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ORIGINAL RESEARCH

RETRACTED ARTICLE: Berberine Reverses Doxorubicin Resistance by Inhibiting Autophagy Through the PTEN/Akt/mTOR Signaling Pathway in Breast Cancer

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Purpose: Berberine (BBR), a traditional Chinese medicine, has been shown effects on inhibiting cancer development. Autophagy-mediated resistance plays an important role in cancer progression; therefore, regulation of autophagy is a novel therapeutic strategy for cancer treatment. However, effects of BBR on autophagy-mediated resistance have not been reported.

Methods: MCF-7 breast cancer cells and the doxorubicin (ADR)-resistant MCF-7 cells (MCF-7/ADR) were used for analysis. Western blotting was conducted to evaluate protein expression; MTT, colony formation, and EdU assays were conducted to assess cell proliferation; transmission electron microscopy was used to monitor autophagy levels; and a xenograft tumor model was established to assess the effects of BBR on reversing doxorubicin resistance.

Results: We confirmed that BBR, recently identified as a suppressor of autophagy, inhibits autophagosome formation in MCF-7/ADR cells. Treatment with BBR blocked the accumulation of the autophagy-associated protein LC3II, resulting in cellular accumulation of p62, reduced cell proliferation, and reversal of doxorubicin resistance. Mechanistically, we found that BBR inhibited autophagy by modulating the PTEN/Akt/mTOR signaling pathway. In vivo, our study showed that BBR exerts clear anti-tumor effects.

Conclusion: The results of this study suggest that BBR reverses doxorubicin resistance in breast cancer cells by inhibiting autophagy. This finding highlights the potential clinical application of BBR in the treatment of breast cancer.

Keywords: breast cancer, berberine, chemoresistance, PTEN, autophagy, ADR

Introduction

Breast cancer is the most common cancer among women worldwide, and is a leading cause of death in developing countries.[1] Doxorubicin (ADR) is the cornerstone drug for the treatment of breast cancer patients and can significantly inhibit cancer progression.[2,3] However, some breast cancer patients relapse owing to ADR resistance, which represents a major therapeutic obstacle in the treatment of this cancer.[4] The reasons for chemotherapy resistance in cancer treatment are multifaceted, and include the increased expression of ABC transporters (including MDR1, P-gp, MRP, and BCRP) and changes in cell membrane permeability that leads to drug efflux; impairment of DNA damage repair mechanisms; autophagy-mediated drug resistance; changes in tumor cell microenvironment; and mutations in drug targets.[5–7] Among these mechanisms, autophagy-mediated chemotherapy resistance has gained increasing attention.[5,6]

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Autophagy, a conservative life process in all eukaryotic cells, plays an important role in maintaining a stable intracellular environment and protein balance.[8,9] However, autophagy plays different roles in tumor cells. Tumor cells can evade apoptosis through autophagy regulation, thereby increasing drug resistance and enhancing tumor cell viability.[10] Numerous drugs have been shown to activate autophagy;[11] however, regulation of autophagy has been reported to both promote and overcome ADR resistance in breast cancer cells.[12,13] Therefore, the key mechanisms by which autophagy mediates ADR resistance in breast cancer remain unclear.

Berberine (BBR), a traditional Chinese medicine, was shown to be an effective anti-tumor agent.[14,15] An in vitro experiment demonstrated that BBR inhibited the proliferation of MDA-MB231 breast cancer cells and may be an effective replacement for the EGFR inhibitor, lapatinib.[14] BBR may inhibit breast cancer by regulating the mitogen-activated protein kinase and Wnt/β-catenin signaling pathways.[15] Studies have shown that BBR inhibits chemotherapy resistance by regulating autophagy in breast cancer cells;[16,17] however, these results were based on the protein expression of LC3II/I and p62 and not on observation of cell autophagy using transmission electron microscopy.[6]

In this study, we showed that BBR reversed ADR resistance by inhibiting autophagy through the PTEN/Akt/mTOR signaling pathway in breast cancer cells. We generated an ADR-resistant breast cancer cell line, MCF-7/ADR and confirmed that BBR inhibited autophagy by inhibiting the expression of phosphatase and tensin homolog (PTEN) and regulating the PTEN/Akt/mTOR signaling pathway. In vivo experiments further showed that BBR exerts marked anti-tumor effects, indicating that this drug has great potential for the treatment of breast cancer patients with ADR resistance.

Materials and Methods

Cell Lines and Reagents

The human breast cancer cell line MCF-7 was purchased from Cell Bank (Chinese Academy of Sciences) and grown in DMEM supplemented with 10% fetal bovine serum (Gibco, USA) at 37°C with 5% CO_2. To establish the ADR-resistant cell line, MCF7 cells were cultured in medium containing increasing concentrations of ADR (Selleck, USA) for 6 months, and the surviving cells were grown in micromolar concentrations of ADR. The cells were then confirmed ADR-resistant (Supplementary Figure 1A), and named MCF-7/ADR. BBR was diluted in DMSO, and was donated by Professor Jiang from the Institute of Materia Medica, Chinese Academy of Medical Sciences & Peking Union Medical College. 3-Methyladenine (3-MA) was purchased from Selleck.

MTT Analysis

MCF-7/ADR cells were seeded in six-well plates at a density of 2 x 10^5 cells per well, and treated with BBR and/or ADR. After 48 h, 100 μL of a MTT (Sigma, USA) solution was added to each well. After 4 h, the MTT solution was discarded and 100 μL of DMSO (Sigma, USA) was added to each well and carefully shaken for 10 min. The absorbance was measured at 550 nm using a spectrophotometer (Bio-Rad, USA).

Colony Formation Assay

Approximately 1 x 10^3 cells per well were seeded in six-well plates, grown for 24 h, and then incubated with BBR and/or ADR. The medium was exchanged every 48 h. Colonies were harvested after 10 days. The cells were washed with PBS, fixed in 4% paraformaldehyde for 15 min, and stained with 1% crystal violet. Colonies were counted using ImageJ software.

EdU Cell Proliferation Assay

A total of 3 x 10^5 cells per well was seeded in 12-well plates, and treated with BBR and/or ADR for 48 h. Cells were assayed using EdU staining (Solarbio, Beijing, China) according to the manufacturer's instructions. Samples were protected from light during all the procedures.

Plasmids and Transfection

MCF-7/ADR cells were seeded in six-well plates at a density of 2 x10^5 cells per well. After 24 h, PTEN siRNA or control siRNA were transfected using Lipofectamine RNAiMAX (Invitrogen, USA), and PTEN expression plasmids were transfected using Lipofectamine 3000 (Invitrogen, USA) according to the manufacturer's instructions.

PTEN siRNA oligonucleotides sequences were as follows:

sense, 5′-CCACGAAGAGAUAAUGGAUGCCAAA-3′;

antisense, 5′-UUUGGCAUCCAUUAUCUCUUCGUGG-3′.

Transmission Electron Microscopy

Cells and tissue samples were fixed in 2% glutaraldehyde in 0.1 M phosphate buffer (pH 7.4) and then post-fixed in 1% OsO4 for 2 h at 4°C. The cells were dehydrated via a graded ethanol series and embedded in LR White resin. The solidified blocks were cut into ultrathin sections and stained with uranyl acetate and lead citrate. According to the manufacturer's instructions, samples were observed under a transmission electron microscope (HT7700 Hitachi, Japan).

Western Blotting

Total protein was extracted using a combination of RIPA buffer (150 mM NaCl, 50 mM Tris-HCl, 0.5% sodium deoxychlorate, 200 mM NaF, 200 mM PMSF, 1.0% NP40, and 1 mM EDTA), PMSF, and phosphatase inhibitors. Lysates (10 uL) were subjected to SDS–PAGE and then transferred to PVDF membranes. The following antibodies were used: anti-MAP1LC3B (LC3) (Abcam, 1:2000), anti-PTEN (CST, 1:1000), anti-p62 (CST, 1:1000), anti-MDR1(CST, 1:1000), anti-mTOR (CST, 1:1000), anti-p-mTOR (CST, 1:1000), anti-Akt (CST, 1:1000), anti-p-Akt (Ser473, CST, 1:1000) and anti-GAPDH (Abcam, 1:3000). Mouse secondary antibody (Gibco, 1:4000), and rabbit secondary antibody (Gibco, 1:4000). Membranes were analyzed using Image software (NIH, USA).

Tumor Xenograft Studies

In total 100uL of MCF-7/ADR cells (4 x 10[6] cells, mixed with 50uL of Matrigel) was subcutaneously injected into nude female mice (BALB/c, 5-weeks-old). When the tumors attained volumes of approximately 40 mm^3, the mice were randomly divided into the following 4 groups (Three mice in each group): The control group, treated with saline; the BBR group, treated with 10 mg/kg BBR by gavage administration; the ADR group, treated with 4mg/kg ADR by intraperitoneal injection; and BBR (10mg/kg) and ADR (4mg/kg) combination treatment group. Tumor volume and body weight were measured every 3 days. The animal experiments conformed to the Guide for the Care and Use of Laboratory Animals (Ministry of Science and Technology of China, 2006) and were approved by the Animal Care and Use Committee of Tongji Medical College of Huazhong University of Science and Technology.

Statistics

Student's *t*-test was used to assess the significance. P value <0.05 was considered statistically significant.

Results

ADR Resistance Is Related to High Levels of Autophagy in MCF-7/ADR Cells

We first measured the endogenous autophagy levels in both MCF-7 and MCF-7/ADR cells, and found higher autophagosome levels, higher expression of the autophagy-associated protein LC3I/II, and lower expression of p62 protein in MCF-7/ADR cells compared with that in MCF-7 cells, showed (Figure 1A and B). This suggested that ADR resistance was related to the high level of autophagy in breast cancer cells.

To verify the relationship between high levels of autophagy and ADR resistance, we treated MCF-7/ADR cells with the autophagy inhibitor 3-MA. The results showed that, with inhibition of autophagy, the expression of MDR1 decreased (Figure 1C), the sensitivity of the cells to ADR increased, and cell activity was significantly inhibited in MCF-7/ADR cells (Figure 1D). Combined, the results indicated that ADR resistance is related to high levels of autophagy in breast cancer cells.

BBR Reverses ADR Resistance

MCF-7/ADR cells were treated with BBR and/or ADR. The results showed that the combination of the two drugs significantly inhibited cell growth in a dose-dependent manner (Figure 2A). These results were also confirmed by colony formation and EdU assays (Supplementary Figure 1B and C). Based on the above experiments, we selected BBR at 100 μM and ADR at 0.517 μM as the optimal drug concentration for the following experiments. After BBR treatment, MCF-7/ADR cells showed decreased expression of the drug resistance-related protein MDR1 (Figure 2B) and increased sensitivity to ADR (Figure 2C), indicating that BBR reverses ADR resistance in MCF-7/ADR cells.

The Reversal of ADR Resistance by BBR Is Related to Inhibition of Autophagy

To verify whether the reversal of ADR resistance by BBR was related to autophagy, MCF-7/ADR cells were treated with BBR and/or ADR for 48 h. The results showed that compared with either ADR or BBR treatment alone, the combination of two drugs significantly decreased the number of autophagosomes, inhibited the expression of the autophagy-associated protein LC3II/I, and increased the protein expression of p62 in MCF-7/ADR cells (Figure 3A and B). In addition, no significant change in

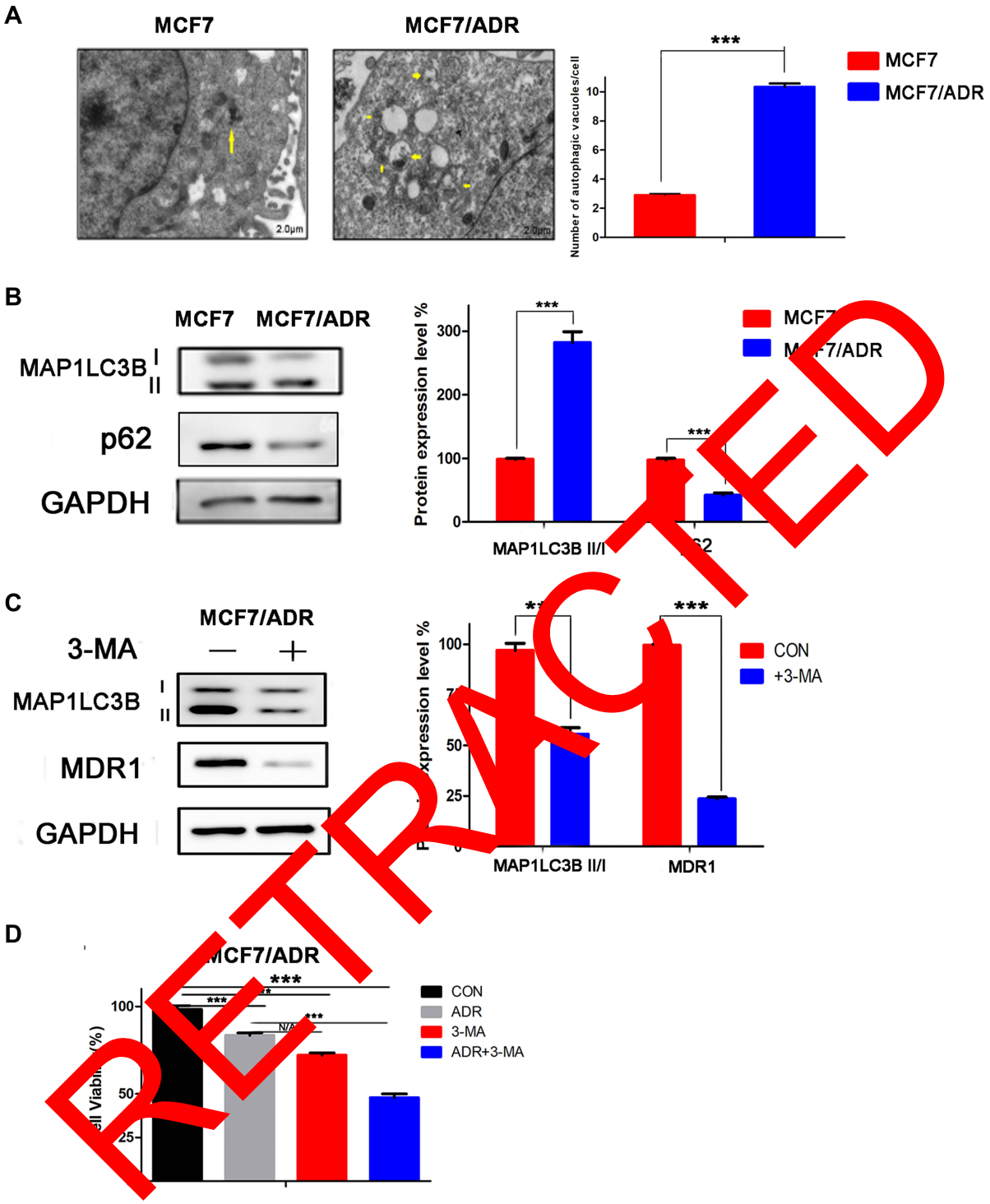

Figure 1 Doxorubicin (ADR) resistance is related to a high level of autophagy in ADR-resistant MCF-7 (MCF-7/ADR) cells. (**A**) MCF-7 and MCF-7/ADR cells were fixed in 2% glutaraldehyde in 0.1 M phosphate buffer (pH 7.4) and then post-fixed in 1% OsO4 for 2 h at 4°C. The cells were dehydrated via a graded ethanol series and embedded in LR White resin. The solidified blocks were cut into ultrathin sections and stained with uranyl acetate and lead citrate. Samples were observed under a transmission electron microscope. MCF-7/ADR cells showed higher autophagosome levels than MCF-7 cells. Yellow arrows indicate Autophagosome. (**B**) Total protein was extracted using a combination of RIPA buffer (150 mM NaCl, 50 mM Tris-HCl, 0.5% sodium deoxycholate, 200 mM NaF, 200 mM PMSF, 1.0% NP40, and 1 mM EDTA), PMSF, and phosphatase inhibitors. Lysates (10 uL) were subjected to SDS–PAGE and then transferred to PVDF membranes. Membranes were analyzed using ImageJ software. Western blotting analysis showed that MCF-7/ADR cells exhibit higher expression of the autophagy-associated protein LC3II/I, and lower expression of p62 protein, than MCF-7 cells. (**C**) MCF-7/ADR cells were treated with the autophagy inhibitor 3-MA (5 mM). Western blotting analysis showed that 3-MA treatment inhibited the expression of LC3II/I and MDR1. (**D**) MCF-7/ADR cells were treated with ADR, 3-MA, or a combination of both. MTT was added after 48 h. After 4 h of incubation, the MTT solution was discarded and DMSO was added for 10 min with slow shaking. Absorbance was measured at 550 nm using a spectrophotometer. The results showed that 3-MA treatment increased the sensitivity of MCF-7/ADR cells to ADR. N/A, not significant; ***p<0.001 (Student's *t*-test).

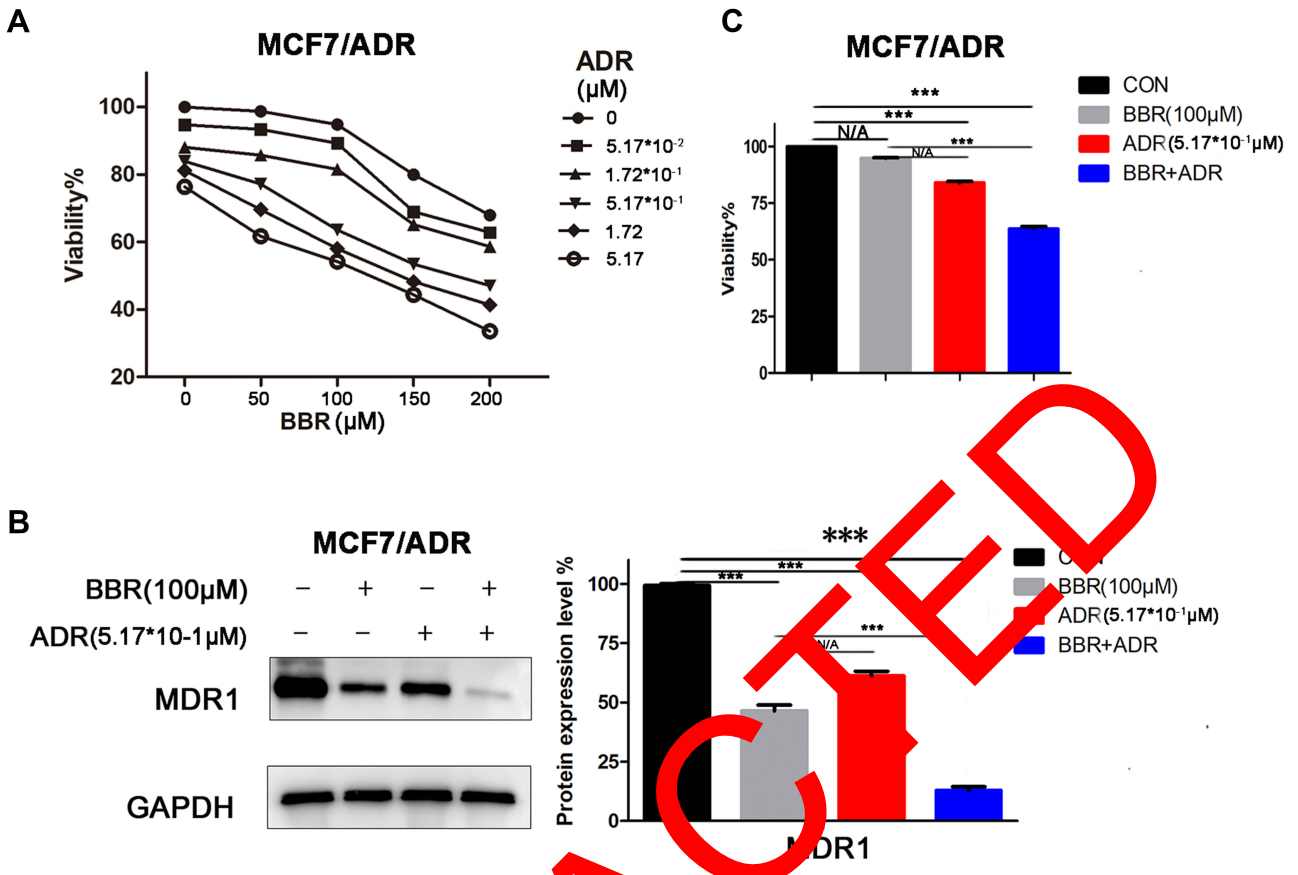

Figure 2 Berberine (BBR) reverses doxorubicin (ADR) resistance in ADR-resistant MCF-7 (MCF-7/ADR) cells. (**A**) MTT analysis showed that combined treatment with BBR and ADR inhibited cell growth in a dose-dependent manner in MCF-7/ADR cells. (**B**) MCF-7/ADR cells were treated with BBR and/or ADR. Western blotting analysis showed that BBR treatment inhibited MDR1 expression in the ADR-resistant cells (BBR, 100 uM; ADR, 0.517 uM). (**C**) MCF-7/ADR cells were treated with BBR and/or ADR. MTT analysis showed that BBR treatment increased the sensitivity of the cells to ADR (BBR, 100 uM; ADR, 0.517 uM). N/A, not significant; ***p<0.001 (Student's *t*-test).

the activity of MCF-7/ADR cells was observed when the cells were treated with a combination of the rapamycin (autophagy activator) and BBR (Figure 3C), further indicating that BBR inhibits autophagy in MCF-7/ADR cells and reverses ADR resistance.

BBR Regulates Autophagy Through the PTEN/Akt/mTOR Signaling Pathway

Various signaling pathways have been verified to regulate autophagy, including the Akt, mTOR, and MAPK signaling pathways.[19] PTEN is a key factor functioning upstream of the Akt/mTOR pathway, and inhibits the expression of phosphatidylinositol-3–Kinase (PI3K) and activity of Akt by blocking the conversion of phosphatidylinositol-4-diphosphate (PIP2) to phosphatidylinositol-3-5-trisphosphate (PIP3).[20,21] To investigate whether BBR regulates cell autophagy through PTEN, and whether BBR treatment affects Akt and mTOR activation, we treated MCF-7/ADR cells with BBR and/or ADR. The results showed that BBR treatment significantly decreased the expression of PTEN, and increased Akt and mTOR activation in MCF-7/ADR cells (Figure 4A). Overall, we confirmed that BBR inhibits autophagy and reverses ADR resistance in MCF-7/ADR cells by regulating the PTEN/Akt/mTOR signaling pathway.

To explore the mechanisms through which BBR reverses ADR resistance, we knocked down or overexpressed PTEN in MCF-7/ADR cells through transfection of siRNA or PTEN expression plasmids (Supplementary Figure 1D). The results showed that the combination of siPTEN transfection and BBR treatment significantly inhibited autophagosome numbers (Figure 4B) and increased phosphorylation of Akt and mTOR in MCF-7/ADR cells (Figure 4C); however, no significant changes were observed in cell autophagy or p-Akt and p-mTOR levels when PTEN overexpression and BBR treatment were combined (Figure 4D and E). In addition, we also found that BBR treatment significantly inhibited

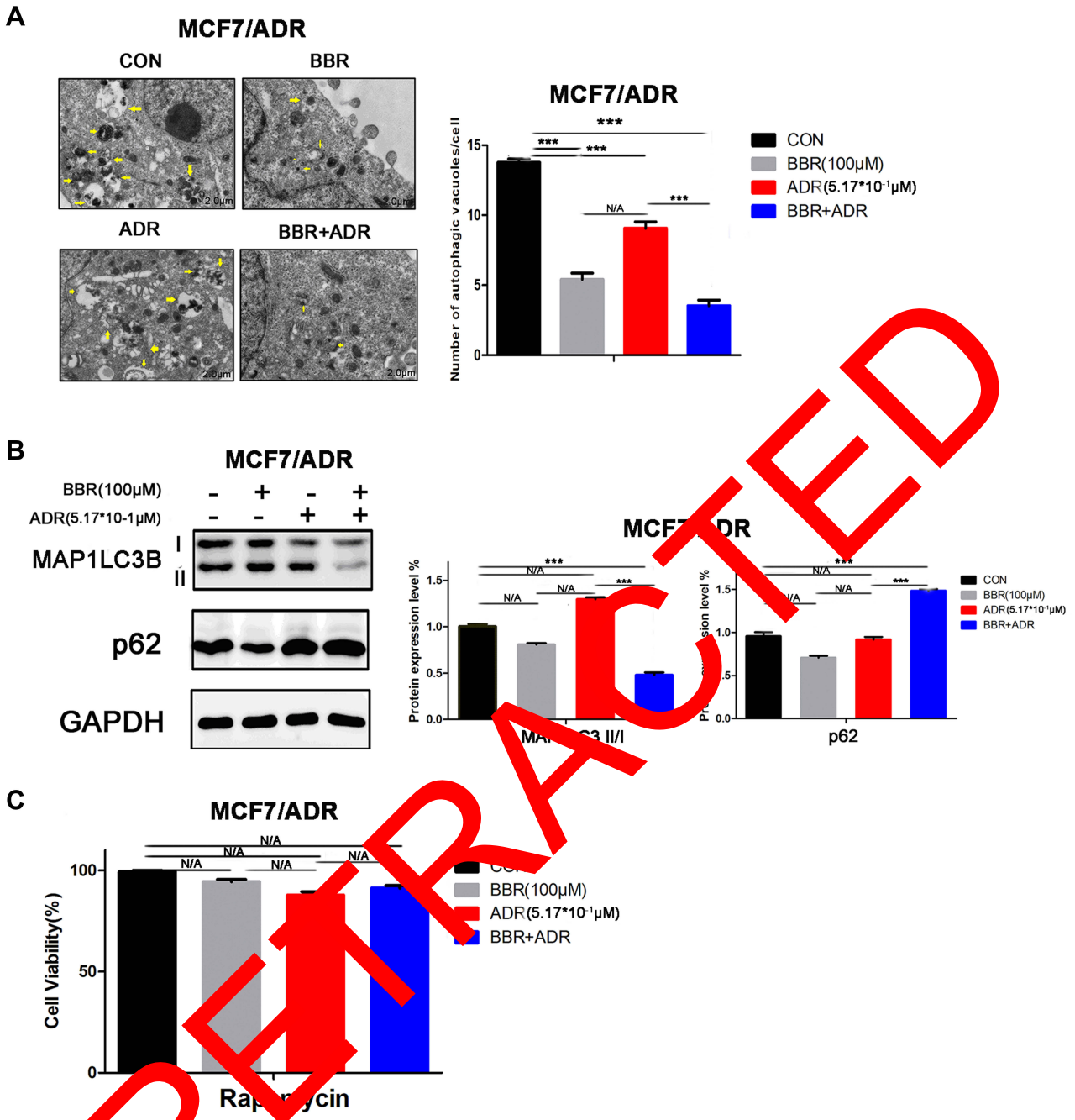

Figure 3 Berberine (BBR)-mediated reversal of doxorubicin (ADR) resistance is associated with inhibition of autophagy. (**A**) ADR-resistant MCF-7 (MCF-7/ADR) cells were treated with BBR and/or ADR. Combined ADR and BBR treatment significantly decreased the number of autophagosomes in the MCF-7/ADR cells (BBR, 100 μM; ADR, 0.517 μM). Yellow arrows indicate Autophagosome. (**B**) MCF-7/ADR cells were treated with BBR and/or ADR. Western blotting analysis showed that combined ADR and BBR treatment led to a significant decrease in the expression of LC3I/II and an increase in that of p62 in MCF-7/ADR cells (BBR, 100 μM; ADR, 0.517 μM). (**C**) After treatment with rapamycin, MCF-7/ADR cells were then treated with BBR and/or ADR. In the presence of rapamycin, BBR treatment induced no significant change in the activity of MCF-7/ADR cells (BBR, 100 μM; ADR, 0.517 μM; rapamycin, 50 nM). N/A, not significant; ***p<0.001 (Student's *t*-test).

the activity of siPTEN-transfected cells, but not that of PTEN-overexpressing breast cancer cells (Figure 4F). Together, these results demonstrate that BBR inhibits autophagy and reverses ADR resistance by inhibiting the PTEN/Akt/mTOR signaling pathway.

BBR Reverses ADR Resistance in vivo

To establish xenograft tumor models, MCF-7/ADR cells were subcutaneously injected into BALB/C nude female mice (Figure 5A). The mice were randomly divided into four groups (control group, ADR-treated

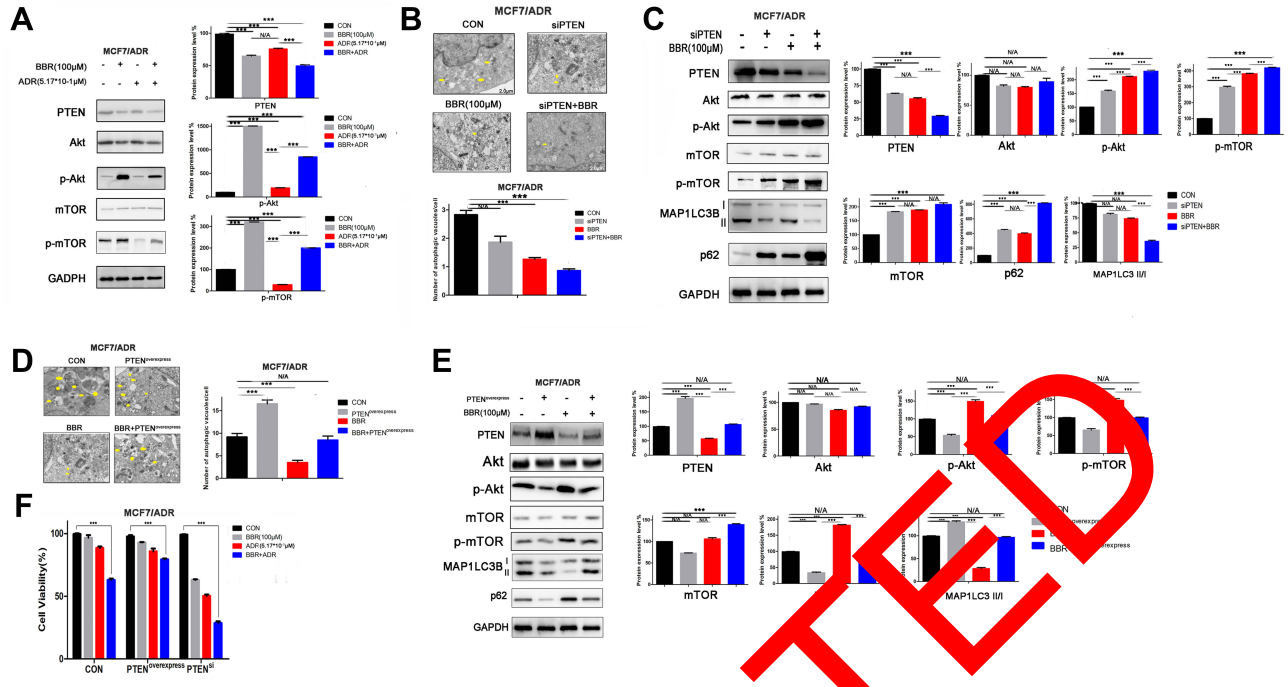

Figure 4 Berberine (BBR) inhibits autophagy and reverses doxorubicin (ADR) resistance t[illegible]inhibition of the [illegible]EN/Akt/mTOR signaling pathway. (**A**) ADR-resistant MCF-7 (MCF-7/ADR) cells were treated with BBR and/or ADR. Western blotting analysis showed that BBR treatment led to a significant decrease in PTEN expression and increased the activation of Akt and mTOR in MCF-7ADR cells (BBR, 100 μM; ADR, [illegible]517 μM). (**B**) MCF-7/ADR cells were treated with BBR and/or transfected with siPTEN. This combined siPTEN and BBR treatment significantly reduced the autop[illegible]gosome numbe[illegible] MCF-7/ADR cells (BBR, 100 μM). Yellow arrows indicate Autophagosome. (**C**) MCF-7/ADR cells were treated with BBR and/or transfected wit[illegible]PTEN. The res[illegible]s showed that the combination of siPTEN and BBR treatment increased Akt and mTOR activation (BBR, 100 μM). (**D**) MCF-7/ADR cells were treated [illegible] BBR and/[illegible]ransfected with PTEN-expressing plasmids. The results showed that PTEN overexpression combined with BBR treatment induced no sig[illegible]changes in au[illegible]ome number in MCF-7/ADR cells (BBR, 100 μM). (**E**) MCF-7/ADR cells were treated with BBR and/or transfected with PTEN-expressing plas[illegible]ls. W[illegible] blotting analysis showed that PTEN overexpression combined with BBR treatment did not lead to significant changes in the levels of phosphorylated Akt and m[illegible]OR (BB[illegible]M). (**F**) Cells overexpressing PTEN or PTEN-knockdown cells were treated with BBR and/or ADR. Analysis by MTT assay showed that BBR treatment sig[illegible]ly inhibited the activity of PTEN-knockdown cells, whereas no significant effects were observed in PTEN-overexpressing breast cancer cells (BBR [illegible] ADR, 0.5 [illegible]μM). N/A, not significant; ***p<0.001 (Student's *t*-test).

group, BBR-treated group, AD[illegible]+BB[illegible]eated group) when the tumors had forme[illegible] The results [illegible]howed that BBR treatment significa[illegible]y in[illegible]ited tumo[illegible] growth, although body weig[illegible] remained [illegible]most unchanged (Figure 5B–D). In[illegible]addition, we extrac[illegible]ed total protein from tumor tissu[illegible] an[illegible] found that BBR treatment inhibited the [illegible]xpres[illegible]n of P[illegible]EN and LC3II/I, and increased the [illegible]xpress[illegible]n of p-Akt (Figure 5E). Togeth[illegible] these [illegible]ata demonstrated that BBR treatment reversed [illegible]DR resistance in vivo.

Discussion

Breast cancer is a malignant tumor and a leading cause of cancer-related morbidity and mortality among women worldwide.[22] Chemotherapy is the main method used for the treatment of breast cancer patients.[23] ADR is widely used in chemotherapy for breast cancer treatment, and its clinical use has achieved great success.[24] However, a subset of patients presents poor survival outcomes owing to ADR resistance.[25]

A study showed that high autophagy levels play an important role in resistance to chemotherapy.[26] Although autophagy-mediated drug resistance in tumor cells has been widely investigated,[27,28] the associated mechanisms remain poorly understood. In this study, we found that the endogenous autophagy level in MCF-7/ADR cells was significantly higher than that in MCF-7 cells. This suggested that ADR resistance might be related to a high level of autophagy, which would enhance the viability of tumor cells and that inhibiting autophagy in MCF-7/ADR cells might reverse this resistance.

The early autophagy inhibitor, 3-MA, inhibits autophagosome formation by down-regulating the activity of PI3K.[29,30] Although 3-MA significantly inhibits autophagy, it is only used in vitro experiments due to its toxicity.[31] Therefore, efficient and low-toxicity autophagy inhibitors must be identified to improve the therapeutic effects of chemotherapy in breast cancer patients.

BBR, a small isoquinoline compound with low toxicity, was recently identified as an inhibitor of autophagy.[17] BBR

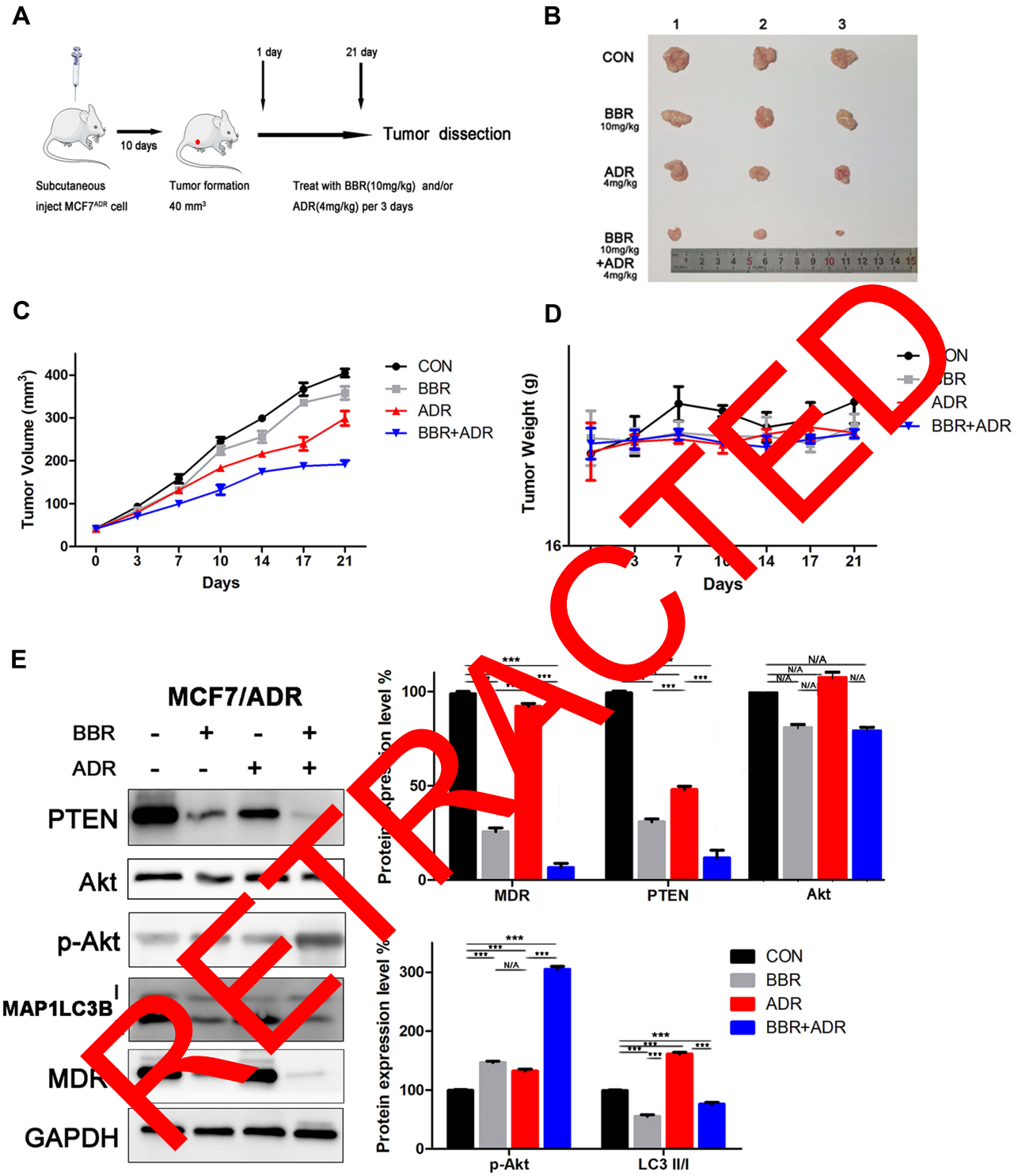

Figure 5 Berberine (BBR) reverses doxorubicin (ADR) resistance in vivo. (**A**) ADR-resistant MCF-7 (MCF-7/ADR) cells were subcutaneously injected into BALB/C nude female mice to establish a xenograft tumor model. (**B**) A combination of BBR and ADR significantly inhibited tumor growth in vivo. (**C**) Tumor volumes were measured every 3 days. The results showed that BBR treatment significantly inhibited tumor growth in vivo. (**D**) Body weight was measured every 3 days. The results showed that BBR and/or ADR treatment did not affect body weight in vivo. (**E**) Western blotting analysis of extracted tumor tissues showed that BBR treatment inhibited the expression of PTEN and LC3II/I and increased Akt phosphorylation levels (BBR, 10 mg/kg; ADR, 4 mg/kg). N/A, not significant; ***p<0.001 (Student's *t*-test).

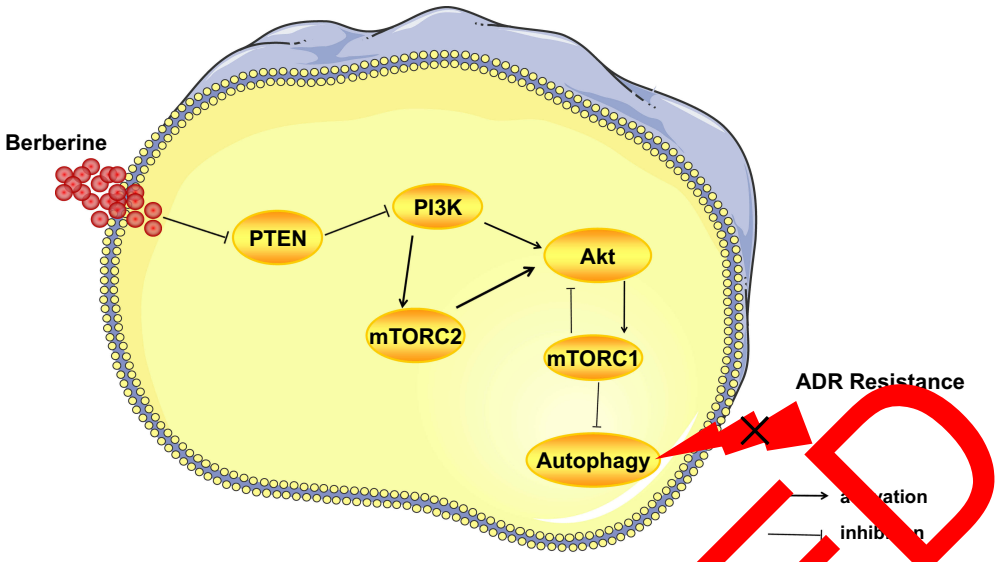

Figure 6 Berberine reverses doxorubicin resistance by inhibiting autophagy through the PTEN/Akt/mTOR signaling pathway in breast cancer. BBR inhibits autophagy, therefore, reversing ADR resistance by inhibiting the PTEN/Akt/mTOR signaling pathway. Akt phosphorylation results in mTORC1 activation and mTORC1 activation has inhibited effects on the PI3K/Akt signaling pathway. A positive regulation exists between the PI3K signaling and mTORC2. Activation of mTORC1 downregulates autophagy, and Akt phosphorylation by mTORC2 also contributes to inhibition of autophagy.

reverses chemotherapy resistance in breast cancer cells, with an IC50 ranging from 10 to 25 uM;[14,32] however, in this research, we showed that the IC50 of BBR was approximately 100uM. As we know, the reasons for chemotherapy resistance are multifaceted. The MCF-7 cells will be totally different after the cells acquire ADR resistance, that is to say, essentially, MCF7/ADR cells have become a completely different cell line from MCF-7. In addition, HER2-positive breast cancer cells and MCF-7 cells are different breast cancer cells, therefore, the different IC50 of BBR among lapatinib-resistant HER2-positive breast cancer cells, MCF-7 cells and MCF7/ADR are reasonable. In this study, we demonstrated that high levels of autophagy in MCF-7/ADR cells protect these cells from the chemotherapeutic effects of ADR, resulting in resistance to this drug. We found that BBR treatment significantly inhibited autophagy and led to a decrease in MCF-7/ADR cell activity, demonstrating its effects on reversing ADR resistance.

As Figure 6 showed, the PI3K/Akt signaling pathway is the upstream of mTORC1, and Akt phosphorylation results in mTORC1 activation.[33] However, mTORC1 activation has feedback loop on the PI3K/Akt signaling pathway and inhibited its activation.[34] The PI3K signaling activates mTORC2, and phosphorylation of mTORC2 contributes to activation of Akt.[35,36] Activation of mTORC1 downregulates autophagy,[37,38] and Akt phosphorylation by mTORC2 also contributes to inhibition of autophagy.[39] As we discussed above, mTORC2 may indirectly suppress autophagy by regulating mTORC1. Given that mTORC1 and mTORC2 both have the ability of suppressing autophagy, therefore, in this research, we detected mTOR and p-mTOR instead of mTORC1 and mTORC2. MCF-7/ADR cells have high level of autophagy, and it might be the reason for ADR resistance. In this study, we showed that BBR inhibits autophagy by inhibiting the expression of PTEN and increasing that of p-Akt and p-mTOR in MCF-7/ADR cells, thereby reversing ADR resistance. In common sense, the upregulation of p-Akt and p-mTOR contributes to cell proliferation and tumor growth.[40,41] We speculate that, in ADR-resistant cells, autophagy is the main mechanism involved in ADR resistance and cancer development, and upregulation of p-Akt and p-mTOR leads to inhibition of autophagy. Owing to time constraints, we did not investigate the mechanisms through which BBR regulates PTEN expression; however, we hope to explore this in the future.

In conclusion, we showed for the first time that BBR, an autophagy inhibitor, effectively inhibits cell growth both in vivo and in vitro, suggesting that BBR has potential for use as a chemical adjuvant for breast cancer treatment. Our findings provide insights into the mechanisms associated with ADR resistance and well as novel therapeutic options for the treatment of breast cancer.

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Disclosure

The authors report no conflicts of interest in this work.

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