



# PLK I contributes to autophagy by regulating MYC stabilization in osteosarcoma cells

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**Background:** PLK1, a typical PLK protein, is the main driver of cancer cell growth and proliferation. It is an inhibitor of the protein kinases that is currently being investigated in clinical studies. It is often used as a tumor marker, as high PLK1 expression correlates with poor prognosis in cancer. Overexpression of MYC is a hallmark of many human cancers. MYC modulates the transcription of thousands of genes that required to coordinate a series of cellular processes, including those essential for growth, proliferation, differentiation, self-renewal and apoptosis. To date, functions of PLK1 and MYC on tumor are mostly studied in separate researches, and studies on their mutual crosstalk are lacking.

**Purpose:** To investigate the mechanism of PLK1 and MYC in regulating progress of osteosarcoma.

**Methods:** Protein level was examined using Western blot. Animal experiments were performed with female FOX CHASE severe combined immunodeficient mice. Mice were randomly divided into experimental or control groups.

**Results:** PLK1 or MYC promoted the proliferation of osteosarcoma cells through the autophagy pathway. PLK1 contributed to MYC protein stabilization. PLK1 inhibition enhanced MYC degradation in osteosarcoma cells. PLK1 inhibition led to a marked decline in MYC protein abundance. The representative MYC target genes were deregulated by PLK1 inhibitors. BI2536 treatment caused a significant delay in xenograft tumor growth in mice injected with U-2 OS cells subcutaneously, with lower mean tumor weight compared to the control group.

**Conclusion:** PLK1 is crucial for MYC stabilization. It promotes cell proliferation by autophagy pathway in osteosarcoma cells. Data validate PLK1 as a potential therapeutic target in osteosarcoma caused by MYC-amplified.

**Keywords:** autophagy, PLK1, MYC, stabilization, osteosarcoma cells

## Introduction

Osteosarcomas are derived from osteoblasts or their precursors, and have a high propensity to metastasize.<sup>1</sup> Osteosarcoma generally involves the metaphyses of long tubular bones, especially the proximal tibia or distal femur.<sup>2</sup> It is one of the most common malignant tumors and the third most common cancer in children, adolescents and young adults (<30 years old).<sup>3</sup> Osteosarcoma comprises two rare clinical subtypes and several high-grade histologic variants, parosteal and periosteal osteosarcoma.<sup>4</sup> In the last three decades, the current treatment options still rely on tumor resection and nonspecific combination chemotherapy, and the five-year survival rate increased from less than 20% to 65–75%. However, if clinically apparent metastases are present, five-year survival rate still remains 0–29%.<sup>5</sup> The

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improvements in the survival have been mostly incremental in patients with osteosarcoma during the past 30 years. Osteosarcoma is one of the most disordered cancers in terms of whole-chromosome and gene copy number changes.<sup>5</sup> Moreover, the expression anomaly of many genes has been considered as a driver of osteosarcoma. For example, *TP53*, *RBI*, *MDM2*, *CDKN2A* and *MYC* have been implicated with certainty.<sup>6</sup> The molecular basis of osteosarcoma is increasingly well defined. It is possible that novel models for discovery and development will be necessary in order to facilitate the development of therapeutic strategies for patients with osteosarcoma. Autophagy pathway has been shown to be one of the most important networks in osteosarcoma.

Autophagy is identified as a highly conserved intracellular degradation process which refers to degrading and recycling damaged or unnecessary cytoplasmic contents into regenerate metabolites for energy and growth through the lysosome-dependent machinery in a stressed state.<sup>7</sup> It occurs at low basal levels in virtually all cells to supervise homeostatic functions such as protein and organelle turnover. It would be rapidly upregulated if cells need to generate intracellular nutrients and energy, for example, growth factor withdrawal, starvation or high bioenergetic demands.<sup>8</sup> Autophagy plays an important role in the physiological process, such as subsequent recycling of cellular products and innate immune response.<sup>9</sup> Therefore, dysfunction of autophagy can result in a wide panel of human diseases, including metabolic, cancer, neurodegenerative, aging, autoimmune, cardiac, infective and neoplastic disorders.<sup>10</sup> Autophagy is proposed to play an important role on cytoprotective function, not only because it contributes to the maintenance of cellular environmental homeostasis by providing cells with metabolic intermediates, but also because it mediates the removal of cytotoxic entities, like invading pathogens.<sup>11</sup> Therefore, the inhibition of autophagy by methods of genetic intervention (the depletion of essential genes such as *ATG5* or *ATG7*) or pharmacological agents (bafilomycin A1, 3-methyladenine) often accelerates the death of cells exposed to cytotoxic conditions.<sup>12</sup> Still, autophagy is also considered a form of programmed cell death called “type II” cell death.<sup>9</sup>

Cancer cells are often exposed to inherent metabolic stress owing to lack of nutrient supplies and hypoxia. Inhibition of autophagy could lead to accelerated apoptosis under metabolic stress, which might limit further tumor progression. This mechanism is critical in the early stages during tumor growth, since the tumor lacks its own blood supply and relies mostly on anaerobic metabolism through

glycolysis instead of oxidative phosphorylation.<sup>13</sup> Impaired autophagy could be an attractive strategy in cancer prevention, because it might suppress the survival mechanism for struggling precancerous cells. Autophagy inhibition compromises the ability of the cancer cell to overcome metabolic stress leading to cell death. The function of autophagy on tumor suppression is first demonstrated in a mouse model: *Beclin1*<sup>+/-</sup> mice exhibit significantly higher incidence of spontaneous tumors (leukemias, hepatocellular carcinomas, lymphomas and lung adenocarcinomas) compared to *Beclin1*<sup>+/+</sup> mice.<sup>14</sup> In a study on samples from nasopharyngeal carcinoma patients treated with chemoradiation, increased *Beclin1* expression positively correlated with poor overall survival, progression-free survival and distant metastasis-free survival.<sup>15</sup> Autophagy defects activated the DNA damage response in vitro and in mammary tumors, increases gene amplification, as well as synergizes with defective apoptosis to promote mammary tumorigenesis.<sup>16</sup> Anticancer activity of KP46 against osteosarcoma cell models is evaluated as significance in combination approaches with autophagy inhibitor.<sup>17</sup> Attenuation of NRF2 antioxidative pathway could sensitize osteosarcoma cells to radiation, where NRF2 antioxidative response was regulated by autophagy-mediated activation of ERK 1/2 kinases.<sup>18</sup>

The oncogene *MYC* is often upregulated in tumors, where its protein stability or overexpression favor cellular growth by inducing stemness and blocking cellular senescence and differentiation. The previous study demonstrated that endogenous *MYC* is involved in autophagy, while its expression is also affected by histone acetylation or DNA-methylation.<sup>7</sup> Autophagy blockage contributes to the increase of total and nuclear *MYC*, leading to enhancement of cell proliferation and colony formation.<sup>19</sup> *MYC* is also controlled by other mechanisms, including growth factors, negative feedback regulation and epigenetic factors.<sup>20</sup> *PLK1* (polo-like kinase 1), a ubiquitously expressed serine/threonine protein kinase, is widely recognized as an oncogene which drives cellular proliferation by promoting mitosis and cytokinesis.<sup>21,22</sup> *PLK1* is frequently considered as a tumor biomarker, as high *PLK1* expression correlates with poor prognosis in various cancers.<sup>23</sup> *PLK1* is found to be involved in autophagy by inhibiting mTORC1, while *PLK1* inhibitor BI2536 treatment increases mTORC1 activation.<sup>24</sup> Pharmacological inhibition of *PLK1* decreases the cell viability and survival via induction of apoptosis and attenuation of autophagy.<sup>25</sup> However, the relationship between *MYC* and *PLK1* is not clear. Here, we aim to investigate that *PLK1* modulated *MYC* stabilization in human osteosarcoma cells.

## Materials and methods

### Cell culture

KHOS, hFOB, U-2 OS, HOB-c, NHOst, MG63 and Saos-2 cells were acquired from the American Type Culture Collection (ATCC).

### Real-time quantitative PCR (qPCR)

Total RNA were extracted using the TRIzol reagent (Invitrogen) followed the manufacturer's protocol. The qPCR experiments were carried out using ChamQ SYBR qPCR Master Mix (Q311-02/03, Vazyme Biotech Co., Ltd, Nanjing, China) on an ABI 7900 system. The primers were designed as follows: MYC(F): 5'-GGA GGA ACA AGA AGA TGA GGA AGA A-3', MYC(R): 5'-AGG ACC AGT GGG CTG TGA GGA G-3'; PLK1(F): 5'-GGC AAC CTT TTC CTG AAT GA-3', PLK1(R): 5'-AAT GGA CCA CAC ATC CAC CT-3'; ACTB(F): 5'-TGT TTG AGA CCT TCA ACA CCC-3', ACTB(R): 5'-AGC ACT GTG TTG GCG TAC AG-3'. Relative gene expression was calculated with the  $2^{-\Delta Ct}$  method using ACTB as the internal control gene. The detection was repeated at least three times.

### Western blot

Cells were washed three times with PBS before lysis in RIPA buffer with 1% NP40 (Sigma-Aldrich, I8896). Adjustments of the protein concentration, SDS PAGE and Western blot were performed as described previously.<sup>26</sup> The following antibodies were purchased from Cell Signaling Technology Inc., LC3 (2775), Atg5 (2630), Atg7 (2631), SQSTM1 (88588); PLK1 (ab70695) was bought from Abcam, ACTB (A1978) was purchased from Sigma-Aldrich Co. LLC., MYC/c-Myc (sc-40) antibody was obtained from Santa Cruz Biotechnology, Inc. The detection was repeated at least three times.

### Soft agar assays

Cells ( $1 \times 10^4$ ) were grown into soft agar in single wells of six-well plates and allowed to incubate for 2 weeks. The resultant colonies were stained with 0.2% crystal violet in buffered formalin for 1 hr. Each well was divided into four quadrants and photographed. Colonies were quantified using ImageJ software using a standard colony quantification macro. The detection was repeated at least three times.

### Tumor xenografts

All animal experiments were approved by Guangxi Medical University, and carried out by Institutional Animal Care and Use Committee guidelines (Guangxi Medical University).

All experiments were performed with female FOX CHASE severe combined immunodeficient (SCID) mice (6 weeks, 14.7–18.3 g). Mice were randomly divided into experimental or control groups. Moreover, mice were treated with BI2536 (40  $\mu\text{g/g}$ ) or DMSO by intraperitoneal injection every other day. When diameters of tumor in the right flank of mice reached at least 5 mm in size, mice were sacrificed and tumor tissue was collected. The experiment was repeated at least three times.

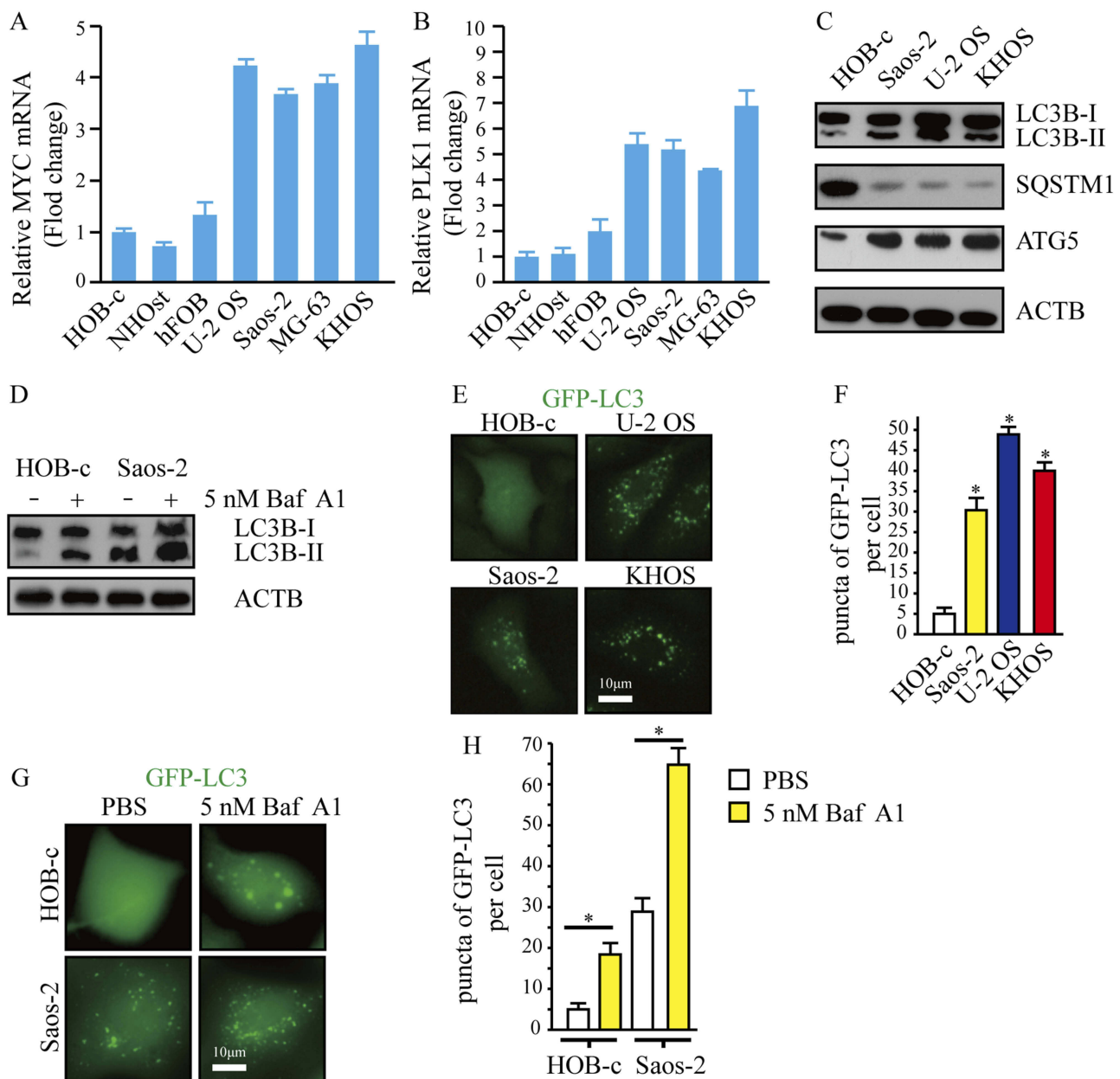
### Statistical analysis

Statistical analyses and graphing were performed using Prism v5.0 (GraphPad). ANOVA analysis of variance was performed for comparative analysis. Dunnett's test was used for pairwise comparisons of multiple treatment groups. *P*-values of  $<0.05$  were considered significant. Error bars in graphs represent the standard error of means. Independent experiments were performed at least three times for each experiment.

## Results

### High expression of MYC and PLK1 may be associated with basal autophagy in osteosarcoma cells

To explore the expression of MYC and PLK1 in osteosarcoma cells, we examined the transcription levels of MYC and PLK1 in osteosarcoma cell lines (hFOB, U-2 OS, Saos-2, MG-63 and KHOS) and normal human osteoblast cell lines (HOB-c and NHOst) by qPCR analysis. The data indicated that the levels of MYC and PLK1 were higher in osteosarcoma cell lines than that in normal human osteoblast cell lines (Figure 1A and B). Next, cellular-basal autophagy was investigated. And we observed that autophagy flux biomarkers LC3-II/LC3-I and ATG5 were obviously higher in osteosarcoma cell lines than that in normal human osteoblast cell line; SQSTM1, which marked degradation by autolysosome pathway, was significantly lower in osteosarcoma cell lines than that in normal human osteoblast cell line (Figure 1C). In order to properly access the autophagic activity, we assessed autophagy flux, the amount of degradation through autophagy, in the presence and absence of a lysosomal inhibitor bafilomycin A1 (Baf A1). Data indicated that LC3-II significantly increased after treatment of Baf A1 (Figure 1D). To further confirm the basal autophagy level in these cell lines, we overexpressed the green fluorescent protein conjugated microtubule-associated protein 1 light chain 3 (GFP-LC3) in osteosarcoma cells and osteoblast cells. Here, GFP puncta suggest the formation of



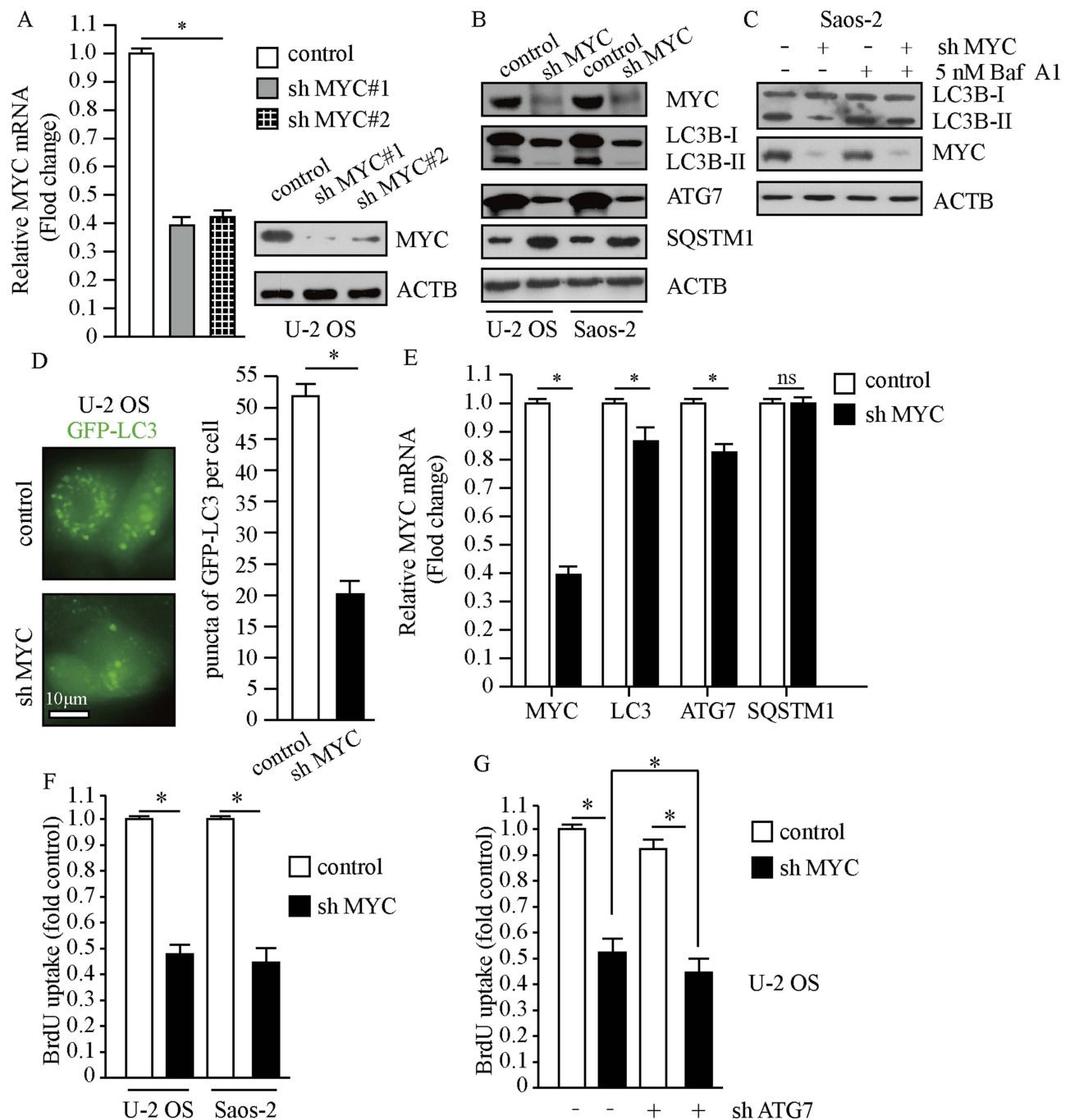
**Figure 1** The expression of MYC or PLK1, and basal autophagy level in osteosarcoma cells. **(A and B)** Total RNA were prepared, and subjected to qPCR. ACTB was used as an internal reference. **(C and D)** Whole cell lysates were prepared, and subjected to Western blot analysis using indicated antibodies. ACTB was used as a loading control. Treatment of 5 nM Baf A1 for 4 hrs. **(E)** Representative fluorescence microscope images of cells stably expressing GFP-LC3. Scale bar: 10  $\mu$ m. **(F)** Puncta of GFP-LC3 per cell in Figure **(E)**. \* $P < 0.01$ . **(G)** Representative fluorescence microscope images of cells stably expressing GFP-LC3, treatment of 5 nM Baf A1 for 4 hrs. Scale bar: 10  $\mu$ m. **(H)** Puncta of GFP-LC3 per cell in Figure **(E)**. \* $P < 0.01$ .

**Abbreviations:** PLK1, polo-like kinase 1; MYC, MYC proto-oncogene.

autophagosomes. Expectedly, osteosarcoma cells showed more GFP puncta than osteoblast cells (Figure 1E and F). Similarly, we quantified the number of LC3 dots in the presence and absence of Baf A1. We observed that LC3 dots clearly increased after treatment of Baf A1 (Figure 1G and H). These results indicate that high expression of MYC and/or PLK1 might be associated with basal autophagy in osteosarcoma cells.

## MYC promotes the proliferation of osteosarcoma cells by the autophagy pathway

To investigate the relationship between MYC and autophagy in osteosarcoma cells, we designed different short hairpin RNA (shRNA) targeting MYC through lentivirus system. As shown in Figure 2A, infection of two MYC shRNAs using lentivirus in U-2 OS cells resulted in markedly decrease of



**Figure 2** MYC promotes the proliferation of osteosarcoma cells. Cells treated with lentivirus carrying MYC shRNA or control shRNA. **(A)** The expression of MYC was examined by qPCR and Western blot. ACTB was used as a loading control. **(B and C)** Whole cell lysates were prepared, and subjected to Western blot analysis using indicated antibodies. Treatment of 5 nM Baf A1 for 4 hrs. **(D)** Representative fluorescence microscope images of cells stably expressing GFP-LC3, scale bar: 10  $\mu$ m (left panel). Puncta of GFP-LC3 per cell (right panel). **(E)** Transcription levels of autophagy factors. ACTB was used as a loading control. **(F and G)** Cellular proliferation was assessed using BrdU assay, n=5. The data are represented as the mean  $\pm$  SEM of five experiments. \* $P$ <0.01.

**Abbreviations:** PLK1, polo-like kinase 1; MYC, MYC proto-oncogene.

MYC expression. Knockdown of MYC resulted in significantly decreased LC3-II/LC3-I and ATG7; meanwhile, accumulation of SQSTM1 suggested dysfunction of autolysosome degradation (Figure 2B). In order to properly access the autophagic activity under the deficiency of MYC, we

examined LC3-II levels after treatment of Baf A1. Results indicated that LC3-II significantly increased after treatment of Baf A1 in MYC knockdown cells (Figure 2C). When we observed GFP-LC3 expression in MYC knockdown cells, we found that GFP puncta were markedly less than that in

control cells ( $P < 0.01$ , [Figure 2D](#)). In consideration of that MYC is a transcription factor, it may affect the amount of autophagy factors through transcription. Next, we examined autophagy factors in transcriptional levels. Results indicated that MYC regulated the transcriptional levels of LC3 and ATG7; however, SQSTM1 hardly changed after loss of MYC ([Figure 2E](#)). In this work, we got a conclusion that loss of MYC reduced autophagy in osteosarcoma cells. Autophagy and MYC are both important mechanisms for cancer cell proliferation.<sup>27–29</sup> We next determined the effect of MYC on osteosarcoma cells proliferation by BrdU assay. As shown in [Figure 2F](#), loss of MYC in U-2 OS and Saos-2 cells did suppress cellular proliferation. However, whether the function of MYC on proliferation depends on autophagy is not clear. Then, we carried out cell proliferation assay when MYC was stably downregulated plus autophagy-deficient condition. The results showed that cellular proliferation was further restrained under autophagy-deficient condition ([Figure 2G](#)). This indicated that the effect of MYC on cellular proliferation partially depended on regulation of autophagy. These data above suggest that MYC contributes to cell proliferation by regulating autophagy in osteosarcoma cells.

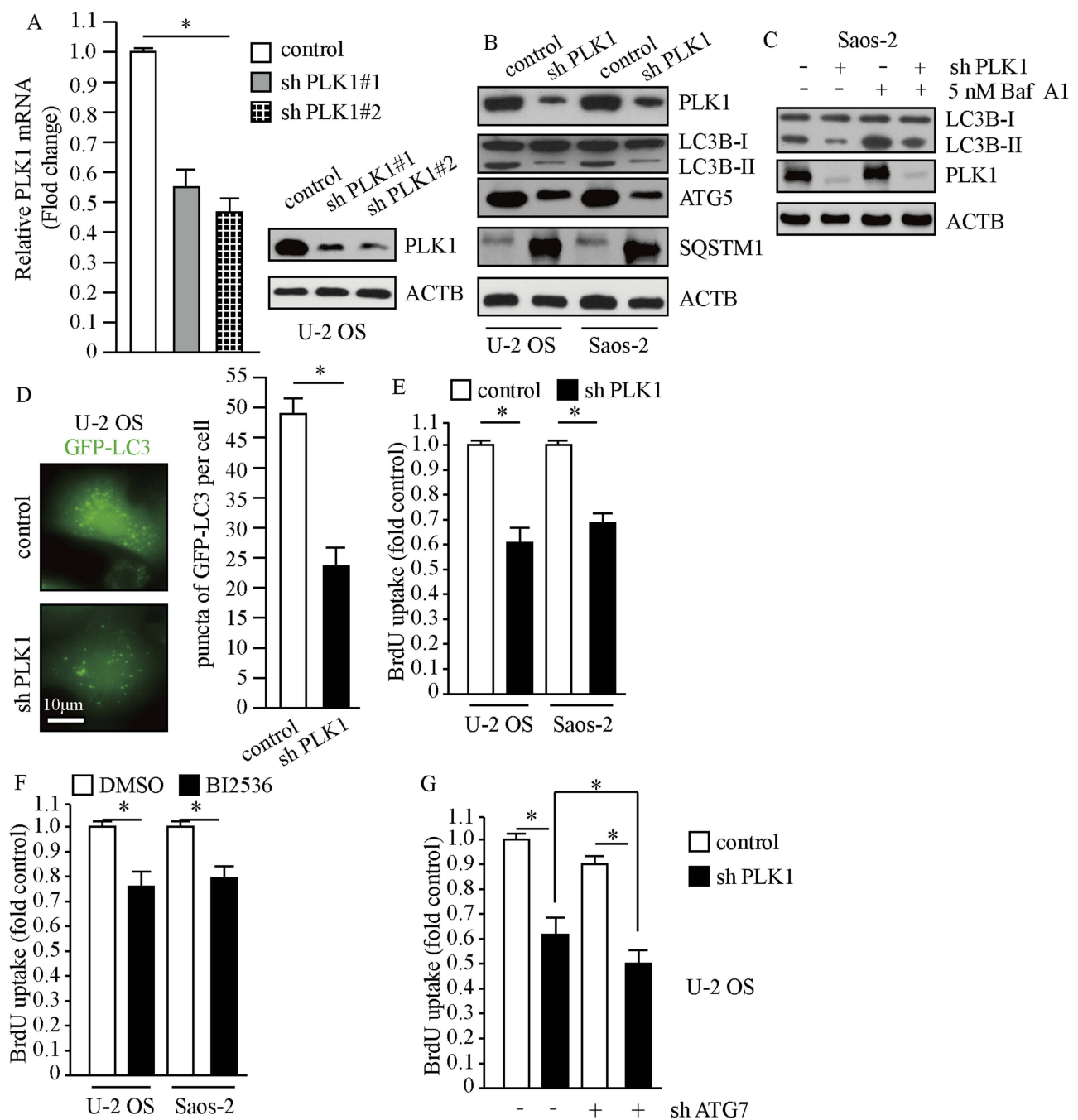
### PLK1 promotes cell proliferation by the autophagy pathway in osteosarcoma cells

To evaluate the efficiency of PLK1 shRNA against PLK1, we detected the mRNA and protein levels of PLK1 after stably infecting U-2 OS cells with lentivirus carrying PLK1 shRNA and control shRNA. The results showed that PLK1 transcriptional levels markedly decreased and PLK1 protein expression also significantly reduced after lentivirus treatment ([Figure 3A](#)). To investigate the implications of PLK1 in osteosarcoma cells, we carried out Western blot and BrdU assays when PLK1 was stably knockdown or treatment with PLK1-specific inhibitor. As shown in [Figure 3B](#), transduction of PLK1 shRNA in U-2 OS and Saos-2 cells caused obvious decrease in LC3-II/LC3-I and ATG5, which indicated restraint of autophagosome formation; and SQSTM1 significantly accumulated after PLK1 knockdown, which suggested deficiency of autolysosome pathway. In order to properly evaluate the autophagic activity in the condition of deficiency of PLK1, we examined LC3-II levels after the treatment of Baf A1. Results indicated that LC3-II significantly increased after the treatment of Baf A1 in PLK1 knockdown cells ([Figure 3C](#)). Then we observed GFP-LC3 expression in PLK1 knockdown cells; we found that GFP puncta were obviously less than that in control cells ( $P < 0.01$ ,

[Figure 3D](#)). The results showed that the loss of PLK1 significantly impaired autophagy. Given that autophagy is an essential mechanism for cancer cell proliferation in basal condition, we performed BrdU assay when PLK1 was stably knockdown or treatment with PLK1-specific inhibitor. Data showed that BrdU uptake markedly decreased in PLK1 knockdown group compared to the control group ( $P < 0.01$ , [Figure 3E](#)). In accordance with above results, cell proliferation was inhibited by PLK1-specific inhibitor BI2536 ( $P < 0.01$ , [Figure 3F](#)). We next carried out cell proliferation assay when PLK1 was stably downregulated plus autophagy-deficient condition. The results showed that cellular proliferation was further restrained under autophagy-deficient condition ([Figure 3G](#)). All of these indicated that the effect of PLK1 on cellular proliferation partially depended on the regulation of autophagy. These data above suggest that PLK1 promotes cell proliferation by autophagy pathway in osteosarcoma cells.

### PLK1 promotes osteosarcoma development by regulating MYC stabilization

To uncover the association between PLK1 and MYC, we performed genetic depletion of PLK1 in osteosarcoma cells U-2 OS and Saos-2. PLK1 knockdown led to a marked decline in MYC protein abundance ([Figure 4A](#), left); however, loss of MYC hardly affected PLK1 expression in this study ([Figure 4A](#), right). To validate these results using pharmacological approaches, osteosarcoma cells were exposed to selective PLK1 inhibitor BI2536. As expected, BI2536 treatment dramatically decreased MYC protein levels, and MYC protein abundance showed decrease in a dose-dependent manner ([Figure 4B](#)). Another selective PLK1 inhibitor BI6727 was also used to treat U-2 OS and Saos-2 cells, time- and dose-dependent loss of MYC protein abundance was observed (data not shown). We sought to understand how PLK1 would impact MYC. In this study, PLK1 knockdown by shRNA led to a slight decrease in MYC mRNA levels; and selective PLK1 inhibitors also caused a moderate decrease in MYC mRNA levels ([Figure 4C](#)). However, PLK1 depletion caused over 80% loss of MYC protein abundance. These raised the possibility that PLK1 might regulate MYC expression mainly through a posttranslational mechanism. MG132, the 26S proteasome inhibitor, nearly rescued the MYC loss resulted from PLK1 inactivation ([Figure 4D](#), top). Rescue of the MYC protein amount by MG132 has also been shown in PLK1 knockdown cells ([Figure 4D](#), bottom). These results support

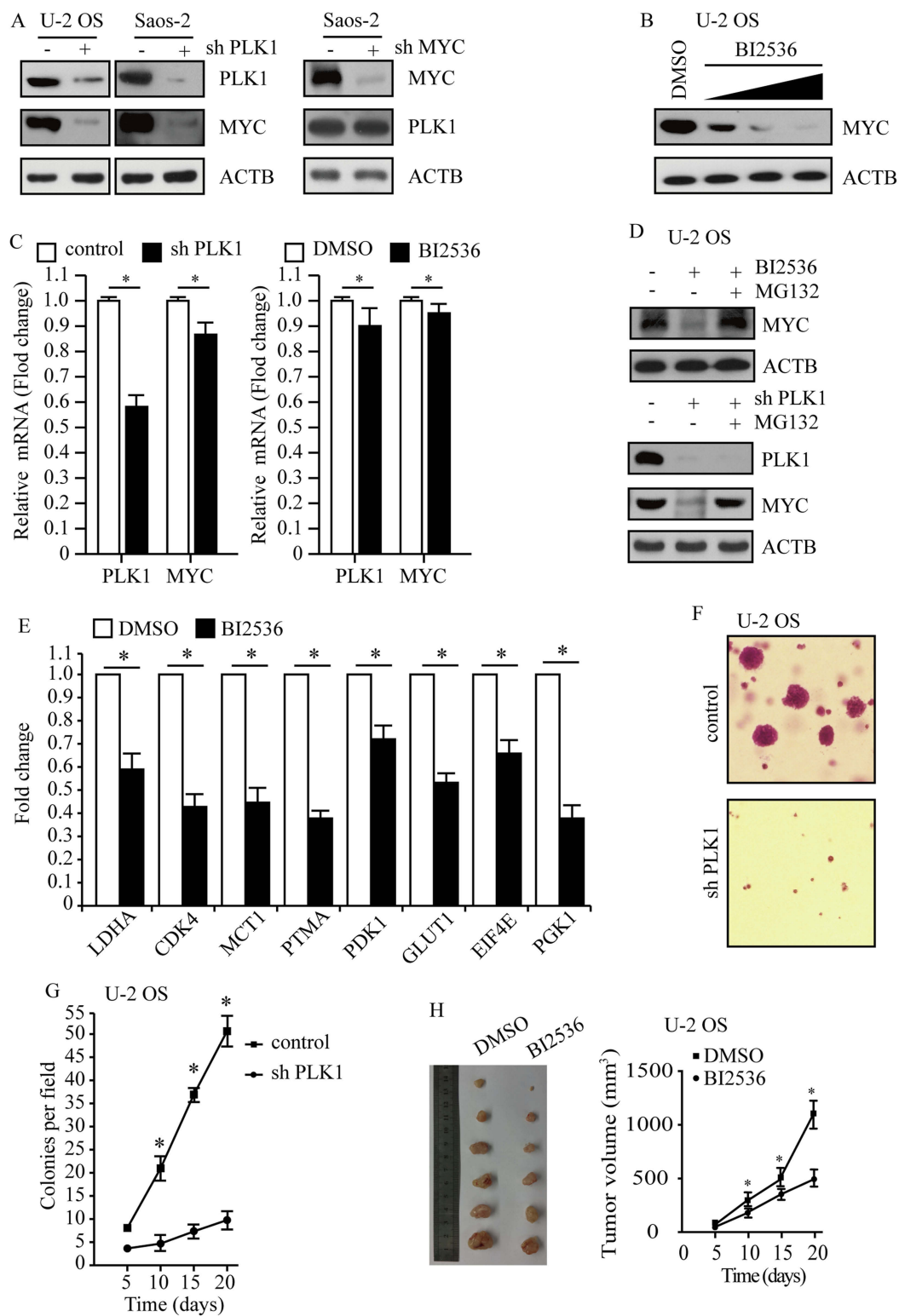


**Figure 3** PLK1 promotes the proliferation of osteosarcoma cells. Cells treated with lentivirus carrying PLK1 shRNA or control shRNA. **(A)** The expression of PLK1 was detected by qPCR and Western blot. ACTB was used as a loading control. **(B and C)** Whole cell lysates were prepared, and subjected to Western blot analysis using indicated antibodies. 5 nM Baf A1 treatment for 4 hrs. **(D)** Representative fluorescence microscope images of cells stably expressing GFP-LC3, scale bar: 10  $\mu$ m (left panel). Puncta of GFP-LC3 per cell, \* $P$ <0.01 vs control cells (right panel). **(E-G)** Cellular proliferation of control and PLK1 shRNA osteosarcoma cells was assessed using BrdU assay,  $n=5$ . **(F)** BI2536 (30 nM) for 24 hrs, \* $P$ <0.01.

**Abbreviations:** PLK1, polo-like kinase I; MYC, MYC proto-oncogene.

that PLK1 regulates MYC mainly by promoting protein stability. It is clear that PLK1 inhibition markedly affected MYC transactivation activities. In this work, we showed that 8 representative MYC target genes were deregulated by PLK1 inhibitor (Figure 4E).

Given that MYC is critical for cancer cell proliferation and development, we next sought to explore whether PLK1 depletion affected osteosarcoma development. We carried out soft agar assay using U-2 OS cells and observed repressed tumorigenesis in PLK1 depletion group compared



**Figure 4** PLK1 promotes osteosarcoma development by regulating MYC stabilization. **(A)** PLK1 and MYC protein levels were analyzed by immunoblot, with ACTB as a loading control. **(B)** Immunoblot detection of MYC in U-2 OS cells after 24 hrs of treatment with BI2536 (5 nM, 15 nM, 30 nM). ACTB was used as a loading control. **(C)** Transcription levels of PLK1 and MYC. ACTB was used as a loading control. **(D)** Immunoblot detection of MYC in U-2 OS cells under treatment with BI2536 (30 nM) for 24 hrs, followed by MG132 (5  $\mu$ M) for another 6 hrs. ACTB was used as a loading control. **(E)** qPCR analysis of representative MYC target genes in U-2 OS cells upon BI2536 (30 nM) treatment for 24 hrs. Data shown represent the means ( $\pm$  SEM) of triplicates. **(F)** Clonogenic assays performed with control and PLK1 shRNA U-2 OS cells. **(G)** The graph shows the quantification of the mean number of colonies at different time points as indicated. **(H)** U-2 OS cells were subcutaneously implanted into female athymic nude mice ( $n=6$  for each experimental condition). The tumor images on day 20 (left panel). Tumor growth curve (mean  $\pm$  SEM) is shown (right panel). \* $P<0.01$  compared to control.

**Abbreviations:** PLK1, polo-like kinase 1; MYC, MYC proto-oncogene.



to control group ( $P < 0.01$ , Figure 4F and G). To examine the effect of PLK1 on tumorigenesis in vivo, we injected  $5 \times 10^6$  U-2 OS cells subcutaneously into athymic nude mice, and mice were treated with BI2536 or DMSO by intraperitoneal injection. Twenty days later, all of the control cells formed visible xenograft tumors; conversely, mice treated with BI2536 showed significantly delayed xenograft tumor growth, with lower mean tumor weight compared to the control group ( $P < 0.01$ , Figure 4H). Similar results were acquired when using Saos-2 cells (data not shown), validating it as a potential therapeutic target in osteosarcoma caused by MYC-amplified.

## Discussion

Using osteosarcoma cells as model systems, we herein identified that PLK1 and MYC were essential for aggressive tumor progression. High expression of MYC and/or PLK1 was associated with basal autophagy in osteosarcoma cells.

PLK1 holds great promise as a therapeutic target. BI2536, a highly specific and potent PLK1 inhibitor, is under multiple clinical trials.<sup>30</sup> And our work indicated that BI2536 effectively inhibit PLK1 in osteosarcoma cells. PLK1 was confirmed for regulation of oncoprotein MYC expression through a posttranslational mechanism. Cells given BI2537 treatment showed more protein stability compared to control cells. Previous studies showed that the direct pharmacological method for inhibition of MYC was notoriously tricky. An approach was ever the modulation of MYC degradation through AURKA inhibition.<sup>31</sup> However, treatment with AURKA inhibitors only modestly decreased MYC protein levels. In addition, abrogation of MYC transcription by CDK7 inhibitors was shown to elicit meaningful therapeutic responses.<sup>32</sup> The pharmacodynamics, efficacy of these compounds and toxicities in patients remain unclear.

In this study, we validated a pharmacologic method exploiting the enforced PLK1 addiction present in osteosarcoma cells. MYC promotes the proliferation of osteosarcoma cells through autophagy pathway, and MYC stabilization is PLK1-dependent. Autophagy plays an important role in amino acid metabolism, cellular structure repair, cell growth, radio resistance and chemo resistance of cancer cells. Perturbation of autophagy may cause intracellular environment imbalance and restrain cell viability. We have shown that treatment with Torin 1 partially rescued cell proliferation, which is reduced by deficiency of MYC or PLK1. Other studies claimed that target gene of autophagy pathway helps to control osteosarcoma

progress.<sup>33,34</sup> However, persistent overactivity of autophagy would result in cell death. We have shown that PLK1 contributed to cell proliferation by autophagy pathway in osteosarcoma cells. Our findings reinforce the likelihood of directing against PLK1 as a therapeutic option in the treatment of osteosarcoma. PLK1 inhibition reduced autophagy-mediated processes, such as amino acid metabolism, DNA repair, cell growth, radio resistance and chemo resistance. In addition, PLK1 inhibition could reduce MYC stabilization and restrain MYC-mediated cell proliferation.

## Abbreviations

PLK1, polo-like kinase 1; mTORC1, mammalian target of rapamycin complex 1; GFP, green fluorescent protein; LC3, microtubule-associated protein 1 light chain 3; ATG, autophagy-related gene; TP53, tumor protein p53; RB1, RB transcriptional corepressor 1; MDM2, MDM2 proto-oncogene; CDKN2A, cyclin dependent kinase inhibitor 2A; MYC, MYC proto-oncogene.

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## Disclosure

The authors report no conflicts of interest in this work.

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