et al ²	567	4	Q	8.8%	2.3%	20
Clark et al ²⁸	837	4	WE	35%	11%	7.6
Liljegren et al ²⁹	381	2	SR	24%	8.5%	10
Forrest et al ⁴⁰	585	4	WE	24.5%	5.8%	6

Abbreviations: IBR = in-breast recurrence; Q = quadrantectomy; RT = radiation therapy; SR = sector resection; WE = wide excision

et al, which included a more generous surgical operation, a quadrantectomy, had the lowest local recurrence rate, suggesting that surgical removal of more tissue adjacent to the tumor favorably affects local control.⁴⁵

In these randomized trials, the arm of patients who did not undergo RT to the whole breast consistently showed higher recurrence rates and a pattern of recurrences that occurred mostly in the tumor bed. These findings question whether irradiation to the whole breast is necessary and have opened the opportunity to investigate PBI in selected patients with breast cancer treated by BCT.

Challenging the Current Standards for Volume and Dose Fractionation of Breast Irradiation

Although it is clear that the exploration of shorter treatment regimens is warranted, especially in view of the fact that new technology has made it possible to homogeneously deliver radiation treatment while better sparing normal tissue, the optimal fractionation regimen for postoperative breast RT has yet to be defined.

Whole-Breast Radiation: Accelerated Fractionation Regimens

Hypofractionated Accelerated Regimens. Hypofractionation (the delivery of dose fractions substantially larger than the conventional 2 Gy) for breast cancer treatment was common in the 1940s and 1950s and, even though successful in achieving tumor control, was found to leave significantly inferior cosmetic results as a result of severe fibrosis and telangiectasia.^{46,47} These late complications resulted from the use of very large fields that included a large proportion of uninvolved skin and tissue surrounding the tumor. Already in 1949, Baclesse had discovered the therapeutic ratio was largely dependent on the field size.⁴⁸ He advocated the use of a "sufficient number of contiguous small fields in rotation" as the future for breast cancer RT.

Baillet et al conducted the first prospective randomized trial studying hypofractionated radiation.⁴⁹ Patients were randomized to receive either "classical" RT consisting of 45 Gy in 25 fractions over 33 days or hypofractionated radiation consisting of 23 Gy in 4 fractions over 17 days. The first 230 patients randomized were followed for a minimum of 4 years. The 5-year actuarial survival was identical in the 2 arms. The local recurrence rates were 7% (9 of 125) in the hypofractionated radiation group and 5% (5 of 105) in the classical RT group, with no significant difference in local control between treatment arms. The study also detailed complications of each treatment groups including arm lymphedema, fibrosis, and telangiectasia. No statistical difference in the overall rate of complications between the treatment groups was noticed: 23% hypofractionated group versus 19% in the classical group.

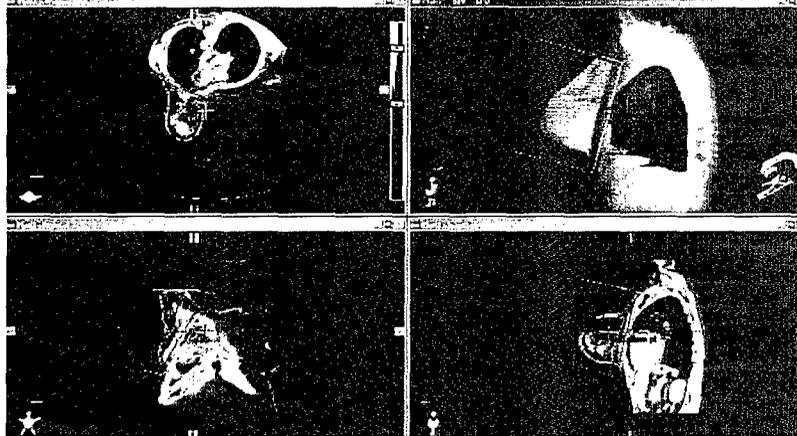
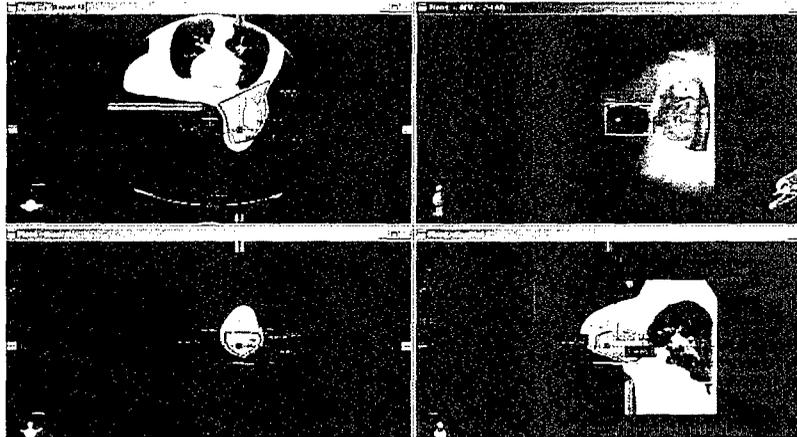
Among a number of retrospective reports on shorter whole-breast radiation fractionation schemes, perhaps the most relevant is by Olivotto et al.⁵⁰ The regimen used a dose of 44 Gy in 16 fractions in 22 days via tangential fields to the whole breast of 186 women with T1 or T2 pathologically node-negative breast cancer. The 5-year actuarial recurrence rate was 6%, which was comparable with other studies of conventional fractionation (over 6 weeks). Additionally, eval-

uations of the cosmetic scores were good or excellent in 89% and 96% of cases according to physicians and patients, respectively. Thirteen percent of patients reported mild infra-mammary telangiectasia at 5-year follow-up.

A Canadian retrospective review of a shorter radiation schedule used in patients with breast cancer after lumpectomy provided the preliminary evidence to further explore that hypofractionation schedule.⁵¹ A total of 298 patients were treated with 40 Gy in 16 fractions at 2.5 Gy per day with opposed tangent fields. Median follow-up for this series was 5.5 years. The 5-year actuarial relapse rate was 3.5%, with overall 5-year survival and disease-specific survival rates of 87.8% and 92.1%, respectively. These results were comparable with those derived from historical controls. The regimen appeared sufficiently safe and effective to be prospectively tested in a subsequent phase III trial.

The controlled randomized trial of Whelan et al compared 2 radiation schedules after lumpectomy in women with lymph-node negative breast cancer.⁵² The trial included women with T1/2 N0 tumors that were completely excised with negative margins. Between 1993 and 1996, 1234 women were randomly assigned to either the "long" arm of 50 Gy in 25 fractions over 35 days or the "short" arm of 42.5 Gy in 16 fractions over 22 days (2.65 Gy per day). The primary endpoint was the assessment of local control in the treated breast. There were a number of exclusion criteria including breast size (distance of separation \geq 25 cm), lack of levels 1 and 2 lymph node dissection, and positive margins. At a median follow-up of 69 months, the 5-year local recurrence-free survival rates were 97.2% in the short-RT arm and 96.8% in the long-RT arm. Overall and disease-free survival rates were also equivalent. The incidence of late skin toxicity was low in both arms, with comparable cosmetic outcome. Specifically, the percentages of patients with an excellent or good global cosmetic outcome at 3 years were 76.8% in the short-RT arm and 77.0% in the long-RT arm; the corresponding data at 5 years were 76.8% and 77.4%, respectively. Although this trial represents an important milestone in the investigation of modern RT in breast cancer, more work needs to be done, for instance, to explore how to integrate a boost to the tumor bed in accelerated whole-breast radiation or how to develop a technique that does not exclude patients with large breasts.

Hypofractionated Nonaccelerated Regimens. In another randomized trial, between 1986 and 1998, 1410 patients with early-stage invasive breast cancer were randomized to 3 different dose fractionation schedules, all delivered over a period of 5 weeks. Of note, although the trial tested hypofractionation, it did not accelerate treatment; rather, overall treatment time remained the same (5 weeks). The 3 schedules were 50 Gy in 25 fractions daily over 5 weeks (2 Gy per fraction), 39 Gy in 13 fractions (3 Gy per fraction), and 42.9 Gy in 13 fractions (3.3 Gy per fraction). The latter 2 schedules are delivered on Monday, Wednesday, Friday, Tuesday, Thursday, etc, 5 times every 2 weeks. Only initial cosmetic results have been reported,⁵³ and the trial has now been incorporated into the UK Coordinating Committee on Cancer Research breast RT fractionation trial, the Standardization of Breast Radiotherapy Trial, which was closed to accrual in September 2002.

Figure 2 Digital Reconstruction and Computed Tomography Planning in a Prone Position**A** Whole-Breast Radiation**B** Partial-Breast Radiation

the target and critical organs. The drawbacks of volume-based IMRT are the increased length of time to deliver the treatment and the labor-intensive dosimetric planning, making it difficult to translate IMRT to a large-scale implementation.⁵⁴ However, recent studies have shown that more simplified techniques have evolved.^{55,56} Chui et al described a practical and simplified technique of delivering IMRT,⁵⁵ which requires significantly less "beam-on" time and dosimetric planning than full-fledged volume-based IMRT, which Hong et al originally described.⁵⁴ The technique still achieves the desired dose homogeneity when compared with conventional tangents.

Lief et al explored the potential application of IMRT to accelerated breast RT with patients treated in a prone position.⁶⁰ This technique involves prescribing a homogeneous dose to the whole breast while a higher dose is delivered to the tumor bed, thereby delivering the equivalent of a concomitant boost (Figure 2A).

Partial-Breast Irradiation Treatment Volume: Rationale for Partial- Breast Irradiation

Partial-breast irradiation is generally administered to the portion of the breast that includes the tumor bed, plus a surrounding margin. The advantage of PBI is that, by limiting the volume treated, it is theoretically possible to increase the dose per fraction and safely accelerate dose fractionation, allowing patients to undergo a more convenient and possibly more economical radiation regimen as part of BCT. The cost depends on the procedure used. External-beam (3D conformal) accelerated RT costs less because of the decreased number of fractions compared with the standard regimen (5 vs. 30). Conversely, the use of IMRT is likely to increase cost compared with standard tangent treatment. Similarly, PBI delivered by brachytherapy is likely to be more expensive given the costs associated with operating room time, anesthesia, specialized instrumentation, and radiation sources.

Identification of patients who should be excluded from the accrual to these PBI trials because they are likely to either be insufficiently treated by accelerated PBI or are more likely to develop complications when exposed to larger doses per fraction is rapidly evolving. For instance, Holland et al found that tumors associated with EIC were more likely to have carcinoma in the remaining breast than tumors without EIC (74% vs. 42%; $P = 0.00001$), suggesting a role for whole-breast radiation when EIC is present in view of a large subclinical burden in the remaining breast.⁶¹ Another factor

Intensity-Modulated Radiation Therapy

Intensity-modulated RT (IMRT) uses a sophisticated computer-controlled radiation beam delivery method to improve the conformation of the dose distribution to the shape of the tumor. This is achieved with variation of the radiation intensity within each beam, as opposed to the uniform beam intensities used by 3-dimensional (3D) conformal RT. Intensity-modulated RT usually incorporates inverse treatment planning, whereby the user initially specifies the organ dose limits and the desired doses to the target tissues. The computer then generates an optimal plan then adheres to the dose limits specified.

To improve upon the dose delivery achieved by 3D conformal RT using breast wedged tangents, IMRT has been applied to breast RT. Intensity-modulated RT aims to improve the dose to all critical normal tissue structures including the heart and lungs. While current studies of IMRT applied to breast radiotherapy have shown its feasibility,⁵⁴⁻⁵⁹ long-term data has yet to determine whether this technique translates to an improvement in the late toxicity profile and cosmesis.

Volume-based IMRT first requires outlining the volumes of interest (target and critical organs) and uses specialized computer treatment planning algorithms to generate a plan that optimally balances the conflicting dose constraints to

predicting a higher risk of recurrence includes the presence of involved margins of excision.^{62,63} Carriers of tumors that lack these features are likely to be better candidates for accelerated PBI trials.

Partial-Breast Radiation Procedures

Currently, the main available methods of delivering PBI are brachytherapy with ≥ 2 plane implants, use of the MammoSite[®] device, or external-beam radiation with use of 3D conformal RT, IMRT, intraoperative electron beam RT, or stereotactic radiosurgery.

Brachytherapy Techniques. When brachytherapy is used, radiation can be delivered either at a low dose rate (LDR) over 4-5 days or at a high dose rate (HDR) with 8-10 large fractions. The target volume is the tumor bed with margins. Advantages are the established role of brachytherapy techniques and shortened overall treatment time compared with standard 6-week external-beam radiation. The disadvantages are the need for an invasive surgical procedure, the dependence on skills and experience of the radiation oncologist performing the procedure, and the risk of complications derived from dose inhomogeneity within the target volume. Although the results of the initial brachytherapy experience were disappointing, more recent studies with careful quality assurance and accurate patient selection have led to excellent local control rates with these techniques.

A trial by Fentiman et al investigated LDR brachytherapy to a total dose of 55 Gy with use of Iridium 192 and reported an unacceptably high breast recurrence rate of 37% (10 of 27 patients) at a median follow-up of 6 years.^{64,65} The investigators attributed the high local recurrence rate to the disproportionate inclusion in this series of younger women with unfavorable tumor characteristics, including median tumor diameter of 3.5 cm in the relapse group, and the presence of lymphovascular invasion, necrosis, positive margins, and involved axillary nodes. Moreover, most women received possibly inadequate implants, with a median number of 9 catheters resulting in treatment to the target volume with insufficient margins.

In a study by Clark et al, HDR brachytherapy delivering a total dose 20-32 Gy was used.⁶⁶ The local failure rate was 15.5% (7 of 45 patients) at 18 months.

King et al conducted a prospective phase I/II study of wide-field brachytherapy after segmental mastectomy for selected patients with breast cancer with intraductal or invasive tumors ≤ 4 cm in size, negative inked surgical margins, and ≤ 3 positive axillary nodes using wide-field double-plane ¹⁹²I brachytherapy implants.⁶⁷ Alternating consecutive cohorts of 10 patients were assigned to receive either continuous LDR brachytherapy of 45 Gy to the target volume over 4 days or fractionated HDR brachytherapy of 32 Gy in 8 fractions of 4 Gy each, given twice a day (b.i.d.) over 4 days. A matched-pair analysis with 94 patients who would have met the eligibility criteria for the study but were treated with conventional external-beam RT during the same time period was performed. With a median follow-up of 75 months, the locoregional recurrence rate was 8% (1 breast recurrence and 3 regional nodal recurrences among 51 cases) in the brachytherapy group, compared with 5% in the external-beam RT group (*P* value not significant).

Similar results were reported by Vicini et al, who conducted a retrospective matched-pair analysis of 174 patients with stage I/II infiltrating ductal carcinoma with tumors < 3 cm, negative EIC, negative surgical margins, and < 3 lymph nodes involved.⁶⁸ One hundred twenty patients (69%) underwent LDR brachytherapy (50 Gy over 96 hours) and 54 patients (31%) underwent HDR brachytherapy (46 patients received 32 Gy in 8 fractions 6 hours apart and 8 patients received 34 Gy in 10 fractions 6 hours apart). Fifty-two percent of the patients received adjuvant tamoxifen and 11% received adjuvant systemic chemotherapy. At a median follow-up of 36 months, there were no statistically significant differences in the 5-year actuarial rates of ipsilateral breast or locoregional recurrences and no differences in disease-free or overall survival.

Perera et al reported a pilot study of 39 patients who underwent HDR brachytherapy.⁶⁹ At a median follow-up of 20 months, 1 local recurrence was reported. Complications of treatment included fat necrosis in 4 patients (10.3%) at the lumpectomy site at 4, 13, and 18 months after implantation.

At a multiinstitutional level, the first preliminary report of Radiation Therapy Oncology Group (RTOG) 95-17 shows promising results.⁷⁰ RTOG 95-17 is a phase I/II multiinstitutional trial investigating brachytherapy alone after lumpectomy in 100 patients with tumors ≤ 3 cm excised with inked negative margins. Exclusion criteria were lobular histology, presence of EIC, and ≥ 4 involved nodes. Thirty-three patients were treated with LDR brachytherapy (45 Gy over 3-5 days) and 66 patients were treated with HDR brachytherapy (34 Gy in 10 b.i.d. fractions over 5 days). The target volume was defined as 2 cm beyond the lumpectomy cavity peripherally and 1 cm superficial and deep. At a median follow-up of 2.7 years (0.6-4.4 years), the incidences of grade III toxicity were 9% in LDR-treated patients and 2% in HDR-treated patients. It was noted that patients who received chemotherapy had a substantially increased risk of complications compared with patients who did not: 55% with LDR brachytherapy and 14% with HDR brachytherapy. Among patients who did not undergo chemotherapy, grade III toxicity occurred in no patients receiving LDR brachytherapy and 4% of patients in the HDR brachytherapy group. Furthermore, acute toxicities related to the surgical procedure in addition to radiation toxicity included breast edema, hematoma, arm edema cellulitis, skin necrosis, abscess formation, wound dehiscence, and breast distortion.⁷⁰

Wazer et al described clinically evident fat necrosis after HDR brachytherapy alone using remote afterloading in 8 of 30 patients (27%) at a median of 7.5 months after the procedure.^{71,72} The incidence of fat necrosis appeared to be related to the increased number of source dwell positions and the volume of implant receiving fractional doses of 340, 510, and 680 cGy. A dose-volume effect was shown such that use of implants of larger volume necessitated lowering the fractional dose in order to minimize the risk of late complications. This emphasizes the importance of the volume of tissue being irradiated and its consequences on the probability of complications.

Keisch et al recently reported the multicenter preliminary experience in 54 patients who were implanted with the MammoSite balloon breast brachytherapy applicator.⁷³ The reason to investigate this device is its potential to be a more

Table 3 Results of Sole LDR and HDR Brachytherapy to the Tumor Bed

Study	No. of Patients	Median Follow-up (Months)	Dose Fractionation	Total Dose (Gy)	Local Recurrence Rate	Good to Excellent Cosmetic Result
HDR Brachytherapy						
Clark et al ⁶⁶	45	18	10 Gy × 2 7 Gy × 4 6 Gy × 6	20 28 36	15.5%	95%
King et al ⁶⁷	26	75*	4 Gy × 8	32	2%*	75%*
Vicini et al ⁶⁸	46 8	36*	4 Gy × 8 3.4 Gy × 10	32 34	0	80%*
Perera et al ⁶⁹	39	20	3.72 Gy × 10	37.2	2.6%	—
Kuske et al ⁷⁰	66	32*	3.4 Gy × 10	34	—	—
Wazer et al ⁷²	32	33	3.4 Gy × 10	34	3%	75%
Keisch et al ⁷³	43	1	3.4 Gy × 10	34	—	88%
Polgar et al (Phase II) ⁷⁵	8 37	57	4.33 Gy × 7 5.2 Gy × 7	30.3 36.4	4.4%	97.8%
Polgar et al (Phase III) ⁷⁵	63	30	5.2 Gy × 7	36.4	0	—
LDR Brachytherapy						
Fentiman et al ⁶⁵	27	72	45 cGy/hour	55	37%	83%
King et al ⁶⁷	27	75*	40 cGy/hour	55	2%*	75%*
Vicini et al ⁶⁸	120	36*	52 cGy/hour	50	0	80%*
Kuske et al ⁷⁰	33	32*	45 cGy/hour	45	—	—

*LDR and HDR combined.

Abbreviations: HDR = high dose rate; LDR = low dose rate

reproducible method of breast brachytherapy that is less dependent on the surgical implant technique. This prospective pilot study tested the use of the MammoSite balloon breast applicator using ¹⁹²I HDR brachytherapy as a sole radiation modality after lumpectomy in women > 45 years of age with stage I breast cancers with negative pathologic margins. The study design consisted of a total dose of 34 Gy, delivered in 10 fractions b.i.d. for 5 days, prescribed to 1 cm from the applicator surface. Only 43 of the 54 patients were found to be eligible for this technique. MammoSite balloon delivery was not feasible in cases of inadequate balloon-to-skin distance, excessive surgical cavity size, poor balloon conformance, or poor skin-to-device spacing. Complications included seromas (3 of 43) and abscess formation (1 of 43). Dose-volume histogram (DVH) analysis of the MammoSite device appeared to compare its use favorably with catheter-based breast brachytherapy. Generally, the MammoSite device treated a larger volume than its interstitial brachytherapy counterparts. The investigators hypothesized that by following the dose-volume cutoffs, fat necrosis would be unlikely to occur, but this prediction warrants further clinical confirmation.

There have been a number of phase I/II trials of brachytherapy as the sole radiation modality to the breast.^{69,72,74} Polgar et al reported the first randomized phase III trial of sole HDR brachytherapy compared with whole-breast RT, with a median follow-up of 30 months.⁷⁵ El-

igible patients were those with unifocal tumors of stage pT1 N0 or pN0-1a. Pure ductal or lobular pT1s tumors, invasive lobular tumors, and presence of EIC were criteria for exclusion. Initially, 45 patients were enrolled onto a phase I/II study of brachytherapy alone with use of interstitial HDR implants consisting of 7 fractions of 4.33 Gy (n = 8) and 7 fractions of 5.2 Gy (n = 37) delivered to the tumor bed. Based on the results of the initial phase I and II study, 126 patients were further randomized to receive 50 Gy whole-breast RT (n = 63) or brachytherapy alone (n = 63). The dose regimen consisted of either 7 fractions of 5.2 Gy HDR brachytherapy (n = 46) or 50 Gy wide-field electron radiation (n = 17). The locoregional control rate was 100% in each arm and the 3-year probabilities of cancer-specific and relapse-free survival were 98.1% and 98.4% in the whole-breast radiation group and 100% and 94.4% in the brachytherapy group, respectively. There was no significant difference in outcome or in the incidence of radiation side effects between the 2 treatment arms; however, because of the small number of patients in each arm, it may not be powered to detect a difference. More prospective randomized data will be required to confirm this. Table 3 summarizes HDR and LDR brachytherapy as sole radiation modality after breast-conserving surgery.^{65-70,72,73,75}

The current experience using brachytherapy for PBI is promising but still limited. The American Brachytherapy Society published guidelines on the use of brachytherapy for

breast cancer, which emphasized the importance of patient selection, careful treatment planning, and use of DVHs and dose homogeneity index.⁷⁶ Nevertheless, brachytherapy has several disadvantages compared with external-beam RT, most importantly its invasiveness. Also, if LDR brachytherapy is delivered, the patient has the additional requirement of an isolation room during treatment delivery. Moreover, long-term cosmetic results are not yet available, and the risk of fibrosis and induration at the implant site remains a concern, especially because it can become quite difficult to routinely examine the treated breast.^{65,77,78}

External-Beam Techniques. An external-beam approach is likely to be more acceptable to the patient, to be more widely reproducible, to generate improved dose homogeneity, and to result in better cosmetic results compared with brachytherapy techniques. Additionally, it can be made available at any institution with a linear accelerator facility and spare the health care costs of an extra surgical procedure and several days of hospitalization (in the case of LDR brachytherapy).

The first and only randomized trial of partial-breast external-beam radiation versus whole-breast radiation is the Christie Hospital Breast Conservation trial, a trial of 708 patients that included tumors ≤ 4 cm in size with infiltrating ductal and lobular histologies.⁷⁹ After lumpectomy, patients were randomized to undergo RT to the tumor bed only (limited-field [LF] group) or to the whole breast and regional nodes (wide-field [WF] group). No systemic therapy was given in either arm. Results of this trial at 8-year actuarial follow-up (median follow-up, 65 months) suggest that the histologic type of the original breast cancer affected local control. In fact, for infiltrating ductal carcinoma, the actuarial breast recurrence rate was 15% for LF radiation versus 11% for WF radiation, whereas for infiltrating lobular carcinoma, the recurrence rates were 34% for LF radiation and 8% for WF radiation. Moreover, in patients with extensive ductal carcinoma in situ, high recurrence rates of 21% (LF group) and 14% (WF group) were also noted. Lumpectomy with LF radiation was feasible; however, the study identified potential patients at higher risk for local recurrence when treated by PBI.

Formenti et al pilot-tested a phase I feasibility study of hypofractionated conformal external-beam RT to the tumor bed in selected postmenopausal women with T1 breast cancers.⁸⁰ The rationale for the study was based on the assumption that a few large fractions can be safely delivered to breast cancers provided that the target volume is sufficiently small and the radiation technique assures maximum sparing of the surrounding normal tissue. Using the radiobiologic linear-quadratic cell survival model with an alpha-beta value for breast carcinoma of 4, a dose of 30 Gy in 5 fractions of 6 Gy per fraction over 10 days was found radiobiologically equivalent to a standard dose of 60 Gy in 30 fractions of 2 Gy. The biologic equivalent dose for late breast tissue complications (including desquamation, fibrosis, erythema, and telangiectasia) was less than or equivalent to that of the standard 60 Gy fractionation. The treatment was found to be feasible in 9 of 10 consecutive patients. At a minimum follow-up of 3 years, there were no recurrences and the patients had "good to excellent" cosmetic results. The technique used was derived from a radiosurgical model of delivering external-beam radiation by multiple noncoplanar

fields directed toward the tumor bed while sparing as much of the normal tissue as possible.⁸¹ Immobilization of the patient in prone position on a dedicated breast board allowed the breast tissue to freely fall through an opening in the board and reduced to a minimum the motion of the target caused by breathing.

Based on the initial pilot study, a phase I/II study funded by a grant from the Department of Defense (DAMD 17-01-1-0345) is currently ongoing. Currently, 47 of 99 planned patients have been accrued to the study, which consists of a regimen of hypofractionated PBI, 30 Gy in 5 fractions over 10 days.⁸² The volume of breast tissue irradiated is the surgical cavity, which is defined at planning computed tomography as the area of postoperative architectural distortion, in conjunction with information derived from mammographic and pathologic findings (Figure 2B). Forty-six of the 47 patients completed treatment with only mild acute toxicity (grade I/II skin toxicity). One patient refused further treatment after 2 fractions with no acute toxicities, but discontinued for personal reasons. At a median follow-up of 17 months (range, 1-39 months), no local recurrences have occurred as of yet. Whereas, in the initial report, 1 of 10 patients could not be treated via the original fractionated radiosurgery-like technique because of the proximity of the lesion to the chest wall. In the next series of 47 patients, the predominant treatment technique was a pair of parallel-opposed mini-tangents.

Baglan et al also piloted a phase I/II study of accelerated PBI in 9 patients.⁸³ Their technique and dose fractionation differed from that used by Formenti et al in that they treated patients in supine position using an active breathing control method to account for breast movement related to respiratory excursion. Additionally, the model of dose fractionation appeared to be extrapolated from the brachytherapy dose fractionation schedules of 34 Gy in 10 fractions b.i.d. over 5 days in 5 patients, followed by 38.5 Gy in 10 b.i.d. fractions over 5 days in the remaining 4 patients. The technique appeared to be feasible and well tolerated.

Finally, intraoperative RT using a linear accelerator electron beam has been investigated by the European Institute of Oncology at the University of Milan, Italy, which uses a linear accelerator with a robotic arm in an operating room, which delivers electron beams of varying energies: 3, 5, 7, and 9 MeV. The radiation beam is collimated using a Perspex tube.⁸⁴ A pilot phase I trial tested different single radiation doses from 10 to 21 Gy after initial quadrantectomy with 1-2 cm clear margins and initial results estimated that a single 21-Gy fraction is radiobiologically equivalent to 60 Gy in 30 fractions in terms of tumor control. However, the initial results of 101 patients were reported with a short median follow-up of 8 months (range, 1-17 months) and concern remains about the effect of such a large single dose on long-term complications, including fibrosis, telangiectasia, and fat necrosis. Advantages of the technique are the even dose distribution achieved by electron-beam RT compared with brachytherapy and the rapidity and potential cost effectiveness of a single treatment.

Research on Genetic Determinants of Long-Term Toxicity

One of the concerns of using larger doses per fraction for breast RT is the potential adverse effects on cosmesis caused by RT-induced fibrosis and skin telangiectasia.^{46,48} Current-

ly, no established markers are available for integration to routine practice to predict which group of patients will develop long-term complications. However, in the future, the recognition of genetic predispositions to these complications will enable the exclusion of high-risk carriers from the trials of accelerated/hypofractionated radiation. In other words, similar to the impact of pharmacogenomics in medical oncology, the field of radiation genomics is also rapidly emerging, permitting identification of individuals with genetic predisposition to inferior repair of the damage caused by ionizing radiation. For instance, relevant genetic polymorphisms have started to emerge, including transforming growth factor (TGF)- β 1 single-nucleotide polymorphism⁸⁵ and mutations of the ataxia telangiectasia mutated (ATM) gene,⁸⁶ which have been associated with individuals who were found to have moderate to severe long-term RT-induced complications.

Quarmany et al investigated whether TGF- β 1 single-nucleotide polymorphisms were associated with the susceptibility of patients with breast cancer to severe radiation-induced normal tissue damage.⁸⁵ They performed polymerase chain reaction–restriction fragment length polymorphism assays for TGF- β 1 gene polymorphisms on DNA obtained from 103 patients with breast cancer who received RT. The G-800A, C-509T, T+869C, and G+915C polymorphic sites were examined, and genotype and allele frequencies of 2 subgroups of patients were calculated and compared. The investigators found that the less-prevalent -509T and +869C alleles were significantly associated with a subgroup of patients who developed severe radiation-induced normal tissue fibrosis ($n = 15$) compared with those who did not ($n = 88$; odds ratio = 3.4 and $P = 0.0036$; odds ratio = 2.37 and $P = 0.035$, respectively). Furthermore, patients with the -509TT or +869CC genotypes were 7-15 times more likely to develop severe fibrosis. These findings imply a role for the -509T and +869C alleles in the biologic mechanisms underlying susceptibility to radiation-induced fibrosis.

Ianuzzi et al showed a significant correlation between ATM gene status and the development of grade 3/4 subcutaneous late effects in breast cancer by using denaturing high-performance liquid chromatography, a powerful technique in detecting missense mutations and small deletions and insertions.⁸⁶ All 3 patients who manifested grade 3/4 subcutaneous late sequelae possessed 2 ATM genes, whereas only 3 of the 43 patients (7%) who did not develop this form of severe toxicity harbored an ATM gene ($P = 0.001$). In contrast, none of the 3 ATM gene carriers who had a single mutation developed a severe subcutaneous reaction.

The future may hold even greater capacity to tailor RT dose-volume fractionation schemes. If fibrosis-associated polymorphic sites in other genes could be identified, it may be possible to detect fibrosis-prone individuals with greater certainty before RT.

Conclusion

Most novel approaches to postoperative RT as part of BCT have included accelerated breast irradiation (ABI). Accelerated breast irradiation to the whole breast or partial breast remains a research approach, as level 1 evidence is currently unavailable to prove its equivalence to standard postoperative RT. Many unresolved issues remain, including optimal patient selection, optimal determination of treatment volume, the

ideal dose-fractionation schedule, and total dose. One of the limitations of the external-beam techniques, especially when IMRT is used, is that the integral dose to the remaining breast tissue is higher with increasing number of fields. In addition, for women undergoing partial-breast RT, practically no information exists regarding potential salvage of recurrences after ABI. Finally, the best sequencing pattern with chemotherapy and the ability to perform salvage therapy after ABI also need to be established. However, because of its potential high impact on the care of most patients with breast cancer, ABI should be a research priority in this disease.

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CLINICAL INVESTIGATION

PRONE ACCELERATED PARTIAL BREAST IRRADIATION AFTER BREAST-CONSERVING SURGERY: PRELIMINARY CLINICAL RESULTS AND DOSE-VOLUME HISTOGRAM ANALYSIS

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Purpose: To report the clinical and dose-volume histogram results of the first 47 patients accrued to a protocol of accelerated partial breast irradiation. Patients were treated in the prone position with three-dimensional conformal radiotherapy after breast-conserving surgery.

Methods and Materials: Postmenopausal women with Stage T1N0 breast cancer were eligible only after they had first refused to undergo 6 weeks of standard radiotherapy. Planning CT in the prone position was performed on a dedicated table. The postoperative cavity was defined as the clinical target volume, with a 1.5-cm margin added to determine the planning target volume. A total dose of 30 Gy at 6 Gy/fraction was delivered in five fractions within 10 days.

Results: The median age of the patients was 67.5 years (range, 51-88 years). The median tumor diameter was 9 mm (range, 1.3-19 mm). In all patients, the prescribed dose encompassed the planning target volume. The mean volume of the ipsilateral breast receiving 100% of the prescription dose was 26% (range, 10-45%), and the mean volume contained within the 50% isodose surface was 47% (range, 23-75%). The lung and heart were spared by treating in the prone position. Acute toxicity was modest, limited mainly to Grade 1-2 erythema. With a median follow-up of 18 months, only Grade 1 late toxicity occurred, and no patient developed local recurrence.

Conclusion: These data suggest that this approach is well tolerated, with only mild acute side effects and sparing of the heart and lung. © 2004 Elsevier Inc.

Hypofractionation, Prone, Partial breast irradiation, Early-stage breast cancer.

INTRODUCTION

The widespread use of screening mammography during the past three decades has generated a new patient population, consisting of postmenopausal women with mammographically detected, nonpalpable, early-stage, invasive breast cancer. These tumors are often T1N0M0, Stage I, estrogen receptor-positive tumors, ideal for breast-conserving therapy (BCT) (1). A more user-friendly regimen than the standard 5-7 weeks of postoperative radiotherapy (RT) has recently become an area of intense research, because in certain patient populations, including the elderly and patients living remote from radiation facilities, BCT and/or postoperative RT appear to be underutilized (2-6). Because no patient subgroup has had a sufficiently low risk of in-breast recurrence to avoid whole breast RT routinely after segmental mastec-

tomy (7), a shorter RT regimen could minimize inconvenience and improve the use of BCT.

The results of five prospective randomized trials testing breast-preserving surgery with or without adjuvant RT have suggested that most failures occur at the tumor bed, thus questioning the necessity for routinely irradiating the whole breast (7-11). The ipsilateral breast tissue outside the tumor bed appears to carry a risk of recurrence or new breast cancer development that is equivalent to that of the contralateral breast (0.5-1% annually), which is routinely not irradiated. Limiting RT to a smaller target than the whole breast has the potential to reduce radiation-induced morbidity. The main advantage of partial breast RT is the opportunity to increase the dose per fraction to accelerate treatment by limiting the volume of treated normal tissue.

Although several groups have focused on brachytherapy as the technique to deliver accelerated partial breast irradi-

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sociated with the hypofractionated schedule, would be identical to that of the standard treatment without a boost. In addition, because the hypofractionated regimen also represents an accelerated protocol in which the total dose is delivered in only 10 days, less tumor proliferation is expected to take place compared with that occurring during the standard treatment. By taking these factors into account, the difference between the BEDs for the two schedules is reduced (Table 2).

Study population

Study eligibility was limited to postmenopausal women with newly diagnosed, nonpalpable, mammographically detected, invasive breast cancer. Menopause was defined as at least 2 years without menstrual periods. In patients who had undergone prior hysterectomy, follicle-stimulating hormone levels were measured for confirmation of postmenopausal status. Only those with pT1, pN0 or sentinel node negative, or N0 clinically if the tumor was <1 cm in size, were eligible. In addition, patients were required to have undergone segmental mastectomy or reexcision with negative surgical margins (at least 5 mm) and to have estrogen and/or progesterone receptor-positive tumors. Antihormonal therapy (tamoxifen or anastrozole) was prescribed in all cases.

The exclusion criteria included previous RT to the ipsilateral breast, extensive intraductal component in the pathologic specimen, a diagnosis of multifocal breast cancer, or the inability to provide informed consent as assessed by the Principal Investigator. All eligible women who were referred to the Radiation Oncology Department at the New York University School of Medicine for RT after breast-conserving surgery for breast cancer were first offered standard conventional 6-week RT. Only women who declined standard RT were given the opportunity to participate in the current protocol by providing informed consent. The New York University institutional review board and the institutional review board of the Department of Defense reviewed and approved all aspects of the study.

Toxicity was assessed every week during treatment. Patients were followed monthly with physical examination for the first 90 days, every 3 months for the first year, every 6 months for the next 4 years, and yearly thereafter to evaluate their status with respect to recurrence, long-term toxicity, and cosmesis. Toxicity was evaluated at each visit according to the Radiation Therapy Oncology Group toxicity scoring criteria. Cosmesis was recorded by the patient at baseline (before RT started) and then every 6 months.

Simulation and treatment planning

Patients were placed in the prone position on a dedicated treatment table for CT planning and treatment (Figs. 1-3). The table has an aperture to allow the breast to fall by gravity away from the chest wall (17). Patient positioning on the table was established by two lateral lasers and one overhead laser. Noncontrast CT images



Fig. 1. Computed tomography simulator and prone breast ~~board~~ table.

were acquired at 3.75-mm-thick intervals from the level of the mandible to below the diaphragm using a GE Light speed helical CT scanner. CT images were transferred to a Varian Eclipse treatment planning system (Varian Cadplan, Varian Medical Systems, Palo Alto, CA). The surgical cavity, identified at CT as the area of architectural distortion in the breast tissue, defined the clinical target volume (CTV) (Fig. 4). When necessary, information obtained from the surgical report, mammography findings, and other available imaging test results were also incorporated. Although not intentionally included by the CTV, the surgical incision was outlined by a wire placed over the incision before CT scanning.

Adding a 1.5-2-cm margin to the CTV created the planning target volume (PTV). After uniform expansion, the PTV was limited anteriorly by the skin and posteriorly by the chest wall. An additional 7-mm margin was added to the PTV to the field edge to account for beam penumbra, for a total margin of 2.2-2.7 cm. The ipsilateral lung and heart were outlined. The normal ipsilateral breast tissue volume was defined by applying radiopaque wires in the supine position at the site of the medial, lateral inferior, and superior borders of the classic opposite tangent breast fields to define the volume that would have been treated by classic whole breast tangents in the supine position.

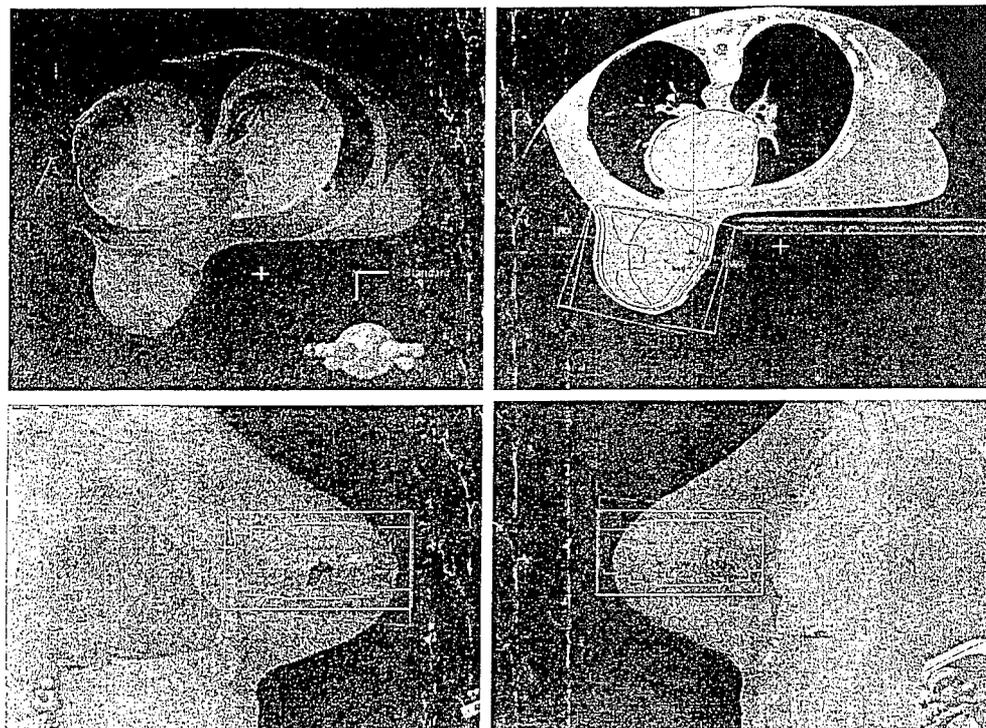


Fig. 4. (Upper) Example of relationship of tumor bed to planning target volume (PTV) demonstrated: tumor bed in red wash, PTV in blue, heart in pink, and lung in light green. PTV represents a 1.5-cm margin on tumor bed. (Lower) Digital reconstructed radiographs, right anterior oblique and left posterior oblique portals for left-sided breast cancer.

isodose surface that encompassed the PTV, typically 95%. Dose inhomogeneity was maintained at <110%.

Additional normal tissue dose guidelines included limiting 50% of the ipsilateral breast volume to <50% of the prescribed dose. In addition, the volume of heart and lung included in the treatment fields was expected to be <10%. Field arrangements were designed to avoid the contralateral breast and ipsilateral lung and heart tissue completely (Fig. 4). The dose fractionation schedule was 30 Gy delivered in five fractions of 6 Gy to the 95% isodose surface, given within 10 days (Monday, Wednesday, Friday, Monday, Wednesday).

Target positioning verification

Treatment room lasers were used to verify consistent positioning of the patient on the table. Daily setup reproducibility was ensured by leveling marks on the torso and triangulation marks placed on the back, ipsilateral side, and breast tissue (Fig. 5). The setup was designed to identify a plane orthogonal to the table that also crossed the tumor cavity. Before each fraction, portal films of each field verified treatment positioning. Accepted variance was limited

to 5 mm from the isocenter position indicated on the digitally reconstructed radiographs (Fig. 6).

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Statistical analysis

An optimal two-stage Simon design was used for this Phase II trial (27). It is based on testing the null hypothesis that the 3-year local recurrence rate is $\geq 9\%$ vs. the alternative that the 3-year local recurrence rate is $\leq 3\%$ (α 0.05; power of 0.80). The study was designed to enroll 31 patients in the first stage and up to 99 patients during the entire trial. If two or fewer local recurrences developed in the first 31 patients who completed at least 1 year of follow-up, accrual would continue up to completion of the second stage. If five or more local recurrences were observed at any point, the trial would be stopped. The trial will be terminated when at most 99 patients have been entered and followed for at least 1 year. Any ipsilateral breast local recurrence, whether a true local recurrence (within the radiation field) or breast local recurrence outside the field, was the main study endpoint (including both isolated recurrence and concomitant with distant disease).

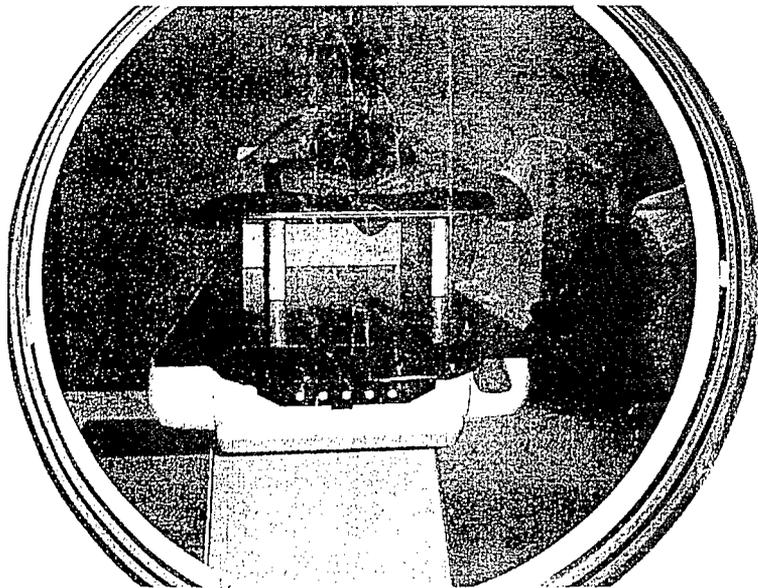


Fig. 2. Positioning and setup. Patient positioned prone on dedicated table that allows target breast tissue to fall freely through opening.

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Dose-volume constraint guidelines

Treatment planning was performed using the CT-defined volumes, most often through an opposed pair of mini-tangents. When required to increase dose distribution ho-

mogeneity, wedges were used. The isocenter was located approximately 5-7 cm from the midline along an axis passing through the center of the PTV. The dose was normalized to 100% at the isocenter before choosing an

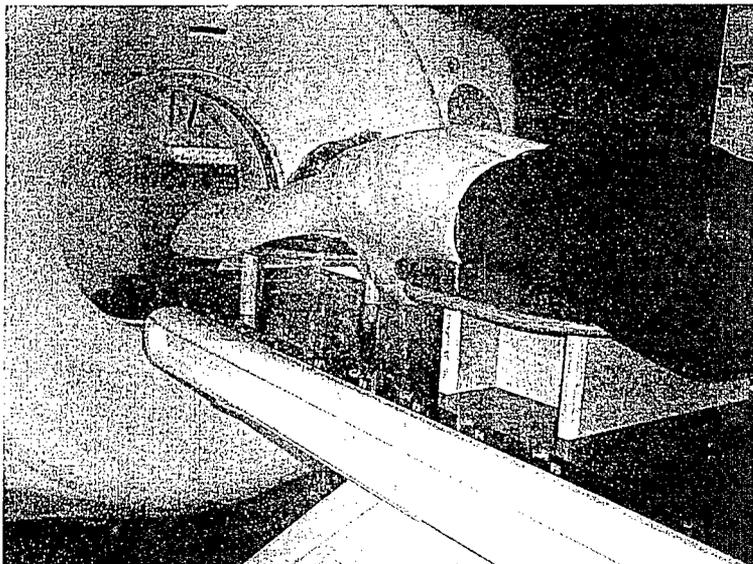


Fig. 3. Patient undergoing computed tomography acquisition of images.

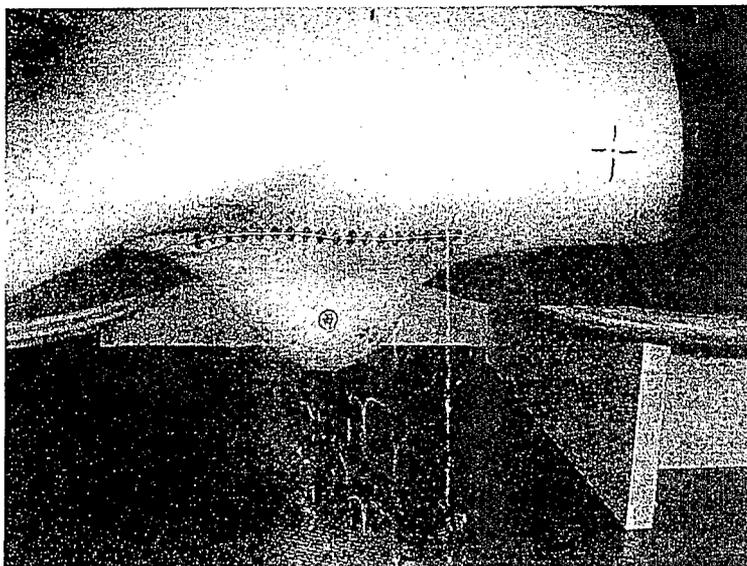


Fig. 5. Target position verification by triangulation marks placed carefully on back, ipsilateral side, and breast.

RESULTS

Clinical results

Between June 2000 and December 2003, 50 patients were enrolled in the study. A summary of the baseline patient and tumor characteristics is provided in Tables 3 and 4, respectively, and includes the mean, median, quartiles, and range for continuous variables and frequency distributions for categorical variables. Of the 50 screened patients, 47 entered the treatment phase and 46 completed treatment. Three patients were lost to follow-up before initiating any treatment, and 1 patient discontinued treatment after two fractions for personal reasons. She reported no acute toxicities.

The median length of follow-up was 18 months (range, 0.3–40.3 months). Of the 46 patients, 30 were followed for ≥ 1 year since the start of treatment without any local recurrences, and the study continues to accrue patients. The follow-up distribution is shown in Table 5.

The most common acute toxicity noted was Grade 1–2 erythema, observed in 28 patients (60% of patients treated; Table 6). A preliminary assessment of late toxicity has indicated that these were primarily Grade 1 (Table 6). A total of 21 late toxicities have occurred in 14 patients. Eight patients had Grade 1 induration before RT, related to the surgery. Cosmetic results were rated as “good/excellent” in 7 patients with 6–12 months of follow-up, 3 patients with 12.1–18 months of follow-up, 5 patients with 18.1–24 months of follow-up, 12 patients with >2 years of follow-up, and 5 patients with >3 years of follow-up. In 2 patients, the cosmetic results were rated as “fair” at 12 and 18 months of follow-up. The remaining patients have had <6 months

of follow-up. In none of the patients was the post-RT score worse than at the baseline postoperative assessment.

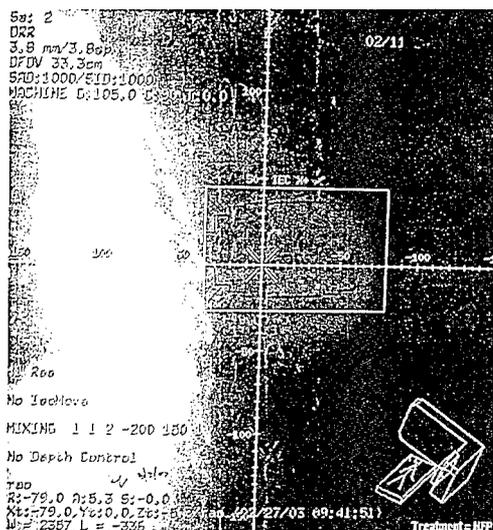
At last follow-up, no patient had developed local recurrence. One patient developed metastatic squamous cell carcinoma of the lung with mediastinal, paraspinal, and osseous metastases 2 months after RT completion. No evidence of malignancy could be found at review of the chest X-ray obtained before undergoing segmental mastectomy. Her condition rapidly deteriorated because of metastatic lung cancer and she died 3 months after completion of the protocol treatment.

Physics results

Of the 47 patients, 43 were treated in the prone position. Four patients were treated in the supine position (as accepted protocol deviations by the principal investigator). Of the 4 patients, 2 could not tolerate prone positioning because of a preexisting physical disability (hemiparesis due to a previous stroke in 1 and multiple sclerosis in 1). The third patient could not be treated in the prone position without treating the arm and contralateral breast because of severe kyphosis, secondary to osteoporosis. In the fourth patient, the tumor bed was located lateral and superior in tail of Spence, and it was better treated in the supine position.

The predominant technique for treatment was a pair of parallel-opposed mini-tangents. This arrangement provided a simplified treatment setup and ensured good coverage, given the constraints imposed by the PTV and its relationship to the table (Fig. 4).

Lawler



(a)



(b)

Fig. 6. (a) Right anterior oblique digital reconstructed radiograph. (b) Right anterior oblique port film.

Dosimetric findings

T8 The dosimetric results are summarized in Tables 7 and 8. The mean and median size of the surgical cavity (CTV) at CT acquisition was 52 cm³ and 34 cm³ (range, 7–379 cm³), respectively. The mean and median volume of the PTV was 228 cm³ and 192 cm³ (range, 57–1118 cm³), respectively.

The mean and median volume of the ipsilateral breast were 1102 cm³ and 1006 cm³, respectively (range, 258–3468 cm³). The mean and median coverage of the PTV by the 30 Gy isodose surface were both 100%.

Dose–volume histograms of the ipsilateral breast volume, lung and heart were generated (Fig. 7). The mean and

Table 3. Baseline patient characteristics (n = 47)

	Patients (n)
Race	
Black	1 (2.1)
Hispanic	2 (4.3)
White	44 (93.6)
Performance status at screening	
0	19 (40.4)
1	24 (51.1)
2	1 (2.1)
Unknown	3 (6.4)
Breast side	
Left	27 (57.5)
Right	20 (42.6)
Hormonal replacement therapy	
Current	4 (8.5)
Past	15 (31.9)
None	27 (57.5)
Unknown	1 (2.1)
Tumor estrogen receptor status	
Negative	1 (2.1)
Positive	46 (97.9)
Tumor progesterone receptor status	
Negative	13 (27.7)
Positive	34 (72.3)
Tumor Her2-neu status by IHC	
0	31 (65.9)
+	7 (14.9)
++	4 (8.5)
+++	3 (6.4)
Unknown	2 (4.3)

Data in parentheses are percentages.

median volume of the ipsilateral breast receiving 100% of the prescription dose was 26% and 27% (range, 10–45%), respectively. The mean and median volume receiving 50% of the prescription dose was 47% and 46% (range, 23–75%), respectively. We found heterogeneity in the dose-volume histogram based on the position of the original tumor bed and the size of the breast. In 25% of patients (12 of 47), to successfully treat the PTV, >50% of the ipsilateral breast volume received >50% of the prescription dose.

Dose to heart and lung

The mean percentage of lung volume receiving 20, 10, and 5 Gy was 0% (range, 0–4%, 0–6%, and 0–10% respectively) for all. The mean percentage of heart volume receiving 20, 10, and 5 Gy was also 0% (Table 8). These doses were less than what has been reported using partial breast irradiation in the supine position (28). Prone posi-

Table 5. Follow-up distribution from start of treatment to last observation

Follow-up (mo)	Patients (n)
0–6	11 (23.4)
6–12	6 (12.8)
12–18	7 (14.8)
18–24	4 (8.5)
24–30	5 (10.6)
30–36	6 (12.8)
36–42	8 (17.1)
Total	47 (100.0)

Data in parentheses are percentages.

Table 6. Acute and late toxicity

Toxicity	Worst grade	Toxicities (n)
Acute (n = 28/47)		
Breast swelling	1	1 (2.7)
Desquamation	1	2 (5.4)
Erythema	2	21 (56.7)
	1	5 (13.5)
Late (n = 14/47)		
Erythema	1	2 (9.5)
Fibrosis	1	2 (9.5)
Hyperpigmentation	1	3 (14.4)
Induration	1	8 (38.1)
Telangiectasia	1	5 (23.8)
Other	1	1 (4.8)

Data in parentheses are percentages.

tioning allowed sparing of these critical structures by allowing the breast tissue to fall away from the chest wall and minimizing breast movement secondary to the respiratory excursion that commonly occurs in the supine position. In the 4 patients treated supine in this study, the median dose to the lung receiving 20, 10, and 5 Gy was 2%, 4%, and 6%, respectively.

DISCUSSION

The current study represents the largest reported experience of three-dimensional conformal external beam RT for APBI as part of BCT. With the limitation of a short median follow-up of only 18 months, these results support the safety and feasibility of the regimen.

Several differences characterize this approach compared

Table 4. Baseline tumor characteristics (n = 47)

Variable	Mean	Q3	Median	Q1	Range
Age (y)	68	77	68	61	52–88
Tumor size (mm)	9.6	13.0	9.0	7.0	1.3–19
Follow-up (mo)	19.0	32.5	16.7	6.2	0.3–40.3

Abbreviations: Q3 = third quartile; Q1 = first quartile.

Table 7. Dosimetric findings: CTV, PTV, and IBV

Dosimetric characteristics	Mean value	Median value	Range
IBV (cm ³)	1102	1006	258-3468
CTV (cm ³)	52	34	7-379
PTV (cm ³)	228	192	57-1118
Maximal dose (% of PD)	110	108	105-117
PTV coverage by 95% isodose surface (%)	100	100	—
Ipsilateral breast coverage (% IBV encompassed by % of PD)			
100% of PD	26	27	10-45
75% of PD	41	40	20-68
50% of PD	47	46	23-75
25% of PD	53	53	27-82
CTV/IBV (%)	5	4	1-22
PTV/IBV (%)	22	20	10-55
CTV/PTV (%)	20	20	6-46

Abbreviations: CTV = clinical target volume (tumor bed); PTV = planning target volume; IBV = ipsilateral breast volume; PD = prescribed dose.

with those reported by other groups studying partial breast RT with an external beam technique. First, the patients in this study received treatment in the prone position (21). The advantages of a prone technique are manifold. Prone positioning considerably reduces the breast tissue motion secondary to both cardiac systole and respiration (29), limiting the excursion of the chest wall to <5 mm (17). With the triangulation technique we developed for positioning, the breast tissue remains a predictably fixed target. In addition, prone positioning allows for exclusion of lung and heart tissue from the treatment fields (30). This is particularly relevant in view of the growing evidence of late morbidities these organs derive from breast irradiation in the supine

Table 8. Dosimetric findings of normal tissue: heart and lung

Dosimetric characteristics	Mean (%)	Median (%)	Range (%)
Ipsilateral lung			
V 20 Gy	0	0	0-4
V 10 Gy	1	0	0-6
V 5 Gy	2	0	0-10
Heart			
V 5 Gy	0	0	0

Abbreviation: V = percentage of volume receiving specified dose.

Values rounded to nearest whole number.

position (31-35). Moreover, in women with pendulous and/or large breasts, treatment in the prone position allows the breast tissue to fall away from the chest wall preventing skin desquamation along the inframammary fold, a common occurrence when treated supine. Finally, based on BED modeling, instead of the approach (twice daily during 5 days) used by Vicini *et al.* (28) and Baglan *et al.* (36), the treatment described consisted of five fractions within 10 days, a schedule that was easy to adhere to, even for elderly patients.

Compared with partial breast RT using brachytherapy, the advantages of prone external beam APBI consist of its noninvasive nature, and the simplicity of the field arrangements and ease of patient setup. Potentially, any RT facility equipped with CT planning and a linear accelerator could adopt this approach.

However, many challenges remain associated with this area of breast cancer radiation research. For example, the exact identification of the target remains to be defined. Placement of clips has been suggested to facilitate the radiographic identification of the cavity; however, signifi-

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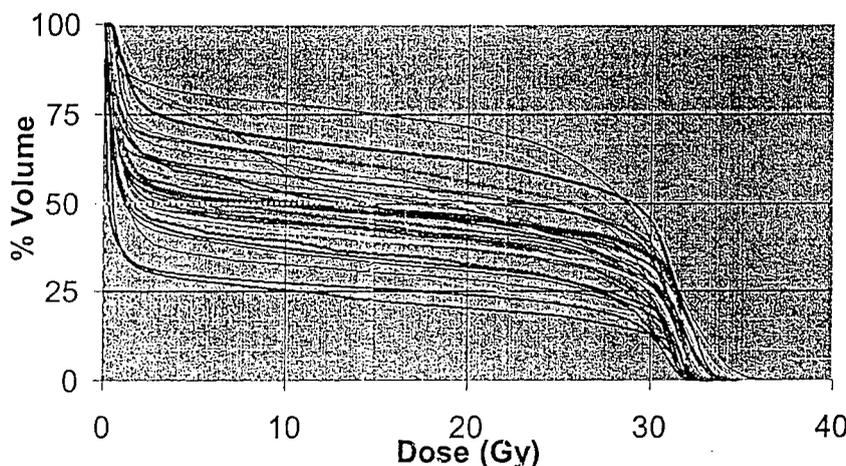


Fig. 7. Dose-volume histogram of ipsilateral breast of 47 patients.

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cant clip migration has been reported, particularly after breast biopsy procedures, making reliance on the technique questionable (37). In the current series of patients, the cavity was identified by CT planning. Owing to our selection criteria, none of the patients had undergone chemotherapy, making it possible to plan and start RT close to the time of surgery, when the postexcision cavity could more easily be identified (Fig. 4). Although we found no correlation with the interval between surgery and the date of CT acquisition of the CTV, it could be possible that with increasing time after surgery, the accuracy of CTV definition by CT might diminish. In the future, if APBI is revealed to be equivalent to standard RT, the argument of delivering it before systemic treatment could be made, in view of its brief course and the optimal visualization of the tumor bed soon after surgery.

The best dose/fractionation regimen for APBI also remains to be determined, in terms of both ensuring optimal tumor control and cosmetic outcome. With regard to the latter, even if it is not predicted by the BED modeling, hypofractionated regimens may carry some risk of late effects, such as breast fibrosis and telangiectasia. Currently, no predictive markers are routinely available to determine which patients will develop radiation-induced late toxicity. In a study by Li *et al.* (22), a statistically significant correlation between the pretreatment plasma levels of transforming growth factor- β 1 (a multifunctional cytokine implicated in tissue fibrosis) was found in patients treated with BCT who developed severe post-RT fibrosis. The regimen used consisted of 40 Gy in 15 fractions to the whole breast. Other studies have revealed that specific polymorphisms of the transforming growth factor- β 1 promoter gene might be associated with the development of severe fibrosis. Quarumby *et al.* (38) reported that patients with the -509TT or +869CC genotypes were 7-15 times more likely to develop severe fibrosis. Future genetic studies might enable the identification of a panel of polymorphic sites associated with fibrosis that could make it possible to prospectively detect "fibrosis-prone" individuals. In the current study, pretreatment blood samples are prospectively collected to test this hypothesis.

A more serious concern is the risk of underdosing the tumor bed. In an associated paper, we have discussed in depth the results obtained by radiobiologic modeling of most currently used partial breast irradiation protocols. All regimens currently used result in inferior BED values for tumor effects compared with those achieved by 60 Gy in 30 fractions during 6 weeks. For the current regimen, the dose chosen was derived by matching the same BED values (75 Gy₂) for tumor control of a standard regimen of 50 Gy in 25 fractions. When the protocol was originally designed, controversy existed regarding the value of adding a boost after 50 Gy to the whole breast, the regimen used in the RT arm of National Surgical Adjuvant Breast and Bowel Project clinical trial B-06. For instance, in a contemporary publication, Hayman *et al.* (39) had addressed the cost-effectiveness of an electron

boost and, based on the evidence available at that time, concluded that its ratio in quality-adjusted life years was "well above the commonly cited threshold for cost-effective care." However, in view of the evidence subsequently generated by the European Organization for Research and Treatment of Cancer trial of a dose-response relation at the tumor bed, the currently used experimental regimen could be inadequate to ensure optimal local control in a nonselected cohort of women treated by BCT (40). Whether the hypofractionated regimen (30 Gy in 5 fractions within 10 days) will be revealed as adequate in ensuring tumor control in the carefully selected population studied in this trial warrants long-term follow-up.

The issue of optimal patients selection also remains unanswered: does a specific subset of women exist for whom partial breast RT is equivalent to whole breast RT? Controversy exists with regard to eligibility for partial breast RT studies. Contrary to the results of Vicini *et al.* (41), who reported a promising 1% local recurrence rate at a median follow-up of 65 months after partial breast brachytherapy, a recent report from another group had a 60-month actuarial rate of ipsilateral recurrence of 16.2% (42). Also, four of the six in-breast recurrences occurred outside the lumpectomy site, even though each of the women with recurrence had originally had a mammographically detected T1 primary (42). We deliberately focused our study on the rapidly growing subset of breast cancer patients, postmenopausal women with mammographically detected tumors, a population in which 96% of the detected breast cancers are T1 lesions (43, 44). Long-term results from the current study will provide important preliminary results on whether a more user-friendly, cost-effective regimen can be safely offered to this population of patients with generally indolent breast cancers.

Finally, characteristic of the current study is that eligible patients also need to have refused to undergo the standard 6-week RT regimen to be offered the current protocol. This approach reflects our bias regarding the ethics of studying a potentially "lesser" treatment in a setting in which the standard therapy has resulted in exceptionally high success rates. Thus, two other important measures of caution were taken. First, eligibility is limited to postmenopausal women with a very low risk of ipsilateral in-breast recurrence, including the requirement for estrogen receptor positivity and antiestrogen treatment and, second, a Stage 2 Simon statistical design with early stopping rules, based on a 5% actuarial recurrence rate at 5 years, was chosen to minimize the risk to the patients who have elected to participate in the protocol.

In view of these results and of the many potential advantages, including increasing compliance to RT, thereby increasing the rate of breast preservation treatment, reducing adjacent normal tissue morbidity, and reducing the cost of postoperative RT (5 vs. 30 treatments), we are continuing the planned accrual of 99 patients to this trial.

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AUTHOR QUERIES

AUTHOR PLEASE ANSWER ALL QUERIES

1

AQ1—AUTHOR: please spell out USC.

AQ2—AUTHOR: please spell out IDEA.

AQ3—AUTHOR: Vicini not first author of ref. 36; Baglan and ref. 36 correct?

AQ4—AUTHOR: changed "5-year" to "60-month" to match unit used for Vicini's data.

AQ5—AUTHOR: please provide the ending page number for ref. 13.

AQ6—AUTHOR: author names and initials and "et al." correct for ref. 19?

AQ7—AUTHOR: Is it correct to add "Jr." to Fowler J in ref. 23?

AQ8—AUTHOR: please give page numbers for ref. 27.

AQ9—AUTHOR: initials for first author, ref. 35, correct ("Marks LBYX") or surname of 2nd author (initials YX) missing? Please check original citation.

AQ10—AUTHOR: please provide the ending page number for ref. 35.

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Table 1. Study schema for Stage I breast cancer postmenopausal, nonpalpable tumors, after segmental mastectomy

	Informed consent	Blood collection for TGF- β
	CT planning in prone position, determination of tumor bed and ipsilateral breast tissue	
Days 1-10	Conformal tumor bed radiotherapy 6 Gy in 5 fractions in 2 wk Days 1, 3, 5, 8, 10	
Day 10	Last day of treatment	Blood collection for TGF- β

METHODS AND MATERIALS

On the basis of the data originated from the initial pilot study (21), a regimen of 30 Gy delivered in five fractions within 10 days was chosen for this study. In addition, because the biologically effective dose (BED) (18) calculations predicted fibrosis as the dose-limiting toxicity, the study included blood collection for measurement of transforming growth factor- β 1 levels in pretreatment plasma, as a marker for the development of post-RT fibrosis (Table 1) (22).

Justification of radiobiologic dose and fractionation

The linear-quadratic model and the BED equation, $BED = (nd)(1 + d/\alpha/\beta)$, derived from this model (18, 23), were used to calculate the appropriate total dose and fraction size for the hypofractionated protocol. In this formula, n is the number of fractions and d is the dose/fraction. This equation was used to calculate the BEDs for early and late responses and tumor control for the hypofractionated schedule (five fractions of 6 Gy delivered within 10 days) and two standard schedules (25 fractions of 2 Gy within 5 weeks, considered the standard treatment without a boost [24] and 30 fractions of 2 Gy within 6 weeks—46 Gy to the entire index breast plus a boost of 14 Gy to the tumor cavity, considered the standard treatment with a boost). These calculations assumed that full repair takes place during the ≥ 24 -h interval between fractions. Table 2 lists the BEDs for tumor control, in addition to the early responses, erythema and desquamation, and late responses, telangiectasia and fibrosis. The BEDs for the normal tissue acute responses were generally lower for the hypofractionated schedule than for the standard treatment regimens, indicating the risk of radiation-induced complications should be lower in the hypofractionated schedule (Table 2).

For tumor control, if we used an α/β value of 10 Gy, the typical value for many tumors (25, 26), in this calculation, the BED computed for the hypofractionated schedule would be substantially lower than that for the standard treatments. However, if the α/β value is set at 4 Gy, as suggested by experiments involving irradiation of human breast cancer cell lines (18-20), the BED calculated and, therefore, the likelihood of tumor control as-

ation (APBI) (12-16), in the early 1990s we started investigating an external beam RT approach for partial breast treatment (17). Prone positioning of the patient rapidly emerged as the best technique, because it minimizes movement of the target breast tissue during breathing and achieves maximal sparing of normal heart and lung tissue. A pilot trial was conducted at the USC/Kenneth Norris Jr. Cancer Center to test the feasibility of a short course of hypofractionated conformal RT to the tumor bed in the prone position as part of a breast conservation protocol in postmenopausal patients with nonpalpable Stage pT1N0 breast cancer. A radiosurgery-like technique of multiple noncoplanar fields was tested, and 10 patients were randomly assigned to five fractions of 5, 5.5, or 6 Gy, on the basis of radiobiologic linear-quadratic modeling. These doses were chosen in view of their radiobiologic equivalence to 50 Gy in 25 fractions when an α/β value of 4 is used for the prediction of tumor control (18-20). Local control and cosmetic results were excellent at a minimal follow-up of 36 months (21).

In 2000, funded by an IDEA grant from the Department of Defense, a Phase I-II trial was initiated in the Department of Radiation Oncology at New York University to determine the feasibility and efficacy of prone, partial breast conformal RT to the tumor bed in postmenopausal women with T1N0M0 breast cancer who had undergone segmental mastectomy and had refused standard postoperative whole breast RT.

Table 2. Biologically effective doses

	α/β (Gy)	Standard (60 Gy/30 Fx)	Standard (50 Gy/25 Fx)	Hypofractionated (6 Gy/5 Fx)
Erythema	8	75 Gy ₈	63 Gy ₈	53 Gy ₈
Desquamation	11	71 Gy ₁₁	59 Gy ₁₁	46 Gy ₁₁
Telangiectasia	4	90 Gy ₄	75 Gy ₄	75 Gy ₄
Fibrosis	2	120 Gy ₂	100 Gy ₂	120 Gy ₂
Tumor	4	90 Gy ₄	75 Gy ₄	75 Gy ₄
Tumor*	4	86 Gy ₄	72 Gy ₄	75 Gy ₄
Tumor	10	72 Gy ₁₀	60 Gy ₁₀	48 Gy ₁₀
Tumor*	10	68 Gy ₁₀	57 Gy ₁₀	48 Gy ₁₀

* Taking into account cell proliferation during course of treatment.

BIOLOGICAL COMPARISON OF PARTIAL BREAST IRRADIATION PROTOCOLS

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Running Title: PBI Protocol BED Analysis

Purpose: To analyze the dose/fractionation schedules currently used in ongoing clinical trials of partial breast irradiation (PBI) by comparing their biologically effective dose (BED) values to those of three standard whole breast protocols, commonly used after segmental mastectomy in the treatment of breast cancer.

Methods and Materials: The BED equation derived from the linear quadratic model for radiation-induced cell killing was used to calculate BEDs for three commonly used whole breast radiotherapy regimens in addition to a variety of external beam, as well as HDR and LDR brachytherapy PBI protocols.

Results: The BED values of most PBI protocols resulted in tumor control BEDs roughly equivalent to a 50 Gy standard treatment, but consistently lower than the BEDs for regimens in which the tumor bed receives a total dose of either 60 Gy or 66 Gy. The BED values calculated for the acute radiation responses of erythema and desquamation were nearly all lower for the PBI schedules, but as expected, the late response BEDs for several PBI regimens were greater than the BEDs for the standard treatments.

Conclusion: BED modeling raises the concern that inadequate dose might be delivered by PBI to assure optimal in-field tumor control. In addition, the BED values calculated suggest an increased risk of fibrosis and telangiectasia for some of the PBI regimens, although this should be tempered by the consideration that relatively small volumes of normal breast tissue receive the full treatment dose.

Biologically effective dose, breast cancer, Partial-breast irradiation (PBI).

INTRODUCTION

The possibility of completing the course of post-segmental mastectomy radiation in a smaller number of treatments over a shorter period of time is very appealing to breast cancer patients. If a shorter regimen proves equivalent to standard treatment, it could represent important progress in terms of cost-effectiveness for radiation therapy. Furthermore, the implementation of a breast cancer radiation protocol that is less cumbersome may help to address the logistical problems faced by many patients, particularly the elderly or those who live distant from a radiotherapy facility. These difficulties cause many patients who are candidates for breast conserving therapy (BCT) either to select mastectomy or worse, to simply forgo the radiotherapy portion of BCT (1-3).

One effort to accomplish this aim was attempted in the 1970s in several countries where breast cancer patients received post-mastectomy radiotherapy to the chest wall and draining nodes involving the use of larger than standard (1.8-2 Gy) fraction sizes, hypo-fractionation. For example, in one series, post-mastectomy breast cancer patients were given 12 fractions to either a maximum absorbed dose of 51.4 Gy or to a minimum target dose of 36.6 Gy specified at the level of mid-axilla (4, 5). Unfortunately, many of the patients treated with these hypo-fractionated protocols subsequently developed chronic radiation injury manifested primarily as fibrosis (4, 5). This discouraging experience rendered radiation oncologists hesitant to re-explore the use of large dose fractions in the treatment of breast cancer.

It is only with the recent recognition of the common topographic pattern of local recurrence after segmental mastectomy that it has become reasonable to question whether it is always necessary to irradiate the entire breast (6-10). Results from five prospective randomized trials are available to better understand this issue (6-9, 11). For instance, in NSABP-06 all recurrences were reported to be within or close to the quadrant of the original tumor (10, 11). In Liljgren *et al.* (9), a significantly higher rate of local recurrence occurred in the arm receiving segmental mastectomy alone compared to the arm receiving segmental mastectomy and post-operative radiotherapy (18.4% versus 2.3%). Again, 77% of the recurrences in the surgery alone arm occurred within the initial tumor bed (9). A similar geographical pattern of local recurrence was recorded in the three other studies (6, 7). When the local recurrence data is classified as "within" versus "outside" the original tumor bed, the risk of recurrence outside the original tumor bed appears to be equivalent (or inferior) to the risk for new primary cancers in the contralateral breast, which conventionally is not irradiated. The incidence of contralateral breast cancer for these studies is within the expected range of 0.5-1% per year as reported in pre-tamoxifen series. These data support the rationale for treating the original tumor bed as the area that could most benefit from the addition of adjuvant radiation, while omitting the remaining breast tissue in the ipsi- and contralateral breast.

Limiting adjuvant radiation to a volume inclusive of the tumor with sufficient margins among selected patients enables the exploration of hypo-fractionated regimens (12-14). A number of protocols have since been developed with the intent to treat the original tumor bed with margins. This approach is based on the rationale that if much of the breast receives a dose below a clinically relevant threshold, it may be possible to

treat a small volume with larger fraction sizes, while maintaining a low risk of late effects. Thus, through treatment of a smaller volume it may be possible to avoid the classic dilemma encountered when a hypofractionated protocol is substituted for a standard treatment plan, which is the choice of either a reduced probability of tumor control or an increased risk for late complications (4, 5). Hypo-fractionated, partial breast irradiation is actively being investigated by the use of several distinct techniques. Evidence is rapidly accumulating as to the feasibility of performing PBI as well as the need for careful patient selection and appropriate techniques to adequately encompass the target volume (15).

Although many PBI protocols are currently being used, relatively little data has been reported to justify the chosen schedules by predicting the biological effects associated with use of large dose fractions delivered over a short period. Since it is possible to compare the anticipated biological effects in terms of tumor control and normal tissue reactions by estimating a "biological dose" through appropriate computations of BED values, we are reporting such calculations to compare the different PBI regimens with three commonly used protocols for whole breast radiation.

METHODS AND MATERIALS

Breast radiation protocols used in the analysis

A. Standard fractionation studies

The fractionation regimen used for the radiation component of breast conservation treatment has varied. The NSABP trials of breast preservation (16, 17), as well as in the recent prospective randomized Canadian trial studying whole breast hypofractionation (18), used 50 Gray in 25 fractions over five weeks (Standard₅₀). An alternative standard regimen is 46 Gy to the whole breast followed by an electron boost of 14 Gy to the tumor bed, a commonly used approach in the United States (19, 20), (Standard₆₀).

In addition, The European Organization for Research and Treatment of Cancer (EORTC) has assessed the role of a boost to the tumor excision site (21-23). In this trial, the entire breast was irradiated with 50 Gy in 25 fractions followed by either no additional treatment or 16 Gy in 8 fractions (either electron therapy or an implant) for a total dose of 66 Gy (Standard₆₆). At 5-year follow-up, the use of the boost significantly reduced the local failure rate to 4.3%, among patients randomized to receive the boost, compared with 7.3% for patients who were given whole breast treatment. These results suggest that irradiating the tumor bed with 66 Gy further reduces the local recurrence rate in BCT. Noticeably the main benefit was derived by patients younger than 40 years, who demonstrated a 46% reduction in the rate of local recurrence at 5 years with the radiation boost.

B. Partial Breast Irradiation Studies

A variety of PBI protocols have been developed with the intent to treat the original tumor bed with margins and are summarized in Tables 1, 2 and 3. This approach is based on the rationale that if much of the breast receives a very limited dose, it may be possible to treat with larger fraction sizes while maintaining a low risk of late effects. A variety of treatment approaches have been used, including interstitial brachytherapy, Mammosite® balloon brachytherapy and external beam radiation using either three dimensional conformal radiotherapy (3D-CRT), intensity modulated radiotherapy (IMRT), or intraoperative electron beam therapy (IORT). A series of brachytherapy PBI trials, design, treatment and results, using both HDR and LDR brachytherapy included in the BED Analysis are described in Table 1. With the exclusion of the Guy's Hospital study, which accepted patients with large tumors and positive margins, these series showed good local control rates of 0-16%, even if often reported with less than 5-year follow-up. Intraoperative radiation therapy (IORT) has been investigated by the European Institute of Oncology at the University of Milan, Italy, delivering electron beams of either 3,5,7, or 9 MeV. Patients either received an IORT dose of 10-15 Gy after initial quadrantectomy with 1-2 cm clear margins, as an anticipated boost to external radiotherapy or an IORT dose of 17-21 Gy to the cavity as the only treatment (24).

An external beam approach to PBI was first used at Christie Hospital where they compared external beam PBI with whole breast radiation for patients with tumors less than 4 cm in size. This study demonstrated a higher incidence of recurrence among infiltrating lobular histology tumors, 34% for PBI versus 8% for whole breast radiation

(25), possibly reflecting the different natural biological course between the two histological types. Two different approaches of external beam radiation PBI have been reported from William Beaumont Hospital and New York University. The external beam series are summarized in Table 2. Formenti *et al.* pilot-tested a phase I feasibility study of hypo-fractionated conformal external beam radiation therapy to the tumor bed (30 Gy in 5 fractions over 10 days) in a small series of selected post-menopausal women with T1 breast cancers (26), using immobilization in the prone position on a dedicated breast board (27). A phase I/II study is currently ongoing at New York University. All patients completed treatment with only mild acute toxicity (28). Baglan *et al.* also piloted an accelerated partial breast radiation protocol in patients with early-stage breast cancer (29). 3D-CRT was used to treat the lumpectomy cavity, plus a 1.5-cm margin. Their technique used an active breathing control method to account for breast movement related to respiratory excursion. More recently, Vicini *et al.* published an update of their PBI experience (30, 31) using 3D-CRT. A dosimetric comparison of the William Beaumont and New York University partial beam irradiation techniques is shown in Table 3. Unfortunately, follow-up for both the brachytherapy and external techniques is too short for adequate assessment of long-term toxicity and fibrosis. As demonstrated in a series from the MD Anderson Cancer Center, the length of time to the expression of 90 % of the ultimate frequency of fibrosis and telangiectasia was 4.7 years (95% CI 4.0 – 4.8) (4).

Calculation of biologically effective doses

The linear-quadratic model (32) was used to determine whether a partial breast radiotherapy protocol should result in a roughly equal probability of tumor control compared with a standard schedule, but without increasing the potential for normal tissue damage. The BED equation employed for these calculations was;

$$\text{BED} = nd\left(1 + \frac{d}{\alpha/\beta}\right) \quad (\text{Eq. 1})$$

where n is the number of fractions, d is the dose per fraction and α/β is a tissue and effect specific parameter associated with the linear-quadratic model (33-35).

A modification to this BED equation was also used to take into account cellular proliferation that may take place during treatment as follows;

$$\text{BED} = nd\left[1 + \frac{d}{\alpha/\beta}\right] - \left[\frac{(\ln 2)T}{\alpha(T_{\text{pot}})}\right] \quad (\text{Eq. 2})$$

where T_{pot} is the potential doubling time and T is the treatment time during which cellular proliferation occurs after any initial lag period (33, 36-38).

Since an interfraction interval of at least 6 hours was used for all of the b.i.d. HDR and external beam treatments, it was likely that full repair of sublethal damage between fractions was permitted. It was therefore not necessary to include an incomplete repair factor in the equation used to calculate BEDs for these protocols.

The equation used to calculate the BEDs for the LDR treatments was;

$$\text{BED} = RT\left\{1 + \left[\frac{2R}{\mu(\alpha/\beta)}\right]\left[1 - \frac{1 - e^{-\mu T}}{\mu T}\right]\right\} \quad (\text{Eq. 3})$$

where R is the dose rate, T is the length of the irradiation, and μ is the repair rate constant which is equal to $\ln 2/t_{1/2}$, with $t_{1/2}$ the tissue repair half-time (39, 40).

RESULTS

BED values

BED calculations were performed for the three chosen standard whole breast external beam radiotherapy protocols and fifteen different hypofractionated PBI regimens, delivered by external beam, HDR and LDR techniques. The BEDs computed are listed in Tables 4 and 5. The selection of the α/β values used for these calculations was based upon those reported in previous studies for the late effects of fibrosis and telangiectasia in addition to the acute radiation reactions of erythema and desquamation, which are 2, 4, 8 and 11 Gy respectively (37, 41, 42). The tumor control BED values were determined using an α/β value of either 4 Gy, which has been suggested for breast carcinoma (43-46) or 10 Gy, which is the approximate value used for most tumors (46, 47). In addition, the BEDs were calculated for the LDR treatments assuming repair half times of either 0.5, 1, 2 or 3 hours. The repair kinetics for the tissues associated with acute and late responses as well as breast carcinoma cells are likely to fall within this range (48). As for the specific repair half-time appropriate for each effect, evidence has been obtained that sublethal damage repair rates are often slower for late-responding normal tissues compared with either early-responding normal tissues or tumors (48, 49), although in some instances this generalization may not be correct (50-52).

BED Calculations taking into account tumor repopulation

It should be noted that all of the PBI treatments are accelerated schedules since the total dose is delivered in less time than the standard whole breast protocols.

Therefore, relatively little cellular proliferation is likely to occur during the course of these treatments as opposed to the standard protocols in which it is probable more extensive repopulation will take place, thereby both decreasing the chances for tumor control but also reducing the severity of acute radiation responses. The lack of tumor repopulation represents a potential advantage to the use of an accelerated partial breast protocol compared with a standard treatment and the BEDs were also calculated assuming cell repopulation during treatment. In order to accomplish this, it was necessary to select values for α , the initial slope of the cell survival curve, as well as for T_{pot} and T . For the purpose of these calculations, values of 0.3 for α (43, 44) 13 days for T_{pot} (53, 54) and a time lag of 14 days were used. However, it must be stressed that the actual values for any given patient may differ significantly. This correction for cell proliferation causes the tumor and acute response standard treatment BED values to decrease by approximately 3-5 Gy. No change would be expected in the fibrosis or telangiectasia BEDs as compensatory proliferation would not be expected to begin until after treatment was complete. In addition, there is no correction to any of the PBI schedules since all of these treatments are accomplished within a period that is shorter than the lag period even in the tumor and acutely responding normal tissues. Taking possible tumor growth during treatment into consideration results in a closer alignment of BED values between the PBI and standard schedules. Of course, if cell proliferation is considered, this also diminishes the BEDs of the early responses for the standard schedules compared with the accelerated PBI schedules. However, it would still be anticipated, based upon the computed BEDs and only a portion of the breast being

irradiated, that the severity of the early responses would remain lower for the PBI treatments compared with the standard protocols.

DISCUSSION

The current work compared BED values at the tumor bed/boost area for PBI regimens versus those from standard whole breast radiation protocols. The tumor control BED values computed for the PBI protocols were uniformly lower than the BEDs for any of the standard schedules when these calculations were performed using an α/β of 10 Gy, considered typical of most tumors (46, 47). In contrast to this generalization, evidence exists from in vitro studies that breast carcinoma cell lines display an α/β value of about 4 Gy (43-46). Use of this α/β with correction for cellular proliferation yielded BED values for the PBI treatments that were generally comparable to the BED obtained for Standard₅₀. However, when compared to either Standard₆₀, a fractionation regimen commonly used in the United States, or to Standard₆₆, the BED values were nearly all lower for the PBI treatments. This is of significance in view of the available evidence for a dose response effect at the boost site, as demonstrated by the finding that the Standard₆₆ treatment resulted in a decreased incidence of tumor recurrence compared with the Standard₅₀ (22).

It is important to note, however, that a basic assumption underlying the use of BED values to predict a particular level of tumor control or normal tissue damage, is that the probability of tumor control or the development of a normal tissue radiation effect is proportional to the BED. This may be correct for certain doses, but it is not true across an entire dose range (55). That is, the tumor control probability may already be sufficiently high, so that it is in a "plateau" region where relatively little benefit would be expected with increasing dose. Similarly, the normal tissue effect curve may be at a

EXTERNAL-BEAM PARTIAL BREAST IRRADIATION

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Abstract

While most studies treating patients with partial-breast irradiation have used brachytherapy, giving such treatment with external-beam techniques has many potential advantages. However, there is only limited published experience of treating patients with partial breast irradiation using external-beam radiation therapy. These include a randomized trial of partial-breast and whole-breast irradiation performed at the Christie Hospital in Manchester, England and pilot studies (using much more rigorous selection criteria and sophisticated treatment planning) from groups at the University of Southern California and New York University (using prone positioning of patients) and the William Beaumont Hospital (using the supine position). A multi-institutional pilot trial based on the latter technique has been completed, which was designed to test the feasibility of using this approach in the cooperative oncology group setting. The unprecedented rapidity with which the study completed its target accrual indicates the degree of interest in this approach.

This review focuses on the rationale and the reported studies of external beam partial breast radiation and identifies some of specific issues and remaining problems associated with this approach.

Rationale for Giving Partial-Breast Irradiation Using External-Beam Techniques

While most studies treating patients with partial-breast irradiation (PBI) have used brachytherapy, in theory an external-beam approach to PBI (EB-PBI) presents many potential advantages. First, it easily allows treatment to be given after lumpectomy, when complete pathological information about the original tumor and the status of the resection margins are available, without subjecting the patient to a second invasive surgical procedure or anesthesia. Second, it is likely that EB-PBI will be easier for radiation oncologists and cooperative oncology groups to adopt than brachytherapy approaches, since the technical demands and quality assurance issues are much simpler. Third, treatment results with EB-PBI may be more uniform between different radiation oncologists, since the outcome depends less on the experience and operative skills of the person performing the procedure than does brachytherapy (especially using interstitial implantation). Fourth, it seems less likely that technical issues arising during EB-PBI will require the procedure to be aborted, as is not infrequently the case when brachytherapy techniques are used. Fifth, EB-PBI is intrinsically likely to generate better dose homogeneity, and possibly, to result in a better cosmetic outcome when compared to brachytherapy. Finally, EB-PBI may be considerably cheaper than brachytherapy techniques, especially if an extra surgical procedure and (for low-dose rate brachytherapy) hospitalization are needed.^{1,2}

Despite these theoretical advantages, there has been very little study of EB-PBI. This may be because of the difficulty of adequately locating the excision cavity and planning multi-field photon treatment plans in the era before CT-based simulation. At present, there are only a few published experiences of EB-PBI. These include a

randomized trial comparing partial-breast and whole-breast irradiation performed in England^{3,4 5} and pilot studies (using much more rigorous selection criteria and sophisticated treatment planning) from groups at the University of Southern California (USC) and New York University (NYU)^{6 7,8} (using prone positioning of patients) and the William Beaumont Hospital (using the supine position).^{9 10} A multi-institutional pilot trial based on the latter technique was recently conducted by the Radiation Therapy Oncology Group (RTOG 0319) under the direction of Dr. Frank Vicini to test the feasibility of using this approach in the cooperative oncology group setting and the study rapidly completed its target accrual (ref).

This review therefore focuses on the techniques and reported outcome of reported studies of EB-PBI. I will also identify some of specific issues and remaining problems associated with this approach.

A Phase III Trial of External-Beam Partial-Breast Irradiation

Only one prospective randomized trial has been performed to compare the efficacy of EB-PBI to whole-breast radiotherapy. This trial was conducted at the Christie Hospital, in Manchester, the United Kingdom.^{3,4 5} Seven hundred and eight patients with tumors 4 cm or smaller of infiltrating ductal or lobular histology were randomized after segmental mastectomy to undergo radiation to a small breast field, including the tumor bed (the limited-field, or "LF" arm) or to the whole breast and regional nodes (the wide field, or "WF" arm). The two arms differed in field size, treatment modality, and dose fractionation. For the LF arm, the dose given was 40-42.5 Gy in eight fractions delivered over ten days, using 8-14 MeV electrons (prescribed to the 100% isodose line) with an

average field size of 8 x 6 cm. For the WF arm, the dose was 40 Gy in 15 fractions, over 21 days, delivered by opposed tangential fields to the breast and a separate anterior supraclavicular/axillary nodal field using 4 MV photons.

With a median follow up of 65 months, the 8-year actuarial overall survival rates were comparable between the arms (72.7% and 71.2% for the LF and WF groups, respectively). The actuarial breast recurrence rates (scoring only first failure sites) were 19.6% for patients in the LF arm and 11% for patients in the WF arm ($p=0.0008$). However, when the data was analyzed according to histological type, the risks of local failure in patients with infiltrating ductal carcinoma were 15% in the LF and 11% in the WF arm, whereas, for patients with infiltrating lobular carcinoma the respective recurrence rates was 34% and 8%. A high recurrence rate was found in both arms for patients with extensive ductal carcinoma in situ (EIC) (21% and 14%, respectively). Importantly, the failure rate outside the quadrant of the original tumor was only 5.5% for patients with IDC in the LF arm. Salvage surgery was possible in 86% and 90% of patients in each arm, respectively. Cosmetic results were worse in the LF arm than the WF arm, with much more fibrosis and telangiectasias in the former group. The authors concluded that, while the recurrence rate in the breast following lumpectomy and wide field irradiation was comparable with others reported in the literature of the time, in selected subsets of patients limited field irradiation resulted in a higher breast recurrence rate.⁴

There were many differences in the way patients in this trial were managed and how patients are treated today. Axillary dissection was not performed, and systemic therapy was not used. Most patients did not have pre- or postoperative mammographic

evaluation, and specimen margins were not evaluated microscopically. Therefore, although the local failure rate was considerably higher in the LF arm than the WF arm for the population as a whole, the much smaller difference between the arms for patients with infiltrating ductal carcinomas actually is quite encouraging that the approach of EB-PBI is worth pursuing. The high rate of telangiectasias in the LF arm is not surprising, considering the high skin dose delivered by pure electron beams, but the increased risk of fibrosis may also be a problem facing EB-PBI approaches using photons. This issue will be discussed at some length below.

Prone External-Beam Partial-Breast Irradiation

Rationale for prone patient positioning

One common challenge that must be addressed by any technique of breast radiotherapy is the anatomic/geometric constraints required to treat the breast tissue volume, a target that is generally shaped as a concave, irregular dome. While several techniques have been studied, treatment of the entire breast using opposed tangent fields in the supine position tends to include some part of the lung and, for left-sided tumors, of the heart. Moreover, respiratory and systolic motion often increases the amount of normal tissue unnecessarily treated.

Positioning patients prone considerably reduces the breast tissue motion due to both cardiac systole and respiration¹¹, limiting the excursion of the chest wall to less than 5 mm¹². In addition, prone positioning allows for exclusion of lung and heart tissue from the treatment fields¹³. This is particularly important in view of the growing evidence that treatment of these organs may cause late morbidity^{14 15 16 17}. Most importantly, treatment

in the prone position with patients placed on a special tabletop that has a hole in it (Figure 1) that allows the breast tissue to fall away from the chest wall allows treatment of the tumor excision cavity by fields that do not include any portions of the heart or lungs.

Figure 2 demonstrates how, when the same patient is imaged either in the supine (Figure 2a) or prone position (Figure 2b), both the shape and the position of the excision cavity vary. When prone, the cavity tends to be dislocated away from the chest wall by gravity.

Initial studies of our group using the prone position

Based on these considerations we initiated a research program at the University of Southern California, (USC), Los Angeles, to study EB-PBI given in the prone position. We started by exploring the physical and dosimetric aspects of multiple non-coplanar fields directed toward the tumor bed in the prone patient.¹² The first dedicated table for prone partial breast treatment was designed. Dosimetry was analyzed for two "radiosurgical" approaches, one using seven fixed horizontal beams and the second using six 45-degree arcs and a 90-degree sagittal arc; both employed a 4 MV x-ray beam with a 32 mm-diameter collimator. Both field arrangements resulted in adequate tumor coverage: the minimum target dose was 83% of the dose maximum in the fixed-beam arrangement and 86% in the multiarc setup.

Originally, we had envisaged using this approach in a radiosurgery-like fashion, with the long term aim of substituting breast radiosurgery for surgical excision for patients with breast cancers measuring 5 mm or smaller. However, although giving such radiosurgery-like treatment was feasible technically, planned excisions performed 8-10 weeks later in the first 3 patients so treated with 15, 18 and 20 Gy demonstrated that residual viable tumor was consistently within the treated target volume. This was despite

the careful selection of the study patients, who each had a tiny mammographically detected tumors, marked by a tantalum clip placed at the time of core biopsy.

This small but significant experience redirected the research goal to the exploration of a hypofractionated approach, directed to treat the post-operative tumor cavity with added margins.

Selection of a dose-fractionation scheme for our subsequent pilot trial of postoperative hypofractionated partial-breast irradiation

The accessibility of the target in patients treated in the prone position, unencumbered by constraints of treating surrounding normal lung or heart tissue, together with the relatively small volume associated with PBI created the ideal conditions to safely explore an accelerated, hypofractionated regimen.

At the time, the only prospective randomized study on this issue was that of Baillet and colleagues at the Necker Hospital in Paris.¹⁸ They reported equivalent local control but inferior cosmetic results at 4 years in elderly patients receiving a hypofractionated regime of 23 Gy delivered in 4 fractions over 3 weeks to the entire breast, compared to a regimen of 45 Gy in 25 fractions given in 5 weeks. Therefore, it became necessary to derive a rationale dose fractionation regimen of accelerated radiation therapy from published preclinical and clinical data.

By applying the linear-quadratic cell survival model with an alpha-beta value for breast carcinoma of 4¹⁹⁻²¹, a dose of 30 Gy given in 5 fractions of 6 Gy per fraction over 10 days was found radiobiologically equivalent in tumor control to a dose of 50 Gy given in 25 fractions of 2 Gy over 5 weeks, the dose commonly used in studies of the National Surgical Adjuvant Breast And Bowel Project (NSABP).²² At the same time, this

hypofractionated scheme resulted in a biologic equivalent dose (BED) for late breast tissue complications²³ (including desquamation, fibrosis, erythema, and telangiectasia) the same as that of 60 Gy in 30 fractions, a regimen used at many institutions to treat the tumor bed (46-50 Gy to the whole breast plus a boost of 10-14 Gy), which has been reported to have excellent cosmetic results.²⁴ Table 1 compares the BED values for these three different fractionation regimens and for the fractionation regimen used in supine EB-PBI, for different endpoints.

Rationale for patient selection criteria for our postoperative hypofractionated pilot trial

The impetus for investigating prone EB-PBI was the epidemiological evidence of a rapidly emerging new breast cancer population in the United States, due to the widespread use of mammographic screening: postmenopausal women with small, estrogen receptor-positive tumors, who commonly have negative nodes and 5- and 10-year survival rates of 95 and 85%, respectively.^{25 26} Because of the limited risk of breast cancer death in this subset of patients, the likelihood that potentially suboptimal radiation therapy would affect survival seemed very small, making it acceptable to conduct trials exploring PBI in this group. Moreover, there is evidence that postoperative radiation therapy has often been omitted for elderly women, especially those with significant comorbid conditions, because of concern that they will not be able to complete (for medical or logistical reasons) six weeks of daily treatment.²⁷⁻²⁹ It appeared that a more cost-effective, user-friendly regimen could best satisfy the needs of this specific population, ideally without compromising local recurrence control and breast-cancer survival. Finally, a radiotherapy technique that completely avoids including any of the lung or

heart is particularly appealing in a patient population where late cardiovascular effects might be added to pre-existing illness.

Results of our pilot Phase I trial (USC)

From January 1997 to June 1998, we conducted a pilot dose-escalation study of hypo-fractionated conformal EB-PBI external-beam radiotherapy to the tumor bed in selected post-menopausal women with T1 breast cancers consecutively seen at the University of Southern California.⁶ All patients were required to be postmenopausal, with non-palpable, mammographically detected tumors measuring less than 1 cm in diameter, which were excised with negative margins, with pathologically negative axillary lymph nodes. The study randomly assigned cohorts of 3 patients each to three dose levels (five fractions of 5, 5.5 or 6 Gy each, respectively, delivered over 10 days). Treatment was found to be feasible in 9 of 10 consecutive patients; the only excluded patient had a tumor cavity that was extremely lateral, (in the tail of Spence), and it was determined that she was best-treated supine. With a minimum follow-up of 3 years, there were no recurrences and all patients had “good or excellent” cosmetic results.

Preliminary results of our subsequent Phase I/II study (NYU)

Because of these encouraging results, we designed a phase I/II study that opened at New York University in 2000 and is currently ongoing. Results on the first 47 patients entered (of the total accrual goal of 99 patients) have been recently reported.^{7,8} Six Gy per fraction are delivered in 5 fractions given over ten days, for a total dose of 30 Gy. After taking a planning CT in the prone position, the post-surgical cavity is defined as the clinical target volume (CTV), and a 1.5 cm margin is added to generate the planning target volume (PTV). An example is given in Figure 3. In this case, opposed tangential

fields with 15° wedges were used. The corresponding dose-volume histogram results show that less than 45% of the ipsilateral breast volume received more than 50% of the prescribed dose.

Among the 47 patients currently on study the mean volume of the ipsilateral breast receiving 100% of the prescribed dose was 26% (range, 10-45%), while the mean volume of the breast contained within the 50% isodose surface was 47% (range, 23-75%). The lung and heart were consistently spared. Acute toxicity was modest, limited mainly to grade 1-2 erythema. With a median follow up of 18 months, only grade 1 late toxicity has occurred, and no patient has developed a local recurrence.

Studies of Supine External-Beam Partial Breast Irradiation

William Beaumont Hospital Experience

The group at William Beaumont Hospital, near Detroit, pilot-tested supine accelerated PBI in 9 patients, using active breathing control to compensate for breast movement related to respiratory excursion.⁹ The dose fractionation scheme chosen was extrapolated from their brachytherapy PBI experience. The first five patients received 34 Gy in 10 fractions given twice daily over 5 days, while the following four patients received 38.5 Gy in 10 fractions. The technique appeared to be feasible and well tolerated. Based on this preliminary data, Vicini and colleagues conducted a Phase I-II study in 31 patients, using eligibility criteria similar to those applied in RTOG trial 95-17.¹⁰ Most patients (29/31) had surgical clips placed at the time surgery to define the lumpectomy cavity. The clinical target volume consisted of the lumpectomy cavity plus a 10-15 mm margin. The planning target volume consisted of the clinical target volume

plus a 1-cm margin to account for breathing motion and daily variability of treatment setup. Active breathing control was not used in this study. In the first six patients the prescribed dose was 34 Gy in 10 fractions given twice daily (with a minimum 6-hour inter-fraction interval) over 5 consecutive days, while for the subsequent 25 patients the prescribed dose was increased to 38.5 Gy in 10 fractions. The study was designed to treat the clinical target volume with less than 10% inhomogeneity and to give a comparable or lower dose to the heart, lung, and contralateral breast than standard whole-breast tangents.

At the time of publication, the median follow-up time for this cohort was 10 months (range: 1–30 months). The only toxicity during treatment was grade 1 erythema. At the initial 4–8-week follow-up visit, 19 patients (61%) experienced grade 1 toxicity and 3 patients (10%) grade 2 skin toxicity. No grade 3 toxicities were observed. The remaining 9 patients (29%) had no observable radiation effects. Cosmetic results were rated as good or excellent in all evaluable patients at 6 months ($n = 3$), 12 months ($n = 5$), 18 months ($n = 6$), and in the 4 evaluable patients followed more than 2 years after treatment. The mean coverage of the clinical target volume by the 100% isodose line (IDL) was 98% (range, 54–100%, median: 100%); its coverage by the 95% IDL, 100% (range, 99–100%). The mean coverage of the planning target volume by the 95% IDL was 100% (range: 97–100%). The mean percentage of the breast receiving 100% of the prescribed dose was 23% (range, 14–39%), while the mean percentage of the breast receiving 50% of the prescribed dose was 47% (range: 34–60%). The study supported feasibility of this approach and generated the background experience for RTOG 0319.

RTOG 0319: a phase I/II trial to evaluate three-dimensional conformal radiation therapy (3D-CRT) confined to the region of the lumpectomy cavity for stage I and II breast cancer.

This study assesses the technical feasibility and acute toxicity of irradiating the region of the tumor bed (identified by surgical clips placed at the time of lumpectomy) with 3D-CRT. Eligible to the trial were newly diagnosed breast cancer patients with Stage I-II disease and negative margins of excision (at least 2mm) after lumpectomy. Patients with up to 3 positive nodes were eligible. Excluded were carriers of tumors larger than 3 cm and patients having either cancers of lobular histology or extensive intraductal component (EIC). A dose per fraction of 385 cGy was delivered on a twice a day schedule, with each treatment separated by a minimum of six hours is used, (Monday-Friday) to a total dose of 38.5 Gy, in ten fractions. The planned accrual of 46 patients was rapidly achieved and the preliminary results are reported on page.....of this issue.

Other studies

A few other groups have begun studies of EB-PBI in the supine position. These include investigators at Evanston Northwestern Healthcare in Evanston, Illinois (giving a dose of 43.2 Gy in 16 once-daily fractions using intensity-modulated radiation therapy)³⁰ and at the institutions of the Dana-Farber/Harvard Cancer Center in Boston (giving 32 Gy in 8 fractions, delivered twice-daily, using conformal photon or mixed photon-electron plans). So far only their very early results show such treatment is feasible with minimal toxicity.³¹

Potential Pitfalls of External-Beam Partial-Breast Irradiation

Preliminary experience with EB-PBI has identified common problems that investigators are likely to encounter when this approach is chosen. One is the correct identification of the excision cavity. The ability of the radiation oncologist to correctly target treatment depends on the type of surgical technique used as well as the time interval between excision and treatment planning. Placing surgical clips at the time of segmental mastectomy to define the cavity boundaries has the advantage of permanently marking the site of excision, but migration of clips following placement has been reported, making reliance on the technique questionable.³² Usually, the post-operative cavity can easily be identified within a few weeks after lumpectomy due to the seroma that rapidly forms, which has fluid-like density and can be easily identified at CT planning. However, if there is too long of a delay between surgery and simulation, the cavity may be very difficult to see. However, if treatment planning is done too soon, it is possible that the lumpectomy cavity and breast will change in size and shape between the time of treatment planning and initial treatment, due to the resolution of postoperative changes. For example, Figure 4 shows a patient who, when first simulated, 18 days after surgery, had a large fluid collection with an air level visible on CT (upper panel). The ipsilateral breast was also enlarged and deformed by post-operative edema. Ten days later, when she came to start treatment (28 days from initial surgery), the size of the breast had decreased, and it also became evident that the excision cavity had changed in size, as confirmed by a new treatment planning CT (Figure 4, lower panel).

Another concern is whether the dose chosen for EB-PBI is adequate for tumor control. We have addressed this issue in a recent manuscript that compares the biological

effective doses used in PBI studies to those delivered to the tumor bed by more standard whole-breast regimens of 50 Gy in five weeks or whole-breast plus boost regimens of 60 Gy in six weeks.³³ It appears that the BED values of most PBI protocols (with either external beam or brachytherapy techniques) resulted in tumor control BEDs roughly equivalent to a 50 Gy standard treatment, but consistently lower than the BEDs for regimens in which the tumor bed receives a total dose of either 60 Gy or 66 Gy. In view of the results of trials demonstrating significantly better local control when a boost is added to the tumor bed,^{34 35} future studies of external beam PBI should consider whether a higher dose should be given.

Finally, when large fraction sizes are used, differences in normal-tissue radiosensitivity are likely to be magnified. There are currently no predictive markers to determine which patients will develop radiation-induced late toxicity. Li and colleagues³⁶ detected a significant correlation between pre-treatment plasma levels of TGF- β 1 (a multifunctional cytokine implicated in tissue fibrosis), and the risk of severe fibrosis among patients treated with breast-conservation therapy. Other studies have revealed that specific polymorphisms of the TGF- β 1 promoter gene could be associated with the development of severe fibrosis. In one study, patients with the -509TT or +869CC genotypes were 7-15 times more likely to develop severe fibrosis.³⁷ Hopefully, studies of “radiation genomics” may result in a panel of markers that can be used to prospectively detect “fibrosis-prone” individuals.

Conclusions and Future Directions

A description of the NSABP/RTOG protocol is included in this issue (page...)

Accrual to this study is the fundamental next step to establish the role of partial breast radiation in the management of early breast cancer. By comparing standard radiation to partial breast radiation in terms of their effect on local recurrence, the trial will be able to establish in a definitive manner the efficacy of PBI. Until then, any form of PBI is an experimental approach to breast cancer radiation and must be conducted as part of an IRB approved clinical trial.

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Figure Legends

Figure 1. Example of a patient undergoing CT-simulation in prone position, on a dedicated treatment table designed for partial-breast radiation.

Figure 2. One month following breast surgery, the same patient as in Figure 1 was scanned both in the prone and supine positions. Radio-opaque markers were placed while supine, to define the lateral extent of the breast and to identify the lumpectomy scar. A supine and a prone scan at the level of the lateral marker are shown to exemplify how the shape and site of the post-segmental excision seroma varies based on patient's position. When prone, the cavity elongates and is more distant from the chest wall.

Figure 3. A set of transverse CT slices (acquired every 0.37 cm, but here displayed every 0.75 cm) for a prone EB-PBI treatment are shown, the with isodose distribution around the tumor bed (CTV, shown in red) and around the PTV (shown in magenta). Opposed tangential fields with 15° wedges were used to improve dose homogeneity. Dose volume histograms of the treatment plan are also displayed.

Figure 4. This patient was originally imaged 18 days after segmental mastectomy (top image). When the patient came to start treatment ten days later (28 days after surgery), it was noted that the ipsilateral breast contour had changed. When imaged again (bottom image) the seroma at the post-operative cavity had partially resolves, with absorption of the air present at the first CT, and the contour and size of the breast had also changed. A new treatment plan was developed.

Table 1**Biologically Equivalent Doses of Different Fractionation Schemes**

Endpoint	α/β	50 Gy/25 fx	30 Gy/5 fx	60 Gy/30 fx	34 Gy/10 fx
Erythema	8 [^]	63 Gy ₈	53 Gy ₈	75 Gy ₈	48 Gy ₈
Desquamation	11 [^]	59 Gy ₁₁	46 Gy ₁₁	71 Gy ₁₁	45 Gy ₁₁
Telangiectasia	4 [^]	75 Gy ₄	75 Gy ₄	90 Gy ₄	63 Gy ₄
Fibrosis	2 [^]	100 Gy ₂	120 Gy ₂	120 Gy ₂	92 Gy ₂
Tumor control*	4	75 Gy ₄	75 Gy ₄	90 Gy ₄	63 Gy ₄
Tumor control*	4	72 Gy ₄	75 Gy ₄	86 Gy ₄	63 Gy ₄

*Taking into account cell proliferation during the course of treatment ^{19 38 21}

[^] Derived from reference ²³