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Clinical significance of p95HER2 overexpression, PTEN loss and PI3K expression in p185HER2-positive metastatic breast cancer patients treated with trastuzumab-based therapies

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Background: Overexpression of p185HER2 is an established poor prognostic factor in breast cancer, portending an aggressive course and potential for early metastasis. On the other hand, monoclonal antibody trastuzumab is widely used in the clinic to target this overexpressed oncogene. Unfortunately, ~30–40% of all patients overexpressing HER2 respond to trastuzumab, warranting further research regarding the structure and additional modulation of the receptor. In this study, we aimed to investigate the response to trastuzumab in terms of the potential roles of several oncogenic pathways (phosphatase and tensin homologue (PTEN) and phosphatidylinositol 3-kinase (PI3K)) and a truncated receptor protein, p95HER2, retrospectively.

Materials and Methods: Paraffin-embedded primary tumour tissues of 100 HER2-positive metastatic breast cancer patients who received trastuzumab with combination cytotoxic chemotherapy were analysed with immunohistochemical method for p95HER2, p85 (PI3K) and PTEN. Relationship between variables were tested via χ^2 , Fischer's exact test and Mann–Whitney *U* tests, wherever appropriate. Progression-free survival (PFS) and overall survival (OS) periods were calculated with Kaplan–Meier method and survival curves of subgroups were compared with log-rank test.

Results: Percentage of patients was found to be 33%, 57% and 42% positive for p95 expression, PTEN and PI3K, respectively. p95-expressing tumours had statistically lower response rates for trastuzumab than tumours not expressing p95 ($P=0.001$). On the contrary, PTEN-expressing tumours had statistically higher response rates for trastuzumab than tumours not expressing PTEN ($P=0.012$). PI3K expression had no significant effect on trastuzumab response. Median PFS for p95-expressing and not expressing tumours were 8 months (95% CI, 2.5–13.4 months) and 22 months (95% CI, 9.9–34 months), respectively ($P=0.0001$). Median PFS for PTEN-expressing and not expressing tumours were 15.3 months (95% CI, 12.6–34 months) and 12.1 months (95% CI, 7.9–16.2 months), respectively ($P=0.04$). Median OS for p95-expressing and not expressing tumours were 24 months (95% CI, 8.3–40.4 months) and 29.1 months (95% CI, 8.6–43.2 months), respectively ($P=0.045$). Median OS for PTEN-expressing and not expressing tumours were 25.1 months (95% CI, 7.5–40.1 months) and 26.8 months (95% CI, 8.1–42 months), respectively, which was not statistically significant ($P=0.5$). Level of PI3K expression had no effect on PFS and OS in our patient population. Presence of visceral metastases HR = 2.38 (95% CI, 1.2–4.5), $P=0.009$, p95 expression HR = 2.1 (95% CI, 1.1–3.7), $P=0.03$ and response to trastuzumab HR = 2.2 (95% CI, 1.18–4.47), $P=0.014$ are identified as factors independently affecting PFS. Response to trastuzumab HR = 1.7 (95% CI, 1.14–3.47), $P=0.013$ was identified as the single parameter influencing survival by Cox regression analysis.

Conclusions: Presence of p95 predicted a poorer response to trastuzumab treatment, shorter PFS and OS in our HER2-positive metastatic breast cancer cohort. In addition, loss of PTEN predicted a poorer response to trastuzumab treatment and shorter PFS but not OS. We could not find an effect of PI3K expression on the above-mentioned parameters.

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HER2 overexpression, which is present in ~20–30% of breast cancers, is a poor prognostic factor for survival and disease progression (Slamon *et al*, 1987).

Amplified HER2 protooncogene has proved to be an extremely important target in the management of breast cancer (Slamon *et al*, 1987). Trastuzumab has been the mainstay of treatment, both for early- and advanced-stage disease, and newer agents that have been approved recently have changed the landscape of HER2-positive breast cancer management in an unprecedented way (Baselga *et al*, 1996; Slamon *et al*, 2001; Moja *et al*, 2012). Despite all these important strides, more than half of the patients are resistant at the start or acquire resistance within a year or so (Cobleigh *et al*, 1999; Vogel *et al*, 2002).

The following mechanisms have been identified as trastuzumab-resistance mechanisms in clinical and preclinical researches: expression of p95HER2, transactivation of HER2 by different tyrosine kinases, such as IGF-1R, loss of PTEN expression and increased signalling in PI3K/Akt pathway due to PI3K mutation (Valabrega *et al*, 2007).

Mechanisms of resistance are complex and currently no predictive biomarkers are available to guide treatment. Biomarkers of potential predictive value that might be associated with trastuzumab response and outcome include the truncated HER2 molecule p95, PTEN mutations and deranged PI3K pathway.

In this study, we retrospectively analysed these three parameters on archival material of patients with HER2-positive advanced breast cancer who have been treated with trastuzumab as first-line treatment and tried to correlate their expression in relation to trastuzumab response and outcome.

MATERIALS AND METHODS

Inclusion criteria. One hundred patients with HER2-positive metastatic breast cancer diagnosed and followed at the Cerrahpasa Medical Faculty Department of Medical Oncology, Istanbul, Turkey, between 2000 and 2011 whose pathologic specimens were available and who received trastuzumab-based therapies first-line were included.

Primary tumour tissues were analysed for p95HER2, PI3K and PTEN by immunohistochemical analysis. Those HER2-positive patients who relapsed in 1 year of completion of adjuvant treatment were excluded.

Approval from the local ethics committee (IRB approval number is B.İST.0/9175) was obtained before the study, along with the informed consent of the patients or their next of kin.

HER2 analysis. HER2 status was analysed utilising Novocastra (Leica Biosystems, Newcastle-upon-Tyne, UK), clone CB11 antibody at 1:80 dilution.

IHC 1+ were deemed as 'negative' and 3+ as 'positive'. IHC 2+ cases were further analysed by FISH or SISH at a Ventana Benchmark XT or LT; amplification is defined as >2.2 HER2/CEP 17 ratio (Wolff *et al*, 2007).

Immunohistochemical staining of p95, PTEN and anti-PI3K (p85) antibody. Paraffin-embedded blocks of primary breast cancer tissue specimens were cut into 5- μ m-thick sections. One section from each block was stained with haematoxylin and eosin as a control. Antigen retrieval was carried out by EDTA following deparaffinisation.

After titration, primary antibody was added manually: rabbit monoclonal [Y112] to p95 NBS1 (Abcam Inc., Cambridge, MA, USA. Cat no: ab32074, lot no: GR50908-1, 1:100 dilution rate). Sections were incubated for 52 min with primary antibody. Sections stayed in haematoxylin staining for 12 min following amplification and ultrawash phases. Counterstain was performed

for 4 min. Slides taken out from the machine were treated in absolute alcohol for 3 \times 3 min following washing. After clearing with xylene for 3 \times 3 min, slides were mounted with different mountant (VWR Int Ltd, DPX Mountant for microscopy, Poole, England).

Rabbit p27 monoclonal (1B4Novacastra, NCL-P27, 1:20 dilution) antibodies for PTEN and rabbit polyclonal to PI3 Kinase p85 alpha + Gamma antibody (Abcam Inc. Cat no: ab74136, lot no: 835-834, 1:50 dilution rate) were utilised for PI3K determination.

Positive controls such as invasive ductal breast carcinoma and squamous cell carcinoma of skin and normal endometrium tissue samples were used for PI3K, P95 and PTEN immunohistochemical staining, respectively. All samples were analysed in the same run.

Evaluation of p95, PTEN and PI3K immunohistochemical staining. Tumours were scored positive for p95 expression if \geq 50% cells showed cytoplasmic staining detected immunohistochemically. Application of p95 antibody caused nucleus staining as well as cytoplasmic. This nucleus staining did not impede the scoring (Scaltriti *et al*, 2010).

PTEN staining was mainly cytoplasmic or/and nuclei. Levels of PTEN expression were scored semiquantitatively based on staining intensity and distribution using immunoreactive score (IRS) as described earlier (Nagata *et al*, 2004). Intensity was scored according to a four-tier system: 0, no staining; 1, weak; 2, moderate; and 3, strong. We attributed one, two, three or four additional points if the percentage of positive cells was <5%, 5–25% to 26–50%, 51–75% or >75%, respectively. Specimens were defined as positive if the score was 7 or greater.

To clarify the intended meaning, tumours were considered positive for PI3K when 50% of the neoplastic cell showed a distinct cytoplasmic staining (Fabi *et al*, 2010).

Treatment evaluation. Treatment response was evaluated by computed tomography every 8 or 12 weeks after the initiation of trastuzumab-based chemotherapy, or whenever clinically requested. The Response Evaluation Criteria in Solid Tumours were used to classify tumour responses. For analysis, complete response and partial response rates were classified as objective response. Progression-free survival (PFS) was defined from the treatment baseline with trastuzumab to disease progression or death. Overall survival (OS) was calculated from the date of initiation of trastuzumab treatment to death due to any cause or loss at the follow-up date.

Statistical analysis. Statistical analysis was done utilising SPSS Version 15. Variables were compared by χ^2 , Fischer's exact and Mann-Whitney *U* tests. RECIST criteria were used for response analysis. Kaplan-Meier curves were drawn to evaluate PFS and OS. Log-rank test was used to evaluate differences between groups.

At univariate analyses, we evaluated factors such as age, adjuvant chemotherapy, ECOG performance status, hormone receptor status, menopause status, adjuvant trastuzumab use, number of metastatic sites, visceral metastases status, brain metastases, tumour grade, trastuzumab-based treatment in the first-step metastatic setting (endocrine versus chemotherapy) and p95, PTEN and PI3K status for their effects on PFS and OS.

All variables that were significant in univariate analysis were entered into a multivariate analysis. In a backward, stepwise fashion, the significant univariate variable with the least significance was eliminated from the multivariate model. This was continued until only significant variables remained. The Cox proportional-hazards model was used to calculate the hazard ratio and 95% confidence intervals. A *P*-value <0.05 was considered significant.

RESULTS

Clinicopathologic characteristics. Median age of all patients was 55 (range 28–76) with 40% being premenopausal. ERBB2 positivity was determined by a 3+ staining by IHC in 94% of the patients. All patients had invasive ductal carcinoma, only two had mixed lobular and ductal carcinoma. Fifty-eight percent ($n=58$) had Grade 3, 40% ($n=40$) Grade 2 and only two patients (2%) had Grade 1 tumours. Hormone receptors were positive in 59 patients. Sixty-four patients had visceral disease. Demographic characteristics were summarised in Table 1.

Treatment. Along with trastuzumab, first-line chemotherapy for metastatic disease included taxanes (82%), capecitabine (2%), vinorelbine (1%) and aromatase inhibitors as hormonal therapy in 15 patients.

Five patients achieved complete remission, 48 had partial remission, 24 had stable disease, whereas 23 progressed despite therapy.

Immunohistochemistry. All patients had adequate tumour tissue for immunohistochemical analysis. Thirty-three patients were found to be positive for p95 expression (33%). Forty-three patients were deemed to be PTEN negative and 57 patients were PTEN positive (57%). Forty-two patients were found to be PI3K positive (42%).

Results of p95, PTEN and PI3K immunohistochemical staining are shown in the Figure 1.

The relation of PTEN, p95, PI3K expression and response to trastuzumab treatment. Those patients with partial or complete remission to trastuzumab were defined as ‘responders’. The relation between response to trastuzumab and p95 expression was evaluated. There were no complete responders among the p95+ group, whereas 14 patients displayed partial response. On the other hand, 34 patients showed partial response, and 5 patients showed complete responses with no p95 immunoreactivity.

This difference between p95 expressors and non-expressors in relation to response to trastuzumab was found to be statistically highly significant ($P=0.001$).

Response to trastuzumab was also investigated in terms of PTEN status. PTEN expressors showed 28% partial response, with 5% complete response, whereas PTEN-negative group showed 20% partial response, with 0% complete response. This difference was again statistically significant ($P=0.012$).

PI3K expressors showed 22% partial response, with 2% complete response, whereas PI3K-negative group showed 26% partial response with 3% complete response. This difference was not statistically significant ($P=0.12$). Response to trastuzumab and p95, PTEN and PI3K status are collectively summarised in Table 2.

PFS and p95, PTEN and PI3K status. The median PFS was found to be 13 months (95% CI, 10.1–16 months) in the whole group of patients who received trastuzumab.

PFS was 8 months (95% CI, 2.5–13.4 months) in p95 expressors versus 22 months (95% CI, 9.9–34 months) in non-expressors ($P=0.0001$) (Figure 2A); 15.3 months (95% CI, 12.6–34 months) in PTEN expressors versus 12.1 months (95% CI, 7.9–16.2 months) in non-expressors ($P=0.04$) (Figure 2B); and 12.8 months (95% CI, 9.2–16.6 months) in the group of patients expressing PI3K versus 14.3 months (95% CI, 8.6–17.1 months) in patients with no PI3K expression ($P=0.2$) (Figure 2C).

Factors influencing PFS by univariate analysis. Median PFS was found to be significantly prolonged in patients responding to trastuzumab and with no visceral metastases. No other factor was identified with an effect on PFS. Those patients responding to treatment with trastuzumab had a median PFS of 23.1 months (95% CI, 12.4–36.6 months), whereas non-responders had a median PFS of 8.2 months (95% CI, 4.9–16.1 months) ($P=0.001$).

Table 1. Demographic characteristics of 100 patients with HER2-positive breast cancer

N = 100	
Age, median (range)	55 (22–82)
ECOG performance status	
0	20
1	75
2	5
Menopausal status	
Premenopausal	40
Postmenopausal	60
Hormone receptor status	
ER(+)/PR(+), ER(+)+PR(+)	59
ER(-)/PR(-)	41
HER2 status	
HER2 IHC 3+	94
HER2 IHC 2+, FISH+	6
Number of metastatic sites	
1	54
2	26
≥3	20
Metastatic site	
Visceral organs	64
Non-visceral organs	36
Histology	
Invasive ductal	98
Invasive ductal+lobular	2
Tumour grade	
Grade 1	2
Grade 2	40
Grade 3	58
Abbreviations: ECOG = Eastern Cooperative Oncology Group; ER = estrogen receptor; FISH = fluorescence in situ hybridization; IHC = immunohistochemistry; PR = progesterone receptor.	

In the group of patients with visceral metastases, median PFS was found to be 11.1 months (95% CI, 7.4–16.6 months), whereas in patients with no visceral involvement this was 28 months (95% CI, 14.9–46.1 months) ($P=0.029$) (Table 3).

Independent factors influencing PFS by Cox regression analysis. Presence of visceral metastases, p95 expression and response to trastuzumab are identified as factors independently affecting PFS (Table 4).

The relation of p95, PTEN and PI3K status and OS. Median OS was found to be 26 months (95% CI, 12.3–44.6 months) in the whole group of patients who received trastuzumab. OS was 24 months (95% CI, 8.3–40.4 months) in p95 expressors versus 29.1 months (95% CI, 8.6–43.2 months) in non-expressors ($P=0.045$) (Figure 3A); 25.1 months (95% CI, 7.5–40.1 months) in PTEN expressors versus 26.8 months (95% CI, 8.1–42 months) in non-expressors ($P=0.5$) (Figure 3B); and 24.8 months (95% CI, 12.5–39.8 months) in the group of patients expressing PI3K versus 26.7 months (95% CI, 9.8–43.2 months) in patients with no PI3K expression ($P=0.42$) (Figure 3C).

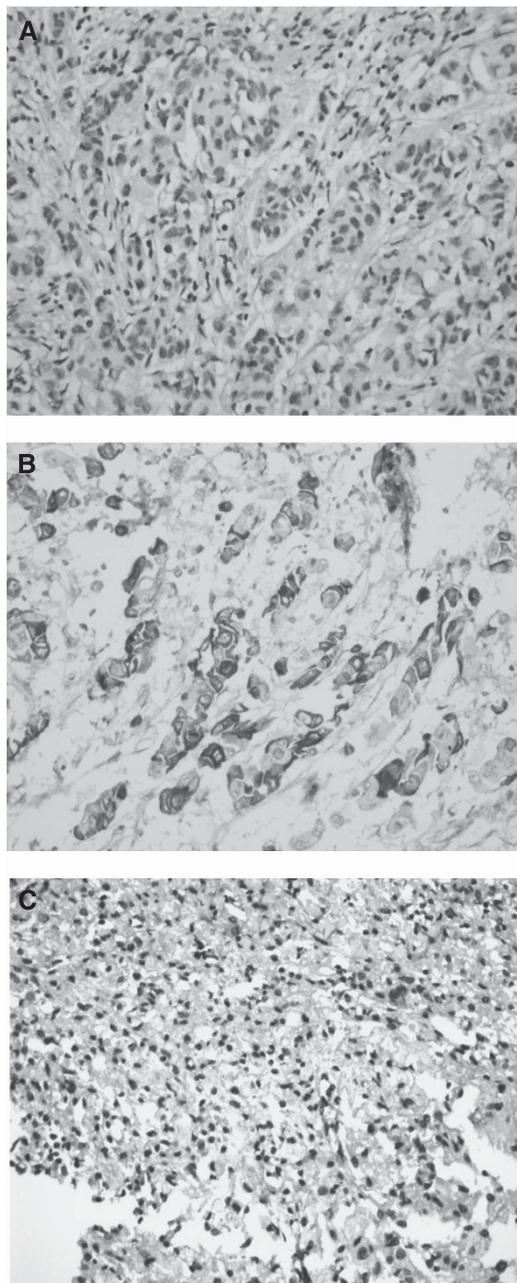


Figure 1. (a) PTEN positive: using immunoreactive score (IRS) and specimens were defined as positive when score was 7 or greater. (b) PI3K positive: tumours were scored when 50% of the neoplastic cells showed a distinct cytoplasmic staining. (c) p95 expression positive: tumours were scored when $\leq 50\%$ cells showed nucleolus and cytoplasmic staining detected with the anti-p95 antibody.

Factors influencing OS by univariate analysis. Response to trastuzumab and absence of visceral metastases are found to be predictors of significantly prolonged OS. No other clinical or pathologic factor has influenced OS. Median OS of responding patients was 32.2 months (95% CI, 16.4–46.8 months), whereas non-responders lived a median of 24 months (95% CI, 14.9–34.1 months). This difference was found to be statistically significant ($P = 0.015$).

In patients with visceral metastases, OS was 22.1 months (95% CI, 17.2–32.3 months), whereas those patients with no visceral metastases enjoyed a median OS of 29.4 months (95% CI, 15.6–42.3 months) ($P = 0.016$) (Table 3).

Independent factors influencing OS by Cox regression analysis.

Response to trastuzumab was identified as the single parameter influencing survival by Cox regression analysis (Table 4).

DISCUSSION

Overexpression of p185HER2 is an established poor prognostic factor in breast cancer, portending an aggressive course and potential for early metastasis. On the other hand, monoclonal antibody trastuzumab is widely used in the clinic to target this overexpressed oncogene. Unfortunately, only $\sim 30\text{--}40\%$ of all patients overexpressing ERBB2 respond to trastuzumab, warranting further research regarding the structure and additional modulation of the receptor. In this study, we aimed to investigate the response to trastuzumab in terms of the potential roles of several oncogenic pathways (PTEN and PI3K) and a truncated receptor protein, p95HER2, by analysing paraffin-embedded archival material retrospectively.

We found the truncated receptor, p95HER2, which is formed by the cleavage of the extracellular domain of p185HER2, in 33% of the specimens that we studied. This truncated receptor is resistant to inhibition by the humanised monoclonal antibody trastuzumab, yet retains the ability to transmit oncogenic stimuli through the signal transduction cascade. It has been reported as one of several mechanisms of resistance to trastuzumab therapy. Yet no extensive patient databases regarding p95HER2 status are available to guide treatment decisions.

Molina *et al* (2002) have reported a p95HER2 positivity of 26.7 and 45.7% in the primary tumour ($n = 337$) and lymph nodes ($n = 81$) of HER2-positive patients by western blot analysis.

Scaltriti *et al* (2010) have found p95HER2 positivity in 26% of the previously treated patients who have received lapatinib and capecitabine on retrospective analysis.

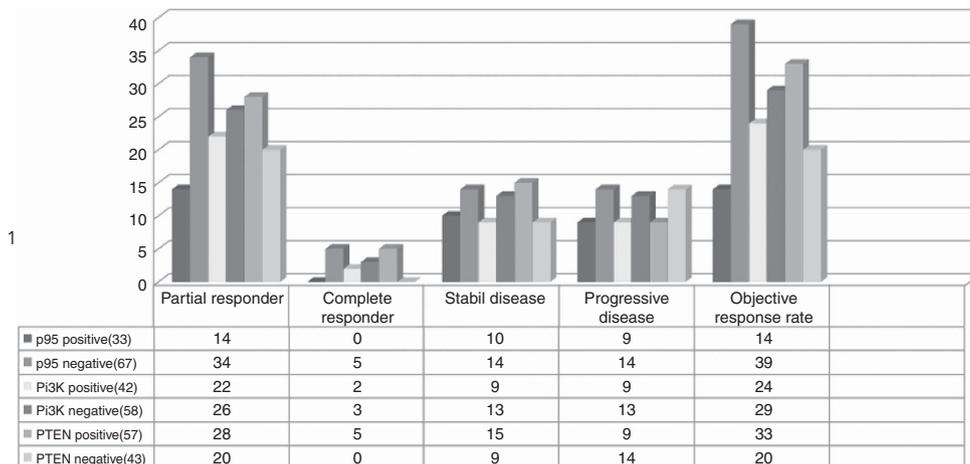
Most of the reported studies that have shown a 30% rate of positivity for p95HER2 expression have utilised western blot technique. Western blot is the current standard for p95HER2 analysis, but it is costly and time consuming. Immunofluorescence and immunoprecipitation techniques are also cumbersome and hard to incorporate into daily practice. We postulated that a standardised IHC might hasten the routine analysis for p95HER2 in all breast cancer patients in daily practice. Our findings are consistent with reports in the literature, which have utilised the methods described above (Scaltriti *et al*, 2010).

In our study, median PFS of patients with p95HER2 expression ($n = 33$) has been found to be 8 months versus 22 months in patients with no expression of p95HER2 ($n = 67$), which is consistent with a significantly shortened time to resistance in trastuzumab-receiving patients who express this truncated receptor protein. Again, a median OS of 24 months in patients with p95HER2 expression in comparison with an OS of 29.1 months in non-expressors points to a decreased survival in patients expressing p95HER2. Cox regression analysis has further substantiated the finding that p95HER2 positivity is a significant independent variable for PFS (HR = 2.1), whereas it has not supported p95HER2 positivity as an independent variable for OS.

Sáez *et al* (2006) have investigated the prognostic role of p95HER2 expression. They have reported that, in 483 patients who had adequate tumour specimen, p95HER2 expressors displayed a disease-free interval, which was considerably shorter than that of non-expressors. This study conclusively showed that p95HER2 expression is an independent prognostic factor for breast cancer patients.

Preclinical studies have yielded evidence that HER2-positive breast tumours that express p95HER2 is intrinsically resistant to trastuzumab. In 46 breast cancer patients, 1 out of 9 patients that

Table 2. The relation of PTEN, p95, PI3K expression and response to trastuzumab treatment



Abbreviations: PTEN = phosphatase and tensin homologue; PI3K = phosphatidylinositol 3-kinase.

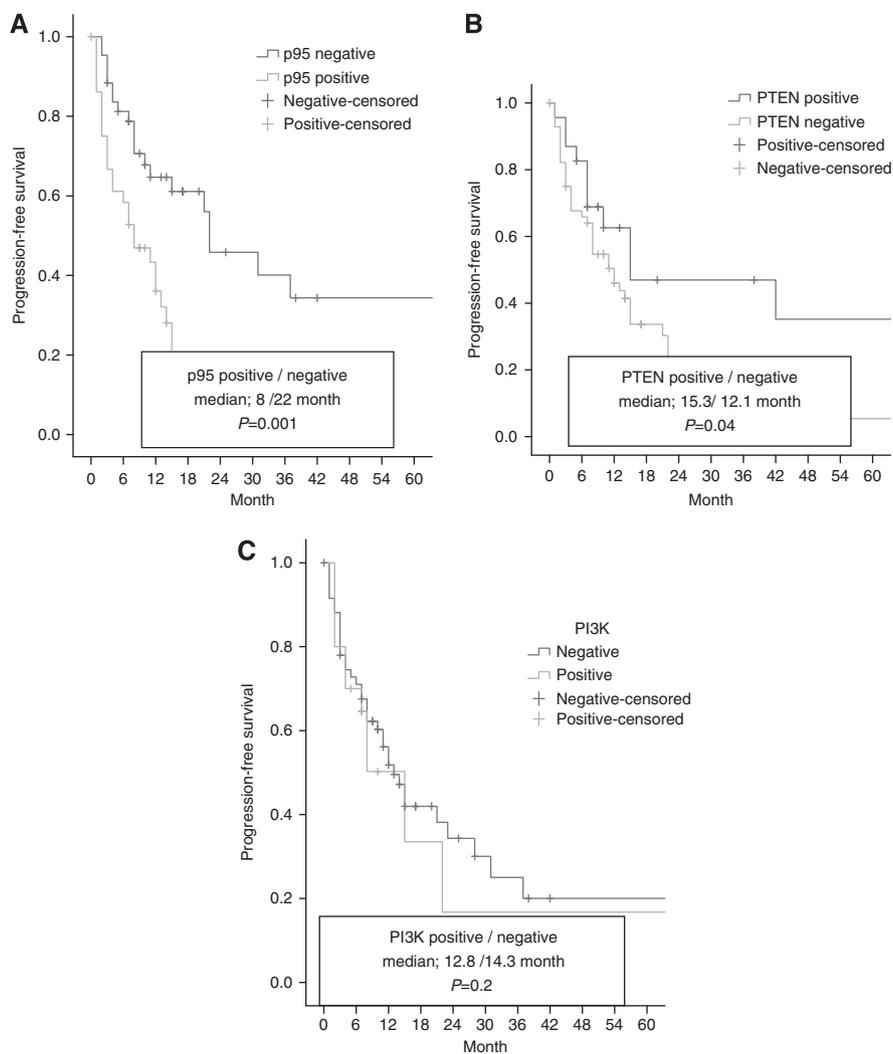


Figure 2. Patients' progression-free survival according to p95, PTEN, PI3K statuses in HER2-positive metastatic breast cancer.

Table 3. Factors influencing PFS and OS by univariate analysis

	PFS	OS
	HR (95% CI)	HR (95% CI)
Age	<i>P</i> = 0.1	<i>P</i> = 0.2
≤ 55 years	1.08 (0.89–1.12)	1.01 (0.9–1.2)
> 55 years	1	1
Adjuvant CT	<i>P</i> = 0.08	<i>P</i> = 0.1
Present (65%)	1.12 (0.92–1.22)	1.2 (0.82–1.32)
Absent (35%)	1	1
Hormone receptor status	<i>P</i> = 0.2	<i>P</i> = 0.3
Positive (59%)	0.98 (0.92–1.1)	0.88 (0.72–1.13)
Negative (41%)	1	1
First metastatic site brain	<i>P</i> = 0.07	<i>P</i> = 0.12
Present (11%)	0.81 (0.66–1.28)	0.91 (0.76–1.08)
Absent (89%)	1	1
Adjuvant trastuzumab	<i>P</i> = 0.12	<i>P</i> = 0.14
Present (28%)	0.88 (0.6–1.31)	0.79 (0.63–1.11)
Absent (72%)	1	1
ECOG performance status	<i>P</i> = 0.04	<i>P</i> = 0.01
0	0.6 (0.24–0.88)	0.55 (0.21–0.84)
1 or 2	1	1
Menopausal status	<i>P</i> = 0.3	<i>P</i> = 0.5
Premenopausal (40%)	0.94 (0.89–1.1)	0.96 (0.91–1.03)
Postmenopausal (60%)	1	1
Tumour grade	<i>P</i> = 0.09	<i>P</i> = 0.09
Grade 1 and 2 (42%)	0.82 (0.61–1.29)	0.84 (0.65–1.20)
Grade 3 (58%)	1	1
Number of metastatic sites	<i>P</i> = 0.06	<i>P</i> = 0.07
≤ 3 sites (80%)	0.8 (0.68–1.18)	0.84 (0.78–1.14)
> 3 sites (20%)	1	1
Trastuzumab-based treatment	<i>P</i> = 0.072	<i>P</i> = 0.081
Chemotherapy + trastuzumab (85%)	0.83 (0.73–1.28)	0.88 (0.70–1.38)
Endocrine treatment + trastuzumab (15%)	1	1
p95	<i>P</i> = 0.01	<i>P</i> = 0.045
Positive (33%)	2.1 (1.1–3.7)	1.24 (1.08–1.87)
Negative (67%)	1	1
PTEN	<i>P</i> = 0.04	<i>P</i> = 0.5
Positive (57%)	0.61 (0.48–0.86)	0.86 (0.78–1.16)
Negative (43%)	1	1
PI3K	<i>P</i> = 0.2	<i>P</i> = 0.42
Positive (42%)	0.98 (0.96–1.11)	0.94 (0.91–1.20)
Negative (58%)	1	1
Visceral metastases	<i>P</i> = 0.009	<i>P</i> = 0.016
Present	2.38 (1.2–4.5)	1.9 (1.18–2.82)
Absent	1	1
Trastuzumab treatment response	<i>P</i> = 0.014	<i>P</i> = 0.015
Absent	2.2 (1.18–4.47)	2.1 (1.12–3.07)
Present	1	1

Abbreviations: CI = confidence interval; CT = chemotherapy; ECOG = Eastern Cooperative Oncology Group; HR = hormone receptor; OS = overall survival; PFS = progression-free survival; PI3K = phosphatidylinositol 3-kinase; PTEN = phosphatase and tensin homologue.

expressed p95HER2 had a response to trastuzumab, while p185HER2 expressing 19 patients out of 37 responded to trastuzumab (Scaltriti *et al*, 2007).

Sperinde *et al* (2010) also reported a shorter PFS and OS in a retrospective study among the group of patients with higher levels

Table 4. Independent factors influencing PFS and OS by Cox regression

	PFS	OS
	HR (95% CI)	HR (95% CI)
Visceral metastases	<i>P</i> = 0.009	<i>P</i> = 0.08
Present	2.38 (1.2–4.5)	1.28 (0.96–2.15)
Absent	1	1
ECOG performance	<i>P</i> = 0.09	<i>P</i> = 0.08
0	0.84 (0.81–1.12)	0.81 (0.72–1.24)
1 and 2	1	1
p95	<i>P</i> = 0.03	<i>P</i> = 0.2
Positive	2.1 (1.1–3.7)	1.14 (0.88–1.49)
Negative	1	1
Trastuzumab treatment response	<i>P</i> = 0.014	<i>P</i> = 0.013
Absent	2.2 (1.18–4.47)	1.7 (1.14–3.47)
Present	1	1

Abbreviations: CI = confidence interval; ECOG = Eastern Cooperative Oncology Group; HR = hormone receptor; OS = overall survival; PFS = progression-free survival.

of p95HER2 and suggested that the presence of p95HER2 might be predictive of resistance to trastuzumab.

Poor response to trastuzumab in those patients who express p95HER2 has paved the way for alternative strategies other than trastuzumab to inhibit the HER2 oncogenic pathway. Lapatinib is a small-molecule TK inhibitor with dual action; the drug inhibits both ERBB1 and ERBB2. Scaltriti *et al* (Scaltriti *et al*, 2007) have shown in *in vitro* studies that have utilised p95HER2-expressing cell cultures that lapatinib has inhibited p95 and AKT downstream phosphorylation, thus inhibiting cell growth, whereas these cells have proven resistant to trastuzumab. Same investigators have also reported the efficacy of lapatinib in patients with p95HER2-expressing breast cancer.

As the antibody-binding extracellular domain is absent, trastuzumab is unable to bind to its target with resulting loss of its efficacy. Recent reports have supported the idea of ‘dual inhibition’, use of an intracellular tyrosine kinase inhibitor, such as lapatinib, alongside with trastuzumab to overcome acquired trastuzumab resistance. Another strategy employed simultaneous use of two different monoclonal antibodies. Two monoclonal antibodies targeting the extracellular domain of ERBB2 receptor with different mechanisms of action, one binding to a different epitope and the other conjugated to a cytotoxin, have recently been approved for clinical use (Baselga *et al*, 2012).

On the other hand, neoadjuvant trials have shown that p95 status and PTEN level had effect on pathologic complete response (Loibl *et al*, 2011; Ignatiadis *et al*, 2012). Loibl *et al* have shown that pathologic complete response rate in the p95-positive tumours was higher than when are compared patients with p95 negative tumours in the patients received trastuzumab-containing treatment in primary HER2 positive breast cancer. Their expectation was that p95 expression measured by IHC indicates response to neoadjuvant trastuzumab-containing treatment in primary HER2-positive breast cancer but not resistance (Loibl *et al*, 2011). Ignatiadis *et al* (2012) demonstrated that PTEN loss and IGF1 activation had increased pathologic complete response probability.

PTEN is a lipid phosphatase that acts as a ‘tumour suppressor’ by limiting the activity of PI3K pathway by removing one phosphate from the catalytically active PIP3. Nagata *et al* (2004) reported the findings from their *in vitro* studies that suggested trastuzumab inhibiting the PI3K/Akt pathway by activating PTEN. PTEN loss is hence associated with resistance to trastuzumab and might be a predictor of lower trastuzumab efficacy.

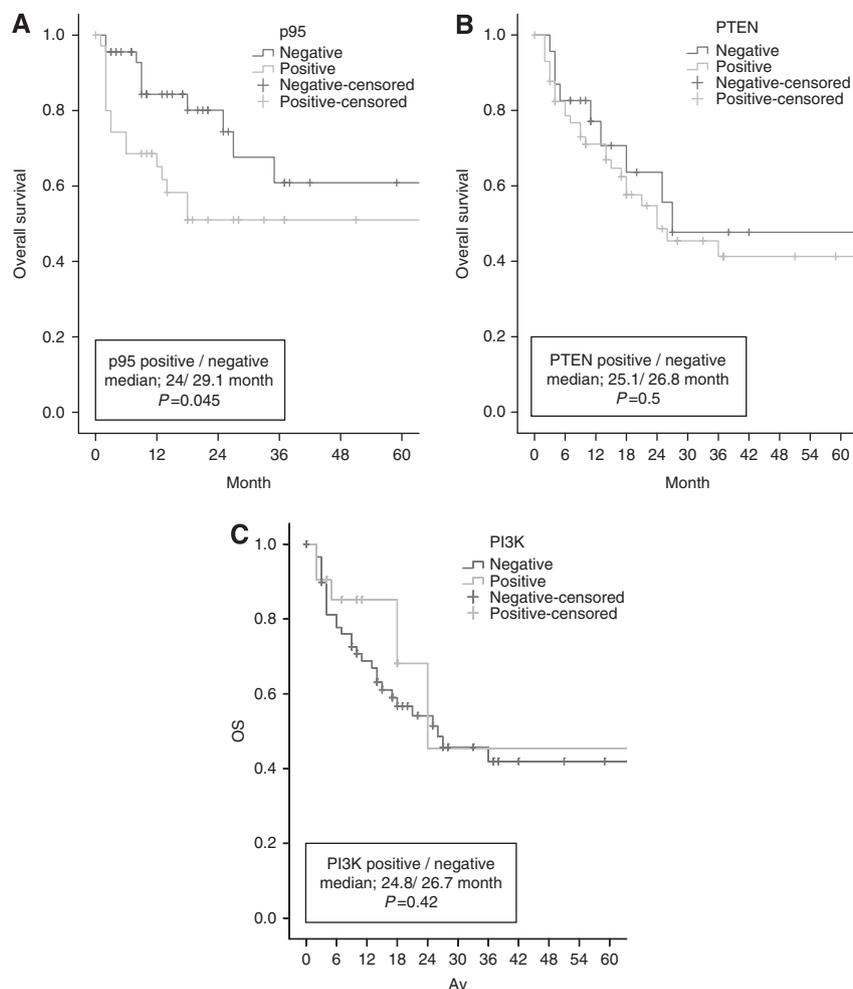


Figure 3. Patients' overall survival according to p95, PTEN, PI3K statuses in HER2-positive metastatic breast cancer.

PTEN loss has been reported in 15–48% of breast cancer cases (Torres *et al*, 2001; Bose *et al*, 2002; Lee *et al*, 2004; Wang *et al*, 2011).

Wang *et al* (2011) reported a shortened PFS associated with PTEN loss in a group of patients with metastatic breast cancer. In the largest study group reported, Esteva *et al* (2010) showed that PTEN loss alone or in combination with PI3K mutations has predicted a decreased response to trastuzumab and a shortened survival. In addition, Faratian *et al* have shown that PTEN expression levels were all associated with significant survival differences in univariate and multivariate analyses. Also, they have demonstrated that PTEN exerted dominant control in downstream pathway activation and resistance to receptor tyrosine kinase (Faratian *et al*, 2009). Fabi *et al* have reported that the PTEN-positive/p-Akt-positive phenotype is associated with prolonged PFS but not with OS. Staining intensity (strong, moderate and weak) and distribution have been the standard criteria for PTEN expression in all these studies (Fabi *et al*, 2010). Following Nagata *et al* (2004), IRS has replaced these criteria as the sole diagnostic criterion for PTEN expression.

We found a 43% PTEN loss in our study group by using IHC based on IRS scoring, which was consistent with what was previously reported in the literature. Our study also showed a lower rate of response to trastuzumab and shorter PFS for PTEN non-expressors (PFS of 12.1 versus 15.3 months). PTEN expression was also associated with a significantly longer duration of trastuzumab efficacy, but no significant association with survival. This finding was also consistent with what was reported in the literature (Nagata *et al*, 2004; Fujita *et al*, 2006; Esteva *et al*, 2010; Wang *et al*, 2011).

PI3K complex is composed of a heterodimer with a p85 regulatory subunit and a p110 catalytic subunit (PIK3CA). In retrospective studies, activating mutations of PIK3CA has been reported in 18–40% of breast cancer, the most common being point mutations involving exons 9 and 20. Exon 20 mutation H1047R is adjacent to the activation loop and gives rise to persistently elevated kinase activity (Isakoff *et al*, 2005; Li *et al*, 2006; Barbareschi *et al*, 2007). PI3K mutations alone or in combination with PTEN loss are also reported to be associated with resistance to trastuzumab.

In the study by Berns *et al* (2007), PI3K mutations alone did not have a significant impact on PFS, but in patients with both PTEN loss and PI3K mutations PFS decreased significantly.

In our study, we used an antibody directed against the p85 regulatory subunit of PI3K. PI3K expression was noted in 42% of the patients. We were not able to show relation of PI3K mutations neither with response to trastuzumab nor with PFS and OS.

In the study by Fabi *et al* (2010), 46% of 73 patients with ERBB2-positive breast cancer expressed PI3K, which was consistent with our findings, but contrary to our study, they have reported a positive association of the PTEN-positive/PI3K-positive phenotype with prolonged PFS but not OS. They reported that Cox regression analysis did not confirm this finding. The study also failed to show the same phenotype predict the response to trastuzumab.

On the other hand, Loibl *et al* prospectively evaluated *PIK3CA* mutations in the 512 participants of the neoadjuvant Geparsixto (G6) study and validated in 225 participants of the GeparQuinto (G5) study. Overall, pathologic complete response rate was

significantly lower in the *PIK3CA* mutant compared with wild group. This effect was only significant within the HER2-positive group. Within the HER2-positive/HR-positive subgroup the *PIK3CA*-mutant patients had a pathologic complete response rate of only 6.5% compared with 30.8% in the wild group ($P=0.005$). In contrast, there was no difference in pathologic complete response rate (42.9% versus 46.1%) according to *PIK3CA* mutation status in the HER2-positive/HR-positive ($P=0.825$) group. This study suggested that patients with *PIK3CA*-mutant HER2-positive/HR-positive breast cancer are resistant to chemotherapy and dual anti-HER2 treatment. Other treatment options are needed to be tested in this group (Loibl *et al*, 2013).

Absence of visceral metastases predictably turned out to be a factor with a significantly favourable impact on both PFS and OS.

Cox regression analysis supported the data that suggested response to trastuzumab, negative p95 status and absence of visceral metastasis are significant prognostic variables for PFS and can help predict disease-free interval; OS of 32.2 months in the trastuzumab-responding group and 29.4 months in the group with no visceral metastasis further substantiate this conclusion. Furthermore, Cox regression analysis confirmed that response to trastuzumab is the single independent factor for OS.

We finally conclude that one out of three ERBB2-positive breast cancer patients (33%) express p95HER2, and p95HER2 is a significant predictive factor for a poor response to trastuzumab and a shorter time to resistance, and thus a poor prognostic factor in terms of PFS and OS. We found that PTEN loss occurred in 43% of our study group and correlated with resistance to trastuzumab and shortened PFS. Our study also showed that immunohistochemical determination of PI3K expression did predict neither response to trastuzumab nor PFS or OS. Significant prolongation of PFS and OS in trastuzumab-responding patients confirms that this is an important predictive factor. We also found out rather predictably that patients with visceral metastases do poorly in terms of both PFS and OS.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Clinical significance of p95HER2 overexpression, PTEN loss and PI3K expression in p185HER2-positive metastatic breast cancer patients treated with trastuzumab-based therapies

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It has been brought to our attention that, as a result of a miscommunication, the antibody used in this study in order to determine the expression of p95 HER2 in metastatic breast cancer patients is in fact directed against p95 NBS1, a component of the MRN complex, and is completely unrelated to p95 HER2.

Therefore, a relationship between p95 HER2 overexpression and outcome cannot be established based on the results described and we wish to retract our paper.

The authors, the editors of *British Journal of Cancer*, and the referees of this paper are grateful to colleagues in the field who have brought this problem to our attention and we apologise for any confusion that has, inadvertently, been caused.