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## Invasiveness and anchorage independent growth ability augmented by PTEN inactivation through the PI3K/AKT/NFκB pathway in lung cancer cells

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### ABSTRACT

PTEN is inactivated in a subset of lung cancer; therefore, we investigated the involvement of PTEN inactivation in invasiveness of lung cancer cells. AKT at Ser473 was phosphorylated in several lung cancer cell lines with loss of PTEN expression. Therefore, we created a tetracycline inducible expression system of wild-type PTEN (PTEN-WT) as well as catalytically (PTEN-G129R) and lipid phosphatase (PTEN-G129E) inactive PTEN mutants using the PC14, PC9 and PC3 lung adenocarcinoma cell lines, in which endogenous PTEN expression was not detected and AKT at Ser473 was phosphorylated by Western blot analysis. Induction of PTEN-WT reduced phosphorylation of AKT and inhibited the transcriptional activity of NFκB, whereas PTEN mutants did not, suggesting that PTEN inactivation results in the activation of the AKT/NFκB pathway in PC14, PC9 and PC3 cells. Furthermore, overexpression of PTEN-WT suppressed anchorage independent growth in soft agar and reduced invasiveness in a trans-well chamber assay of PC14 cells. Neither PTEN-G129R nor PTEN-G129E had suppressive effects on anchorage independent growth and invasiveness. Augmentation of invasiveness by constitutively active AKT was also shown in mouse NIH3T3 cells. Therefore, it was strongly indicated that activation of the PI3K/AKT/NFκB pathway by PTEN inactivation results in augmented invasiveness in lung cancer cells and lipid phosphatase activity of PTEN plays a key role in this process.

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### 1. Introduction

The PTEN (phosphatase and tensin homologue deleted on chromosome 10) tumor suppressor gene is frequently deleted or mutated in a wide variety of human cancers, including glioblastoma [1], melanoma [2], prostate cancer [3], breast cancer [4], lung cancer [5], and endometrial cancer [6]. In addition, PTEN germline mutations are responsible for the development of Cowden disease, Bannayan-Zonana syndrome [7,8] and Lhermitte Duclos disease, in which disorganized hamartomas appear in various organs [9]. Besides functioning as a tumor suppressor, PTEN is also essential for embryonic development [10,11]. PTEN encodes a protein that has sequence homology with phosphatases which dephosphorylate both tyrosine and serine/threonine phosphates on proteins [12–14]. PTEN is also capable of dephosphorylating inositol phospholipids [15]. In particular, PTEN dephosphorylates phosphatidylinositol-3,4,5-triphosphate (PIP3) and phosphatidylinositol-4,5-bisphosphate (PIP2). Formation of these lipids is catalyzed by phosphoinositol 3-kinase (PI3K) upon stimulation with growth factors [16]. PIP2 and PIP3 are both

involved in the PI3K signaling pathway [15,17–19]. One important downstream target of PI3K is the AKT serine/threonine kinase [19]. AKT is recruited to the plasma membrane by PIP3, and then phosphorylated at Thr308 by protein dependent kinase 1 (PDK1). For full activation, AKT needs to be subsequently phosphorylated at Ser473 by PDK2. Activated AKT leaves the membrane and phosphorylates its downstream targets such as Bad [20], IKKα and mTOR [20,21]. AKT activation induces expression of the anti-apoptotic Bcl-2, activation of NFκB, inhibition of Forkhead family of transcription factors, and inactivation of pro-apoptotic Bad [22–25]. AKT-mediated modifications of above target genes ultimately result in cellular transformation, survival, proliferation and invasion of a variety of cancers [26–29].

Lung cancer is the leading cause of cancer death in the world [30], and approximately 90% of patients with lung cancer ultimately die from metastatic disease [31]. Metastasis is the end result of a complex series of steps involving multiple tumor-host interactions [32]. One important step in this process is invasion of cancer cells. PTEN is inactivated in a subset of and Akt is activated frequently in lung cancer. However, it is unknown whether PTEN plays any role in lung cancer cell invasion and whether such an effect is mediated through the PI3K/AKT/NFκB pathway. To address this question, we first screened several lung cancer cell lines for the status of PTEN and AKT. We then constructed a PTEN inducible system using the

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PC14 lung cancer cell line, in which endogenous PTEN is absent and AKT is phosphorylated. The results indicate that PTEN inactivation plays an important role in the invasiveness of lung cancer cells and this process is mediated by the PI3K/AKT/NF- $\kappa$ B pathway.

## 2. Materials and methods

### 2.1. Cell culture

PC3, PC9 and PC14 cells were cultured in RPMI-1640 medium (Sigma Aldrich, St. Louis, MO) supplemented with 10% fetal bovine serum (Invitrogen, Carlsbad, CA) at 37 °C in a humidified incubator with 5% CO<sub>2</sub>.

### 2.2. Construction of PTEN expression vectors and transfection

PTEN cDNA was cloned as described by Myers et al. [33]. Briefly, total RNA was extracted from A549 cells using Trizol (Life Technologies), and the first-strand cDNA was synthesized using oligo(dT) and Superscript RNaseH2 RT, according to the manufacturer's protocol (Life Technologies). PTEN cDNA was amplified using forward (5'-CGCGAATTCGCCATGGCAGCCATCATCAAAGAGATCGTTAGCAGAAACAAAAGGAGATATCAAGAGGATGGATTGCACTTAGAC-3') and reverse (5'-CGCGAATTCAGACTTTTGTAAATTTGTGTATGCTGATCTTCATCAAAAGGTTCAATCTCTGGATCAGAGTCAGTCGGAGGTGTCAGA-3') primers and Pfu DNA polymerase (Stratagene), and amplified cDNA was cloned into pcDNA 3 and a tetracycline inducible vector pcDNA4/TO. The PTEN-G129R and PTEN-G129E mutants were generated by site-directed mutagenesis. By using FUGEN (Roche), PC14 cells were first stably transfected with a regulatory plasmid pcDNA6/TK, and clones resistant to blasticidin (10  $\mu$ g/ml) were then stably transfected with the pcDNA4/TO-PTEN-WT, pcDNA4/TO-PTEN-G129R, and pcDNA4/TO-PTEN-G129E expression vectors. Double transfectants were selected in the medium containing blasticidin (10  $\mu$ g/ml) and zeocin (50  $\mu$ g/ml). PTEN expression was induced by addition of tetracycline (2  $\mu$ g/ml) and was verified by Western blot analysis. pcDNA-PTEN-WT, pcDNA-PTEN-G129R and pcDNA-PTEN-G129E vectors used for transient transfection studies.

### 2.3. Western blot analysis

Cell lysates were prepared in ice-cold RIPA buffer (10 mM Tris-HCl pH7.5, 150 mM NaCl, 2 mM EDTA, 1% NP40, 1% sodium deoxycholate, 0.1% SDS). Cellular debris was removed by centrifugation at 12,000  $\times$  g for 5 min at 4 °C. One hundred  $\mu$ g of proteins were subjected to SDS-PAGE using 2–15% or 7.5% polyacrylamide gels (PIERCE), proteins were immunoblotted onto Hybond-PVDF membrane (Amersham-PharmaciaBiotech), and labeled with antibodies. AKT and phospho-AKT (Ser473) antibodies were obtained from Cell Signaling Technology. PTEN, GAPDH, Tubulin and horseradish peroxidase-conjugated secondary antibodies were obtained from Santa Cruz Biotechnology. Primary and secondary antibody labeling blots were treated with Super Signal West Pico chemiluminescent substrate (Pierce), exposed to Hyperfilm ECL (Amersham-PharmaciaBiotech), and developed.

### 2.4. Proliferation assay

Mock, pcDNA4/TO-PTEN-WT, pcDNA4/TO-PTEN-G129R, and pcDNA4/TO-PTEN-G129E transfected PC14 cells were seeded into 96-well plates (7.5  $\times$  10<sup>4</sup> cells/ml) and treated with tetracycline (2  $\mu$ g/ml) for 24 h. At the end of the incubation period, cell numbers were counted by a luminometric method using a CytotoxGlo kit (Promega).

### 2.5. Luciferase reporter assay

Mock, pcDNA4/TO-PTEN-WT, pcDNA4/TO-PTEN-G129R, pcDNA4/TO-PTEN-G129E stably transfected PC14 cells were transfected with pGL3-NF $\kappa$ B-promoter-Luc (0.5  $\mu$ g/well) and with pRL-Renilla (0.05  $\mu$ g/well). For PC9 and PC3 cells; Mock, pcDNA4/TO-PTEN-WT, pcDNA4/TO-PTEN-G129R, pcDNA4/TO-PTEN-G129E transiently co-transfected with pGL3-NF $\kappa$ B-promoter-Luc (0.5  $\mu$ g/well) and with pRL-Renilla (0.05  $\mu$ g/well). Following transfection, cells were treated with tetracycline (2  $\mu$ g/ml) and cultured for an additional 24 h. Luciferase activities were then measured using a luciferase Assay System Kit (Promega).

### 2.6. Soft agar colony assay

Anchorage independent growth was determined by a soft agar colony assay as described [34]. Briefly, 5  $\times$  10<sup>4</sup> cells were prepared in 3 ml of medium containing 0.4% noble agar (Difco), and layered onto 5 ml of bottom layer containing 0.5% noble agar (Difco). Two  $\mu$ g/ml tetracycline was added to both layers. Plates were incubated for 2–3 weeks, developed colonies were fixed and stained with HBSS containing 1.5% glutaraldehyde and 0.06% methylene blue, and visible colonies were counted.

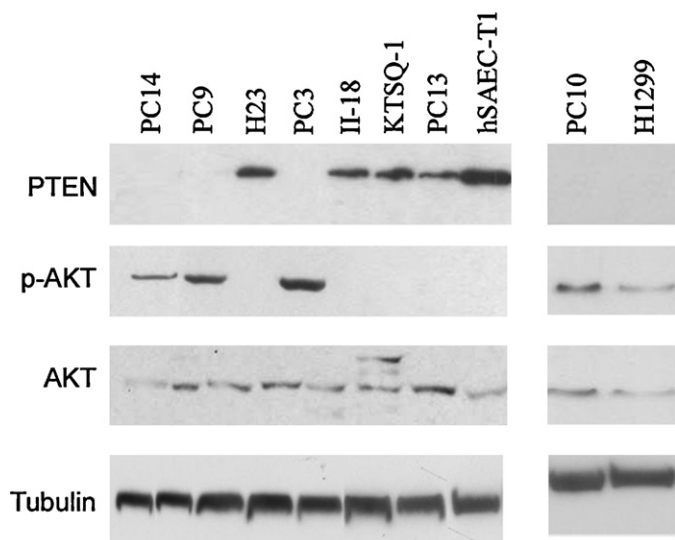
### 2.7. Cell invasion assay

Cell invasion assays were carried out using a trans-well matrigel invasion chamber (Becton Dickinson Labware). The chambers were hydrated with 1% BSA in RPMI-1640 for 1 h at room temperature, then placed into 24-well tissue culture plates containing 750  $\mu$ l of RPMI-1640 with 10% FCS. For invasion study, we transiently transfected PC9 and PC3 cells with pcDNA-PTEN-WT, pcDNA-PTEN-G129R, pcDNA-PTEN-G129E and stably transfected PC14 cells with pcDNA4/TO-PTEN-WT, pcDNA4/TO-PTEN-G129R, pcDNA4/TO-PTEN-G129E expression vectors. All cells were trypsinized, washed twice in PBS, and 1  $\times$  10<sup>4</sup> cells were added to each trans-well chamber and allowed to migrate to the bottom chamber for 24 h. Two  $\mu$ g/ml tetracycline was added to both chambers. After 24 h, cells on the upper surface of the filter were then removed by wiping with a cotton swab, and the number of migrated cells was determined. The extent of migration was expressed by normalizing the number of PTEN-WT, PTEN-G129R and PTEN-G129E expressing cells by that of empty vector transfected cells. Ten individual wells were counted for every experiment. Error bars representing S.E. and P<sub>s</sub> were calculated by repeated measurements of ANOVA (Graphpad Software), followed by a Student–Newman–Keuls test.

## 3. Results

### 3.1. Effects of PTEN expression on the PI3K/AKT/NF $\kappa$ B pathway in lung cancer cells

We first examined expression levels of PTEN in 9 lung cancer cell lines and in an immortalized small airway epithelial cell line, hSAEC-T1 [35], by Western blot analysis (Fig. 1). PTEN expression was detected in H23, II-18, KTSQ-1 and PC13 cells, but the amounts of PTEN protein in these cell lines were slightly lower than that in hSAEC-T1 cells. PTEN was not detected in the remaining five cell lines, PC14, PC9, PC3, PC10 and H1299, suggesting that PTEN is inactivated in these cell lines. It was previously reported that both allele of PTEN gene is deleted in PC10 and its promoter is methylated in PC14 and H1299 cells [5,36,37]. Consistent with these findings we did not observe any PTEN expression in these cells. Since AKT is downstream of the PTEN pathway and is often phosphorylated in



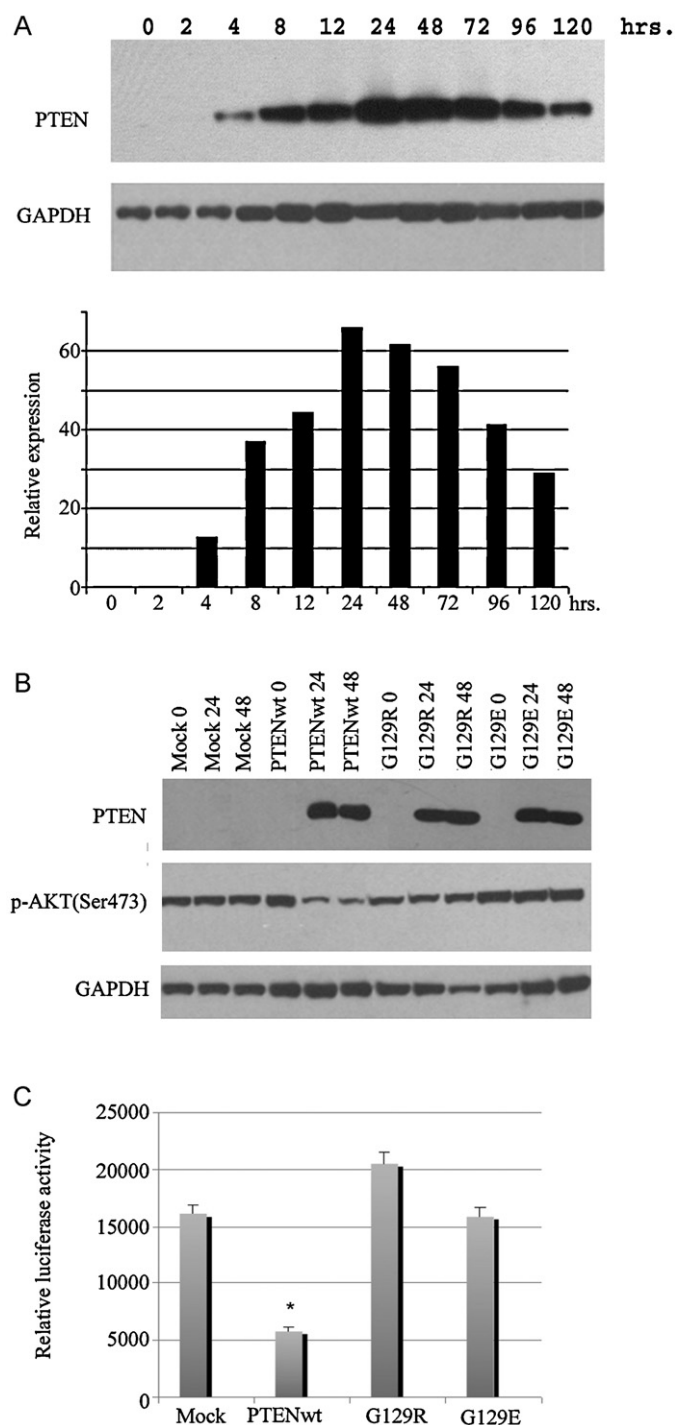
**Fig. 1.** Determining the levels of PTEN, phospho-AKT, and AKT in 9 lung cancer cell lines and an immortalized small airway epithelial cell line. Western blot analysis of PTEN, p-AKT and AKT protein expression in 9 NSCLC cell lines and one immortal lung epithelial cell. All cells were cultured in included in RPMI-1640 containing 10% FCS. Cells were lysed and then 100 microgram protein were fractionated on 4–20% gradient gel. Proteins were blotted onto PVDF membrane and labeled against indicated antibodies.

cells with PTEN inactivation, we next investigated the expression and phosphorylation of AKT in these cell lines. AKT was detected in all the cell lines examined. AKT at Ser473 was phosphorylated in five cell lines, PC14, PC9, PC3, PC10 and H1299, all of which showed the absence of PTEN protein. Therefore, it was strongly indicated that PTEN inactivation results in the activation of AKT in these lung cancer cell lines.

To examine the effect of PTEN expression in lung cancer cells, tetracycline-inducible PTEN vectors were constructed and transfected into PC14 cells, in which endogenous PTEN expression was not detected by Western blot analysis. Vectors carrying wild-type PTEN (PTEN-WT) as well as catalytically (PTEN-G129R) and lipid phosphatase (PTEN-G129E) inactive PTEN mutants were prepared for this study as described in Materials and Methods. These vectors were stably transfected into PC14 cells, transiently transfected in PC9 and PC3 cells, and PTEN induction after tetracycline treatment was confirmed by Western blot analysis. Representative results of PTEN induction are shown in Fig. 2A. Wild-type PTEN expression was detected 4 h after tetracycline treatment, reached the maximum level at 24 h, and continued up to 120 h after the treatment. We were also able to obtain PTEN-G129R and PTEN-G129E mutant-inducible cells. Induction of PTEN after 24 and 48 h of tetracycline treatment in PTEN-WT, PTEN-G129R and PTEN-G129E transfected cells are shown in Fig. 2B.

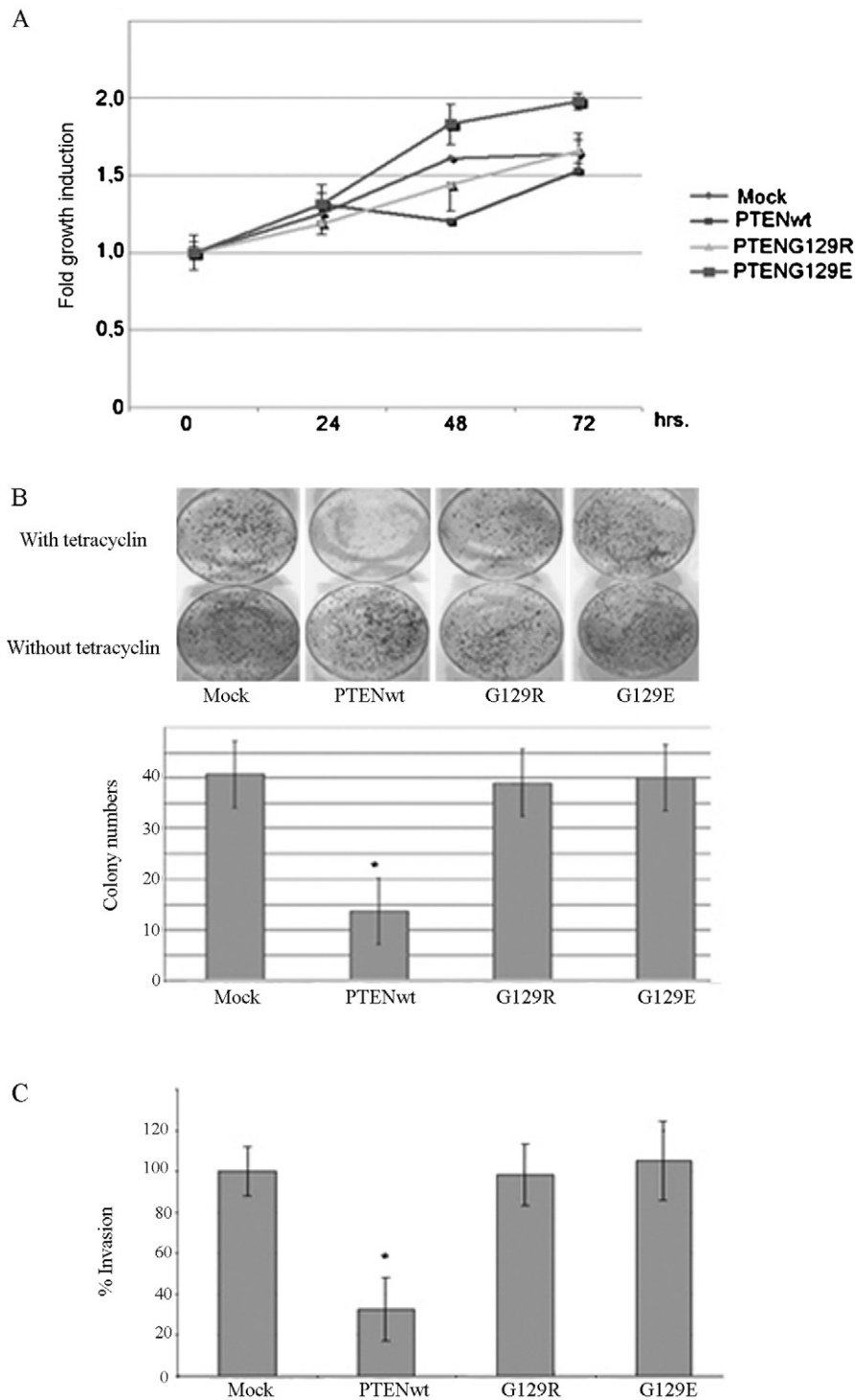
We next examined the effects of induced PTEN expression on phosphorylation levels of AKT in PC14 cells (Fig. 2B). The amount of phosphorylated AKT was decreased at both 24 h and 48 h after tetracycline treatment in PTEN-WT transfectants. In contrast, such a decrease was not observed in mock, PTEN-G129R and PTEN-G129E transfectants. Therefore, AKT phosphorylation was confirmed to be partly due to PTEN inactivation in PC14 cells.

NFκB is a downstream target of the PI3K/AKT pathway; therefore, we next examined the effects of PTEN expression on NFκB activity by a reporter assay. Cells expressing PTEN-WT, PTEN-G129R and PTEN-G129E were transiently transfected with an NFκB luciferase reporter vector and a renilla luciferase vector as internal control. Expression of wild type PTEN significantly inhibited



**Fig. 2.** Ectopic expression of PTEN and its effect on AKT phosphorylation and NFκB activity on PC14 cells. Cells stably transfected with PTEN-WT expression vector were treated with tetracycline (2 μg/ml) (A). Expressions of PTEN, p-AKT, and AKT were determined 0, 24 and 48 h after tetracycline treatment in mock, PTEN-WT, PTEN-G129R and PTEN-G129E transfected PC14 cells (B). The effects of PTEN-WT, PTEN-G129R and PTEN-G129E expression on NFκB activity (C). Error bars indicate S.D., \* $p < 0.05$  comparing PTENwt transfected cells to mock, G129R and G129E transfected cells.

NFκB activity; however, expression of PTEN mutants did not (Fig. 2C). These results indicate that PTEN can suppress the AKT/NFκB pathway through its lipid phosphatase activity in PC14 cells.



**Fig. 3.** The effects of ectopically expressed PTEN on anchorage dependent or independent growth and invasiveness of PC14 cells. Cell proliferation was determined with using luminometric method at 0, 24, 48, 72 time points (A). To determine the effects of PTEN-WT, PTEN-G129R and PTEN-G129E expression on anchorage independent growth, cells transfected with above plasmid were treated with 2  $\mu$ g/ml tetracycline, after 3 weeks developed colonies were methanol fixed, stained with toluidine blue, and visible colonies were counted (B). The effects of PTENwt, G129R and G129E expression on PC14 cells invasion.  $1 \times 10^4$  PC14 cells were seeded in to growth factor reduced matrigel invasion chamber in serum-free medium which included 2  $\mu$ g/ml tetracycline. Chemoattractant conditions were created by addition of 10% FCS containing RPMI-1640 medium. After 24 h invading cells were fixed, stained and counted. Error bars indicate S.D., \* $p < 0.05$  comparing PTENwt transfected cells to mock, G129R and G129E transfected cells.

### 3.2. Effects of PTEN expression on anchorage independent growth and invasiveness of lung cancer cells

We next examined the biological effects of PTEN-WT, PTEN-G129E and PTEN-G129R on PC14 cells. As shown in Fig. 3A, there was no significant difference on the growth rate between the mock

transfectants and cells expressing PTEN-WT, PTEN-G129E or PTEN-G129R under standard culture conditions. Since ability of cells to grow independently of adhesion is a feature of cancer cells, we examined the effect of PTEN expression on the anchorage independent growth of PC14 cells by a soft agar colony formation assay. As shown in Fig. 3B, tetracycline-induced expression of wild type



PTEN inhibited the growth of PC14 cells in soft agar, but neither PTEN-G129E nor PTEN-G129R had such an effect on PC14 cells. Therefore, anchorage independent growth but not anchorage dependent growth was suppressed by wild-type PTEN expression in PC14 cells.

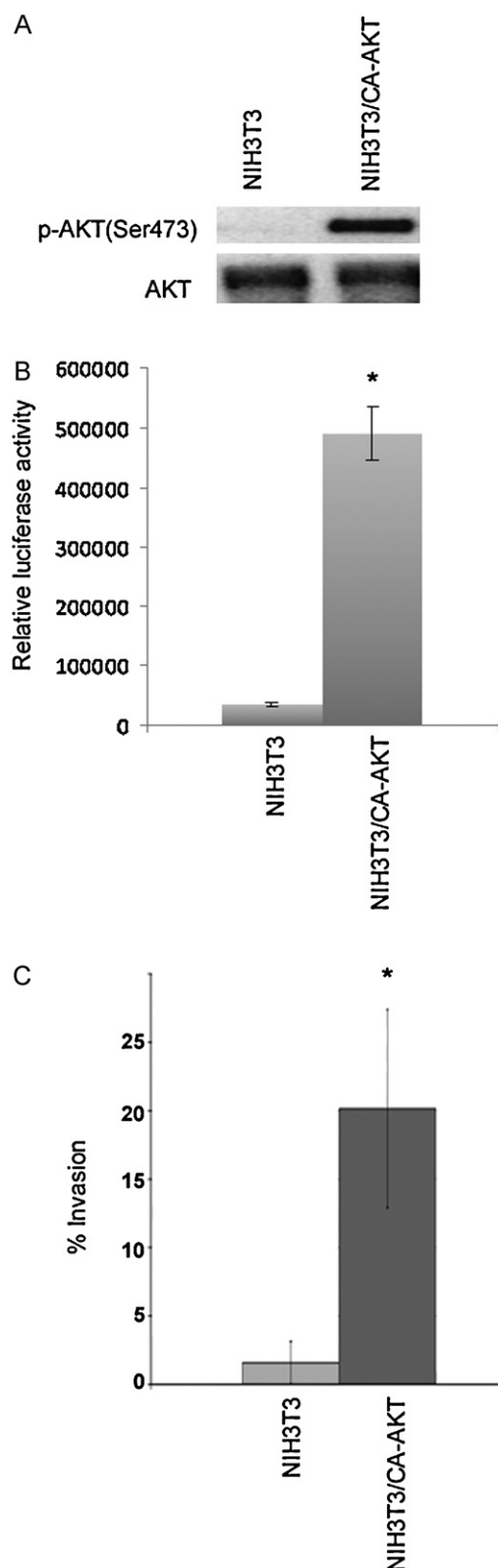
To further explore whether PTEN inhibits cell invasion, we next performed a cell invasion assay using PC14 transfectants. As shown in Fig. 3C, cell invasiveness was reduced by 72% in PC14 cells expressing wild-type PTEN compared to a mock transfectant. Such invasiveness was not suppressed in cells expressing PTEN-G129E and PTEN-G129R, suggesting that inhibition of invasion was dependent on lipid phosphatase activity of PTEN. To confirm our results and to discard cell specific findings PTEN-negative PC9 and PC3 cells were transiently transfected with PTEN-WT, PTEN-G129R and PTEN-G129E. We observed that ectopic expression of PTEN can suppress PC9 and PC3 cell invasion by inhibition of AKT/NFkB pathway through its lipid phosphatase activity (Fig. 5).

### 3.3. Effects of PTEN expression on invasiveness of mouse NIH3T3 cells

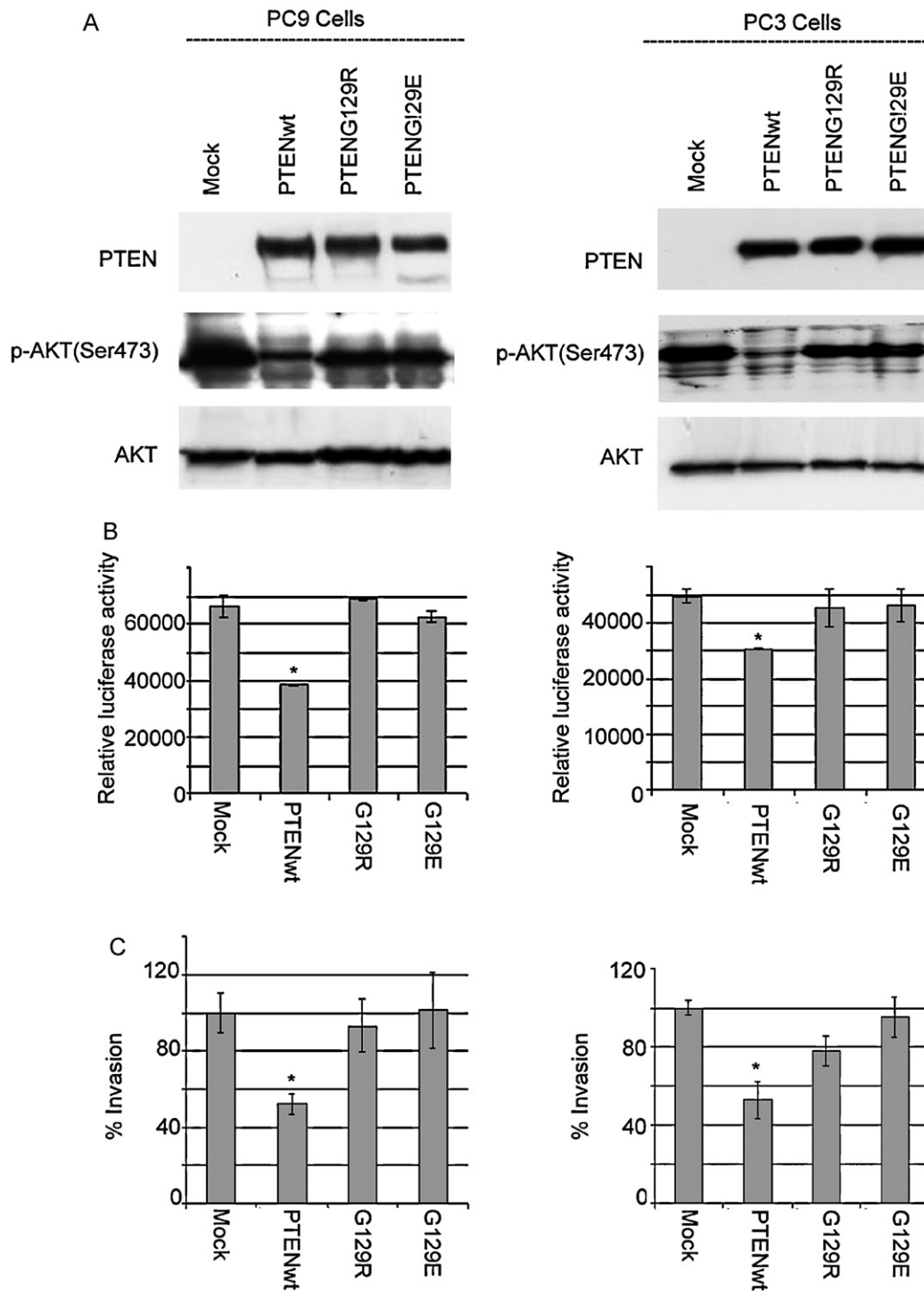
Since the AKT activity was robustly affected by PTEN activity in PC14, PC9 and PC3 cells, we assumed that regulation of cell invasiveness by PTEN might be dependent on AKT activity in cells. To confirm this assumption, NIH3T3/CA-AKT cells expressing constitutively active AKT [38] were assessed by a cell invasion assay. AKT is constitutively phosphorylated in NIH3T3/CA-AKT cells but not in parental NIH3T3 cells (Fig. 4A), and NFkB activation was shown by a reporter assay (Fig. 4B). Therefore, we compared the invasiveness of parental NIH3T3 cells and NIH3T3/CA-AKT cells by a cell invasion assay. As shown in Fig. 4C, NIH3T3/CA-AKT cells showed 7 times higher invasiveness in comparison with parental NIH3T3 cells. These results support our hypothesis that cell invasiveness is largely regulated by AKT and NFkB activities in all PC14, PC9, PC3 and NIH3T3 cells.

## 4. Discussion

Lung cancer is the most common cause of cancer death worldwide [39]. Metastases are the major cause of death from cancer; however, molecular mechanisms of lung cancer metastasis remain largely unclear. In normal lung tissues, high levels of PTEN expression were detected in 100% [40], while, in lung cancer cell lines, PTEN expression was lost in 44% and reduced in 29% [41]. Our results indicates that PTEN expression is lost in ~50% of NSCLC cells. This finding was in good agreement with previous findings, showing that high levels of PTEN expression were detected in normal lung tissue [40], while PTEN expression was lost in 44% and reduced in 29% of lung cancer cell lines [41]. Moreover, PTEN deletion was reported to occur in 2% of NSCLC cells [5]. Therefore, it is likely that deletion is not a common mechanism of loss of PTEN expression. Noro et al. [37] reported that the PTEN gene is not deleted but its promoter region is hypermethylated in PC14 cells. Moreover, they also reported that, following 5-aza-dC treatment, PTEN mRNA and protein was increased in PC14 cells. They also showed in the same article that the mechanism of loss of PTEN expression in PC9 cells is histone deacetylation [37]. Furthermore, Soria et al. [36] reported that PTEN promoter is hypermethylated in H1299 cells and PTEN mRNA was increased after 5-aza-dC treatment in this cell line. It was reported that overexpression of phosphorylated AKT and loss of PTEN expression are associated with poor prognosis of patients with NSCLC [40]. In our previously published study, levels of AKT phosphorylation were enhanced by EGF treatment in PC3, PC9, PC14 and H1299 cells without PTEN expression, but unchanged in H18 and PC13 cells with PTEN expression [42]. This result further



**Fig. 4.** The effects of AKT activation on NFkB activity and cellular invasiveness on NIH3T3 cells. We used NIH3T3 and CA-AKT expressing NIH3T3/CA-AKT cells for this experiment (A). To determine the effect of AKT activity on NFkB activation these cells were co-transfected with pGL3-NFkB-promoter-Luc (0.5 µg/well) and with pRL-Renilla (0.05 µg/well) vectors, 24 h after transfection cells were lysed and luciferase activities were measured (B). Akt activation can induce cellular invasion in NIH3T3 cells (C). Error bars indicate S.D., \* $p < 0.005$  comparing NIH3T3/CA-AKT and NIH3T3 cells.



**Fig. 5.** Ectopic expression of PTEN and its effects on AKT phosphorylation, NFκB activation and cellular invasion on PC9 and PC3 cells. PC9 and PC3 cells were transiently transfected with pcDNA-PTENwt, pcDNA-PTEN-G129R, pcDNA-PTEN-G129E expression vectors by FUGEN HD transfection reagent. After 24 h of transfection PTEN expressions and their effects on AKT phosphorylations were determined by western blot analysis (A). PC9 and PC3 cells were co-transfected with PTENwt, PTEN-G129R and PTEN-G129E expression vectors and with pRL-*Renilla* (0.05 μg/well) vectors and 24 h after transfection cells were lysed and luciferase activities were measured (B). Cells were transiently transfected with pcDNA-PTENwt, pcDNA-PTEN-G129R, pcDNA-PTEN-G129E expression vectors by FUGEN HD transfection reagent. After 24 h cells were counted and  $1 \times 10^4$  cells were seeded in to growth factor-reduced invasion chamber in serum-free medium containing 2 μg/ml tetracycline. Chemoattractant conditions were created by addition of RPMI-1640 medium containing 10% FCS, after 24 h invasive cells were fixed, stained and counted (C). Error bars indicate S.D., \* $p < 0.05$  comparing PTENwt transfected cells to mock, G129R and G129E transfected cells.

supports the importance of PTEN expression in the regulation of AKT phosphorylation in lung cancer cells. Therefore, we assumed that PTEN inactivation and its effect on the PI3K/AKT/NFκB pathway could be important in lung cancer cell invasion. To address our hypothesis, we first examined the expression status of PTEN pro-

tein in 9 lung cancer cell lines. PTEN expression was lost in 5 and reduced in 4 of the 9 cell lines when compared with an immortalized small airway epithelial cell line. These results are consistent with previous results [40]. We also found increased AKT activities in cell lines with loss of PTEN expression. Therefore, AKT activ-

ity is well associated with the expression of PTEN in these 9 cell lines.

We then pursued the effect of PTEN expression on anchorage dependent and independent growth of PC14 cells. We first determined the *in vitro* growth rates of mock, PTEN-WT, PTEN-G129R and PTEN-G129E expressing PC14 cells, and found that all cells have similar proliferation rates, suggesting that PTEN activity does not affect PC14 cell proliferation under standard culture conditions. Furnari et al. [43] reported that PTEN-G129R and PTEN-G129E expression did not change the glioblastoma cell proliferation rates but PTEN-WT expression inhibited proliferation by the 7th day. Our results are not consistent with their findings; however, we determined the rate of proliferation only after 3 days. We next examined the effects of wild-type and mutant PTEN expression on anchorage independent growth. Only wild-type PTEN expression inhibited anchorage independent growth but neither catalytically inactive nor lipid phosphatase dead PTEN had an effect to inhibit the growth. Previous studies also showed that PTEN expression inhibits the anchorage independent growth of hepatoma [44], breast cancer and melanoma cell lines [45].

PTEN expression has been also shown to suppress invasion of breast cancer, glioma and colon cancer cells [46–48]. Therefore, we next attempted to elucidate whether PTEN inactivation is associated with invasion of lung cancer cells. We used PC14, PC9 and PC3 cells, which lack endogenous PTEN expression, for this experiment. We stably transfected PC14 cells and transiently transfected PC9 and PC3 cells with mock, PTEN-WT, PTEN-G129E, and PTEN-G129R. PTEN-WT inhibited the invasion of PC14, PC9 and PC3 cells respectively 72%, 48% and 46%, but mutants of PTEN did not, suggesting that lipid phosphatase activity of PTEN is essential for NSCLC cell invasion. PTEN can suppress prostate cancer cell [49] and glioma cell [47] invasion, but the mechanism of this suppression is different between prostate cancer cells and glioma cells. Shukla et al. [49] reported that PTEN can suppress prostate cancer cell invasion through the suppression of the PI3K/AKT pathway by its lipid phosphatase activity, however, Maier et al. [47] reported that the PTEN lipid phosphatase domain is not required for invasion of glioma cells. Our results clearly indicate that PTEN suppresses lung cancer cell invasion through its lipid phosphatase activity. Recently, Zhang et al. [50] reported that microRNA-21 promotes invasion of lung cancer cells by repressing expression of PTEN, however, they didn't elucidate the molecular mechanisms of PTEN-mediated inhibition of lung cancer cell invasion. Since NFκB is a major target of activated AKT, we attempted to find interactions between the AKT/NFκB activity and lung cancer cell invasion. Therefore, reporter vectors for NFκB luciferase and renilla luciferase were co-transfected in mock, PTEN-WT, PTEN-G129R and PTEN-G129E expressing PC14 cells. The result indicated that only wild-type PTEN inhibits NFκB activity, and implies that PTEN inhibits NFκB activity through its lipid phosphatase activity and PTEN can inhibit lung cancer cell invasion through the suppression of the PI3K/AKT/NFκB pathway. To further confirm our hypothesis, we used parental NIH3T3 and NIH3T3CA-AKT cells, in which constitutively active AKT is overexpressed [38]. AKT activation induced NFκB activation and cellular invasion in NIH3T3 cells, supporting that AKT-mediated NFκB activation is necessary for lung cancer cell invasion.

In summary, we report here for the first time that activation of the AKT/NFκB pathway is necessary for the anchorage independent growth and invasion of lung cancer cells, and PTEN expression can suppress both processes by inhibiting the AKT/NFκB pathway.

#### Conflict of interest statement

The authors declare no conflict of interest for this article.

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**Update**

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## Erratum

# Erratum to “Invasiveness and anchorage independent growth ability augmented by PTEN inactivation through the PI3K/AKT/NFκB pathway in lung cancer cells” [Lung Cancer 73 (3) (2011) 302–309]

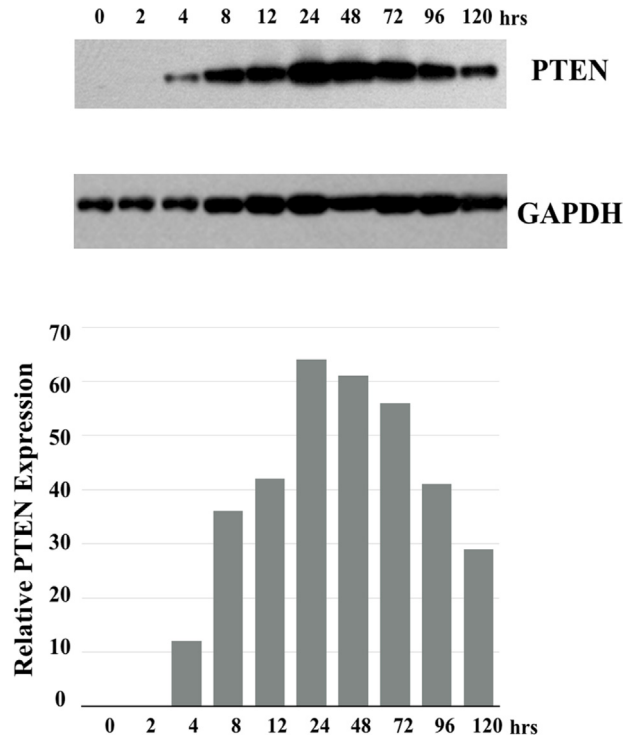


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The publisher regrets that the authors mistakenly inserted the incorrect GAPDH line on Fig. 2A. All densitometric analyses and values were calculated correctly with using correct GAPDH line in previously figure too. Mistake was just put wrong GAPDH on figure. A corrected Fig. 2A with the correct GAPDH line is now below.



The publisher would like to apologise for any inconvenience caused.

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