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ORIGINAL RESEARCH

RETRACTED ARTICLE: Tangeretin inhibits hepatocellular carcinoma proliferation and migration by promoting autophagy-related BECLIN1

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Background: Hepatocellular carcinoma (HCC) is a particularly prevalent type of liver cancer and is one of the deadliest malignancies in Asia. Tangeretin is a biological compound extracted from traditional Chinese herbs and has been shown to have potential antitumour properties; however, its mechanism remains largely unknown. Therefore, we sought to determine the role of Tangeretin in HepG2 cells subjected to antitumour treatment.

Materials and methods: Cell proliferation was quantified using CCK-8, EdU and colony formation assays, and cell migration was quantified using transwell migration and wound healing assays. Protein expression was assessed using Western blot analysis. Small interfering RNA was used to interfer protein expression. Immunoprecipitation was performed to detect the protein-protein interactions.

Results: Tangeretin decreased cell proliferation and increased G2/M arrest. Tangeretin decreased cell migration. Tangeretin increased the LC3II/LC3I ratio and decreased p62 expression in HepG2 cells. Furthermore, the knockdown of BECLIN1 expression in HepG2 cells partially converted the Tangeretin-induced inhibition of proliferation, migration and autophagy. In addition, Tangeretin activated the JNK1/Bcl-2 pathway and disturbed the interaction between Bcl-2 and BECLIN1. Together, our findings demonstrate that Tangeretin inhibited the proliferation and migration of HepG2 cells through JNK/Bcl-2/BECLIN1 pathway-mediated autophagy.

Conclusion: Our study contributes to the understanding of the inhibitory mechanism of Tangeretin on HCC development.

Keywords: hepatocellular carcinoma, Tangeretin, BECLIN1, JNK1

Introduction

Liver cancer is the third leading death of cancer worldwide, and it seriously threatens human health. There are approximately 850,000 new cases and 600,000 deaths every year in the world.[1] Although the diagnosis and treatment technologies of liver cancer have made great progress, the five-year survival rate is still extremely low.[2] In China, HCC is the most common type of primary liver cancer and has a high recurrence rate and a poor prognosis.[3] Therefore, it is urgent to find a more effective treatment strategy for liver cancer.

The effect of autophagy in hepatocytes is worthy of concern. Autophagy contributes to maintaining hepatocyte homeostasis, and it plays an important role in preventing malignant transformation.[4] It has been confirmed that autophagy plays a suppressive role in hepatocellular carcinoma (HCC) tumourigenesis. Takamura

et al found the accumulation of nonfunctional proteins and organelles in hepatocytes after knocking out autophagy-related gene 5 (ATG5) and autophagy-related gene 7 (ATG7).[5] The conditional knockout of ATG7 in mouse liver results in hepatomegaly and metabolic disorders.[6,7]

BECLIN1, the mammalian orthologue of yeast autophagy-related gene 6 (ATG6), is also a mammalian-specific gene involved in autophagy. Qu et al found that a heterozygous mutation disrupted the BECLIN1 autophagy gene, promoting hepatocyte tumourigenesis.[8] Previous studies have suggested that BECLIN1 contains a leucine-rich nuclear export signal that is required for its autophagy and tumour suppressor function.[9,10] Huang et al found that aspirin induced BECLIN1-dependent autophagy in human HCC cells.[11] The expression of BECLIN1 in HCC is associated with clinicopathological parameters and prognostic significance.[12] Therefore, these studies have demonstrated that BECLIN1 is an HCC biomarker.

5,6,7,8,4′-Pentamethoxyflavone (Tangeretin; for its structure, see Figure 1A) is one of the plant-derived flavonoids found in tangerine, sweet orange, and other citrus peels and has been shown to possess a variety of pharmacological activities, including antioxidative, anti-inflammatory, and antitumour properties.[13] Tangeretin exerts antiasthmatic effects by reducing the levels of Th2 and Th17 cytokines and by increasing IFN-γ levels and inhibiting PI3K and Notch1 signalling.[14] Tangeretin demonstrated anti-inflammatory activity by inhibiting NF-κB/TNF-α/iNOS signalling.[15] Tangeretin was also found to be beneficial against 7,12-dimethylbenz(a)anthracene-induced oxidative stress in breast cancer-bearing animals.[17] In addition, Tangeretin inhibited cancer cell growth by inducing G1 arrest or apoptosis in human non-small-cell lung cancer cells.[18] However, the role of Tangeretin in hepatocellular damage remains unclear.

In this study, we examined the effect of Tangeretin on hepatocellular carcinoma cells and elucidated the possible molecular mechanisms responsible for its anticancer activity.

Materials and methods

Reagents

Tangeretin (S2363) was obtained from Selleck (Shanghai, China); anti-BECLIN-1 antibody (ab62557) was purchased from Abcam (Cambridge, UK). Anti-LC3 (#12741S), anti-p62 (#5114S), anti-caspase-3 (#9662S) and anti-cleaved caspase-3 (#9661S) antibodies were obtained from Cell Signaling Technology (Danvers, MA). Anti-Bcl-2 (PRS3335), anti-phospho-Bcl-2 (SAB4504350), anti-phospho-JNK (SAB4504449), and anti-JNK (SAB4200176) antibodies were obtained from Sigma-Aldrich (Shanghai, China). Lipofectamine RNAiMAX reagent (13778150) was obtained from Thermo Fisher Scientific (Waltham, MA). A Cell-Light™ EdU Apollo® In Vitro Imaging Kit (C10310) was purchased from RiboBio (Guangzhou, China). A Transwell Migration Assay was purchased from Life Sciences (Tewksbury, MA, USA). Wound healing culture inserts were obtained from IBIDI GmbH (Martinsried, Germany).

Cell culture

The HCC line HepG2 was purchased from the Type Culture Collection of the Chinese Academy of Sciences (Shanghai, China). HepG2 cells were maintained at 37 °C in humidified conditions of 95% air and 5% CO_2 in DMEM supplemented with 10% heat-inactivated foetal bovine serum, 2 mM glutamine, and 1% penicillin-streptomycin.

Cell viability assay

HepG2 cells were incubated in 96-well plates at a density of 5×10^3 cells for 24 h. The cells were treated with the indicated concentrations of Tangeretin for 24 h and then incubated with Cell Counting Kit-8 (CCK-8) reagent for 2 h at 37°C. Absorbance was measured at 450 nm on a microplate reader.

Cell cycle analysis

HepG2 cells were treated with the indicated concentrations of Tangeretin for 24 h and then fixed with 75% ethanol at 20°C. The ethanol-fixed cells were resuspended in PBS containing ribonuclease A (100 mg/ml) and incubated for 1 h at 37°C. Next, the cells were stained with propidium iodide (50 mg/ml) and incubated for 30 min at room temperature in the dark. The data were acquired and analysed using a flow cytometer.

Colony formation assay

HepG2 cells were seeded into 60 mm dishes (200 cells/dish) and then incubated with 0, 30, 60 and 90 μg/ml Tangeretin for 2 weeks to form colonies. Cells were fixed with methanol for 15 min, and then the cells were stained with 0.1% crystal violet for 20 min at room temperature. Colonies containing ≥50 cells were manually

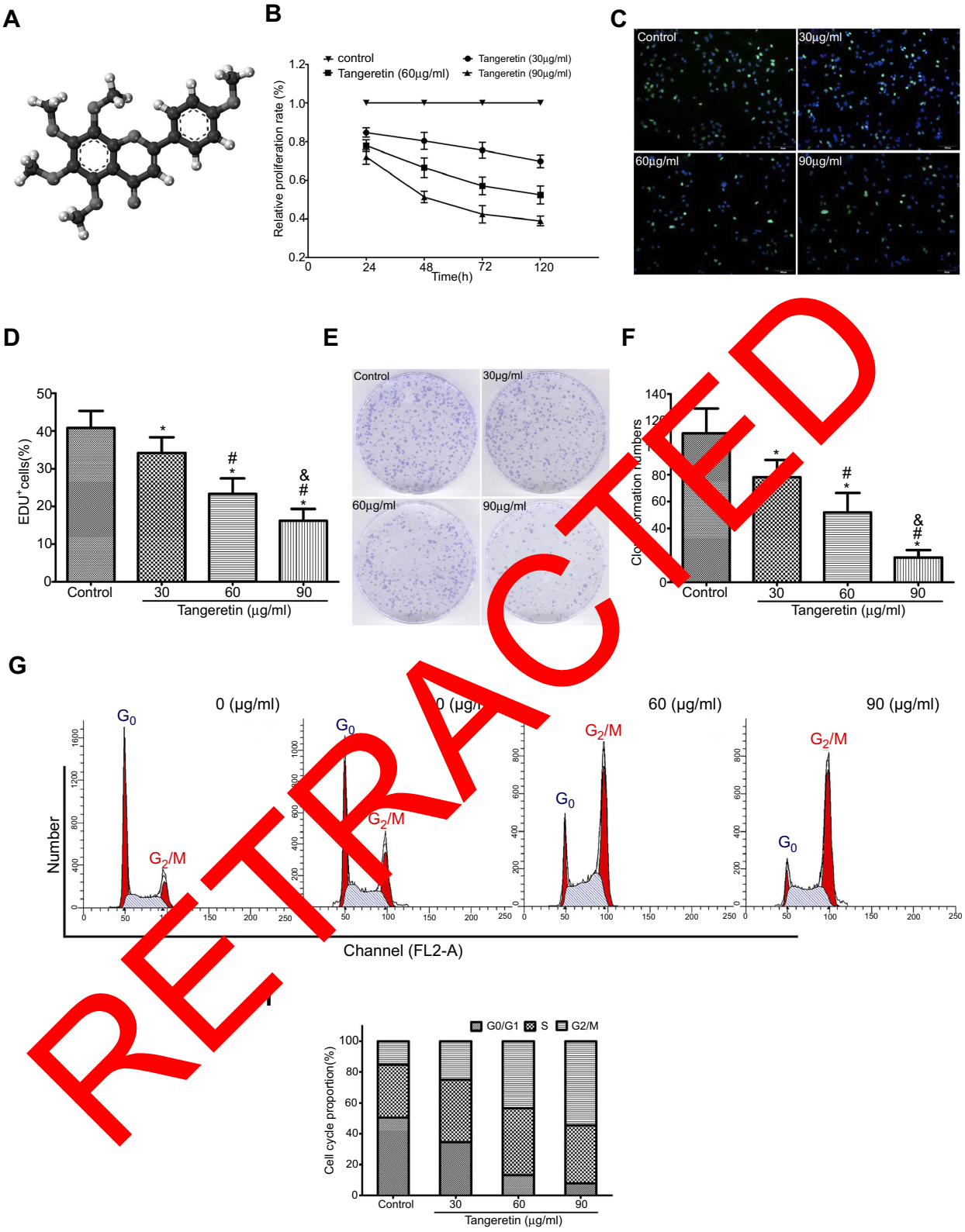

Figure 1 Tangeretin inhibited the proliferation of HepG2 cells.

Notes: (**A**) Molecular structure of Tangeretin. (**B–G**) HepG2 cells were treated with the indicated concentrations of Tangeretin (0, 30, 60 and 90 μg/mL) for 24 h. Then, (**B**) CCK-8 assays were used to measure cell viability. (**C**) EdU labelled the HepG2 cells for 2 h. Immunofluorescence of EdU (green) and nuclei (DAPI, blue; ×10). Scale bar=25 μm. (**D**) The graph summarizes the data of the percentage of EdU cells. (**E**) HepG2 cells subjected to a colony formation assay. (**F**) The graph summarizes the colony formation assay data. Error bars represent the SD. of the mean ($n \geqq 6$; *vs control group, $P<0.05$; #vs 30 μg/mL Tangeretin group, $P<0.05$; &vs 60 μg/mL Tangeretin group, $P<0.05$). (**G**) Cells were harvested and stained with propidium iodide as outlined in the Materials and Methods. The flow cytometric analysis histograms are shown, and (**H**) the percentage of cells in G2/M phase is shown as a bar graph.

counted under a microscope. Each assay was performed in triplicate.

Transwell migration assay

Cell migration was measured using a Transwell Migration Assay according to the manufacturer's instructions. The transwells for the HepG2 cells required overnight precoating of 10 μg/ml collagen before seeding. Cells (1×10^6/ml) were seeded into transwell inserts and incubated overnight, followed by Tangeretin treatment at different concentrations for 24 h. ImageJ (1.48v) software (National Institutes of Health, Bethesda, Md, USA) was used to obtain an average cell count of the four stained membrane images. Each assay was repeated in triplicate.

Wound healing assay

Wound healing culture inserts were used to analyse wound healing. According to the manufacturer`s instructions, HepG2 cells were plated at a concentration of 1×10^5 cells/ml and incubated for 24 h, after which the culture inserts were removed. Images of the movement of cells into the scratch area were taken every 6–12 h until the scratch area had closed using a microscope. Wound healing was analysed using TScratch software. Each assay was repeated in triplicate.

Western blot analysis

HepG2 cells were grown in 6-well plates to approximately 60–70% confluence for 24 h and then treated with Tangeretin at the indicated concentrations. Then, cells were harvested and subjected to Western blot analysis. Briefly, equal amounts of total protein (30 or 40 μg) were separated using 10% or 15% SDS-PAGE and transferred onto polyvinylidene fluoride membranes. Subsequently, the membranes were blocked in 5% dry milk in TBST for 1 h at room temperature and then incubated with primary antibodies diluted in TBST and 0.2% bovine serum albumin overnight at 4 °C. Proteins were visualized using the Omega lumc system (Aplegen, San Francisco, CA), and densitometric analysis was performed using the ImageJ software.

Small interfering RNA (siRNA)

HepG2 cells were transfected with a nontarget control siRNA or a BECLIN1 siRNA by using Lipofectamine 3000. After 48 h of transfection, the cells were treated with Tangeretin (90 μg/mL) for 24 h. Western blot analysis was used to detect the interference efficiency, and the immunoblotting steps were conducted as previously described.

Immunoprecipitation (IP)

Total protein were extracted by radioimmunoprecipitation assay (RIPA) lysis buffer. Immunoprecipitation was performed using PureProteome Protein G Magnetic Beads (LSKMAGG10; Millipore, Billerica, MA) based on the manufacturer's guidelines. Two microliters of primary antibody or immunoglobulin (IgG) was used for immunoprecipitation or the control, respectively. Blots were incubated overnight at 4 °C with designated primary antibodies at a dilution of 1:1,000 unless noted otherwise. Proteins visualized and densitometric analysis were conducted as previously described.

Statistical analysis

The results of at least three independent experiments are presented as the means±standard deviations (SDs). For statistical analysis, statistical significance was analysed using Tukey's multiple comparison tests and one-way analysis of variance. Data analysis was performed with GraphPad Prism (GraphPad Software, Inc., La Jolla, CA, USA). Statistical significance was considered at $p<0.05$.

Results

The effect of Tangeretin on the proliferation of HepG2 cells

To determine whether Tangeretin influences the proliferation of HCC cells, we first examined the effect of Tangeretin on the proliferation of HepG2 cells with the CCK-8 assay. HepG2 cells were treated with different concentrations of Tangeretin (0, 30, 60 and 90 μg/ml) for 24 h. As shown in Figure 1B, Tangeretin decreased cell viability in a dose-dependent manner. Second, EdU staining and colony formation assays were performed. The results confirmed that Tangeretin decreased cell proliferation (Figure 1C and D) and colony formation (Figure 1E and F) in a dose-dependent manner.

To further evaluate the inhibitory effect of Tangeretin on HepG2 cell proliferation, we measured cell cycle progression by using flow cytometry. HepG2 cells were treated with 0, 30, 60 and 90 μg/ml Tangeretin for 24 h respectively, and then the cell cycle was measured. As shown in Figure 1G and H, Tangeretin-treated HepG2 cells accumulated in G2/M phase, and when the concentration of Tangeretin reached 90 μg/ml, the number of cells

in G2/M phase increased from 21% to 50%, which was accompanied by a decrease of cells in G1 phase (compared to the control). These findings suggest that Tangeretin suppresses the proliferation of HCC cells.

The effect of Tangeretin on the migration of HepG2 cells

Subsequently, we detected the effect of Tangeretin on cell migration. HepG2 cells were treated with different concentrations of Tangeretin for 24 h in serum-free medium, and transwell assays were performed. As shown in Figure 2A and B, Tangeretin significantly inhibited cell migration in a dose-dependent manner, and 75% inhibition was observed at a concentration of 90 μg/ml Tangeretin. CCK-8 assays showed that antiproliferation had no effect on antimigration activity (Figure 2C). Furthermore, our results demonstrated that Tangeretin significantly decreased wound healing and migration (Figure 2D and E).

Tangeretin triggers autophagy in HepG2 cells

Disordered apoptosis is one of the key characteristics of tumour cells. Caspase cleavage and cell cycle arrest are important in apoptosis. Apoptosis in tumour cells is an important aspect of most antitumour studies. We investigated whether Tangeretin decreased cell proliferation and migration by enhancing the rate of apoptosis. As shown in Figure 3, Tangeretin failed to induce caspase-3 cleavage. Notably, Tangeretin increased the LC3II/LC3I ratio and reduced p62 expression in HepG2 cells in a dose-dependent manner (Figure 3A and B). Additionally, immunofluorescence imaging revealed the distribution of LC3 in the cytosol, with a faint nuclear signal also being observed in HepG2 cells, and we observed a strong nuclear signal upon Tangeretin treatment (Figure 3C and D). These results suggested that Tangeretin triggered autophagy but not apoptosis in HepG2 cells.

Effect of the knockdown of BECLIN1 on HepG2 cell autophagy

BECLIN1 is a key regulator of autophagy.[11] A disruption in BECLIN1 reduced autophagy and tended to initiate the spontaneous formation of HCC in mice.[8] To further clarify whether Tangeretin inhibits the proliferation, migration and autophagy of HepG2 cells through BECLIN1 signalling, we knocked down BECLIN1 with a specific siRNA (Figure 4A). First, we performed EdU assays and transwell migration assays to investigate whether the down-regulation of BECLIN1 affects HepG2 cell proliferation and migration, respectively. The results clearly indicated that the knockdown of BECLIN1 markedly enhanced cell proliferation and migration, but this phenomenon was markedly attenuated by Tangeretin (Figure 4B–E).

Subsequently, we verified that BECLIN1 is involved in Tangeretin-induced autophagy. HepG2 cells transfected with BECLIN1-siRNA were treated with Tangeretin at a concentration of 90 μg/ml for 24 h, and the expression levels of BECLIN1, LC3 and P62 were analysed by Western blot. Our results showed that BECLIN1 was knocked down successfully, the LC3II/LC3I ratio declined and p62 expression increased significantly, and Tangeretin weakened the downtrend (Figure 4F–G). The results of immunofluorescence imaging and Western blot analysis were consistent (Figure 4H and I). These results suggest that Tangeretin-induced cell autophagy is BECLIN1-dependent.

Tangeretin activates JNK and disrupts the Bcl-2/BECLIN1 association

B-cell lymphoma-2 (Bcl-2) interacts with BECLIN1 to inhibit BECLIN1-dependent autophagy.[20] Wei et al found that the stress-activated signalling molecule C-Jun N-terminal protein kinase 1 (JNK1) mediated the phosphorylation of Bcl-2 and then phosphorylated Bcl-2 to dissociate from the BECLIN1/Bcl-2 complex, resulting in BECLIN1 release and the initiation of autophagy.[20] Therefore, we investigated whether Tangeretin affected Bcl-2 phosphorylation. As shown in Figure 5A and B, Tangeretin treatment increased the phosphorylation level of Bcl-2. We next examined the effect of Tangeretin on the BECLIN1/Bcl-2 complex and found that Tangeretin dramatically disrupted the association between BECLIN1 and Bcl-2 (Figure 5C and D).

We next sought to identify the upstream kinase responsible for the Tangeretin-induced phosphorylation of Bcl-2 and the disruption of BECLIN1 binding. JNK is the most frequently implicated Bcl-2 kinase that phosphorylates Bcl-2,[21,22] and our results showed that Tangeretin attenuated the knockdown of BECLIN1-induced cell proliferation and migration. Therefore, we determined whether Tangeretin was responsible for the regulation of the JNK pathway in HepG2 cells. We investigated the effects of

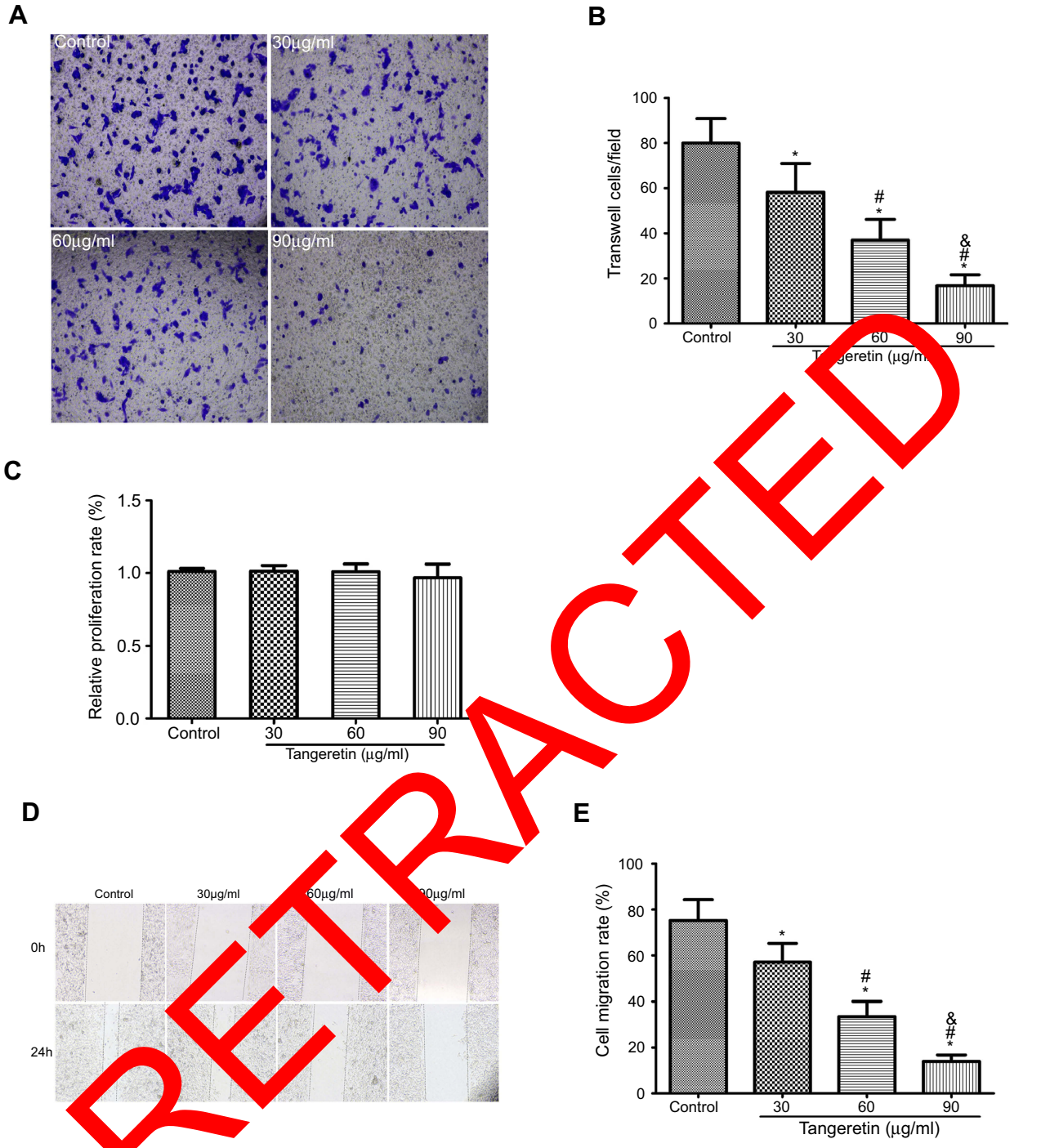

Figure 2 Tangeretin inhibited the migration of HepG2 cells.
Notes: HepG2 cells were treated with the indicated concentrations of Tangeretin (0, 30, 60 and 90 μg/mL) for 24 h in serum-free medium. (**A**) Representative images of transwell membranes stained with crystal violet (×10). Scale bar=25 μm. (**B**) The results represent the average of three experiments. Error bars represent the SD of the mean (**P<0.01). (**C**) CCK-8 assays were used to measure cell viability. (**D**) Wound healing and cell migration assays were used to measure cell migration. (**E**) Error bars represent the SD of the mean (n≥6; *vs control group, P<0.05; $^{\#}$vs 30 μg/mL Tangeretin group, P<0.05; $^{\&}$vs 60 μg/mL Tangeretin group, P<0.05).

Tangeretin on the phosphorylation of JNK in HepG2 cells. In the present study, the immunoblot assay showed that Tangeretin increased the phosphor-JNK level (Figure 5E and F). These results suggest that Tangeretin activates the JNK pathway.

Discussion

HCC is the most common type of primary liver cancer that accounts for 85–90% of all cases.[23] Tangeretin, an extract from citrus peels with multifaceted anticancer activity, is commonly used to treat cancer in China. However, the

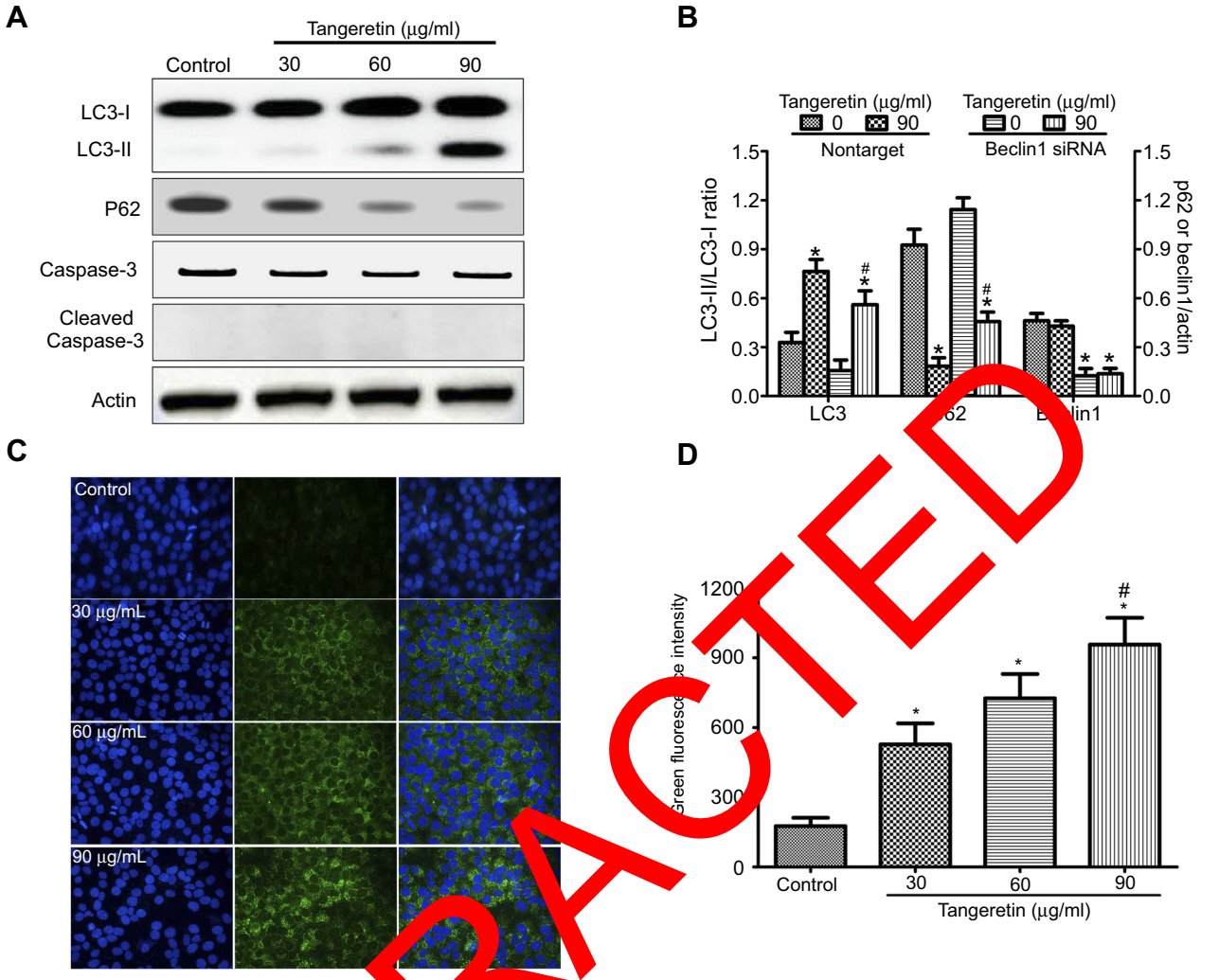

Figure 3 Tangeretin induces autophagy in He[illegible] cells.
Notes: HepG2 cells were treated with the [illegible]cated concentr[illegible]ns of Tangeretin (0, 30, 60 and 90 μg/mL) for 24 h. Then, (**A**) the levels of LC3, p62, BECLIN1, and Actin were examined. (**B**) Relative levels of LC[illegible] co[illegible]red with those [illegible]C3-I; relative levels of p62 compared with those of actin. (**C**) Immunofluorescence of LC-3 (green) and nuclei (DAPI, blue; ×40). Scale bar=25 μm. (**D**) Th[illegible]ea of LC3 dots per cell was quantified using ImageJ. Data are shown as the mean±SD of three independent experiments (*vs control group, $P<0.05$; #vs 30 [illegible]g/mL Tangeretin [illegible]up, $P<0.05$; &vs 60 μg/mL Tangeretin group, $P<0.05$).

underlying m[illegible]olecular [illegible]gets and [illegible]fficacy of Tangeretin in cancer tr[illegible]ment [illegible]emain [illegible]cl[illegible]r. In the present study, we demon[illegible]rated th[illegible] Tangeretin activated JNK, decreased Bcl-2 ph[illegible]orylation, and prevented the formation of Bcl-2 and [illegible]CLIN1, thereby driving the BECLIN1-dependent autop[illegible]agy associated with HepG2 cell death (Figure 6).

Tangeretin is a traditional Chinese flavonoid medicinal herb,[13] and it has a wide range of pharmacological effects.[14–16] In recent years, studies have found that Tangeretin has an antitumour effect.[17,24–26] Notably, it inhibited cancer cell proliferation in human cancer cell lines derived from squamous cell carcinoma, gliosarcoma, leukaemia, melanoma, colorectal cancer, gastric carcinoma, lung carcinoma, breast carcinoma and oral cancer cells.[27,28] Consistent with the aforementioned reports, we found that Tangeretin decreased HepG2 cell proliferation and migration.

Autophagy is a multistep process that is related to autophagy-related genes (ATGS).[23] Some studies have focused on the paradoxical roles of autophagy in tumour progression and promotion and suggested that autophagy acts as a double-edged sword in cancer cells.[29,30] Basic autophagy maintains genomic stability to suppress tumourigenesis, but activated autophagy promotes cancer cell survival and development.[31,32] Yi Rong et al found that the Tangeretin derivative suppressed CL1-5 lung cancer cell growth via the mechanisms of G2/M cell cycle arrest,

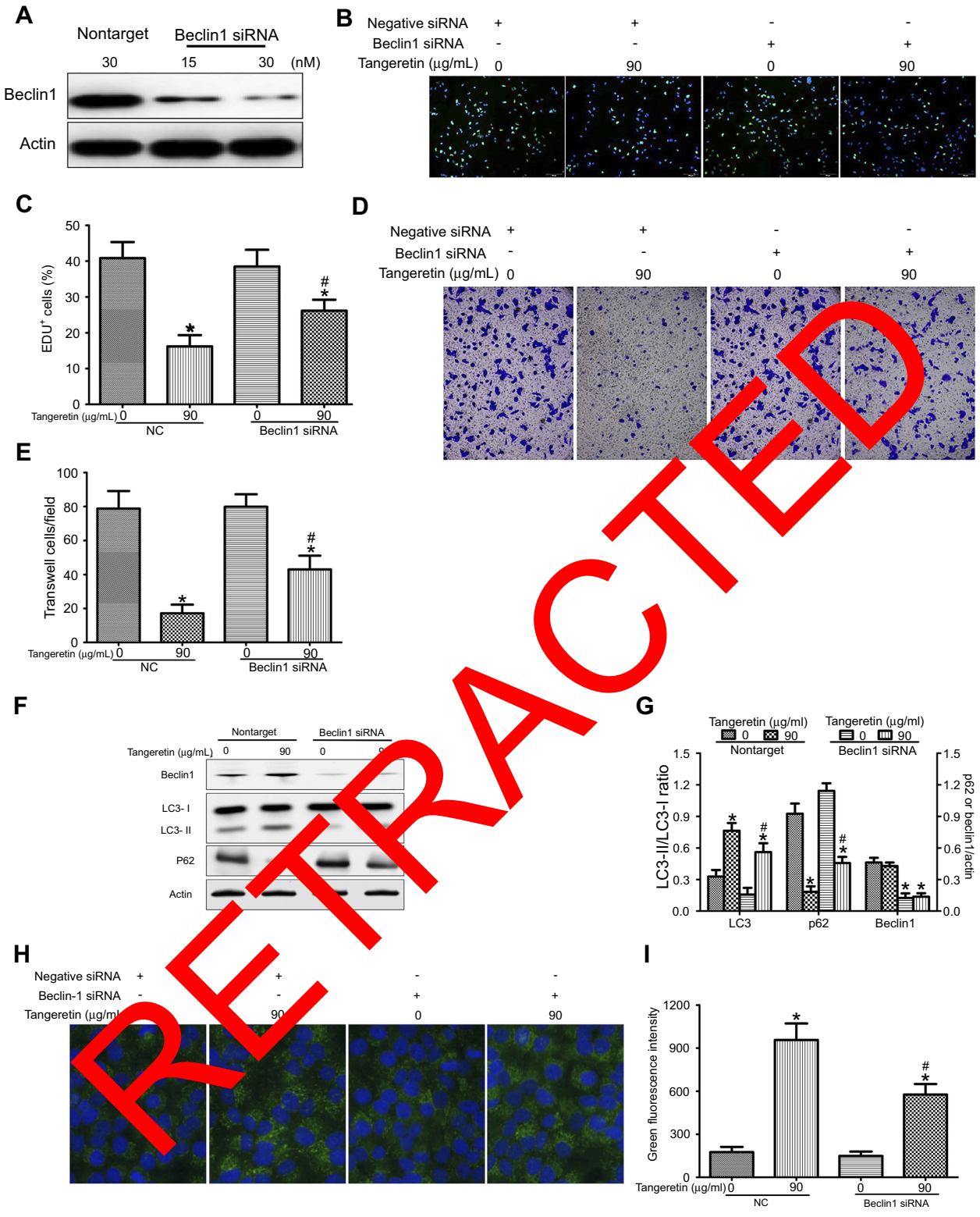

Figure 4 Tangeretin-induced HCC cell autophagy is BECLIN1-dependent.

Notes: (**A**) HepG2 cells were transfected with 15 or 30 nM BECLIN1 siRNA or nontarget siRNA for 48 h. Protein expression of BECLIN1 and GAPDH in HepG2 cells. (**B–I**) HepG2 cells were transfected with 30 nM BECLIN1 siRNA or nontarget siRNA for 48 h, and then HepG2 cells were treated with 90 μg/mL Tangeretin for 24 h. (**B**) EdU labelled the HepG2 cells for 2 h. Immunofluorescence of EdU (green) and nuclei (DAPI, blue; ×10). Scale bar=25 μm. (**C**) The graph summarizes the percentage of EdU cells. (**D**) HepG2 cells subjected to a colony formation assay. (**E**) The graph summarizes the colony formation assay data. (**F**) Levels of BECLIN1, LC3, p62, and Actin. (**G**) Relative levels of LC3-II compared with those of LC3-I; relative levels of p62 or BECLIN1 compared with those of actin. (**H**) Immunofluorescence of LC-3 (green) and nuclei (DAPI, blue; ×40). Scale bar=25 μm. (**I**) The area of LC3 dots per cell was quantified using ImageJ. Data are shown as the mean±SD of three independent experiments (*vs control group, $P<0.001$; #vs nontarget and 90 μg/mL Tangeretin treatment group, $P<0.01$).

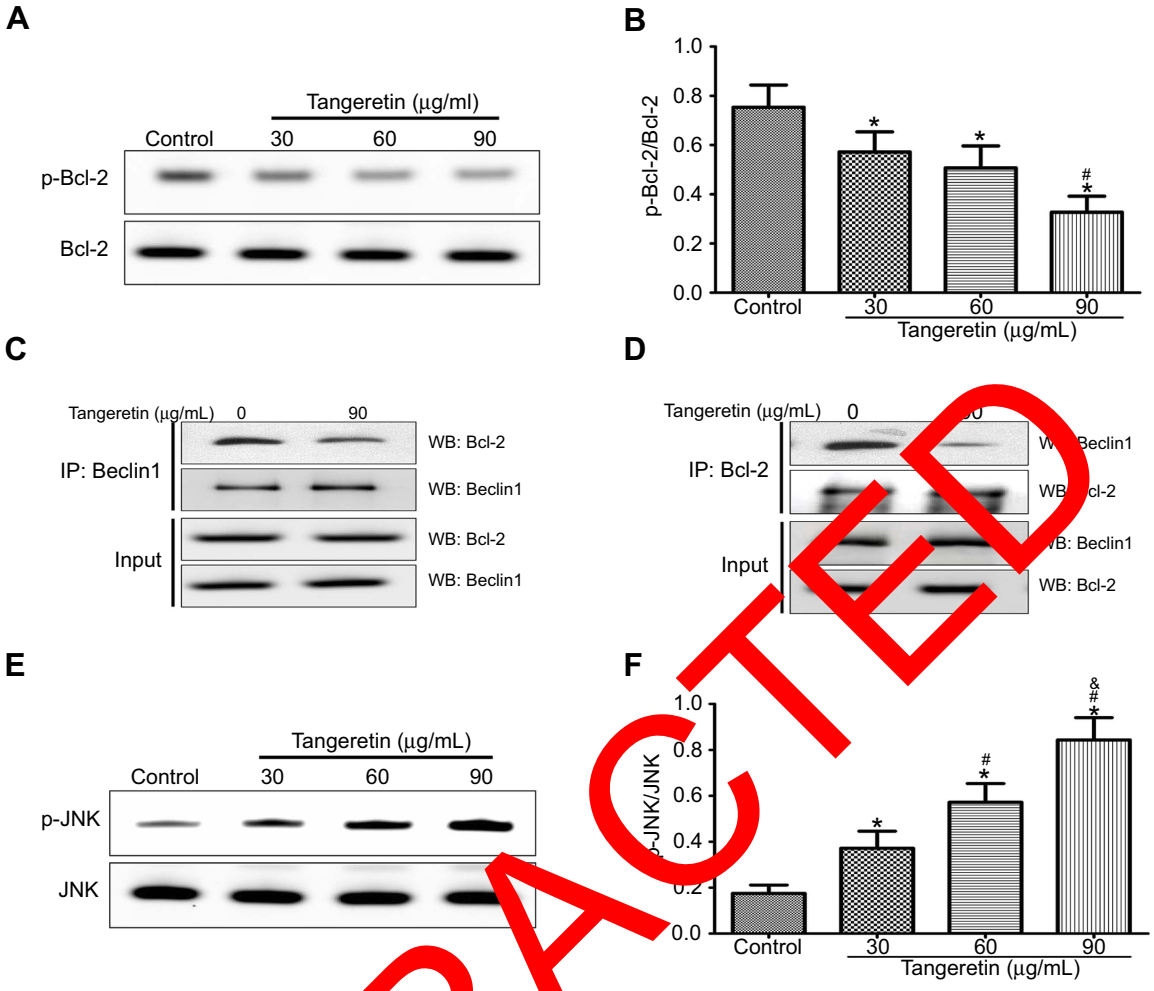

Figure 5 Tangeretin enhances JNK activity and disrupts the Bcl-2/Beclin1 interaction.

Notes: (**A**) HepG2 cells were treated with the indicated concentrations of Tangeretin (0, 30, 60 and 90 μg/mL) for 24 h. Protein expression of Bcl-2 and p-Bcl-2 in HepG2 cells. (**B**) Densitometry was used to determine the fold expression of p-Bcl-2 compared with that of Bcl-2. Data are shown as the mean±SD of three independent experiments (*vs control group, $P<0.05$; #vs 30 μg/mL Tangeretin group, $P<0.05$). (**C** and **D**) HepG2 cells were treated with 90 μg/mL Tangeretin for 24 h. (**C**) Protein expression of Bcl-2 after BECLIN1 immunoprecipitation in HepG2 cells. (**D**) Protein expression of BECLIN1 after Bcl-2 immunoprecipitation in HepG2 cells (n≥3). (**E**) HepG2 cells were treated with the indicated concentrations of Tangeretin (0, 30, 60 and 90 μg/mL) for 24 h. Protein expression of JNK and p-JNK in HepG2 cells. (**F**) Densitometry was used to determine the fold expression of p-Bcl-2 compared with that of Bcl-2. Data are shown as the mean±SD of three independent experiments (*vs control group, $P<0.05$; #vs 30 μg/mL Tangeretin group, $P<0.05$; &vs 60 μg/mL Tangeretin group, $P<0.05$).

autophagy and apoptosis.[20] Our current findings also revealed that Tangeretin induced HepG2 cell death via BECLIN1-dependent autophagy. Interestingly, Tangeretin, at a concentration of more than 120 μg/mL, successfully induced apoptosis in HepG2 cells (Figure S1A and B). Therefore, we hypothesize that the regulation of Tangeretin is coordinated through two aspects: by maintaining basic autophagy at a low-dose concentration and by promoting apoptosis at a high-dose concentration.

Some studies have indicated that cellular and viral Bcl-2 family members inhibit autophagy and that the cellular Bcl-2/BECLIN1 complex dissociates.[33,34] Our data also showed that the JNK1 signalling pathway is responsible for Bcl-2 phosphorylation after Tangeretin treatment, which leads to a disruption in the Bcl-2/BECLIN1 complex and the release of the inhibitory activity of Bcl-2 on Beclin 1-dependent autophagy in HepG2 cells. Bcl-2 is one of the most important oncogenes in apoptosis research, and in most studies, the phosphorylation of Bcl-2 is associated with its antiapoptotic function.[35] Therefore, we conclude that Bcl-2 is related to a high dose of Tangeretin-induced apoptosis.

Conclusion

In conclusion, we identified a signalling mechanism that regulates Tangeretin-induced autophagy in HepG2 cells involving the JNK1-mediated phosphorylation of Bcl-2 and a disruption in the Bcl-2/BECLIN1 complex. This is the first work to report that Tangeretin, via the BECLIN1-

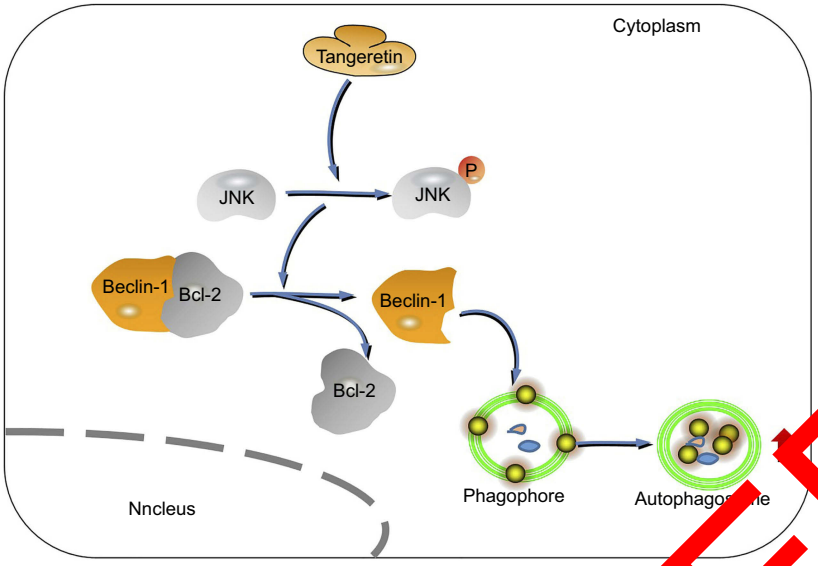

Figure 6 Schematic illustrating the working principle of Tangeretin-related signalling in HepG2 cells.
Notes: We propose that Tangeretin maintained the phosphorylation state of JNK in HepG2 cells, thereby activ g BECLIN1-d ndent a phagy associated with HepG2 cell death.

dependent autophagy pathway, deceases hepatocellular carcinoma proliferation and migration.

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Disclosure

The authors report no conf of inter in this work.

Refere ces

1. Xiao S, Liu Z, eng R, et al. Aptamer-mediated gene therapy enhanced antitumo tivity against human hepatocellular carcinoma in vitro and in vi . *J Control Release*. 2017;258:130–145. doi:10.1016/j.jconrel.2017.05.017
2. Ding XX, Zhu QG, Zhang SM, et al. Precision medicine for hepatocellular carcinoma: driver mutations and targeted therapy. *Oncotarget*. 2017;8(33):55715–55730. doi:10.18632/oncotarget.18382
3. Wei QZ, He LL, Wang XY, Wu L, Gong LH, Song XR. [Study on autophagy and apoptosis induced by amiodarone combined with glycyrrhetinic acid in HepG2 cells]. *Sichuan Da Xue Xue Bao Yi Xue Ban*. 2018;49(5):689–693.
4. Liu L, Liao JZ, He XX, Li PY. The role of autophagy in hepatocellular carcinoma: friend or foe. *Oncotarget*. 2017;8(34):57707–57722. doi:10.18632/oncotarget.17202
5. Tak A, Komatsu M, ara T, et al. Autophagy-deficient mice d elop multiple liver tumors. *Genes Dev*. 2011;25(8):795–800. i:10.1101/gad. 16211
6. rinkovic M, rung M, Buljubasic M, Novak I. Autophagy m lation in c cer: current knowledge on action and therapy. *Oxid Longev*. 2018;2018:8023821. doi:10.1155/2018/8023821
7. M, Waguri S, Ueno T, et al. Impairment of starvation-induced and constitutive autophagy in Atg7-deficient mice. *J Cell Biol*. 2005;169(3):425–434. doi:10.1083/jcb.200412022
8. Qu X, Yu J, Bhagat G, et al. Promotion of tumorigenesis by heterozygous disruption of the BECLIN 1 autophagy gene. *J Clin Invest*. 2003;112(12):1809–1820. doi:10.1172/JCI20039
9. Liang XH, Yu J, Brown K, Levine B. 1 contains a leucine-rich nuclear export signal that is required for its autophagy and tumor suppressor function. *Cancer Res*. 2001;61(8):3443–3449.
10. Liang XH, Jackson S, Seaman M, et al. Induction of autophagy and inhibition of tumorigenesis by BECLIN 1. *Nature*. 1999;402(6762):672–676. doi:10.1038/45257
11. Huang Z, Fang W, Liu W, et al. Aspirin induces BECLIN-1-dependent autophagy of human hepatocellular carcinoma cell. *Eur J Pharmacol*. 2018;823:58–64. doi:10.1016/j.ejphar.2018.01.031
12. Qiu DM, Wang GL, Chen L, et al. The expression of BECLIN-1, an autophagic gene, in hepatocellular carcinoma associated with clinical pathological and prognostic significance. *BMC Cancer*. 2014;14:327. doi:10.1186/1471-2407-14-327
13. Benavente-Garcia O, Castillo J. Update on uses and properties of citrus flavonoids: new findings in anticancer, cardiovascular, and anti-inflammatory activity. *J Agric Food Chem*. 2008;56(15):6185–6205. doi:10.1021/jf8006568
14. Liu LL, Li FH, Zhang Y, Zhang XF, Yang J. Tangeretin has anti-asthmatic effects via regulating PI3K and Notch signaling and modulating Th1/Th2/Th17 cytokine balance in neonatal asthmatic mice. *Braz J Med Biol Res*. 2017;50(8):e5991. doi:10.1590/1414-431X20176071
15. Wu J, Zhao YM, Deng ZK. Tangeretin ameliorates renal failure via regulating oxidative stress, NF-kappaB-TNF-alpha/iNOS signalling and improves memory and cognitive deficits in 5/6 nephrectomized rats. *Inflammopharmacology*. 2018;26(1):119–132. doi:10.1007/s10787-017-0394-4

16. Eun SH, Woo JT, Kim DH. Tangeretin inhibits IL-12 expression and NF-kappaB activation in dendritic cells and attenuates colitis in mice. *Planta Med*. 2017;83(6):527–533. doi:10.1055/s-0042-119074
17. Periyasamy K, Baskaran K, Ilakkia A, Vanitha K, Selvaraj S, Sakthisekaran D. Antitumor efficacy of tangeretin by targeting the oxidative stress mediated on 7,12-dimethylbenz(a) anthracene-induced proliferative breast cancer in Sprague-Dawley rats. *Cancer Chemother Pharmacol*. 2015;75(2):263–272. doi:10.1007/s00280-014-2629-z
18. Li YR, Li S, Ho CT, et al. Tangeretin derivative, 5-acetyloxy-6,7,8,4'-tetramethoxyflavone induces G2/M arrest, apoptosis and autophagy in human non-small cell lung cancer cells in vitro and in vivo. *Cancer Biol Ther*. 2016;17(1):48–64. doi:10.1080/15384047.2015.1108491
19. Debatin KM. Activation of apoptosis pathways by anticancer drugs. *Adv Exp Med Biol*. 1999;457:237–244.
20. Wei Y, Pattingre S, Sinha S, Bassik M, Levine B. JNK1-mediated phosphorylation of Bcl-2 regulates starvation-induced autophagy. *Mol Cell*. 2008;30(6):678–688. doi:10.1016/j.molcel.2008.06.001
21. Maundrell K, Antonsson B, Magnenat E, et al. Bcl-2 undergoes phosphorylation by c-Jun N-terminal kinase/stress-activated protein kinases in the presence of the constitutively active GTP-binding protein Rac1. *J Biol Chem*. 1997;272(40):25238–25242.
22. Yamamoto K, Ichijo H, Korsmeyer SJ. BCL-2 is phosphorylated and inactivated by an ASK1/Jun N-terminal protein kinase pathway normally activated at G(2)/M. *Mol Cell Biol*. 1999;19(12):8469–8478.
23. Huang F, Wang BR, Wang YG. Role of autophagy in tumorigenesis, metastasis, targeted therapy and drug resistance of hepatocellular carcinoma. *World J Gastroenterol*. 2018;24(41):4643–4651. doi:10.3748/wjg.v24.i41.4643
24. Morley KL, Ferguson PJ, Koropatnick J. Tangeretin and nobiletin induce G1 cell cycle arrest but not apoptosis in human breast and colon cancer cells. *Cancer Lett*. 2007;251(1):168–178. doi:10.1016/j.canlet.2006.11.016
25. Dong Y, Cao A, Shi J, et al. Tangeretin, a citrus polymethoxyflavonoid, induces apoptosis of human gastric cancer AGS cells through extrinsic and intrinsic signaling pathways. *Oncol Rep*. 2014;31(4):1788–1794. doi:10.3892/or.2014.3034
26. Hirano T, Abe K, Gotoh M, Oka K. Citrus flavone tangeretin inhibits leukaemic HL-60 cell growth partially through induction of apoptosis with less cytotoxicity on normal lymphocytes. *Br J Cancer*. 1995;72(6):1380–1388.
27. Pan MH, Chen WJ, Lin-Shiau SY, Ho CT, Lin JK. Tangeretin induces cell-cycle G1 arrest through inhibiting cyclin-dependent kinases 2 and 4 activities as well as elevating Cdk inhibitors p21 and p27 in human colorectal carcinoma cells. *Carcinogenesis*. 2002;23(10):1677–1684.
28. Walle T, Walle UK. Novel methoxylated flavone inhibitors of cytochrome P450 1B1 in SCC-9 human oral cancer cells. *J Pharm Pharmacol*. 2007;59(6):857–862. doi:10.1211/jpp.59.6.0012
29. Onorati AV, Dyczynski M, Ojha R, Amaravadi RK. Targeting autophagy in cancer. *Cancer*. 2018;124(16):3307–3318. doi:10.1002/cncr.31335
30. Liu B, Wen X, Cheng Y. Survival or death: disequilibrating the oncogenic and tumor suppressive autophagy in cancer. *Cell Death Dis*. 2013;4:e892. doi:10.1038/cddis.2013.422
31. Yang ZJ, Chee CE, Huang S, Sinicrope FA. The role of autophagy in cancer: therapeutic implications. *Mol Cancer Ther*. 2011;10(9):1533–1541. doi:10.1158/1535-7163.MCT-11-0047
32. Cao Z, Zhang H, Cai X, et al. Luteolin promotes cell apoptosis by inducing autophagy in hepatocellular carcinoma. *Cell Physiol Biochem*. 2017;43(5):1801–1812. doi:10.1159/000484066
33. Maiuri MC, Le Toumelin G, Criollo A, et al. Functional and physical interaction between Bcl-X(L) and a BH3-like domain in Beclin-1. *Embo J*. 2007;26(10):2527–2539. doi:10.1038/sj.emboj.7601689
34. Pattingre S, Tassa A, Qu X, et al. Bcl-2 antiapoptotic proteins inhibit Beclin 1-dependent autophagy. *Cell*. 2005;122(6):927–939. doi:10.1016/j.cell.2005.07.002
35. Bassik MC, Scorrano L, Oakes SA, Pozzan T, Korsmeyer SJ. Phosphorylation of BCL-2 regulates ER Ca^{2+} homeostasis and apoptosis. *Embo J*. 2004;23(5):1207–1216. doi:10.1038/sj.emboj.7600104

Supplementary material

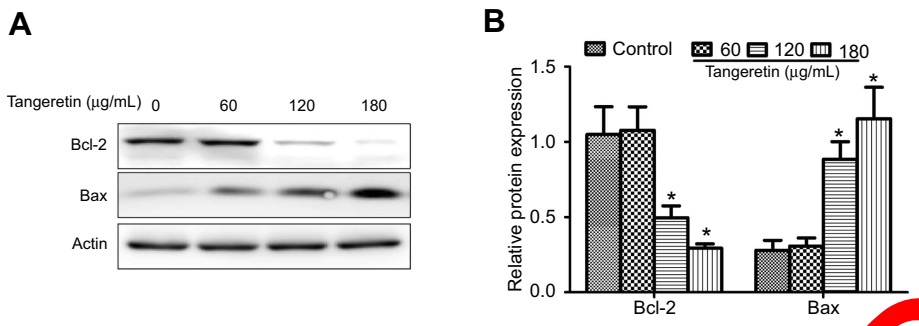

Figure S1 Effect of tangeretin on the expression of Bcl-2 and Bax in HepG2 cells.
Notes: HepG2 cells were treated with the indicated concentrations of Tangeretin (0, 60, 120 and 180 μg/mL) for 24 h. Then, (**A**) the levels of Bcl-2, Bax, and GAPDH were examined. (**B**) Relative levels of Bcl-2 and Bax compared with GAPDH, respectively (*P<0.05).