

Immunohistochemical Phenotype of Breast Cancer during 25-Year Follow-up of the Royal Marsden Tamoxifen Prevention Trial

Simone I. Detre¹, Susan Ashley², Kabir Mohammed², Ian E. Smith³, Trevor J. Powles⁴, and Mitch Dowsett¹

Abstract

The randomized, double-blinded Royal Marsden Tamoxifen Breast Cancer Prevention Trial in healthy high-risk women started in 1986 and is still blinded. Eligible participants ($n = 2,471$) were randomly assigned to tamoxifen (20 mg/d) or placebo for 8 years. Analysis in 2006 showed a 30% risk reduction of estrogen receptor (ER)-positive invasive breast cancer mostly in the posttreatment period. Biomarker analysis in this population may identify any subgroup-specific preventive effects tamoxifen. After a median follow-up of 18.4 years, 242 patients had developed invasive cancer, 134 on placebo and 108 on tamoxifen. From these, 180 tissue blocks were available and ER, progesterone receptor (PgR), Ki67, HER2, and EGFR were immunohistochemically analyzed. A 32% reduction in ER⁺ and PgR⁺ invasive cancers resulted after 8 years of treat-

ment. Quantitative levels of ER and PgR were lower in the tamoxifen-treated group, significantly so for ER ($P = 0.001$). These lower ER levels were restricted to the posttreatment period ($P = 0.018$). Among the ER⁺ group, there was a similar proportional decrease in PgR⁺ and PgR⁻ tumors by tamoxifen. The median levels of Ki67 were similar in both arms. The numbers of HER2-positive and EGFR-positive cancers were higher in the tamoxifen arm but not significantly so. In conclusion, the preventive effects of tamoxifen result in reduced ER-positive but not ER-negative tumors and reduced ER expression in the ER-positive cases largely confined to the posttreatment period. Overall reductions in PgR expression are explained by lower frequency of ER-positive cases. Impact on Ki67, HER2, and EGFR was modest. *Cancer Prev Res*; 10(3); 171–6. ©2017 AACR.

Introduction

In vivo laboratory evidence that the incidence of breast cancer could be reduced and an observed reduction in the risk of new contralateral breast cancer resulting from adjuvant treatment of women with primary breast cancer with the selective estrogen receptor modulator (SERM), tamoxifen (1, 2), indicated that this drug could be used to prevent breast cancer in healthy women. The first trial, the Royal Marsden Prevention Trial (RMPT), began recruitment in 1986 (3). Three other major randomized, placebo-controlled trials of tamoxifen given for between 5 and 8 years were conducted. Together with the RMPT, these recruited a total of more than 25,000 healthy women at increased risk of breast cancer. Overview of these trials confirmed a significant reduction in the risk of developing breast

cancer of 33% that, among invasive tumors, was restricted to a reduction in the incidence of ER-positive disease (by 44%; ref. 4). A reduction in risk persisted for at least 15 years (4, 5). These positive data alongside the low incidence of side effects with tamoxifen have led to it being recommended for use by regulatory bodies as a risk reduction strategy in healthy women at increased risk of breast cancer.

The phenotype of primary breast tumors is a major determinant of the medical treatment of patients, and certain key features are associated with long-term prognosis. ER and HER2 are assessed in all tumors for treatment selection and progesterone receptor (PgR) and the proliferation marker Ki67 in most for the assessment of prognosis. Information on these biomarkers in patients developing breast cancer either during or after risk reduction therapy with tamoxifen is therefore important for better understanding of the likely benefits of such treatment as well as for the identification of any subgroup-specific preventive effects. Other than ER status, there have been few reports on any differences in the phenotype of breast cancers developing during or after the tamoxifen treatment period. We previously reported that in 67 tumors from the RMPT (35 placebo, 32 tamoxifen arm), median ER levels were lower in the tumors developing in tamoxifen-treated patients (6). At that time, when most patients were still on their randomized treatment (median follow-up, 70 months), there was no reduction in breast cancer incidence.

The most recent report of the clinical outcome of the trial was at a median of 13 years 2 months (maximum, 19 years 10 months; ref. 5). After that length of follow-up, 186 patients had

¹Ralph Lauren Centre for Breast Cancer Research, Royal Marsden Hospital NHS Trust, London, United Kingdom. ²RDSU – Research and Development, Royal Marsden Hospital NHS Trust, Sutton, United Kingdom. ³Breast Unit, Royal Marsden Hospital NHS Trust, London, United Kingdom. ⁴Cancer Centre London, Wimbledon, London, United Kingdom.

Note: Supplementary data for this article are available at Cancer Prevention Research Online (<http://cancerprevres.aacrjournals.org/>).

Corresponding Author: Mitch Dowsett, Ralph Lauren Centre for Breast Cancer Research, 4th Floor Wallace Wing, Royal Marsden Hospital NHS Trust, Fulham Road, London SW3 6JJ, United Kingdom. Phone: 207-8082887; Fax: 207-8082808; E-mail: mitch.dowsett@icr.ac.uk

doi: 10.1158/1940-6207.CAPR-16-0247-T

©2017 American Association for Cancer Research.

Detre et al.

developed invasive cancer (104 placebo, 82 tamoxifen; HR, 0.78; $P = 0.10$) and 139 of these were ER-positive (86 placebo; 53 tamoxifen; HR, 0.61; $P = 0.005$). The HRs for the 8-year treatment period and the posttreatment period were 0.77 ($P = 0.3$) and 0.48 ($P = 0.004$), respectively.

In the meantime, the NSABP have reported (7) the microarray gene expression analysis of 108 tumors from their P1 tamoxifen prevention trial, 69 placebo and 39 tamoxifen-treated. ER expression, whether measured by semiquantitative immunohistochemistry (IHC) or gene expression, was lower in the 27 ER-positive tumors on tamoxifen than in the 57 ER-positive tumors in the placebo group. The only other gene to show substantial differential expression was *GFRA1*, which codes for the Glial cell line-derived neurotrophic receptor α -1, also known as Glial cell line-derived neurotrophic factor receptor (GDNFR). Our group has reported that activation of this receptor in ER-positive breast cancer is associated with resistance to tamoxifen and aromatase inhibitors (8).

The primary objective of the current study was to determine whether randomization to possible risk reduction treatment with tamoxifen or placebo was associated with differences in the commonly measured phenotypic markers ER, PgR, HER2, and Ki67 as well as EGFR. The last of these is uncommonly expressed in ER-positive tumors and is associated with tamoxifen resistance when it is (9). The study was conducted in tumors from the RMPT which at its most recent analysis had completed more than 20 years of follow-up (5) and gave us the opportunity to fulfill a secondary objective, that is, to determine whether any phenotypic differences varied according to whether the patients were in the on-treatment or posttreatment period at the time of tumor presentation.

Materials and Methods

The trial (1 SRCTN07027313) was approved by the Royal Marsden Hospital Ethics Committee. Consent to use tissue for research was provided by all patients in whom tumors arose after September 1, 2006, when the Human Tissue Act became active. The study design and clinical outcome data have previously been published (5). A total of 2,494 healthy women were randomly assigned to oral tamoxifen (20 mg/d) or placebo for a treatment period of 8 years. Participants, medical professionals, and laboratory staff remain blind to the randomized treatment unless unblinding was specifically requested and the analyses are based on an intention to treat.

IHC analyses for ER, PgR, Ki67, HER2, and EGFR were undertaken on sections from formalin-fixed paraffin wax-embedded blocks using reagents listed in Supplementary Table S1. The IHC staining was performed on a Dako Autostainer using REAL kits for all biomarkers except HER2. FISH analyses (PathVysion) were carried out on HER2-positive cases when scored as IHC2+. Hematoxylin and eosin-stained slides were used to confirm presence of invasive breast carcinoma. *In situ* breast cancers were excluded. If patients received neoadjuvant therapy, core-cut biopsies taken at diagnosis were used; otherwise sections from the excision biopsy were taken.

ER and PgR were scored as *H*-scores (range, 0–300; ref. 10). The positivity cutoff for ER and for PgR *H*-score was >1 to equate closely to that recommended in ASCO/CAP guidelines (11). Ki67 was assessed as percentage of positivity of nuclear stained cells and had no designated cutoff. EGFR was scored as

percentage positive membrane staining and deemed positive if the score was greater than 1. HER2 was considered positive if the IHC score was assessed as 3+ by ASCO/CAP criteria (12) or if assessed as 2+ and FISH analysis showed HER2/CEP17 ratio of >2.0.

All analyses were carried out blind to randomization with the trial statistician supplying pathology numbers and case details. All statistical analyses were performed by the trial statistician. The cutoff point for the current analysis was October 1, 2010. The primary endpoint was the occurrence of invasive breast cancer. Invasive breast cancer-free survival was calculated using the Kaplan-Meier method. Noninvasive breast cancers were censored. The Cox proportional hazards model was used to check for the treatment effect and HR with 95% confidence interval (CI) reported. A secondary planned analysis of ER-positive invasive breast cancer was also done. Biomarker data were summarized and compared between treatment arms in the overall patient population and in subgroups according to ER status and diagnosis of cancer during treatment or posttreatment. The continuous biomarker variables were summarized using mean and 95% CI and median and interquartile range. The scores were then compared using the nonparametric Mann-Whitney *U* test. Categorical variables were summarized using number of observations and percentages according to treatment arms and compared using χ^2 test.

Results

The current IHC analysis was conducted in all available tumors that arose by October 1, 2010 (median follow-up, 18.4 years; maximum, 23.7 years). By that time, 242 patients had developed invasive cancer, 134 on placebo and 108 on tamoxifen (HR, 0.80; 95% CI, 0.62–1.02; $P = 0.076$; Table 1). Of these, 187 were ER-positive, 108 on placebo and 79 on tamoxifen (HR, 0.72; 95% CI, 0.54–0.97; $P = 0.028$). The HR in the posttreatment period for all patients was 0.74 (95% CI, 0.53–1.02; $P = 0.067$) and for ER-positive cases was 0.68 (95% CI, 0.47–0.99; $P = 0.048$). A complete updated clinical report of the trial will be published separately. The efficacy endpoints included in this report are sufficient to allow full interpretation of the tumor-based biomarker data.

IHC data were available from 179 patients. Reasons for non-availability of data were: 38 tumor blocks could not be retrieved from sites; 12 subjects either had no written consent for biomarker analysis recorded or declined; 11 samples had too little tumor to assess biomarkers. A similar proportion of tumors was available in the IHC cohort for each of the 2 arms: placebo, 75% (100 of 134); tamoxifen 73% (79 of 108). The major demographics of the population are shown in Table 2. In the tamoxifen arm in the IHC cohort, there were 54 ER-positive and 25 ER-negative tumors (1 ER-negative/PgR-positive) compared with 86 ER-positive, 14 ER-negative in the placebo arm. The difference in the proportions of ER-positive and ER-negative tumors between the arms was statistically significant (χ^2 : $P = 0.008$).

In the overall follow-up period, PgR-positive status was also lower in the tamoxifen arm than in the placebo arm (63% vs. 76%, $P = 0.06$; Table 3). This was only statistically significant beyond 8 years ($P = 0.039$), but the proportions were little different from those in the first 8 years (Table 4). Overall, 76 (76%) tumors were ER-positive/PgR-positive in the placebo arm compared with 49 (62%) in the tamoxifen arm.

Table 1. Summary of invasive breast cancer occurrence in tamoxifen and placebo arms in the BCPT by October 1, 2010, for all and patients with ER⁺ tumors during and after the treatment period

Invasive cancers	HR (95% CI)	Cox (P)
A. Complete trial population		
All patients		
Overall follow-up (events: <i>n</i> = 242)		
Placebo (<i>n</i> = 134)	1	0.076
Tamoxifen (<i>n</i> = 108)	0.80 (0.62-1.02)	
During treatment period (events: <i>n</i> = 93)		
Placebo (<i>n</i> = 49)	1	0.589
Tamoxifen (<i>n</i> = 44)	0.89 (0.60-1.34)	
Posttreatment period (events: <i>n</i> = 149)		
Placebo (<i>n</i> = 85)	1	0.067
Tamoxifen (<i>n</i> = 64)	0.74 (0.53-1.02)	
ER-positive		
Overall follow-up (events: <i>n</i> = 187)		
Placebo (<i>n</i> = 108)	1	0.028
Tamoxifen (<i>n</i> = 79)	0.72 (0.54-0.97)	
During treatment period (events: <i>n</i> = 75)		
Placebo (<i>n</i> = 42)	1	0.290
Tamoxifen (<i>n</i> = 33)	0.78 (0.50-1.23)	
Posttreatment period (events: <i>n</i> = 112)		
Placebo (<i>n</i> = 66)	1	0.048
Tamoxifen (<i>n</i> = 46)	0.68 (0.47-0.996)	
B. IHC subset		
Overall follow-up (<i>n</i> = 179)		
Placebo (<i>n</i> = 100)	1	0.100
Tamoxifen (<i>n</i> = 79)	0.78 (0.58-1.05)	
ER-positive (<i>n</i> = 139)		
Placebo (<i>n</i> = 85)	1	0.007
Tamoxifen (<i>n</i> = 54)	0.63 (0.45-0.88)	
ER-negative (events: <i>n</i> = 40)		
Placebo (<i>n</i> = 15)	1	0.127
Tamoxifen (<i>n</i> = 25)	1.65 (0.87-3.12)	

As in the earlier 13-year median follow-up clinical report (6), there was a greater preventive effect of tamoxifen in the post-treatment period in this IHC cohort (0–8 years: 40 tamoxifen, 44 placebo; beyond 8 years: 39 tamoxifen, 56 placebo; Table 3). There was no significant difference in the proportions of ER-positive versus ER-negative tumors between the treatment arms in the first 8 years but only 64% were ER-positive in the tamoxifen arm after 8 years compared with 86% in the placebo arm ($P = 0.014$).

Among the ER-positive tumors, the ER level as estimated by *H*-score was somewhat lower in tamoxifen-treated tumors but this was not statistically significant either overall ($P = 0.053$) or in the separate time periods (Tables 3 and 4). PgR levels also showed nonsignificant trends to being lower in the ER-positive cases.

There were 12 HER2-positive cases in the tamoxifen arm and 10 in the placebo. Fifteen cases were EGFR-positive in the tamoxifen arm and 12 in the placebo arm (Table 3; $P = NS$ for HER2 and EGFR).

The median level of Ki67 was 10.2% in both the tamoxifen and placebo arms overall and was also little different between the arms in the 2 time periods (Tables 3 and 4). The mean levels were, however, higher among the tamoxifen-treated patients indicating a skewed distribution that was particularly apparent in the post-8-year period. These higher values of Ki67 in the overall time period are apparent in both the ER-positive and ER-negative treated groups (Fig. 1).

Discussion

Tamoxifen was the first SERM to be shown to be effective at breast cancer risk reduction in healthy women. The benefit–harm ratio is sufficiently favorable for its use to be approved by regulatory agencies in defined high-risk groups in Europe and the United States. This position has been established as a result of 4 large randomized trials, including the RMPT reported here (13–15). The RMPT results on breast cancer incidence are largely consistent with those in the other trials, although the reduced incidence of invasive breast cancer did not emerge until later than in other trials. This may be partly a matter of chance or may be affected by the greater familial risk for the RMPT population than that of the other trials with possible differences in the phenotypical profile of the familial cancers (5, 6). There is, therefore, interest in important phenotypic features of the tumors presenting in the RMPT trial on or after their preventive treatment, such as ER, PgR, HER2, and Ki67.

To provide maximum statistical power for the analyses, we collected and analyzed as many invasive breast cancers that occurred prior to 2010 in the trial as possible. The data therefore provide an update on breast cancer incidence beyond the most recent full publication of the trial (5) and from the most recent overview analysis (4). As expected, the data are no different for the first 8 years of follow-up during which treatment was given. But with the longer follow-up, the total number of invasive breast cancers increased from 186 to 242, for the most part after 8 years post-randomization. The significantly reduced incidence of invasive breast cancer after tamoxifen treatment occurred exclusively in ER-positive disease.

Nearly three quarters of the 242 breast cancers were collected and had sufficient tissue for analysis. While the absence of the whole cohort may lead to some bias, the proportions of patients with tumors available for IHC were very similar in each of the 2 arms such that the conclusions from the cohort are likely to be representative of the whole trial.

Table 2. Major demographics of the IHC sample set

	Tamoxifen	Placebo
Number of patients	79	100
Age: median (range), y	48 (37-67)	49 (30-67)
HRT, <i>n</i> (%)	17 (21)	21 (21)
Size: median (range), mm	15 (4-50)	15 (2-60)
Grade, <i>n</i> (%)		
I	13 (16)	16 (16)
II	24 (30)	35 (35)
III	23 (29)	30 (30)
Others ^a	19 (25)	19 (19)
Nodal status, <i>n</i> (%)		
Positive	22 (28)	22 (22)
Negative/Unknown	77 (72)	78 (78)
Follow-up time, y		
0-8	40	44
>8	39	56
ER ⁺ cases		
All	54	85
0-8 y	29	37
>8 y	25	48
ER ⁻ cases		
All	25	15
0-8 y	11	7
>8 y	14	8

^aOthers – unknown, moderate, poor, well, not assessable.

Detre et al.

Table 3. Comparison of biomarker expression between placebo and tamoxifen groups in overall follow-up period

Parameter	Tamoxifen (n = 79)	Placebo (n = 100)	P
ER			
Median <i>H</i> -score (IQR)	86.4 (0–163.9)	150.8 (73.6–184.6)	0.001
ER ⁺			
Median <i>H</i> -score (IQR)	135.8 (84.0–182.2)	164 (110.6–191.4)	0.053
Positive	54 (68%)	85 (85%)	
Negative	25 (32%)	15 (15%)	0.008
PgR			
Median <i>H</i> -score (IQR)	52.9 (0–153.7)	87.2 (1.3–168.4)	0.180
Median <i>H</i> -score (IQR)	110.7 (58.8–184.5)	115.9 (66.9–180.6)	0.643
Positive	50 (63%)	76 (76%)	
Negative	29 (37%)	24 (24%)	0.064
ER/PgR			
ER ⁺ /PgR ⁺	49 (62%)	76 (76%)	0.800 ^a
Status			
ER ⁺ /PgR ⁻	5 (6%)	9 (9%)	
ER ⁻ /PgR ⁻	24 (30%)	15 (15%)	
ER ⁻ /PgR ⁺	1 (1%)	0	
Ki67			
Median % + (IQR)	10.2 (5.1–34.5)	10.2 (4.2–18.3)	0.280
HER2			
Positive	12 (15%)	10 (10%)	
Negative	67 (85%)	90 (90%)	0.294
EGFR			
Positive	15 (19%)	12 (12%)	
Negative	64 (81%)	88 (88%)	0.205

^aP value relates to the difference between PgR⁺ and PgR⁻ among the ER⁺ by χ^2 test.

Given that it is estimated that many years are required for a breast carcinoma to develop from an initiation event to clinical presentation, reductions in breast cancer incidence in the first few years of prophylactic tamoxifen are likely to be due predominantly to an impact on pre-existing occult disease (16). However, it seems likely that the majority of invasive breast cancers presenting in the post-8-year period in this trial would be due to a

primary preventive mechanism on either initiation or early promotional events.

Tamoxifen is known to impact on PgR and Ki67 expression in established ER-positive breast cancer (17, 18). In our studies of neoadjuvant use of tamoxifen, the early increase seen in PgR after a few weeks of tamoxifen due to an early agonist effect of tamoxifen fell back to levels that are no different to

Table 4. Comparison of biomarker expression between placebo and tamoxifen groups in on-treatment and posttreatment follow-up periods

Parameter	N	Years 0–8, on treatment			Years >8, posttreatment		
		Tamoxifen	Placebo	P	Tamoxifen	Placebo	P
ER		40	44		39	56	
All	Median <i>H</i> -score (IQR)	83.0 (0–151.9)	118.9 (30.7–181.2)	0.043	107.5 (0–182.3)	162.1 (103.0–195.0)	0.018
ER ⁺	Median <i>H</i> -score (IQR)	104 (71.2–165.0)	148.5 (81.1–182.7)	0.148	162.8 (110.5–191.4)	169.5 (134.2–196.3)	0.390
All	Positive	29 (73%)	37 (84%)		25 (64%)	48 (86%)	
	Negative	11 (27%)	7 (16%)	0.196	14 (36%)	8 (14%)	0.014
PgR							
All	Median <i>H</i> -score (IQR)	55.2 (0–111.3)	73.4 (0.8–167.6)	0.582	52.9 (0–167.7)	101.3 (3.5–168.4)	0.272
PgR ⁺	Median <i>H</i> -score (IQR)	92.3 (52.3–172.8)	96.5 (67.0–180.8)	0.988	146 (90.6–187.7)	121.4 (59.6–180.0)	0.291
All	Positive	27 (68%)	32 (73%)		23 (59%)	44 (79%)	
	Negative	13 (32%)	12 (27%)	0.601	16 (41%)	12 (21%)	0.039
ER/PgR							
	ER ⁺ /PgR ⁺	26	32		23	44	
	ER ⁺ /PgR ⁻	3	5		2	4	
	ER ⁻ /PgR ⁺	1	0		0	0	
	ER ⁻ /PgR ⁻	10	7		14	8	
Ki67							
All	Median % +ve (IQR)	9.9 (4.7–20.4)	9.1 (3.3–18.3)	0.660	10.9 (5.4–47.0)	10.9 (4.6–18.2)	0.180
HER2							
All	Positive	5 (12%)	6 (14%)		7 (18%)	4 (7%)	
	Negative	35 (88%)	38 (86%)	0.877	32 (82%)	52 (93%)	0.105
EGFR							
All	Positive	6 (15%)	6 (14%)		9 (23%)	6 (11%)	
	Negative	34 (85%)	37 (86%)	0.892	30 (77%)	50 (89%)	0.104

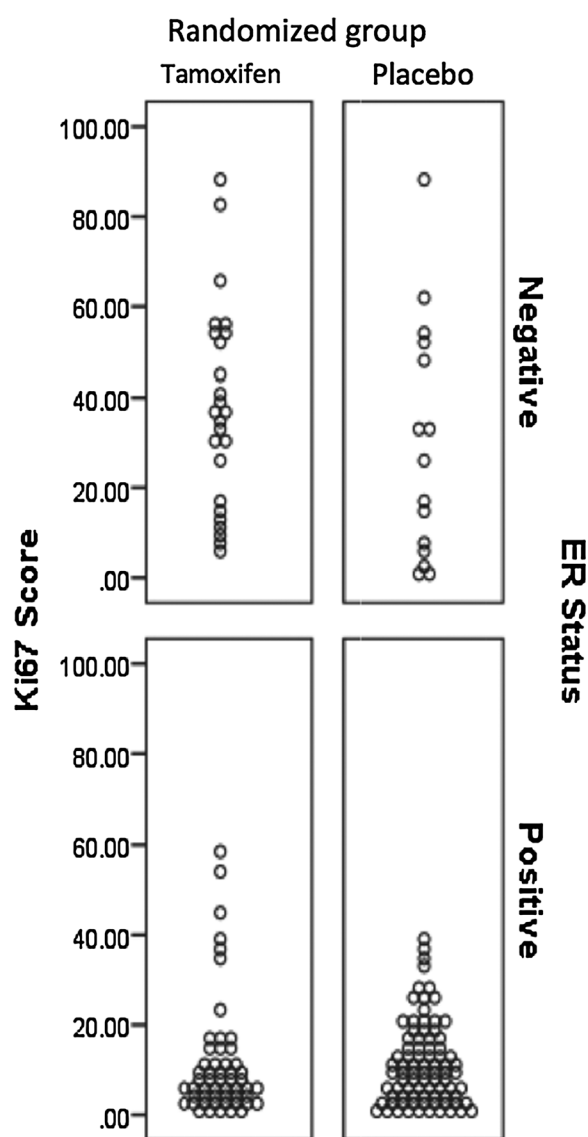


Figure 1.
Expression of Ki67 according to treatment arm and ER status.

the overall population after 12 weeks. Ki67 levels, on the other hand, were initially suppressed and remained suppressed. The observations on phenotype for tumors that present during treatment may therefore be affected by regulatory effects of treatment rather than being representative of the intrinsic tumor phenotype. In contrast, in the post-8-year period of follow-up, any differences would be expected to be representative of the intrinsic phenotype of cancers that survived initiation or promotion during treatment or were initiated posttreatment.

The major findings in this study are that the reduction in the incidence of breast cancer continues to be only in ER-positive disease even beyond 8 years and those ER-positive tumors tend to also have lower ER levels than that in the placebo population. These effects are similar to those reported by Kim and colleagues (7), although in that article, the data were from

women having received a median of only 4.5 years of randomized therapy (15). Our findings provide evidence against ER-negative cancers arising from ER-positive precursors because by now we should be seeing a reduction in ER-negative cancers. In fact, there appears to be a consistent increase in ER-negative cancers in the tamoxifen trials (4) including in this study. We and others have observed that patients with breast cancer with ER-positive primary breast cancers that relapse on tamoxifen therapy in a minority of cases exhibit ER-negative recurrences (19). Thus, at least some of these ER-negative tumors in the treated women in RMPT may have presented as ER-positive disease if they had not been treated with tamoxifen. A substantial switch of ER-positive to ER-negative status in a subclinical tumor under the influence of tamoxifen could mask any preventive effect of tamoxifen on ER-negative subclinical tumors in this and other tamoxifen prevention studies (20). The lower frequency of PgR-positive disease in the tamoxifen arm appears to relate largely to the reduced incidence of ER-positive disease.

Ki67 is a frequently used marker of proliferation and is associated with poorer prognosis in breast cancer overall and in patients with ER-positive disease treated with endocrine therapy (21). The median levels of Ki67 did not differ between the cancers in the tamoxifen and placebo arms in RMPT, but there was an excess of patients with particularly high levels in the tamoxifen-treated patients. Given that Ki67 is well-known to be more highly expressed in ER-negative tumors, the excess of such tumors contributed to but did not appear to be completely responsible for the higher Ki67 levels.

The incidence of HER2 positivity and EGFR positivity both of which are features of poor prognosis disease was numerically higher in the cancers in the tamoxifen arm but the differences did not approach statistical significance.

In summary, in the RMPT trial with prolonged follow-up, there was an overall decrease in breast cancer incidence. The marked decrease in the incidence of ER-positive disease was partly offset by an increase in ER-negative disease. Decreased PgR and increased Ki67 levels in the cancers in the tamoxifen arm were explained by the greater numbers of ER-negative cancers. The minor increases in Ki67, HER2, and EGFR and decreases in ER and PgR proximity are each generally associated with poorer outcome in primary disease presenting in the absence of endocrine therapy, but these differences were relatively minor and the majority of breast cancers that developed during or in the decade after tamoxifen preventive therapy presented as ER-positive/PgR-positive disease.

Disclosure of Potential Conflicts of Interest

M. Dowsett reports receiving commercial research grant from and is a consultant/advisory board member of Radius. No potential conflicts of interest were disclosed by the other authors.

Authors' Contributions

Conception and design: I.E. Smith, T. Powles, M. Dowsett

Development of methodology: S. Detre

Acquisition of data (provided animals, acquired and managed patients, provided facilities, etc.): T. Powles, M. Dowsett

Analysis and interpretation of data (e.g., statistical analysis, biostatistics, computational analysis): S. Ashley, K. Mohammed, M. Dowsett

Writing, review, and/or revision of the manuscript: K. Mohammed, I.E. Smith, T. Powles, M. Dowsett

Detre et al.

Administrative, technical, or material support (i.e., reporting or organizing data, constructing databases): S. Detre, K. Mohammed

Study supervision: T. Powles

Other (wrote the first draft): S. Detre

Acknowledgments

We are grateful to the participants, investigators, and pathologists involved with the RMPT trial and to staff of the Academic Biochemistry Department who undertook many of the analyses.

Grant Support

All authors received funding from the Da Costa International Fund for Breast Cancer Prevention Foundation and the Royal Marsden Hospital NIHR Biomedical Research Centre.

The costs of publication of this article were defrayed in part by the payment of page charges. This article must therefore be hereby marked *advertisement* in accordance with 18 U.S.C. Section 1734 solely to indicate this fact.

Received October 5, 2016; revised December 19, 2016; accepted December 19, 2016; published OnlineFirst January 18, 2017.

References

- Jordan VC. Effect of tamoxifen (ICI 46,474) on initiation and growth of DMBA-induced rat mammary carcinomata. *Eur J Cancer* 1976;12:419–24.
- Cuzick J, Baum M. Tamoxifen and contralateral breast cancer. *Lancet* 1985;2:282.
- Powles TJ, Hardy JR, Ashley SE, Farrington GM, Cosgrove D, Davey JB, et al. A pilot trial to evaluate the acute toxicity and feasibility of tamoxifen for prevention of breast cancer. *Br J Cancer* 1989;60:126–31.
- Cuzick J, Sestak I, Bonanni B, Costantino JP, Cummings S, DeCensi A, et al. Selective oestrogen receptor modulators in prevention of breast cancer: an updated meta-analysis of individual participant data. *Lancet* 2013;381:1827–34.
- Powles TJ, Ashley S, Tidy A, Smith IE, Dowsett M. Twenty-year follow-up of the Royal Marsden randomized, double-blinded tamoxifen breast cancer prevention trial. *J Natl Cancer Inst* 2007;99:283–90.
- Kote-Jarai Z, Powles TJ, Mitchell G, Tidy A, Ashley S, Easton D, et al. BRCA1/BRCA2 mutation status and analysis of cancer family history in participants of the Royal Marsden Hospital tamoxifen chemoprevention trial. *Cancer Lett* 2007;247:259–65.
- Kim C, Tang G, Pogue-Geile KL, Costantino JP, Baehner FL, Baker J, et al. Estrogen receptor (ESR1) mRNA expression and benefit from tamoxifen in the treatment and prevention of estrogen receptor-positive breast cancer. *J Clin Oncol* 2011;29:4160–7.
- Morandi A, Martin LA, Gao Q, Pancholi S, Mackay A, Robertson D, et al. GDNF-RET signaling in ER-positive breast cancers is a key determinant of response and resistance to aromatase inhibitors. *Cancer Res* 2013;73:3783–95.
- Nicholson S, Sainsbury JR, Halcrow P, Chambers P, Farndon JR, Harris AL. Expression of epidermal growth factor receptors associated with lack of response to endocrine therapy in recurrent breast cancer. *Lancet* 1989;1:182–5.
- Andersen J, Orntoft TF, Poulsen HS. Immunohistochemical demonstration of estrogen receptors (ER) in formalin-fixed, paraffin-embedded human breast cancer tissue by use of a monoclonal antibody to ER. *J Histochem Cytochem* 1988;36:1553–60.
- Hammond ME, Hayes DF, Dowsett M, Allred DC, Hagerty KL, Badve S, et al. American Society of Clinical Oncology/College Of American Pathologists guideline recommendations for immunohistochemical testing of estrogen and progesterone receptors in breast cancer. *J Clin Oncol* 2010;28:2784–95.
- Wolff AC, Hammond ME, Schwartz JN, Hagerty KL, Allred DC, Cote RJ, et al. American Society Of Clinical Oncology/College Of American Pathologists guideline recommendations for human epidermal growth factor receptor 2 testing in breast cancer. *J Clin Oncol* 2007;25:118–45.
- Cuzick J, Forbes J, Edwards R, Baum M, Cawthorn S, Coates A, et al. First results from the International Breast Cancer Intervention Study (IBIS-I): a randomised prevention trial. *Lancet* 2002;360:817–24.
- Veronesi U, Maisonneuve P, Rotmensz N, Bonanni B, Boyle P, Viale G, et al. Tamoxifen for the prevention of breast cancer: late results of the Italian Randomized Tamoxifen Prevention Trial among women with hysterectomy. *J Natl Cancer Inst* 2007;99:727–37.
- Fisher B, Costantino JP, Wickerham DL, Cecchini RS, Cronin WM, Robidoux A, et al. Tamoxifen for the prevention of breast cancer: current status of the national surgical adjuvant breast and bowel project P-1 study. *J Natl Cancer Inst* 2005;97:1652–62.
- Radmacher MD, Simon R. Estimation of tamoxifen's efficacy for preventing the formation and growth of breast tumors. *J Natl Cancer Inst* 2000;92:48–53.
- Clarke RB, Laidlaw IJ, Jones LJ, Howell A, Anderson E. Effect of tamoxifen on Ki67 labelling index in human breast tumours and its relationship to oestrogen and progesterone receptor status. *Br J Cancer* 1993;67:606–11.
- Dowsett M, Ebbs SR, Dixon JM, Skene A, Griffith C, Boeddinghaus I, et al. Biomarker changes during neoadjuvant anastrozole, tamoxifen, or the combination: influence of hormonal status and HER-2 in breast cancer—a study from the IMPACT trialists. *J Clin Oncol* 2005;23:2477–92.
- Johnston SR, Saccani-Jotti G, Smith IE, Salter J, Newby J, Coppen M, et al. Changes in estrogen receptor, progesterone receptor, and pS2 expression in tamoxifen-resistant human breast cancer. *Cancer Res* 1995;55:3331–8.
- Esserman LJ, Ozanne EM, Dowsett M, Slingerland JM. Tamoxifen may prevent both ER+ and ER- breast cancers and select for ER- carcinogenesis: an alternative hypothesis. *Breast Cancer Res* 2005;7:R1153–8.
- Dowsett M, Nielsen TO, A'Hern R, Bartlett J, Coombes RC, Cuzick J, et al. Assessment of Ki67 in breast cancer: recommendations from the International Ki67 in Breast Cancer working group. *J Natl Cancer Inst* 2011;103:1656–64.

Cancer Prevention Research

Immunohistochemical Phenotype of Breast Cancer during 25-Year Follow-up of the Royal Marsden Tamoxifen Prevention Trial

Simone I. Detre, Susan Ashley, Kabir Mohammed, et al.

Cancer Prev Res 2017;10:171-176. Published OnlineFirst January 18, 2017.

Updated version Access the most recent version of this article at:
doi:[10.1158/1940-6207.CAPR-16-0247-T](https://doi.org/10.1158/1940-6207.CAPR-16-0247-T)

Supplementary Material Access the most recent supplemental material at:
<http://cancerpreventionresearch.aacrjournals.org/content/suppl/2017/01/18/1940-6207.CAPR-16-0247-T.DC1>

Cited articles This article cites 21 articles, 6 of which you can access for free at:
<http://cancerpreventionresearch.aacrjournals.org/content/10/3/171.full#ref-list-1>

Citing articles This article has been cited by 1 HighWire-hosted articles. Access the articles at:
<http://cancerpreventionresearch.aacrjournals.org/content/10/3/171.full#related-urls>

E-mail alerts [Sign up to receive free email-alerts](#) related to this article or journal.

Reprints and Subscriptions To order reprints of this article or to subscribe to the journal, contact the AACR Publications Department at pubs@aacr.org.

Permissions To request permission to re-use all or part of this article, use this link
<http://cancerpreventionresearch.aacrjournals.org/content/10/3/171>.
Click on "Request Permissions" which will take you to the Copyright Clearance Center's (CCC) Rightslink site.