# MiR-106b and miR-93 regulate cell progression by suppression of PTEN via PI3K/Akt pathway in breast cancer

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Accumulating evidences have revealed that dysregulated microRNAs (miRNAs) involve in the tumorigenesis, progression and even lead to poor prognosis of various carcinomas, including breast cancer. MiRNA-106b-5p (miR-106b) and miRNA-93-5p (miR-93) levels were confirmed to be significantly upregulated in breast cancer clinical samples ($n = 36$) and metastatic cell line (MDA-MB-231) compared with those in the paired adjacent tissues and normal breast epithelial cell line (MCF-10A). Moreover, further research stated that the capability of migration, invasion and proliferation changed along with the altered expression of miR-106b and miR-93 in breast cancer. PTEN, the tumor-suppressor gene, was discovered to be reduced in breast cancer tissues or MDA-MB-231 cells with high levels of miR-106b and miR-93, which were inversely expressed in PTEN overexpression tissues or cells. Based on the investigation, miR-106b and miR-93 induced the migration, invasion and proliferation and simultaneously enhanced the activity of phosphatidylinositol-3 kinase (PI3K)/Akt pathway of MCF-7 cells, which could be blocked by upregulation of PTEN. Furthermore, suppression of PTEN reversed the function induced by anti-miR-106b and anti-miR-93 in MDA-MB-231 cells, indicating that PTEN was directly targeted by these miRNAs and acted as the potential therapeutic target for breast cancer therapy. In short, reductive PTEN mediated by miR-106b and miR-93 promoted cell progression through PI3K/Akt pathway in breast cancer.
*Cell Death and Disease* (2017) **8,** e2796; doi:10.1038/cddis.2017.119; published online 18 May 2017

Breast cancer was currently the most prevalent cancer among women in developed countries.[1] In recent years, approximately 22.9% of all female cancers were diagnosed all over the world and cases in China account for 12.2% of all newly diagnosed breast cancers and 9.6% of all deaths from breast cancer worldwide.[2,3] Despite the great breakthroughs in boosting drug sensitivity and surgical technique, palindromia and metastasis still occurred frequently and remained the major reasons for death in advanced breast cancer. Diagnosis and treatment at earliest could decrease the incidence of tumor progression. Recently, increasing attention was paid to exploring underlying molecular markers correlated with recrudescence and metastasis for the early diagnosis. This provided possible therapeutic targets for breast cancer.

MicroRNAs (miRNAs) are widely existed in various species such as animals, plants and viruses.[4] These small, endogenous, non-coding RNAs negatively regulate the target messenger RNAs (mRNAs) by acting on the 3′-untranslated regions (3′-UTRs) of the target genes via repression of protein translation or inducing mRNAs degradation.[5] MiR-106b-25 cluster contains three pre-miRNAs named miR-106b, miR-93 and miR-25. Interestingly, miR-106b and miR-93 share identical seed regions, indicating that these two miRNAs may exert prevailing functions in this cluster.[6] By report, miR-106b participated in promoting the progression of prostate cancer[7] and hepatitis B virus-associated hepatocellular carcinoma.[8] In addition, high level of miR-106b determined the tumor-promoting effects of

TGF-$\beta$ in breast cancer.[9] Accordingly, miR-93 has been reported to have a critical role in determining lung cancer progression by downregulating DAB2 expression.[10] Moreover, miR-93 was found to promote tumor growth and angiogenesis by targeting integrin-$\beta$8 in human glioblastoma.[11] For breast cancer, research has revealed that restraining of miR-93 could repress metastasis of breast cancer.[5] All of these indicated that miR-106b and miR-93 had relevant roles in breast cancer progression. However, the specific molecular mechanism of miR-106b or miR-93 on improving breast cancer progression has been rarely researched as yet.

PTEN, known as phosphatase and tensin homolog located on chromosome 10, is widely acknowledged as one of the most frequently deleted or mutated genes in diverse human tumors. It functions in converting phosphatidylinositol-3,4, 5-triphosphate (PIP3) into a diphosphate product (PIP2), inducing the antagonism of the phosphatidylinositol-3 kinase (PI3K) pathway and subsequently restraining tumor progress such as cell growth, apoptosis, adhesion, migration and invasion.[12,13] Currently, PTEN is widely researched and has been demonstrated to suppress the development of various carcinomas. Aberrant expression of miR-21 contributed to HCC growth and spread by modulating PTEN expression and PTEN-dependent pathways.[14] Moreover, PTEN, together with SPRY2 and PP2A, drived tumorigenesis and metastasis in prostate cancer.[15] For breast cancer, decreased PTEN expression has been reported to correlate with aggressive

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breast cancer phenotype and poor prognosis of the disease.[16,17] However, whether miR-106b and miR-93 could collectively regulate PTEN expression in breast cancer remained unclear.

In general, the aim of this article is to find the molecule marker of breast cancer for better diagnosis and provides the considerable therapeutic strategies for breast cancer. Our results imply that PTEN is the direct target of miR-106b and miR-93, whose cancer-promoting function can be reversed by upregulation of PTEN in breast cancer.

## Results

**The expression of miR-106b and miR-93 was enhanced in breast cancer tissues and cells.** The levels of miR-106b and miR-93 were detected using qRT-PCR in 36 pairs of tumor samples and the matched adjacent nontumor tissues from patients with breast cancer. The outcomes showed that the expression of the two miRNAs was markedly higher in tumor tissues than that in the corresponding adjacent nontumor tissues (Figure 1a). In addition, the identical condition was also observed in the cell level of breast cancer. Compared with the miR-106b and miR-93 expression in breast cancer cell lines MCF-7 and MDA-MB-231, the levels of the two miRNAs in MCF-10A cells were obviously reduced. Moreover, there was also a significant difference between the two miRNA expression in the high metastatic cell line MDA-MB-231 and in MCF-7 with a lower metastatic ability (Figure 1b), suggesting that these two miRNAs were associated with the progression of breast cancer.

**PTEN was the direct target gene of miR-106b and miR-93 in breast cancer.** Based on the software (TargetScan Human 7.1 (Massachusetts Institute of Technology (MIT), Cambridge, MA, USA) and microRNA.org), PTEN was among the numerous possible targets of miR-106b and miR-93 (Figure 1c). We chose PTEN to do further research for the two miRNAs just exerted inverse function with PTEN in breast cancer. MiR-106b and miR-93 have been demonstrated as oncogenes in breast cancer, whereas PTEN was widely known as a tumor-suppressor gene. Moreover, the two miRNAs and PTEN were both reported to have significant roles in breast cancer. In comparison with PTEN expression in breast cancer samples, the level of PTEN in the paired adjacent nontumor tissues was distinctly increased according to the qRT-PCR and immunohistochemistry (IHC) staining (Figures 1d and f). Similarly, it was also the truth in the cell level as PTEN was highly expressed in the cell line MCF-10A compared with that in breast cancer cell lines MCF-7 and MDA-MB-231 (Figure 1e). Immunofluorescence (IF) staining revealed a high level of PTEN in MCF-7 cells, which had a lower expression of the two miRNAs. However, an exactly reverse expression of PTEN was observed in MDA-MB-231 cell with a higher level of miR-106b and miR-93 (Figure 1f), all of which illustrated that PTEN expression was inversely correlated with miR-106b and miR-93 in breast cancer (Figure 1g).

To further discuss whether PTEN was directly targeted or suppressed by the two miRNAs, luciferase reporter assays were performed in MCF-7 and MDA-MB-231 cell lines.

Obviously decreased luciferase activity was observed in MCF-7 cells with co-transfection of miR-106b mimics and wild-type PTEN 3′-UTR (Figure 2a). Moreover, the luciferase activity was increased when anti-miR-106b and wild-type PTEN 3′-UTR were co-transfected into MDA-MB-231 cells (Figure 2b). However, mutation in the 3′-UTR of PTEN blocked the effect of miR-106b or anti-miR-106b with wild-type PTEN 3′-UTR. According to the reporter assays, the influence from miR-93 was the same as miR-106b in the cell lines MCF-7 and MDA-MB-231 (Figures 2c and d). In addition, qRT-PCR, western blot and IF staining showed the decreased PTEN expression after transfection with miR-106b mimics or miR-93 mimics in MCF-7 cells (Figures 2e and g). Moreover, suppression of miR-106b or miR-93 enhanced the level of PTEN in MDA-MB-231 cells (Figures 2f and h), both of which matched the conclusion *in vivo* based on IHC staining (Figures 2i and j).

**The capacity of migration, invasion and proliferation was regulated by miR-106b and miR-93 in breast cancer.** To further explore the effects of miR-106b and miR-93, wound-healing and transwell assays were utilized to measure the migration and invasion ability of breast cancer cells. Based on the wound-healing assays, the altering in width of the experimental group in MCF-7 transfected with miR-106b mimics or miR-93 mimics was evidently obvious compared with that of the control group with miR-NC. Accordingly, transwell assays indicated that the invasive capability was particularly boosted as upregulation of miR-106b or miR-93 in MCF-7 cells. The transfection efficiency of MCF-7 cells with miRNA mimics (miR-106b or miR-93 mimics) was shown in the Supplementary Figure 1 (Figures 1a and b). Contrarily, the migratory capacity was decreased and the number of MDA-MB-231 cells passing through the matrigel in the experimental group was significantly reduced compared with that of cells in the control (Figures 3a and b). Similarly, after treatment with miR-106b mimics or miR-93 mimics in MCF-7 cells, the colony number was extremely increased, which coincided with the growth curve obtained from Cell Counting Kit-8 (CCK8) assays. Furthermore, a higher level of Ki67, a typical marker of proliferation, was presented in MCF-7 cell with overexpressed miR-106b or miR-93 according to the IF staining, which also matched the results of the proliferation assays just verified above. However, the proliferative ability was significantly attenuated via knocking down of miR-106b or miR-93 in MDA-MB-231 cells on the base of colony formation, CCK8 and IF staining (Figures 3c–e). In addition, the growth curve of tumor formation *in vivo* also revealed the promoting impact of the two miRNAs (Figure 4a). Moreover, in order to further validate the growth ability mediated by these miRNAs *in vivo*, the tumor tissues were removed from the killed nude mice for IHC staining with Ki67 antibody and the results were consistent with our guess that miR-106b or miR-93 overexpression enhanced the growth of breast cancer (Figure 4c). Moreover, Figures 4b and d also validated this hypothesis indirectly.

**MiR-106b and miR-93 mediated cell migration, invasion and proliferation by targeting PTEN.** As proved, over-expression of miR-106b or miR-93 induced the migration,
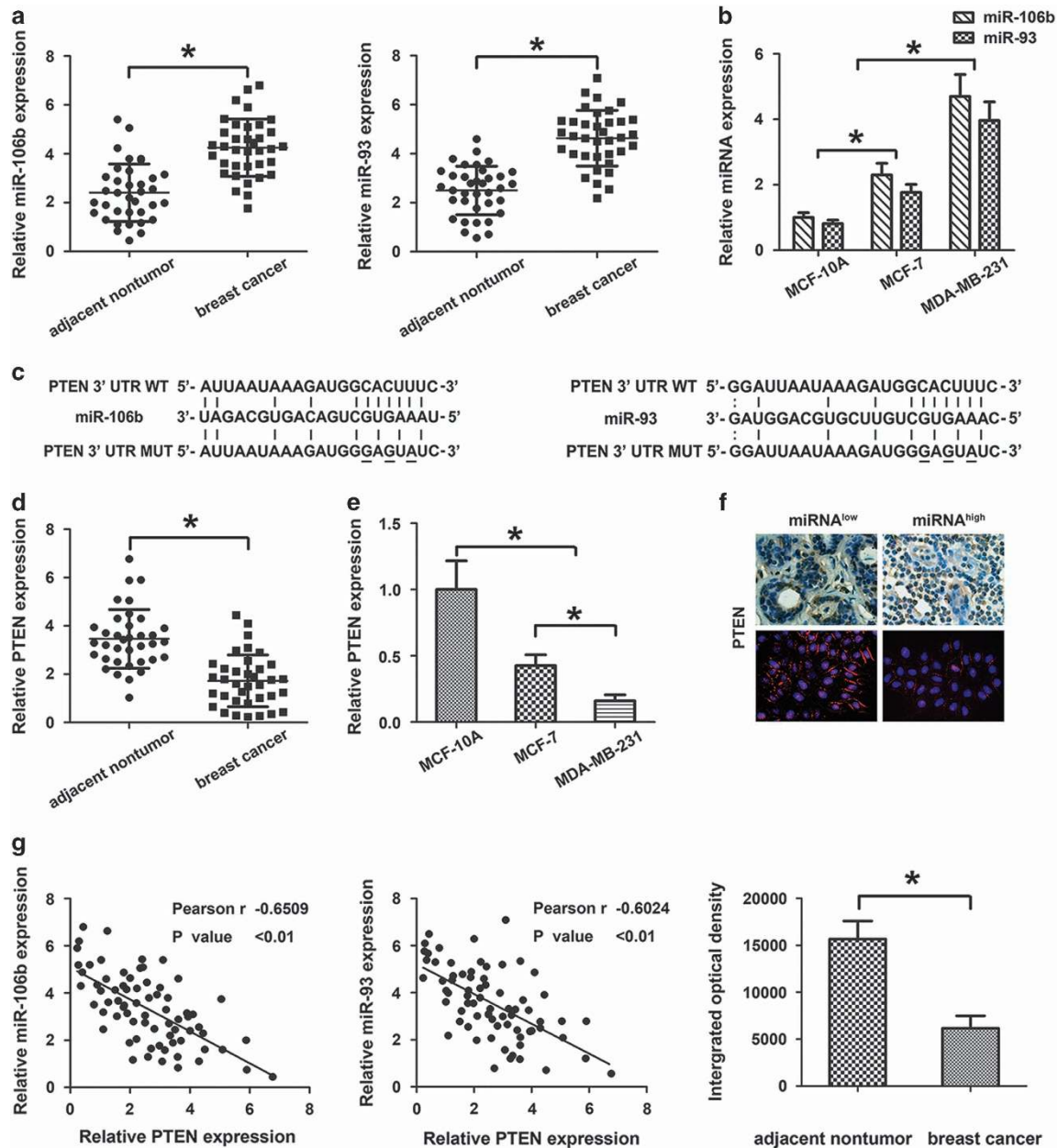
**Figure 1** The inverse relationship between the levels of the two miRNAs (miR-106b and miR-93) and PTEN. (**a**) The relative level of the two miRNAs in breast cancer tissues and matched adjacent nontumor tissues. (**b**) The expression of the two miRNAs in the cell level (MCF-10A, MCF-7 and MDA-MB-231). (**c**) The results of the software (TargetScan Human 7.1 and microRNA.org.) (**d**) The relative PTEN expression in the tissue level (breast cancer tissues and adjacent nontumor tissues). (**e**) The relative PTEN expression in the cell level (MCF-10A, MCF-7 and MDA-MB-231). (**f**) In the tissues and cells (adjacent nontumor tissues or MCF-7 cells) with a lower expression of the two miRNAs, PTEN level was obviously higher than that in tissues and cells (breast cancer tissues or MDA-MB-231 cells) with higher expressed miRNAs. (**g**) The inverse relationship between the two miRNAs and PTEN. Each experiment was independently performed at least three times. Data were presented as mean ± S.D. (*$P < 0.05$)

invasion and proliferation of MCF-7 cells. The increased miRNAs restrained the expression of PTEN as well. The two miRNAs played roles by targeting PTEN could be verified through recovering the level of PTEN. When miR-106b mimics or miR-93 mimics and PTEN were co-transfected into MCF-7 cells, we interestingly found the ability of migration and invasion was recovered compared with that in MCF-7 cells overexpressed just miR-106b or miR-93 (Figures 5a and b). Similarly, experiment on proliferation

exhibited the increased growth trend after transfection with miR-106b mimics or miR-93 mimics. However, upregulation of PTEN reversed the increased proliferative ability induced by miR-106b or miR-93 overexpression (Figures 5c–e).

By contraries, knockdown of the endogenous highly expressed miR-106b or miR-93 significantly weakened the migratory and invasive character in MDA-MB-231 cells, which was blocked by downregulation of PTEN (Figures 6a and b). Moreover, the results of proliferation showed the homologous
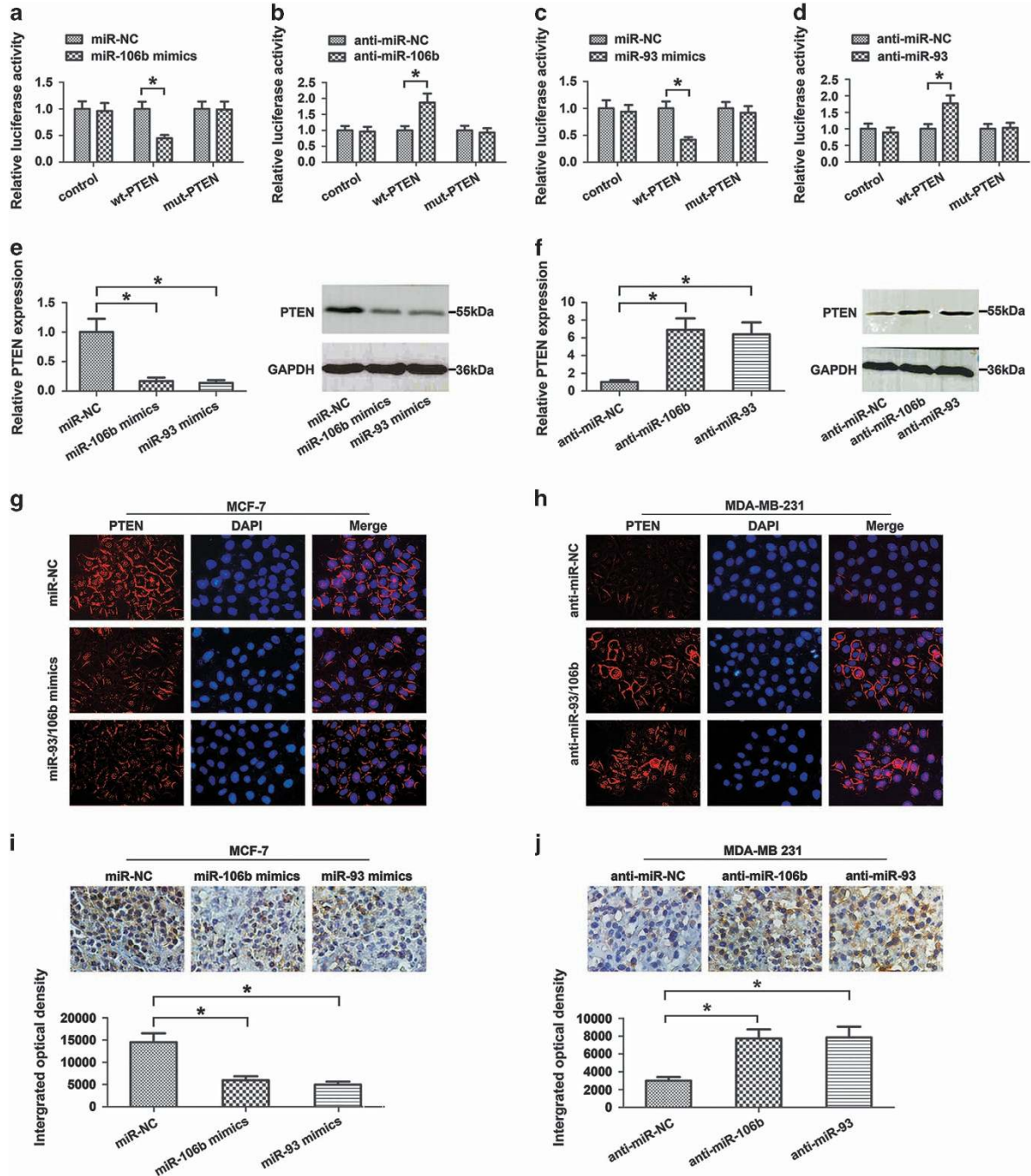
**Figure 2** MiR-106b and miR-93 directly targeted PTEN in breast cancer. (**a** and **c**) The relative luciferase activity of MCF-7 was tested after co-transfection with Wt PTEN 3′-UTR genes and miR-106b mimics or miR-93 mimics. (**b** and **d**) The relative luciferase activity was detected after Wt PTEN 3′-UTR genes and anti-miR-106b or anti-miR-93 were co-transfected into MDA-MB-231 cells. (**e** and **f**) qRT-PCR and western blot assays showed the altering expression of PTEN after transfection with miRNA mimics (miR-NC, miR-106b mimics and miR-93 mimics) or anti-miRNA (anti-miR-NC, anti-miR-106b and anti-miR-93) (**g**) PTEN level was reduced in MCF-7 cells transfected with miR-106b mimics or miR-93 mimics according to the IF assay. (**h**) Higher expression level of PTEN was presented in MDA-MB-231 cells treated with anti-miR-106b or anti-miR-93. (**i** and **j**) The expression of PTEN in tumor tissues was examined by IHC assay. Each experiment was independently performed at least three times. Data were presented as mean $\pm$ S.D. (*$P < 0.05$)

tendency as migration and invasion assays. Suppression of PTEN relieved the effect of reduced level of miR-106b or miR-93 (Figures 6c–e). In short, all the outcomes above explained that miR-106b or miR-93 mediated cell migration, invasion and proliferation probably via targeting PTEN.

**Activated PI3K/Akt pathway was involved in breast cancer progression.** It has been widely known that PTEN negatively regulated the activity of PI3K/Akt pathway. Moreover, we have already testified that miR-106b and miR-93 directly targeted PTEN. Therefore, we intended to validate
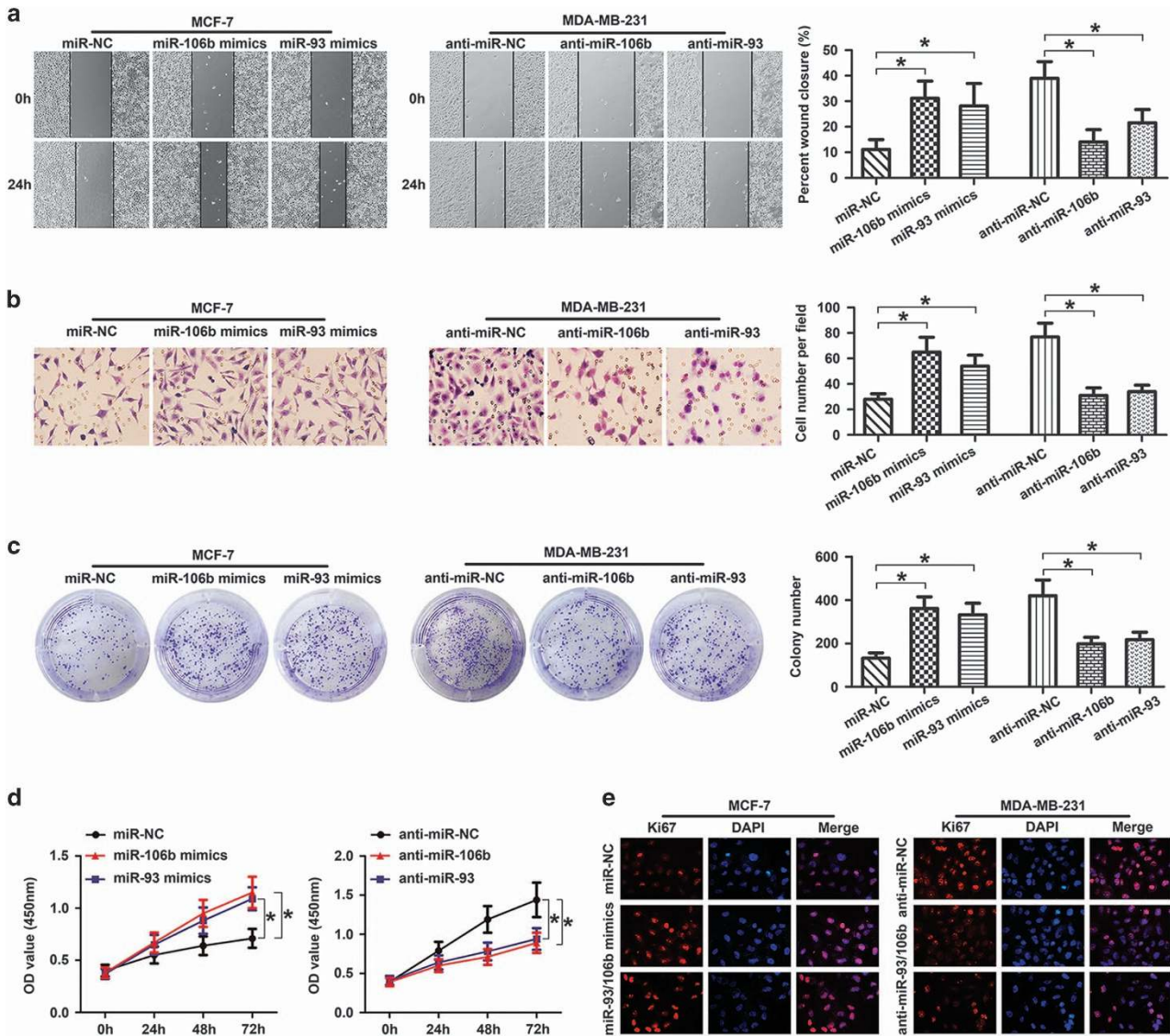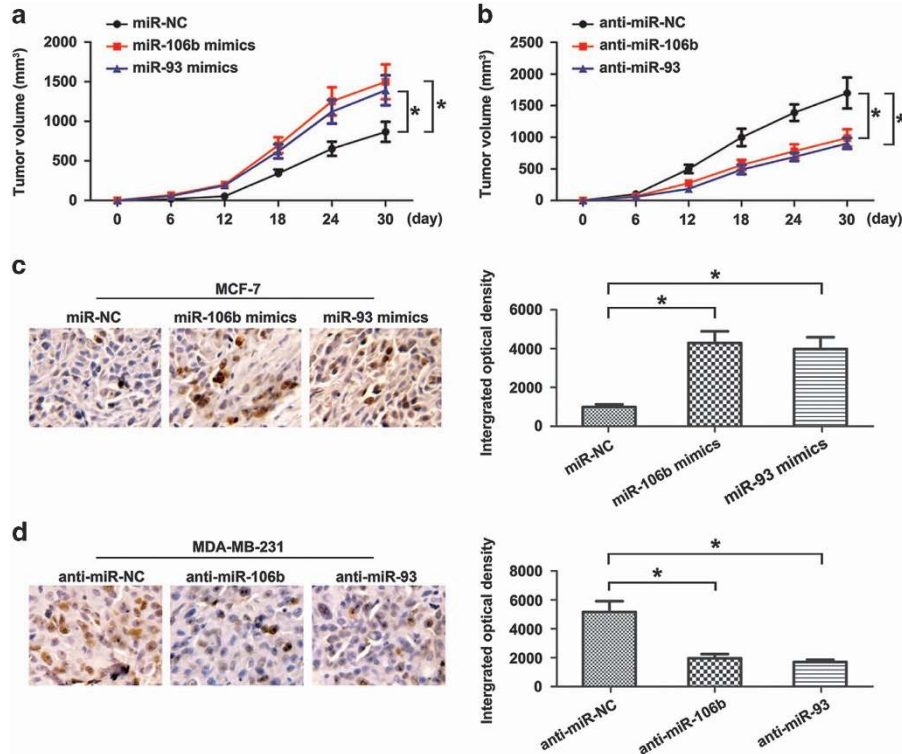
**Figure 3** MiR-106b, miR-93 regulated the capacity of cell migration, invasion and proliferation *in vitro*. The ability of cell migration and invasion in MCF-7 cells with miR-NC, miR-106b mimics or miR-93 mimics and in MDA-MB-231 cells transfected with anti-miR-NC, anti-miR-106b or anti-miR-93 based on wound-healing (**a**) and transwell assays (**b**). The proliferative character in MCF-7 cells transfected with miR-NC, miR-106b mimics or miR-93 mimics and in MDA-MB-231 cells with anti-miR-NC, anti-miR-106b or anti-miR-93 according to colony formation (**c**), CCK8 (**d**) and IF assays (**e**). Each experiment was independently repeated at least three times. Data were presented as mean ± S.D. (*$P < 0.05$)

whether there was a reinforcing relationship between the two miRNAs and PI3K/Akt and the function of PTEN through the process. The protein levels of p-Akt 308 and p-Akt 473 were markedly increased after transfection with miR-106b mimics or miR-93 mimics into MCF-7 cells compared with the control. However, the total level of Akt protein still remained unchanged. Next, MCF-7 cells were co-transfected with miR-106b mimics or miR-93 mimics and PTEN. Interestingly, we discovered the expression of p-Akt 308 and p-Akt 473 was recovered. PTEN blocked the effect of upregulated miR-106b or miR-93 (Figures 7a and b). As expected, MDA-MB-231 cells were co-transfected with anti-miR-106b or anti-miR-93 and siPTEN. Results exhibited that the influence of anti-miR-106b or anti-miR-93 could be reversed by

downregulation of PTEN, indicating that the two miRNAs regulated PI3K/Akt pathway through suppression of PTEN (Figures 7c and d).

As proved, the capability of migration, invasion and proliferation was regulated by miR-106b and miR-93 via targeting PTEN. The two miRNAs simultaneously promoted the PI3K/Akt pathway through their inhibitory effect on PTEN in breast cancer cells. However, whether miR-106b and miR-93 regulated cell progression by inhibiting PTEN via PI3K/Akt pathway remained unknown. To further identify the function of PI3K/Akt pathway in breast cancer cells, siAkt was utilized in MDA-MB-231 cells to inhibit the expression of Akt protein (Figure 7e). Furthermore, the capability of migration, invasion and proliferation was attenuated obviously in the

**Figure 4** Upregulation of miR-106b or miR-93 promoted the proliferative capacity of breast cancer *in vivo*. (**a-d**) MCF-7 and MDA-MB-231 cells were subcutaneously implanted into the right flank of each nude mouse to form tumors. When bearing palpable tumors, the mice were injected intratumorally with miR-106b mimics, miR-93 mimics, anti-miR-106b or anti-miR-93 and their negative controls three times per week for 4 weeks. (**a** and **b**) The growth curve of tumor tissues was measured every 6 days. (**c** and **d**) The expression of Ki67 in tumor tissues was tested by IHC analysis. Each experiment was independently repeated at least three times. Data were presented as mean $\pm$ S.D. (*$P < 0.05$)

group treated with siAkt compared with that in the control (Figures 7f–j). Altogether, miR-106b and miR-93 mediated cell progression through suppression of PTEN via PI3K/Akt pathway in breast cancer.

## Discussion

Altered expression of miRNA is strongly implicated in a broad range of cancers, and several studies have shown that certain miRNAs may be correlated with tumor progression and prognosis. Understanding the molecular regulation of miRNA is of great value for the future development of novel therapeutic strategies. In our study, we discovered that miR-106b and miR-93 were overexpressed in breast cancer tissues and cells. Upregulation of miR-106b and miR-93 promoted cell migration, invasion and proliferation in breast cancer *in vitro* and tumor growth *in vivo*. Moreover, we identified PTEN as the common target of miR-106b and miR-93 that subsequently regulated the activity of PI3K/Akt pathway.

MiRNAs, acting as critical tumor suppressors or promoters, have been proved by enormous studies to participate in the development of breast cancer. MiR-205 suppressed cell growth and migration in breast cancer by targeting ErbB3 and VEGF-A.[18] Inversely, upregulation of miR-181a expression by TGF-$\beta$ was found to promote breast cancer metastasis.[19] For miR-106b, study showed that it targeted

FUT6 to promote cell migration, invasion and proliferation in human breast cancer.[20] MiR-93 was also identified as a functional dysregulated miRNA that was significantly higher in triple-negative breast cancer.[21] Contrary to the effect in breast cancer, miR-106b induced apoptosis and suppressed invasion in thyroid cancer.[22] Accordingly, miR-93 also inhibited tumor growth and early relapse of human colorectal cancer.[23] These controversial findings indicated that either miR-106b or miR-93 may have different roles depending on different tumor and tissue types. In this study, higher levels of miR-106b and miR-93 were found in breast cancer tissues, indicating that they were involved in the progression of breast cancer. Functional assays showed that upregulation of miR-106b or miR-93 in MCF-7 cells significantly promoted the capacity of cell migration, invasion and proliferation. In addition, reducing the expression level of miR-106b or miR-93 in MDA-MB-231 cells obviously attenuated cell migration, invasion and proliferation, which further verified our hypothesis. Moreover, analysis in xenograft mouse model showed that upregulation of miR-106b or miR-93 promoted tumor growth and *vice versa*. Taken together, we reached the conclusion that miR-106b and miR-93 functioned as oncogenes and promoted the progression of breast cancer.

Efficient evidences emphasized the fact that not only a single miRNA can target multiple molecules,[24] but also a series of miRNAs modulate one common target in neoplastic and normal cells.[25] Currently, a variety of genes were identified
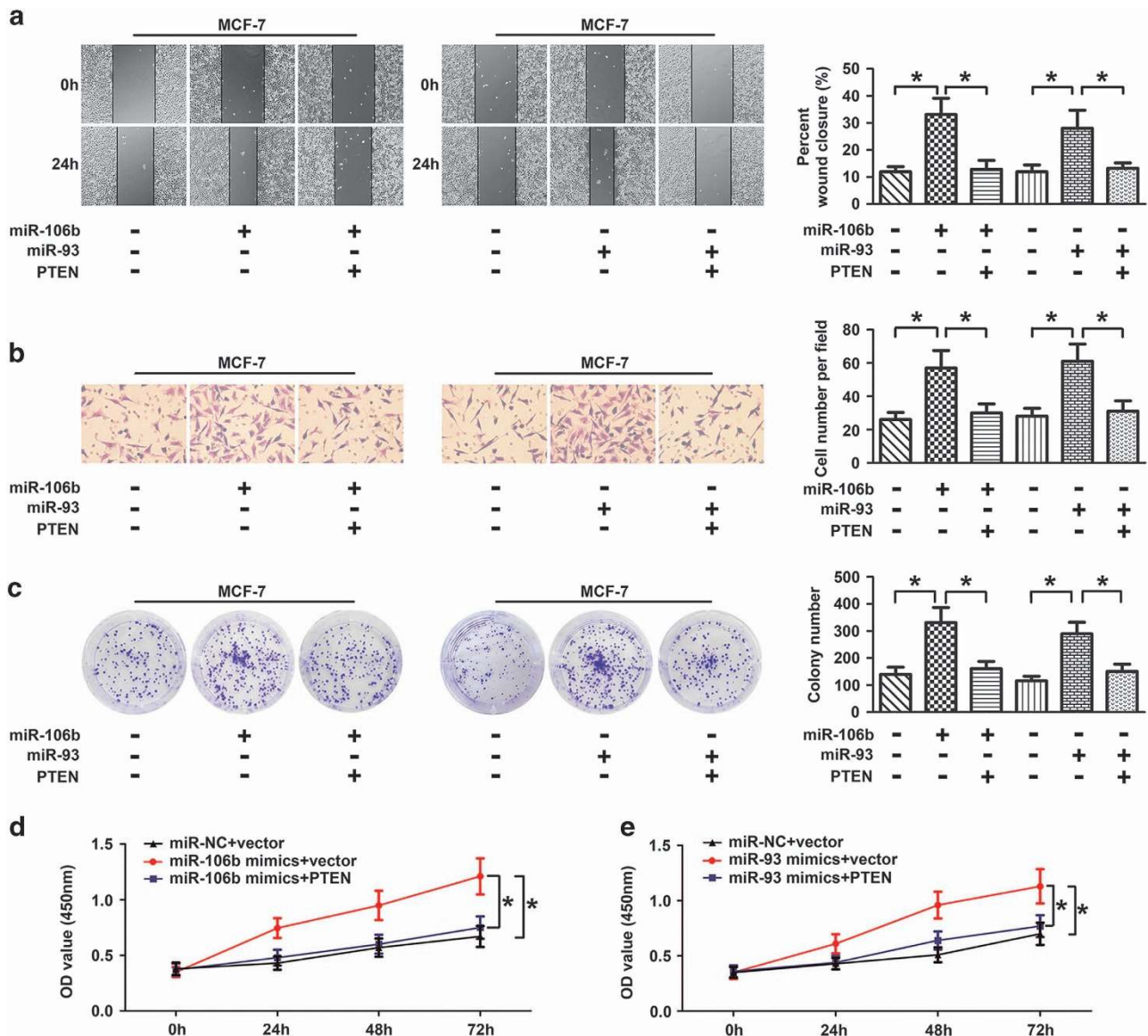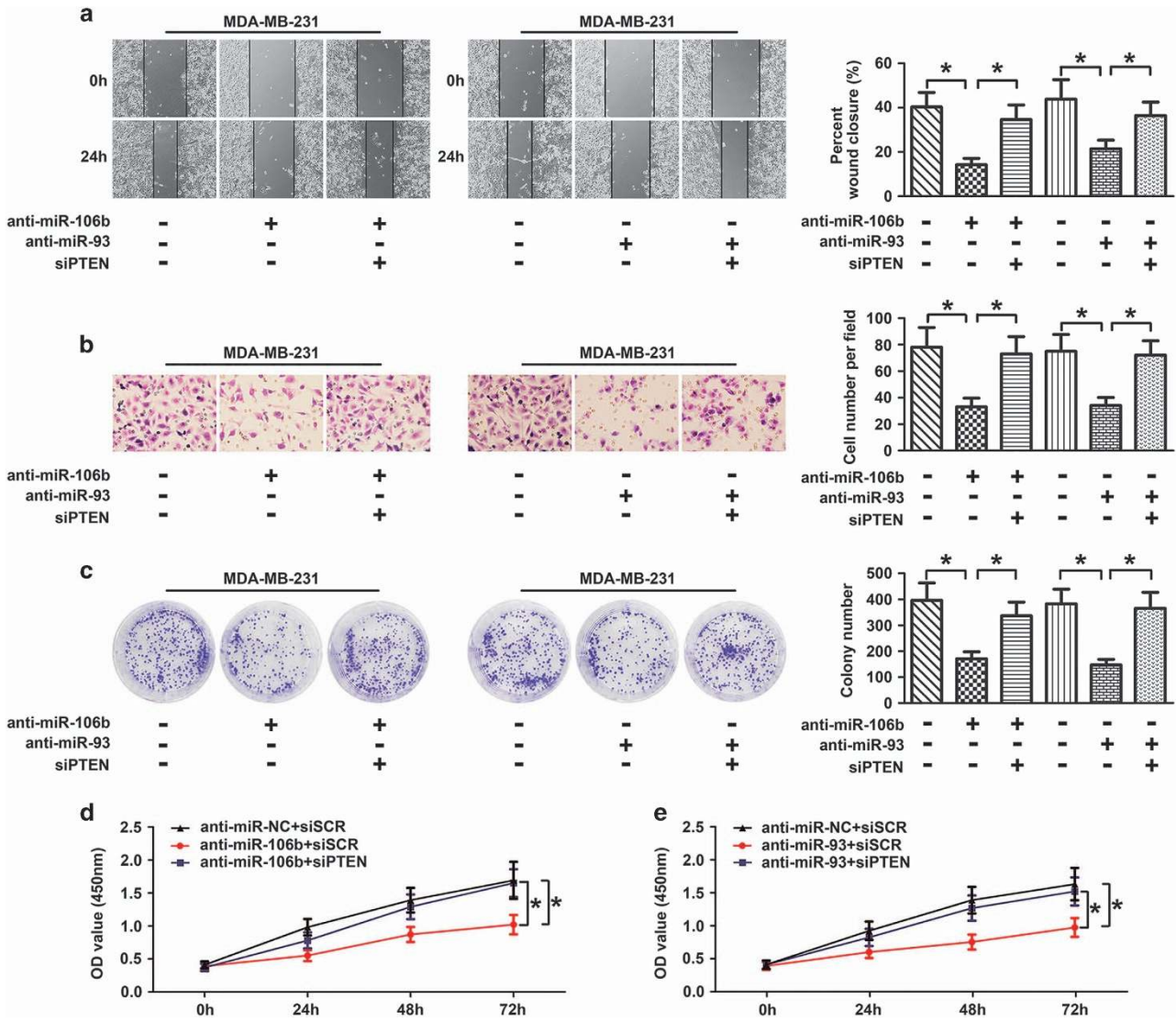
**Figure 5** MiR-106b and miR-93 targeted PTEN to promote cell progression in MCF-7 cells. (**a-e**) MCF-7 cells were co-transfected with miRNA mimics (miR-NC, miR-106b mimics or miR-93 mimics) and the target mRNA (control vector or PTEN). Upregulation of PTEN blocked the effect induced by overexpressed miR-106b or miR-93 in MCF-7 cells. Representative results of wound-healing assay (**a**), transwell assay (**b**), colony formation assay (**c**) and CCK8 assay (**d** and **e**) in MCF-7 cells. Each experiment was independently repeated at least three times. Data were presented as mean ± S.D. (*$P < 0.05$)

as the target of miR-106b including Prrx1,[26] Smad7[27] and caspase-7.[28] MiR-93 was also reported to function as a tumor promoter via regulating diversity of tumor-suppressor genes such as NRF2,[29] Dab2[30] and cyclin G2.[31] More interestingly, certain researches revealed that either miR-106b or miR-93 could directly target one common gene named PTEN in many other cancers.[32,33] In our research, we found that PTEN was the direct target of both miR-106b and miR-93. Upregulation of miR-106b and miR-93 in MCF-7 cells reduced the expression level of PTEN, whereas downregulation in MDA-MB-231 cells showed the opposite result. The effect of miR-106b and miR-93 on cell migration, invasion and proliferation of breast cancer was reversed by the alternation of PTEN expression, suggesting that PTEN was the downstream target to mediate

the effect of miR-106b and miR-93. These data together indicated that miR-106b and miR-93 regulated the cell characteristic of breast cancer by, at least partly, targeting PTEN.

Akt is a serine/threonine kinase and phosphorylates a host of cellular proteins, including GSK3$\alpha$, GSK3$\beta$, FoxO transcription factors, MDM2, BAD and p27KIP1 to facilitate survival and cell cycle entry.[34] As a lipid phosphatase, PTEN has been proved to suppress the activity of Akt kinase and even further restrain tumor progression. The activation of PTEN induced by MAF1 was observed to suppress Akt-mTOR signaling in liver cancer.[35] Moreover, loss of tumor-suppressor PTEN and subsequent activation of PI3K/Akt pathway promoted human prostate cancer aggressiveness.[36] Particularly, studies have

**Figure 6** Reductive miR-106b or miR-93 targeted PTEN to attenuate cell progression in MDA-MB-231 cells. (**a-e**) MDA-MB-231 cells were co-transfected with anti-miRNA (anti-miR-NC, anti-miR-106b or anti-miR-93) and the target mRNA (siSCR or siPTEN). The influence from anti-miR-106b or anti-miR-93 was reversed by downregulation of PTEN in MDA-MB-231 cells. Representative results of wound-healing assay (**a**), transwell assay (**b**), colony formation assay (**c**) and CCK8 assay (**d** and **e**) in MDA-MB-231 cells. Each experiment was independently repeated at least three times. Data were presented as mean ± S.D. (*$P < 0.05$)

shown that miR-10b regulated the self-renewal of the breast cancer stem cells phenotype by inhibiting PTEN and subsequently maintaining Akt pathway activation.[37] As expected, our results showed that upregulation of PTEN in MCF-7 cells attenuated the promoting effect of overexpressed miR-106b and miR-93 on PI3K/Akt pathway. Further investigation showed that reduced PTEN expression level reversed the impact of PI3K/Akt induced by suppression of miR-106b or miR-93 in MDA-MB-231 cells. As proved, p-Akt 308 and p-Akt 473, the phosphorylation of Akt, promoted tumor invasion and chemoresistance of breast carcinoma.[38,39] In this article, when siAkt was utilized to inhibit the expression of p-Akt 308 and p-Akt 473 in breast cancer, the capability of cell migration, invasion and proliferation was significantly attenuated, indicating that the phosphorylation of Akt did have a role in the progression of breast cancer. Taken together, miR-106b and

miR-93 mediated cell migration, invasion and proliferation by suppression of PTEN via PI3K/Akt pathway in breast cancer.

In general, the current research showed that miR-106b and miR-93 both targeted one common target PTEN, subsequently altering the activation of PI3K/Akt pathway. Moreover, miR-106b and miR-93 promoted cell migration, invasion and proliferation *in vitro* and tumor growth *in vivo* through the regulation of PTEN/PI3K/Akt pathway. This highlights the therapeutic potential of miR-106b and miR-93 in breast cancer and provides novel candidate targets for prevention and treatment of breast cancer. In addition, how miR-106b and miR-93 regulate the expression of other target genes in the progression of breast cancer or in a broad scope of other cancers remains to be further explored in the near future.
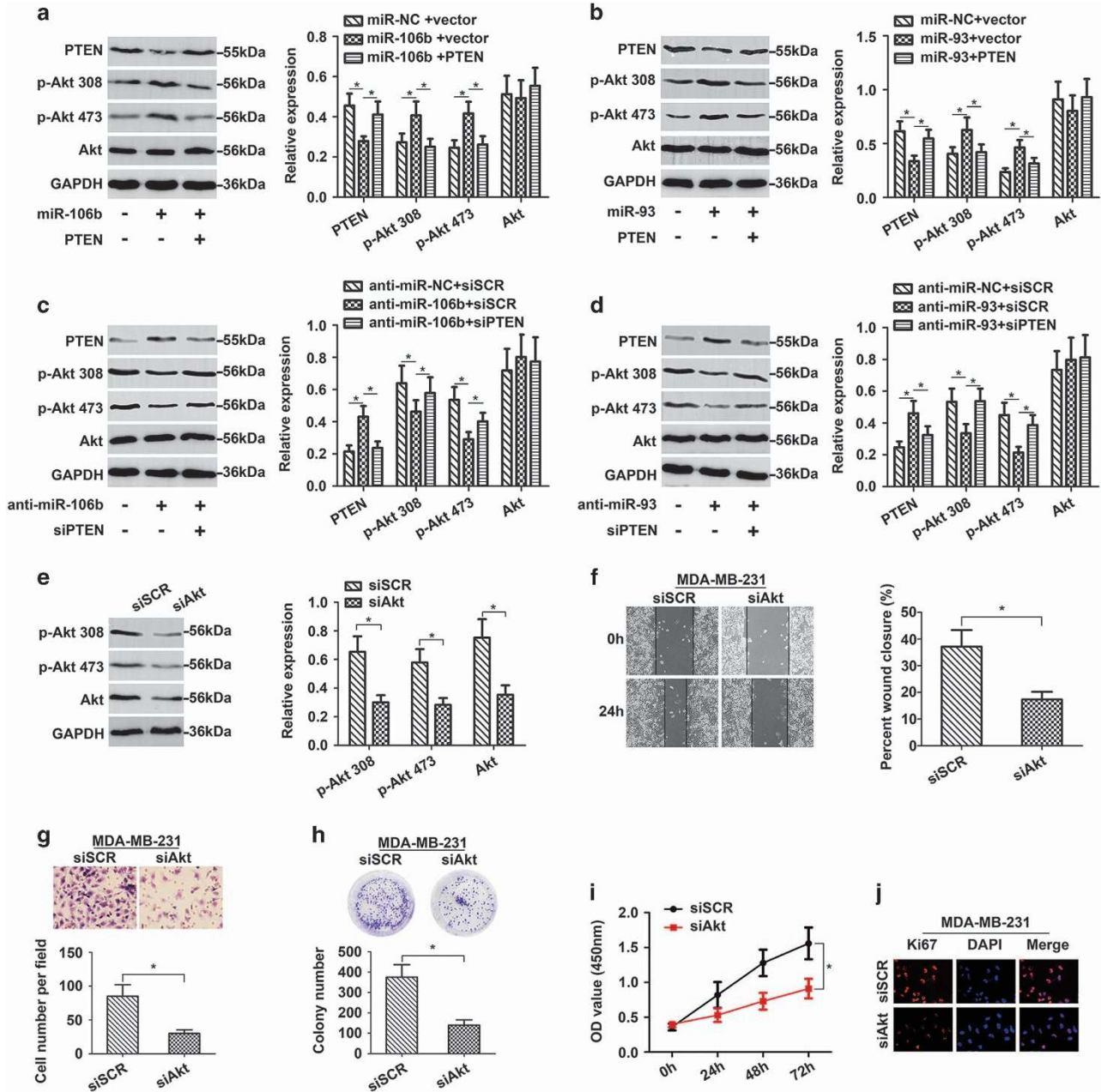
**Figure 7** MiR-106b and miR-93 regulated the activity of PI3K/Akt pathway by suppression of PTEN. (**a** and **b**) The primary Akt protein level was measured after co-transfection with miRNA mimics (miR-NC, miR-106b mimics or miR-93 mimics) and the target mRNA (control vector or PTEN) in MCF-7 cells. (**c** and **d**) The primary Akt protein level was detected after co-transfection with anti-miRNA (anti-miR-NC, anti-miR-106b or anti-miR-93) and the target mRNA (siSCR or siPTEN) in MDA-MB-231 cells. (**e**) SiAkt was utilized in MDA-MB-231 cells to inhibit the expression of Akt and the primary Akt protein level was measured by western blot analysis. The capacity of cell migration, invasion and proliferation was decreased after treatment with siAkt based on the results of wound-healing (**f**), transwell (**g**), colony formation (**h**), CCK8 (**i**) and IF assays (**j**). Each experiment was independently repeated at least three times. Data were presented as mean ± S.D. (*$P < 0.05$)

## Materials and Methods

**Cell culture.** Human breast cancer cells (MCF-10A, MCF-7 and MDA-MB-231) were purchased from KeyGEN Company (Nanjing, China) and both maintained in Dulbecco's modified Eagle's medium (DMEM) containing 10% fetal bovine serum (FBS; Gibco, Grand Island, NY, USA) and 1% penicillin–treptomycin (HyClone, Logan, UT, USA) and incubated at 37 °C in a 5% $CO_2$ humidified atmosphere.

**Real-time PCR analysis.** qRT-PCR was utilized to measure the expression levels of miRNAs and mRNAs. Total RNA from surgical tissues and cultured cells was extracted by using TRIzol reagent (Ambion, Austin, TX, USA) according to the

manufacturer's instructions and then reverse transcription was performed. The expression levels of miRNA and mRNA were assessed with qRT-PCR using Power SYBR Green (Applied Biosystems, Forster, CA, USA) by an Applied Biosystems 7500 Sequence Detection system. The expression levels of miRNA and mRNA were defined based on the threshold cycle (Ct), and relative expression levels were calculated using the $2^{-\Delta\Delta Ct}$ method. The expression levels of U6 small nuclear RNA and GAPDH mRNA were used as reference genes.

**Tissue samples of patients.** Thirty-six pairs of breast cancer tissues and their adjacent non-cancerous tissues were collected from patients who underwent

surgical resections at the Second Affiliated Hospital of Dalian Medical University from January 2014 to March 2016 after obtaining informed consent. The investigation project and the informed consent have been approved by the Ethics Committee of the Second Affiliated Hospital of Dalian Medical University. The extracted specimens were confirmed to be breast cancer tissues with pathological diagnosis according to the International Union against Cancer (UICC). The specimens were immediately frozen in liquid nitrogen and then stored at − 80 °C for analysis.

**IHC analysis.** After the xenograft tumor was harvested, it was immediately fixed in 10% formaldehyde, dehydrated series of alcohol and then embedded in paraffin. In all, 0.5 mm thick slices were cut, dried deparaffinized, rehydrated and then put on the IHC slides. Then tissue slices were deparaffinized, rehydrated and immersed in 3% hydrogen peroxide for 10 min in order to consume the endogenous peroxidase. After washing with phosphate-buffered saline (PBS), the tissue slices were incubated with Ki67 antibody (Abcam, Cambridge, UK) and PTEN antibody (Proteintech, Chicago, IL, USA) at a dilution of 1 : 1000 and 1 : 150, respectively, at 4 °C overnight. The secondary streptavidin–horseradish peroxidase-conjugated antibody staining (Santa Cruz Biotech, Santa Cruz, CA, USA) was performed at room temperature for 60 min. Finally, the sections were counterstained with hematoxylin for 30 s and sealed with Neutral gum. Images were obtained from a light microscope (40 × 10). The results of the experiments were analyzed by software Image-Pro plus 6.0 (Media Cybernetics, Bethesda, MD, USA).

**IF analysis.** IF staining was performed after fixing MCF-7 and MDA-MB-231 cells in 10% formaldehyde for 40 min. Nonspecific binding was blocked with a 5% bovine serum albumin (BSA) blocking buffer for 1 h at room temperature. The cells were incubated with rabbit polyclonal antibody specific for PTEN (Proteintech) and Ki67 (Abcam) diluted at 1 : 200 and 1 : 1000, respectively, in 1% BSA-blocking buffer overnight under the condition of 4 °C. After washing with PBS, the cells were then incubated with secondary antibody (Proteintech) diluted at 1 : 400 in 1% BSA blocking buffer for 30 min under the condition of avoiding light at 37 °C. The cells were washed with PBS and fixed in DAPI (Solarbio, Beijing, China) for 5 min at room temperature. Images were obtained from a fluorescence microscope (20 × 10).

**Luciferase assay.** MCF-7 and MDA-MB-231 cells ($5 \times 10^4$ cells per well) were seeded in 24-well plates and allowed to settle for 24 h. Cells were co-transfected with wild-type or mutant reporter plasmid, miR-106b mimics (miR-93 mimics) or anti-miR-106b (anti-miR-93) and pRL-TK renilla plasmid (Promega, Madison, WI, USA) using Lipofectamine 2000. Forty-eight hours after the transfection, the lysates were collected and the activities of firefly and Renilla luciferases were measured by a Dual-Luciferase Reporter System (Promega) and normalized to those of Renilla luciferase activities. The mean of the results from the cells with miR-NC or anti-miR-NC was set at 1.0. Data are presented as the mean value ± S.D. for triplicate experiments.

**Western blot analysis.** The extracted MCF-7 and MDA-MB-231 cells were split using cell lysates (KeyGEN Company) with protease inhibitor cocktail (Biotool, Houston, TX, USA). Whole-cell proteins were electrophoresed under the conditions in 12% polyacrylamide gels. The separated proteins were transferred to a polyvinylidenedifluoride membrane. Nonspecific binding was blocked with 5% skimmed milk for 2 h at 37 °C. The membrane was then incubated with PTEN (1 : 1500 diluted; Proteintech), p-Akt 308, p-Akt 473 and Akt antibody (1 : 1000 diluted; Abgent, San Diego, CA, USA) at 4 °C overnight. A GAPDH antibody (1 : 2500 diluted; Bioworld, Minneapolis, MN, USA) was used as a control. Next, the membrane was incubated with peroxidase-conjugated anti-rabbit IgG (1 : 5000 diluted; Thermo, Boston, MA, USA). Images were obtained from multifunctional gel imaging system (ImageQuant LAS 500, General Electric, Fairfield, CT, USA).

**Tumorigenicity assays in nude mice.** Four-week-old male BALB/c athymic nude mice were purchased from the Animal Facility of Dalian Medical University and fed with sterilized food and water. All animal experiments were approved by the Committee on the Ethics of Animal Experiments of the Dalian Medical University, China. To establish the breast cancer xenografts, approximately $2 \times 10^6$ cells (MCF-7, MDA-MB-231) were inoculated subcutaneously into the right flank of each nude mouse, respectively. When bearing palpable tumors, mice were randomly divided into six groups, each group containing six mice. Then, the mice were injected intratumorally with miRNA mimics (miR-106b mimics, miR-93 mimics) or anti-miRNA (anti-miR-106b, anti-miR-93) and the corresponding negative controls

three times per week for 4 weeks and the length and width of tumors were measured every 6 days. The tumor volume was calculated by the following formula: tumor volume $= 1/2$ (length × width$^2$). Thirty days later, the mice were killed and the tumor tissues were harvested for use in further experiments.

**Oligonucleotides, plasmids, siRNA and transfection.** MiR-106b mimics, miR-93 mimics, negative control oligonucleotides (miR-NC), miR-106b inhibitors (anti-miR-106b), miR-93 inhibitors (anti-miR-93), negative control oligo-nucleotide (anti-miR-NC) and PTEN pEGFP-N2 vector (PTEN), empty vector (vector), small interfering RNA of PTEN or Akt (siPTEN, siAkt), scramble siRNA of PTEN or Akt (siSCR) were purchased from RiboBio (Guangzhou, China). MiR-106b and miR-93 level was enhanced by miR-106b mimics or miR-93 mimics and upregulated PTEN was completed by transfection with PTEN in MCF-7 cells. MiR-106b, miR-93 and PTEN were knocked down using anti-miR-106b, anti-miR-93 or siPTEN in MDA-MB-231 cells. Transfection was performed using the Lipofectamine 2000 reagent (Invitrogen, Carlsbad, CA, USA) according to the manufacturer's instructions. The transfection efficiency was evaluated by fluorescence microscopy by calculating the percentage of fluorescein-labeled cells.

**Wound-healing assay.** MCF-7 and MDA-MB-231 cells were seeded ($4 \times 10^5$ cells per well) in 12-well plates. One night after inoculation, the cell layer was scratched using a pipette tip when adherent cells were observed. Next, images of cell morphology were captured at initiation time and 24 h under the Olympus microscope (Olympus Corporation, Tokyo, Japan) (10 × 10). The migratory ability was quantified and normalized by relative gap distance. The results of the experiments were analyzed by software Ipwin 32.

**Transwell invasion assay.** The invasive potential of MCF-7 and MDA-MB-231 cells was measured in 6.5 $\mu$m transwell with 8.0 $\mu$m Pore Polycarbonate Membrane Insert (Corning, New York, NY, USA) according to the manufacturer's instructions. The filter of top chamber was matrigel-coated with 100 $\mu$l of diluted matrigel following the standard procedure and incubated at 37 °C for 2 h. The lower chambers were filled with 500 $\mu$l of DMEM containing 10% FBS as chemoattractant for a further 24 h. Cells were serum-free starved overnight, harvested, and resuspended in migration medium (DMEM medium with 0.5% BSA). Then, the suspension of 4000 cells in 100 $\mu$l migration medium was added into each top chamber. After the cells were incubated for 25 h, the noninvading cells that remained on the upper surface were removed with a cotton swab. The invasive cells on the lower surface of the membrane insert were fixed in 75% methanol, and then stained with Wright–Giemsa. The cells that had invaded the Matrigel and reached the lower surface of the filter were counted under a light microscope (40 × 10).

**Cell proliferation assay.** CCK8 (Biotool) was used to measure the proliferative ability of MCF-7 and MDA-MB-231 cells. A density of $2 \times 10^3$ cells per well were seeded into 96-well plates containing complete DMEM (100 $\mu$l) in triplicate for each condition and were maintained in an incubator at 37 °C and 5% $CO_2$. CCK8 solution (10 $\mu$l) was added to each well and incubated for 4 h. Then, OD was measured by water-soluble tetrazolium salt assay using microplate computer software (Bio-Rad Laboratories, Hercules, CA, USA) according to the protocol of the CCK8 assay kit (Biotool). Absorbance at 450 nM (A450) was read on a microplate reader (168–1000 Model 680, Bio-Rad Laboratories), and proliferation curves were plotted.

**Colony formation assay.** Approximately, 500 MCF-7 or MDA-MB-231 cells were seeded in six-well plates (9.62 cm$^2$) and made into single-cell suspension and then cultured in DMEM containing 10% FBS for 10 days. Cell colonies were fixed with 10% formaldehyde for 40 min, stained with 0.1% crystal violet at room temperature for 20 min and then photographed.

**Statistical analysis.** Each experiment was performed at least in triplicate. Data are displayed as mean ± S.D. and analyzed by SPSS 13.0 (SPSS Inc., Chicago, IL, USA). The significance of differences in multiple comparisons was determined using Student's *t*-test. $P < 0.05$ was considered to be statistically significant.

## Conflict of Interest

The authors declare no conflict of interest.

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Supplementary Information accompanies this paper on Cell Death and Disease website (http://www.nature.com/cddis)