

PLAC1 Enhances Metastatic Potential and is Associated with PI3K/AKT/NF- κ B Signaling Pathway in Colon Cancer

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Abstract

Background: To better explore the underlying mechanism of liver metastatic formation by placenta-specific protein 1 (PLAC1) in human colorectal cancer, we investigated the proliferation, invasion and angiogenic capabilities of human colorectal cancer cell lines with different liver metastatic potentials as well as the mechanism of action of PLAC1 in the metastatic process.

Methods: The expression of PLAC1 was detected by reverse transcriptase PCR, western blot and real-time PCR. The effect of PLAC1 on metastatic potential was determined by proliferation, invasion, and angiogenesis assays, including an in vitro coculture system consisting of cancer cells and vascular endothelial cells that were used to detect the relationship between cancer cells and angiogenesis. In addition, we also determined PLAC1 downstream targets that preferentially contribute to the metastatic process.

Results: PLAC1 was expressed in HT-29, WiDr and CaCo-2 colorectal cancer cells but not in Colo320 colorectal cancer cells. PLAC1 could not only significantly enhance the proliferation of CoLo320 and human umbilical vein endothelial cells (HUVECs) but could also promote the invasion of CoLo320 cells. The angiogenesis of HUVECs was enhanced by PLAC1 in a dose-dependent manner. In cocultured systems, angiogenesis was significantly increased by coculture with HT-29 cells. In addition, PLAC1 could promote angiogenesis in coculture with HT-29 cells. Furthermore, PLAC1-enhanced metastatic potential of colorectal cancer cells was dependent on activation of the PI3K/Akt/NF- κ B pathway.

Conclusions: The activation of PI3K/Akt/NF- κ B signaling by PLAC1 may be critical for the metastasis of colorectal cancer cells. According to our results, we suggest that modification of PLAC1 function might be a promising new therapeutic approach to inhibit the aggressive spread of colorectal cancer.

Background

Colorectal cancer (CRC) is one of the most common malignant tumors that seriously threatens human health. There are almost 1.36 million new CRC cases, and it causes more than a million patient deaths annually worldwide. It has the third highest incidence of malignant tumors in the world, ranking third in males and second in females, and it also ranks as the second leading cause of cancer-related death after lung cancer.¹ The present treatments for colorectal cancer are radical surgical operation, chemotherapy, radiotherapy, immunotherapy and targeted therapy. However, many patients with colorectal cancer are diagnosed at an advanced stage, when surgical intervention is no longer effective to treat this disease. At least 40% of patients with colorectal cancer develop metastases,² and there are no highly effective approaches against disseminated colorectal cancer. Therefore, new, nonsurgical therapeutic strategies are urgently needed for the treatment of advanced or metastatic colorectal cancer. There have not been highly effective approaches against metastasis of colorectal cancer so far. Recently, research on the microenvironment of solid tumors has shown that chemokines and their receptors have key functions in cancer metastatic processes, and chemokines play specific roles in the regulation of angiogenesis, the

activation of a tumor-specific immune response and the induction of tumor cell proliferation in an autocrine or paracrine fashion.³⁻⁵

Placenta-specific protein 1 is encoded by placenta-specific gene 1, which is a recently discovered placental antigen with limited normal tissue expression and fundamental roles in placental function and development.⁶ During embryo implantation, the invasion of trophocytes into the endometrium and the formation of blood vessels are very similar to the growth, invasion and migration of tumors.⁷ Recently, increasing evidence has revealed that PLAC1 expression is activated in a variety of human cancers, including gastric, non-small-cell lung, liver and colorectal, and epithelial ovarian and breast cancer, as well as primary colorectal adenocarcinoma.⁸⁻¹² In addition, increased expression of PLAC1 was found to be positively correlated with the degree of tumor invasion, lymph node metastasis and distant metastasis.¹³

Recent studies showed that PLAC1 is expressed at high levels on the surface of trophoblast cells in the placenta and at low levels in the testis but is otherwise absent in normal somatic tissues. PLAC1 is expressed in human fetal tissues, and circulating PLAC1 mRNA increases during pregnancy^{14,15} and as a result of preeclampsia, fetal injury and implantation failure.¹⁶ Many genes normally expressed in the embryo become reactivated in cancer cells, and PLAC1 was the first such cancer/testis gene that related placentation to cancer. Silva, et al. first reported that PLAC1 RNA was expressed in human cancer cell lines covering 17 different malignancies, including colorectal cancer. PLAC1 expression detected by IHC was upregulated in other cancers, such as serous endometrial adenocarcinoma and late-stage colon and liver cancer.^{17,18} There is a growing body of evidence showing that PLAC1 is frequently activated in a wide variety of cancer types and promotes cancer progression.¹⁹ Overall, these data suggest that PLAC1 may have diagnostic value as a tumor-selective biomarker in colon cancer and other malignancies.

The aim of the present study was to investigate the effect of PLAC1 on metastatic potential and the underlying mechanism in colorectal cancer cells and to clarify the mechanism of PLAC1 in metastasis and the interactions between colorectal cancer cells and stromal cells in the tumor microenvironment. We wished to determine whether circulating levels of PLAC1 protein serve as a biomarker in preoperative and pretreatment colorectal cancer. Furthermore, our study will provide data to demonstrate that the phosphatidylinositol PI3K/Akt/NF- κ B signaling pathway probably plays an important role in PLAC1 simulation and that this process is involved in the development and metastasis of colorectal cancer. Understanding the biological mechanisms responsible for the regulation of PLAC1 may enable better molecularly targeted therapies for the treatment of patients with metastatic colorectal cancer. PLAC1 may be regarded as a potential cancer-testis-placenta (CTP) antigen therapeutic target for treating patients with metastatic colorectal cancer.

Materials And Methods

Reagents and antibody

Recombinant human PLAC1 and anti-human PLAC1 antibodies were provided by R&D System Inc. (Minneapolis, MN, USA). LY294002 (PI3K inhibitor) was ordered from Cell Signaling Technology (Beverly,

MA, USA). The Akt inhibitor was purchased from BioVision (Mountain View, CA, USA). The Akt, phospho-Akt (Ser473), PI3K p85, phospho-PI3K p85 (Tyr 458)/p55 (Tyr199), NF- κ B p65, and phospho-NF- κ B p65 (Ser536) antibodies were purchased from Cell Signaling Technology (Mountain View, CA).

Cell culture

Human colorectal cancer cells (HT-29, WiDr, CaCo-2 and Colo320) were obtained from American Type Culture Collection (Rockville, MD, USA). HT-29 was incubated in McCoy's medium containing 10% FBS (Gibco, Grand Island, NY, USA). WiDr and CaCo-2 cells were maintained in minimum essential medium eagle (MEME) with 10% FBS. RPMI-1640 medium with 10% FBS was used to culture Colo320 cells. HUVECs were obtained from Kurabo Co., and incubated in HuMedia-EB2 medium containing 2% FBS, 5 ng/ml bFGF, 10 mg/ml heparin, 10 ng/ml epidermal growth factor, and 1 mg/ml hydrocortisone.

RT-PCR Analysis

Total RNA from colorectal cancer cells was extracted by using an Isogen Kit, and the concentration of RNA was measured spectrophotometrically. Five microliters of total RNA was mixed with random hexamers and dNTP mix, incubated at 65°C for 5 min, chilled on ice, and then reverse-transcribed into cDNA using a cDNA Synthesis Mix, which included 10 \times RT buffer, 25 mM MgCl₂, 0.1 MDTT, RNaseOUT and 200 U SuperScript III RT (Invitrogen, San Diego, CA, USA) at 50°C for 50 min. The reaction was discontinued at 85°C for 5 min. One microliter of each reaction mixture was used as a template for PCR. The following forward and reverse primers were used: PLAC1, 5'-TTCACCAGTGAGCACAA AGC-3' and 5'-CCAGTCTATGG AGCACAGCA-3'. Amplification reactions were performed using a DNA Thermal Cycler.

Western blot analysis

Colorectal cancer cells and HUVECs (1 \times 10⁶/mL) were lysed in protein lysis buffer. Then, the protein concentrations were measured with a BCA protein assay kit (Pierce, Rockford, USA). The lysates (30 μ g per lane) were separated by 10% SDS-polyacrylamide gel electrophoresis and transferred to polyvinylidene membranes. The membranes were incubated in blocking buffer for 60 min at RT. The blocking buffer included 5% nonfat dry milk solubilized into Tris-buffered saline comprising 0.1% Tween 20 (TBS-T). After three 5 min washes with TBS-T, the cells were immunoblotted with each primary antibody, diluted 500- to 1,000-fold by primary antibody dilution buffer and incubated overnight at 4°C. Then, the membrane was washed with TBS-T three more times and subjected to incubation with the HRP-conjugated secondary antibody for 1 hr at RT. The antibody complex was detected by using the ECL Western blotting observation and analysis system.

Real-Time quantitative RT-PCR

The qPCR was performed using a LightCycler apparatus. Freshly isolated RNA was converted to cDNA using the PrimeScriptTM TR Regent kit (Takara Bio Inc., Shiga, Japan), and the PCR was performed using the TaqMan[®] Gene Expression Assay Kit (Applied Biosystems, Foster City, CA, USA). In brief, a mixture of

1 µl of total RNA and 1 µl of oligo dT primer was incubated at 37°C for 15 min and 85°C for 5 sec for reverse transcription. The PCR was then performed in a 20 µl final volume containing the following: up to 20 µl of H₂O, 10 µl of TaqMan® Universal PCR Master Mix, No AmpErase® UNG (2×)²—ordered separately, 1 µl of 20× TaqMan® Gene Expression Assay Mix, and 9 µl of cDNA diluted in RNase-free water. After an initial incubation at 94°C for 15 sec, temperature cycling was initiated with each cycle (a total of 45-50 cycles) as follows: denaturation at 95°C for 10 sec, hybridization at 60°C for 30 sec, and elongation at 72°C for 30 sec. The fluorescence signal was acquired at the final step of hybridization. Melting curves were obtained with a temperature range of 65-95°C, read every 0.2°C, held for 5 sec, and then incubated at 65°C for 1 min. Cycling conditions of GAPDH were consistent with the above steps. A standard curve for each run was generated from serial dilutions of cDNA of the HT-29 cell line. The mRNA expression level of PTEN was normalized to that of GAPDH and shown as the mean ± standard deviation (s.d.). Relative mRNA expression of PTEN was calculated using the following formula: $A/G \div A_0/G_0$, in which A and G are the relative mRNA copy numbers of PTEN and GAPDH, while A₀ and G₀ are the relative mRNA levels of PTEN and GAPDH from the standard cDNA dilutions as control.

Proliferation assay

The colorectal cancer cells and HUVECs were planted at a density of 3×10^3 cells/100 µl into 96-well flat-bottomed plates and cultured overnight. The medium was exchanged, and the cells then cultured in the medium alone (control) or in the medium that included different concentrations of PLAC1 and anti-PLAC1 antibody. After 72 hr of incubation, 10 µl of WST-1 reagent was added to each well, and the cells were incubated for another 4 hr. Then, the cell proliferation was measured by the WST-1 Cell Proliferation Assay System (Takara Bio Inc., Shiga, Japan). The absorbance was determined using a microplate reader at a test wavelength of 450 nm and a reference wavelength of 690 nm.

Invasion assay

The effect of PLAC1 on the invasive capability of human colorectal cancer cell lines and HUVECs was measured by using Matrigel-coated invasion chambers. The transwell chambers are separated by a PET membrane coated with Matrigel Matrix such that only invasive cells can migrate through the membrane to the reverse side. After rehydration for 2 hr in a humidified incubator at 37°C. The cells were seeded at a density of 1×10^5 cells/well into the inner chambers of a cell culture insert and incubated at 37°C for 24 hr with various concentrations of PLAC1. After 24 hr of incubation, cells that did not pass through were removed from the upper surface of the membrane by scrubbing gently with cotton-tipped applicators. The cells that invaded the reverse side of the membrane were fixed with 70% ethanol, stained with Giemsa solution, and counted in five random fields of the low filter surface under a microscope at 200× magnification.

Angiogenesis assay

To explore the effect of PLAC1 on tubule formation by HUVECs, HUVECs and fibroblasts were coincubated in basal medium using an angiogenesis kit according to the manufacturer's protocols. First,

HUVECs and fibroblasts were cocultured in 24-well plates with basal medium. The media were exchanged every two days with media containing various concentrations of PLAC1, with cocubation continuing for a total of 11 days. The coculturing system was stained with anti-CD31 antibody. The area of angiogenesis was measured quantitatively over ten different microscope fields for each well using an image analyzer (Kurabo Co.).

Angiogenic activity during cocultivation with colorectal cancer cells

To further examine the influence of colorectal cancer cells on tubule formation by HUVECs. HT-29 or Colo320 cells were cocubated with HUVECs/fibroblasts adopting a double chamber technique in 24-well plates. Colorectal cancer cells (2×10^4 cells/well) were plated in transwell chambers consisting of polycarbonate membranes with 0.45 μm pores, and the cells were allowed to adhere overnight. Then, the transwell chambers were placed in the HUVEC/fibroblast coculture plate, and the medium was exchanged on the sixth day. Cells were incubated for 11 days, and HUVEC tubule formation was measured as described above.

Statistical analysis

Using the *t*-test for paired observations or one-way ANOVA with a post hoc test (Dunnett multiple comparison) for multiple group comparisons, comparisons between groups were made. Statistical significance was provided, $p < 0.05$. Data are presented as the mean \pm s.d. Each experiment was performed in triplicate.

Results

Expression of PLAC1 in colorectal cancer cell lines

Expression of PLAC1 mRNA was detected in HT-29, WiDr and CaCo-2 cells but not in Colo320 colorectal cancer cells using RT-PCR (Figure 1A). Similarly, by immunoblotting, HT-29, WiDr and CaCo-2 colorectal cancer cell lines were analyzed for the expression of PLAC1 protein (Figure 1B). We previously determined the liver-metastatic capability of human colorectal cancer cell lines by intrasplenic liver metastatic assay and classified them into either the high liver metastatic group (HT-29, WiDr) or the low liver metastatic potential group (CaCo-2, Colo320).² In the present study, we found that there was a positive relationship between the relative quantity of PLAC1 mRNA and metastatic potential. In other words, expression of PTEN mRNA in the high metastasis group (HT-29 and WiDr) was significantly higher than in the low metastasis group (CaCo-2 and Colo320, $*P < 0.01$, Figure 1C).

Effect of PLAC1 on the proliferation of colorectal cancer cells and HUVECs

We next examined the proliferative effects of PLAC1 over a range of concentrations in colorectal cancer cells and HUVECs. The proliferative assay results showed that PLAC1 enhanced proliferation of Colo320 cells in a dose-dependent manner (compared with 0 ng/ml of PLAC1, $**p < 0.05$, $*p < 0.01$), and there was

no significant promotion of proliferation in HT-29, WiDr and CaCo-2 cells (Figure 2A). The growth of HUVECs was significantly enhanced by PLAC1 in a concentration-dependent manner when compared with controls (** $p < 0.05$, * $p < 0.01$), and this enhancement of proliferative capability was inhibited by the anti-PLAC1 antibody (compared with 100 ng/ml of PLAC1, * $p < 0.01$, Figure 2B).

The roles of PLAC1 in the invasive behavior of colorectal cancer cells and HUVECs

After pretreatment (or no treatment) with PLAC1, Colo320 cells were cultured for 24 hrs. At that point, the invasive capability was assessed. PLAC1 was found to enhance the invasiveness of Colo320 cells (Figure 3A) and HUVECs (Figure 3B) in a dose-dependent manner. The 100 ng/ml of PLAC1 was the most effective ($p < 0.01$). On the other hand, the invasive ability was blocked by anti-PLAC1 antibody in Colo320 cells and HUVECs (compared with 100 ng/ml of PLAC1, * $p < 0.01$).

Effect of PLAC1 and colorectal cancer cells on HUVEC tube formation

To further investigate the role of PLAC1 in the microenvironment, we focused on the interaction between tumor cells and stromal cells by characterizing angiogenic activity in cells cocultured with fibroblasts and HUVECs and the effect of PLAC1 in this system. HUVEC tube formation was significantly enhanced by the presence of PLAC1 in a dose-dependent manner (compared with 0 ng/ml of PLAC1, * $p < 0.01$, Figure 4A).

Effect of colorectal cancer cell coculture and PLAC1 on HUVEC tube formation

We next investigated the influence of colorectal cancer cell lines with different metastatic potentials on HUVEC tube formation using a double-chamber cell culture system. Tube formation was significantly enhanced by coculture with HT-29 cells compared with control (HUVECs and fibroblasts only) or coculture with Colo320 cells (* $P < 0.01$) (Figure 4B). Moreover, the presence of PLAC1 significantly promoted tube formation in the Colo320 cell coculture system (* $P < 0.01$). In contrast, the enhanced tube formation of HUVECs was significantly inhibited by the addition of anti-PLAC1 antibody in the HT-29 cell coculture system (* $P < 0.01$) and was not inhibited by anti-PLAC1 antibody in the Colo320 cell coculture system (* $P < 0.01$).

Activation of the PI3K, Akt and NF- κ B signaling pathway after PLAC1 stimulation in human colorectal cancer cells and HUVECs

We used colorectal cancer cell lines and HUVECs to examine the activation of the PI3K/Akt/NF- κ B signaling pathway, a downstream target of PLAC1. PLAC1 treatment increased PI3K phosphorylation in a dose-dependent manner in HT-29, Colo320 cells and HUVECs (Figure 5A). The Akt kinase activity of colorectal cancer cells was remarkably enhanced by PLAC1 stimulation in a concentration-dependent manner (Figure 5B). Stronger activation of NF- κ B phosphorylation activity was observed in HT-29, Colo320 cells and HUVECs stimulated by PLAC1 for 15 min in a dose-dependent manner (Figure 5C).

Activation of the PI3K/Akt/NF- κ B signaling pathway after the stimulation of PLAC1 in colorectal cancer cells and HUVECs

To investigate the effect of PI3K inhibitor (LY294002) and Akt kinase inhibitor on the activation of NF- κ B in HT-29, Colo320 cells and HUVECs after stimulation by PLAC1, HT-29, Colo320 and HUVECs were pretreated with 50 μ M PI3K inhibitor (LY294002) and 50 μ M Akt kinase inhibitor for 5 minutes, then 100 ng/ml of PLAC1 was added to the culture medium and incubated for 15 minutes. The proteins were extracted and separated by SDS-PAGE and transferred to membranes, and the membranes were probed with an antibody directed against phospho-NF- κ B. The results showed that PLAC1-mediated phospho-NF- κ B was significantly blocked by 50 μ M of LY294002 and Akt kinase inhibitor. These data indicate that PLAC1 enhanced the metastatic potential of colorectal cancer depending on the upregulation of the PLAC1/PI3K/Akt NF- κ B signaling pathway (Figure 6).

Discussion

Liver is one of the most common metastatic organs of colorectal cancer. Synchronous liver metastasis occurs in approximately 25% of patients, and advanced liver metastasis occurs in 30-40% of patients with colorectal cancer. Liver metastasis becomes the leading cause of death for patients with advanced colorectal cancer after the surgical removal of the primary tumor, with nearly 45% of patients dying from the primary tumor and 83% of patients with recurrent cases dying from the liver metastasis.²⁰ For this reason, the mechanism of colorectal cancer metastasis to the liver was explored; this mechanism is expected to be used for suppressing the invasion and metastasis of the tumor and to eventually provide a new approach to the prevention and treatment of colorectal cancer metastasis in clinical practice. Placenta-specific protein 1 is a new member of the cancer-testis antigen family. It is characterized by its restricted expression in germ cells and placental trophoblastic tissues and its extensive expression in tumor tissues.²¹ The protein is closely related to the growth of the placenta and embryo and plays an important role in regulating the formation of the placenta and stabilizing the connection between the placenta and the mother, thus acting as a biological indicator to predict the prognosis of pathological pregnancy and embryo transfer. PLAC1 is extensively expressed in tumor tissue.²² CT antigen is overexpressed in various tumor types, while its expression is restricted to germ cells for normal tissues. Germ cells cannot be recognized by T cell receptor (TCR) gene-modified T cells due to the lack of expression of major histocompatibility complex (MHC) molecules, which are responsible for antigen presentation. This feature makes these cells a potential target for cancer immunotherapy. PLAC1 is a membrane protein with immunogenicity. Although there is still no clear understanding of the effect of PLAC1 on tumor biological functions, its gene plays a very important role in tumor tissue expression and localization of cell surface proteins in placental tissue. Therefore, the CT antigen may act as an ideal target for tumor immunotherapy.²³

Placental growth is vital to embryo development. There are many similarities between the implantation and development of an embryo and the invasion and growth of the tumor. Similar to malignant cells, trophoblast cells migrate and invade into the uterus and its vessels to nourish the developing fetus.²⁴

Likewise, downregulation of immune responses is another common feature for cancer and placenta.²⁵ Other studies have shown that the PLAC1 gene is significant for tumor growth and invasion.²⁶ To understand the functions of the PLAC1 gene in tumor cells and the role of PLAC1 in the metastasis of colorectal cancer and its mechanism, we explored the relationship between PLAC1 expression and liver metastasis of colorectal cancer, its effect on the metastatic potential of colorectal cancer cells and its mechanism. We found that the expression of PLAC1 was closely related to the liver metastasis potential of colorectal cancer cells, and the expression of PLAC1 in cells with extensive liver metastasis was dramatically higher than in those with less liver metastasis. The expression of PLAC1 in colorectal cancer patients was proven to be associated with differentiation degree, depth of invasion, lymph node metastasis, distal metastasis, degree of malignancy and prognosis, suggesting that the abnormal expression of PLAC1 plays an important role in the development, progression and liver metastasis of colorectal cancer. PLAC1 may act as a tumor marker for assessing the malignancy, liver metastasis and prognosis of colorectal cancer.²⁷ To investigate the effects of PLAC1 on the metastatic potential of colorectal cancer, we assessed cell proliferation, invasion, and neovascularization. The results showed that exogenous PLAC1 could significantly increase the proliferation and invasion of the PLAC1-negative colorectal cancer cell line Colo320 in a dose-dependent manner, while there was no obvious enhancing effect on proliferation and invasion observed in PLAC1-positive colorectal cancer cells, such as HT-29, WiDr and CaCo-2. The enhanced expression of PLAC1 was related to factors such as invasion depth, lymph node metastasis and distal metastasis of colorectal cancer, suggesting that abnormal expression of PLAC1 may play an important role in the development of colorectal cancer and liver metastasis. PLAC1 had a potentiating effect on the proliferation and invasion of HUVECs, which was positively correlated with concentration. Koslowski M et al.¹³ showed that PLAC1 was expressed in up to 37.8% of primary tumor specimens, especially in 82.3% and 54.6% of primary breast cancer and tumor cell lines, respectively. Silencing of the PLAC1 gene and anti-PLAC1 antibody can significantly inhibit the motility, proliferation and invasiveness of breast cancer cells.²⁸ Moreover, silencing PLAC1 by siRNA and blocking PLAC1 by anti-PLAC1 antibody led to a decrease in phosphorylated protein kinase B (PKB), also is called Akt, levels.^{13, 29-30} This result suggested that AKT kinase activation is involved in the execution of the downstream effect of PLAC1. Taken together, PLAC1 may be involved in tumor progression. To mimic the effect of PLAC1 on tumor angiogenesis in the microenvironment, we conducted tumor neovascularization *in vitro* by using a coculture system consisting of gastric cancer cells and stromal cells and assessed the effect of gastric cancer cells with different PLAC1 expression on neovascularization. PLAC1 potentiated the neovascularization of HUVECs in a dose-dependent manner. The effect on neovascularization of HUVECs was significantly greater in the PLAC1-positive colorectal cancer cell line HT29 coculture than in the PLAC1-negative cell line Colo320 coculture. In a culture system consisting of colorectal cancer cells HT-29 and HUVECs + fibroblasts, the enhanced neovascularization was inhibited by the addition of anti-PLAC1 antibody in the presence of HT-29 cells. In the culture system consisting of Colo320 and HUVECs + fibroblasts, exogenous PLAC1 enhanced neovascularization in HUVECs. These results indicated that PLAC1 mainly enhanced the proliferation, invasion, neovascularization, and metastatic potential of colorectal cancer cells in PLAC1-positive colorectal cancer cells. Inhibition of PLAC1 expression can be a potential target for inhibiting colorectal cancer metastasis. The effect of PLAC1 on the microenvironment

of colorectal cancer cells can be assessed in a more objective and realistic manner by using the constructed coculture system mimicking the microenvironment, which is of importance to understanding the specific mechanisms of growth, invasion and metastasis of tumor cells. We also investigated the relationship between PLAC1 and phosphorylation of each member of the PI3K/Akt signaling pathway, aimed at exploring the mechanism by which PLAC1 enhances proliferation, invasion and neovascularization of colorectal cancer cells. Our results showed that phosphorylation of PI3K, Akt and NF- κ B was closely related to PLAC1, and the PI3K/Akt/NF- κ B signaling pathway was activated by PLAC1 in a dose-dependent manner. This suggested that PLAC1 promoted the proliferation, invasion and neovascularization of colorectal cancer cells through the PI3K/Akt/NF- κ B signaling pathway. There was an extensive and close association between the PI3K/Akt signaling pathway and the genesis and metastasis of tumors. The imbalance of the PI3K/Akt signaling pathway may trigger an array of procedures concerning cell growth, proliferation, apoptosis, exercise, invasion, cell cycle regulation, and telomerase activation, which may subsequently be involved in colorectal cancer development, progression and immune escape.³¹⁻³³ Activation of the PI3K/Akt signaling pathway may further activate the proliferation, differentiation, apoptosis, migration, and cell cycle regulation of its downstream target proteins and mediating cells. As a nuclear transcription factor downstream of the PI3K/Akt signaling pathway, NF- κ B is a multidirectional gene transcription factor commonly occurring in eukaryotic cells. It activates the transcription of various genes in cellular processes, including genes related to inflammatory responses, cell proliferation, differentiation and apoptosis. When cells are stimulated by specific cytokines, phosphorylation of the Akt protein in the PI3K/Akt signaling pathway induces a series of linked enzyme-catalyzed reactions that lead to the phosphorylation of inhibitory subunit alpha of NF- κ B (I κ B- α) downstream and dissociation from NF- κ B. NF- κ B is activated and migrates into the nucleus to bind to corresponding sites on DNA, inducing corresponding biological effects.^{34,35} Currently, much attention has been paid to the PI3K/Akt signaling pathway, which may potentially be a highly specific target for anticancer therapy.

In summary, PLAC1 can promote the proliferation, invasion and neovascularization of colorectal cancer cells, enhancing the metastatic potential of colorectal cancer. The mechanism of this effect was related to the upregulation of cascade transmission among PI3K/Akt/NF- κ B pathway members. Further research is still needed to identify the downstream target of the PI3K/Akt/NF- κ B pathway for the enhanced metastatic potential of colorectal cancer mediated by PLAC. Subsequent topics of the research group include the inhibition of cascade transmission among members of the PI3K/Akt/NF- κ B pathway, analysis of interactions between PLAC1 target genes and target pathways, as well as PLAC1 TCR gene-modified T cells as an anti-tumor immunotherapy. It was speculated that PLAC1 may act as a potential target for the treatment of colorectal cancer, and elucidation of the above issues may facilitate the clinical treatment of colorectal cancer with positive expression of PLAC1.

Conclusion

The PLAC1/PI3K/Akt/NF- κ B cascade may be critical for colorectal cancer cells to metastasize. Based on our results, we suggest that cancer-targeted therapies directed against PLAC1 represent a promising new

strategy against advanced colorectal cancer.

Abbreviations

PLAC1: placenta-specific protein 1;

CTP: cancer-testis-placenta;

PI3K: phosphatidylinositol 3-kinase;

Akt: protein kinase B

NF- κ B: nuclear factor B;

PIP₃: dephosphorylate phosphatidylinositol 3,4,5-triphosphate;

TCR: T cell receptor;

HUVEC: human umbilical vein endothelial cell;

MHC: major histocompatibility complex;

Declarations

Ethical Approval and Consent to participate

Not applicable.

Consent for publication

All authors have read the manuscript and approved the final version.

Availability of data and material

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author contributions

All authors contributed to the conception and design of the study, acquisition of data, or analysis and interpretation of data. JCM, ZKZ, DRL, LL, JD, CWP, CSZ and YZC collected data; JCM, ZKZ, and DRL contributed to the analysis and the interpretation of data; and JCM drafted the manuscript. All authors contributed to critically revising the manuscript for important intellectual content and approved the final manuscript.

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Figures

Figure 1A

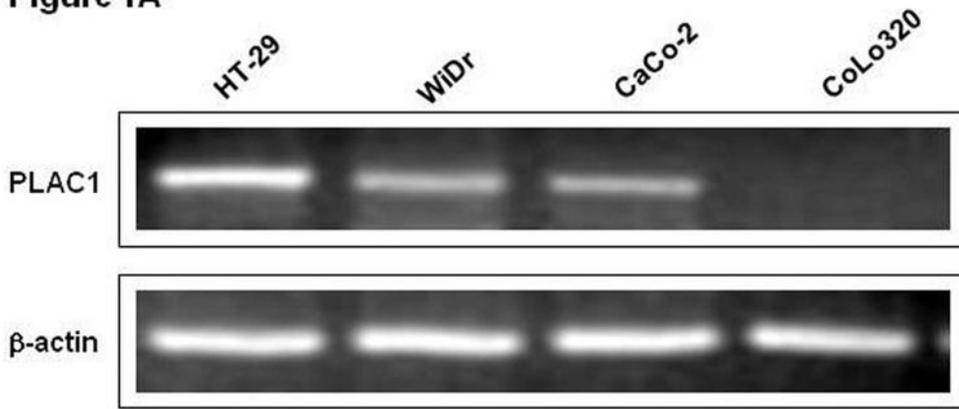


Figure 1B

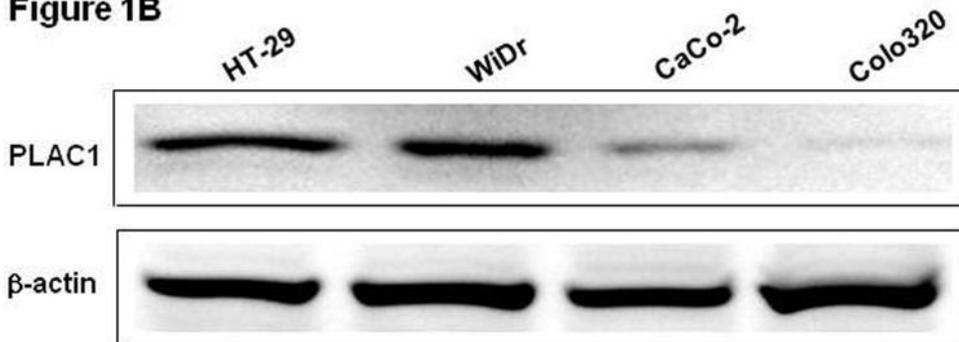


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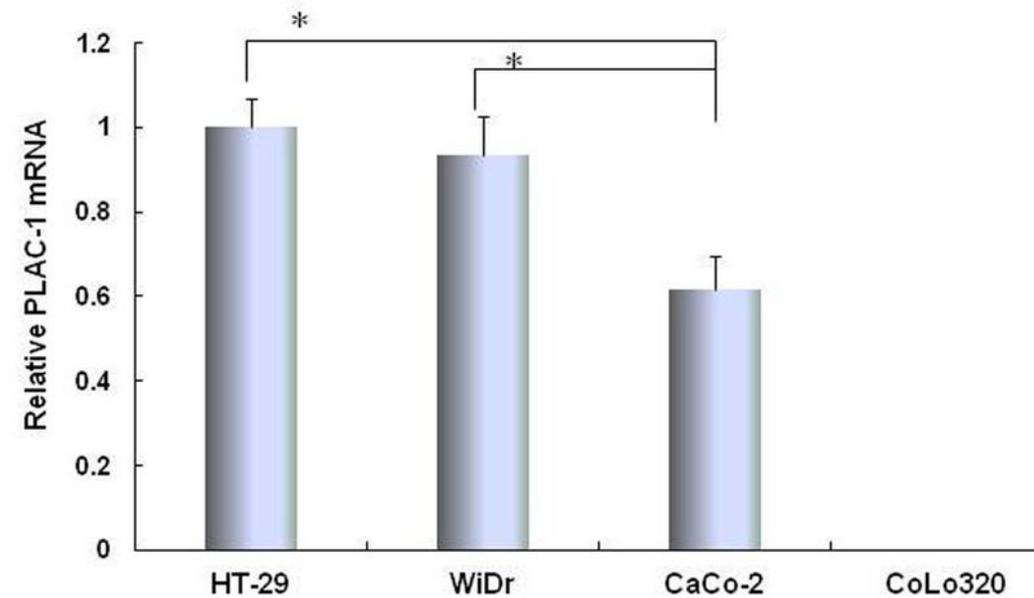


Figure 1

Expression levels of PLAC1 in colorectal cancer cell lines. (A) PTEN and IGF-1R mRNA were detected by RT-PCR in colorectal cancer cells. PCR-amplified products of reverse-transcribed mRNA (cDNA) from GenBank, using primers specific for PLAC1 PCR products, were separated through 2% agarose gels and stained with ethidium bromide. β -actin served as a loading control. (B) The protein expression of PLAC1 in colorectal cancer cell lines was determined in whole-cell lysates by Western blotting analysis. The 30

µg/ml total cell lysate was subjected to 10% SDS-PAGE and transferred to a polyvinylidene difluoride membrane. The membrane was probed with antibodies to PLAC1. β-actin acted as a loading control. (C) Relative expression of PLAC1 mRNA in colorectal cancer cell lines compared to GAPDH was assessed using semiquantitative RT-PCR. The relative expression of PLAC1 mRNA was significantly higher in HT-29 and WiDr cells compared with CaCo-2 and Colo320 cells (*p<0.01). Multiple comparisons were performed by one-way ANOVA followed by Dunnett's test. Bars indicate s.d.

Figure 2A

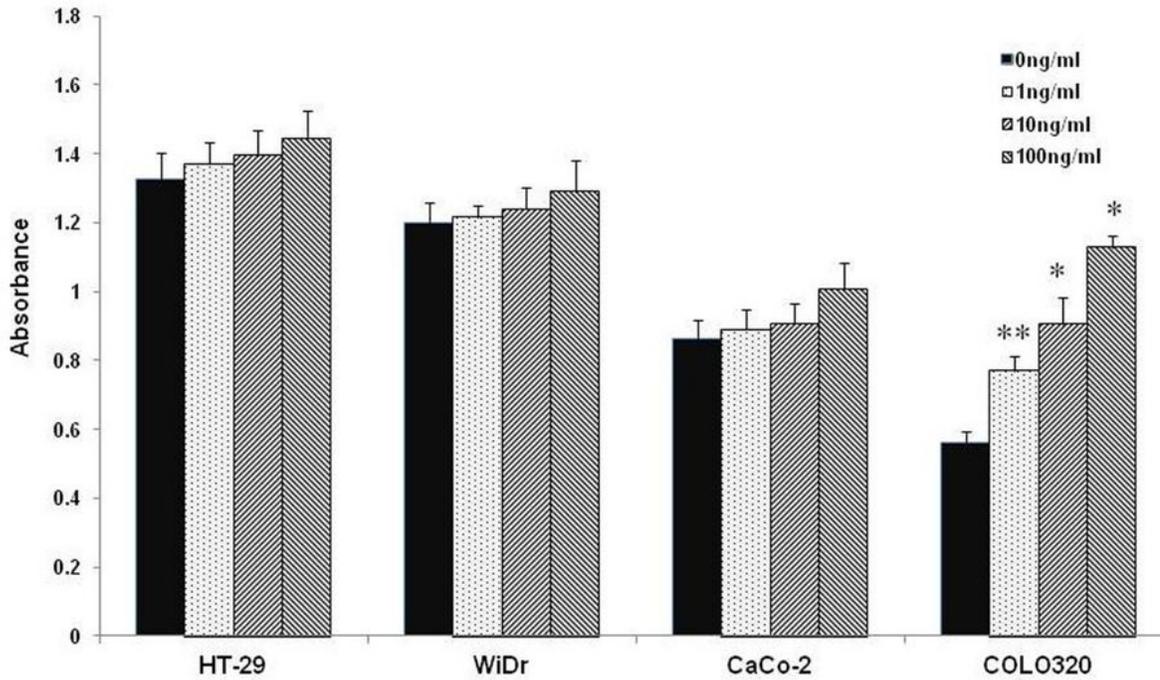


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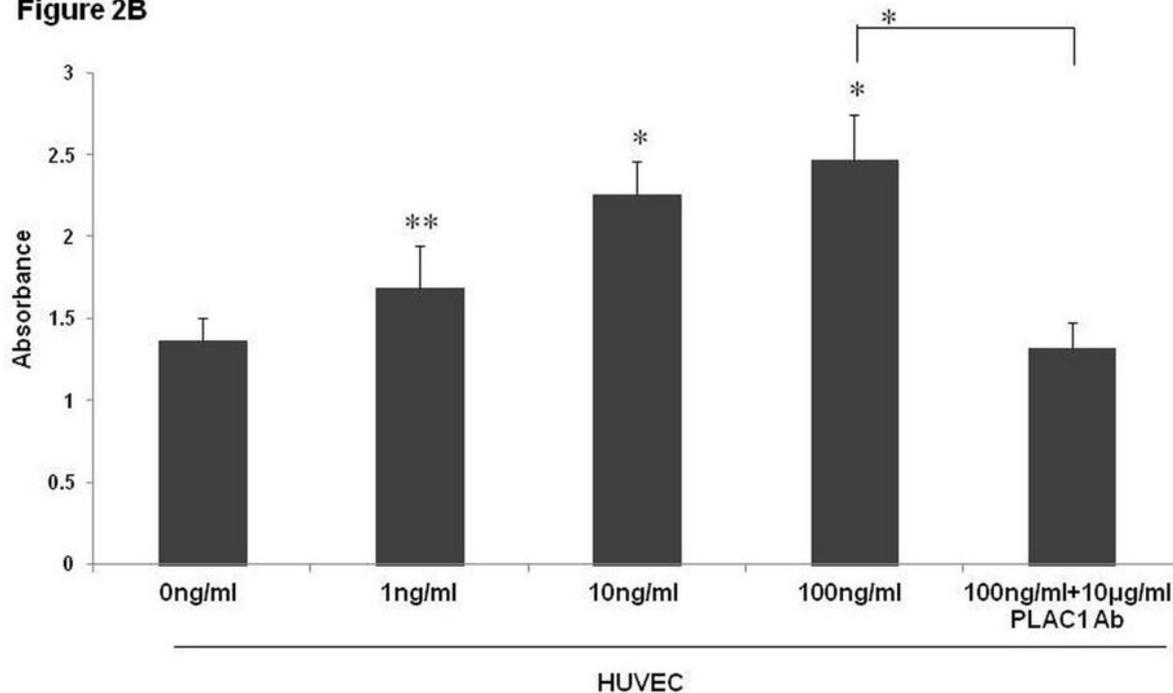


Figure 2

PLAC1 promoted the proliferation of colorectal cancer cells. (A) HT-29, WiDr, CaCo-2 and Colo320 cells were cultured in the presence of different concentrations of PLAC1 for 72 hrs. Cell proliferation was determined by the Premix WST-1 Cell Assay System, and absorbance was read at 450 nm. The reference wavelength is 690 nm. (B) The effect of PLAC1 and anti-PLAC1 antibody on the proliferation of HUVECs. HUVECs were incubated in medium containing different concentrations of PLAC1 or anti-PLAC1 antibody for 72 hrs. Multiple comparisons were performed by one-way ANOVA followed by the Dunnett test. Bars indicate SD. ** = $p < 0.05$, * = $p < 0.01$, compared with control (0 ng/ml).

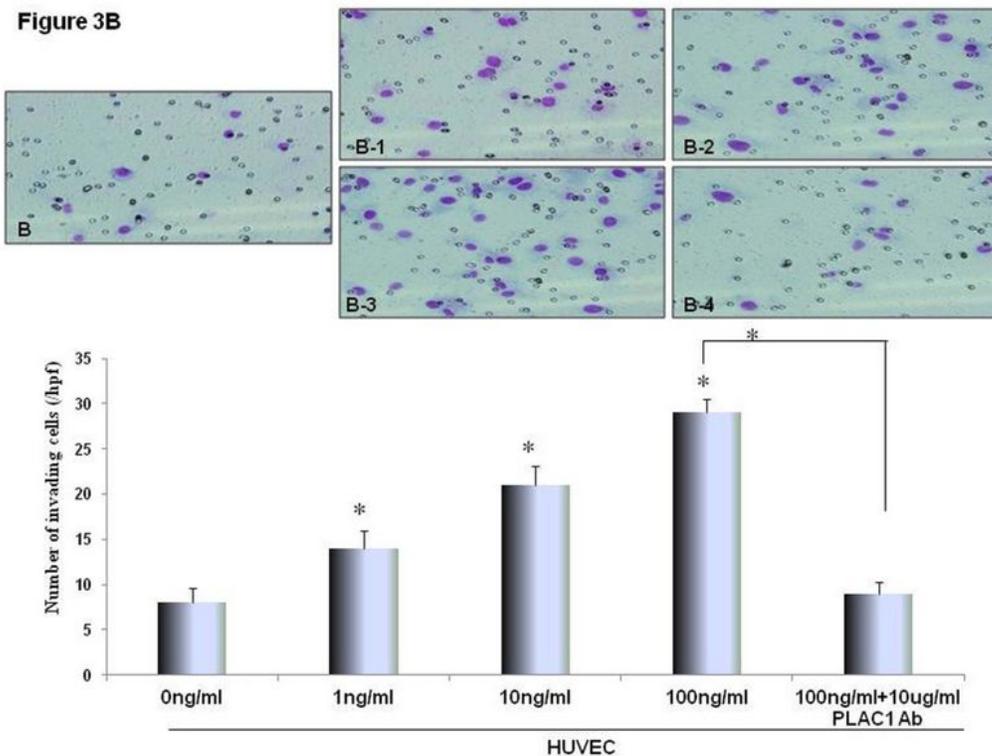
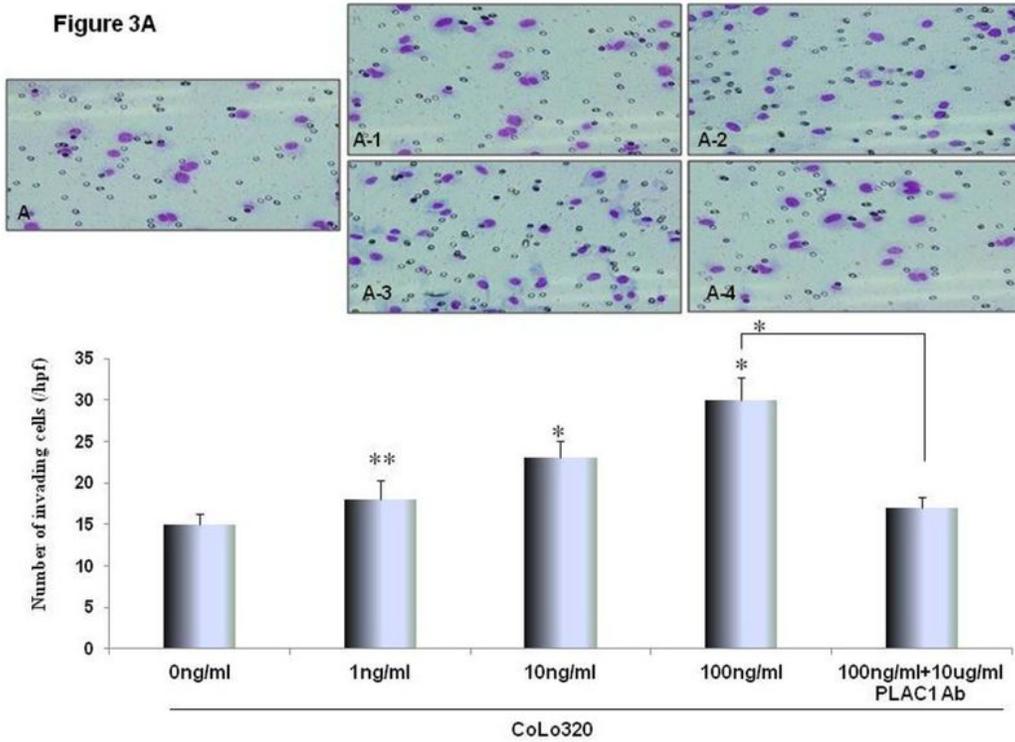
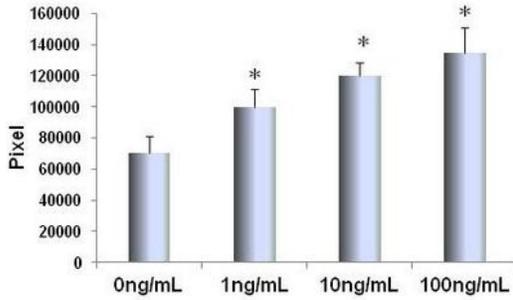
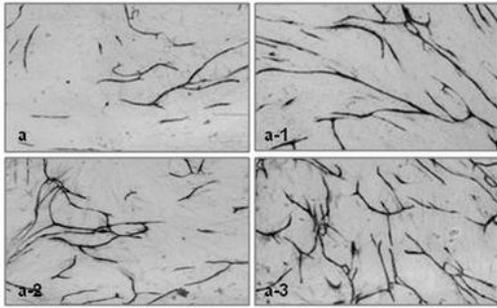
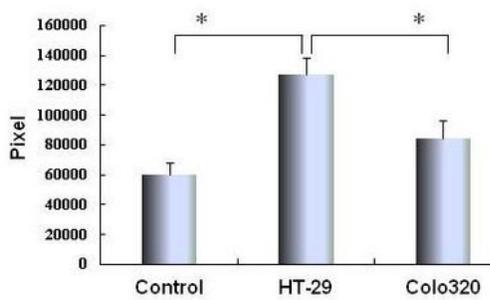
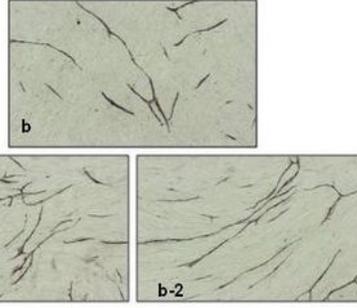
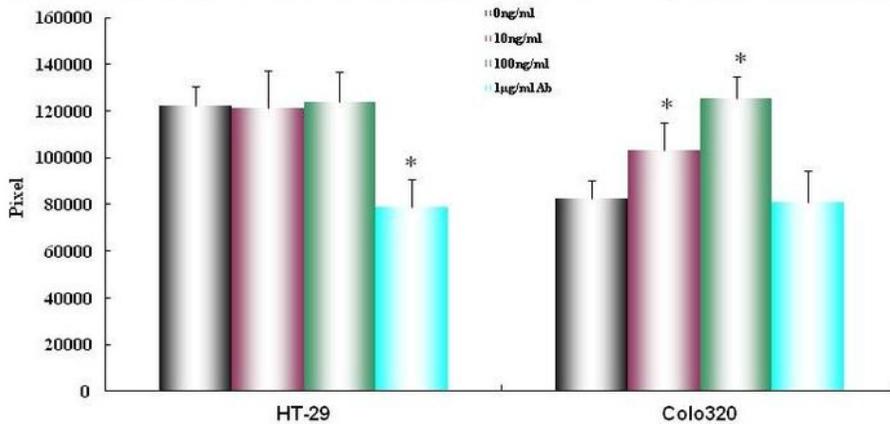
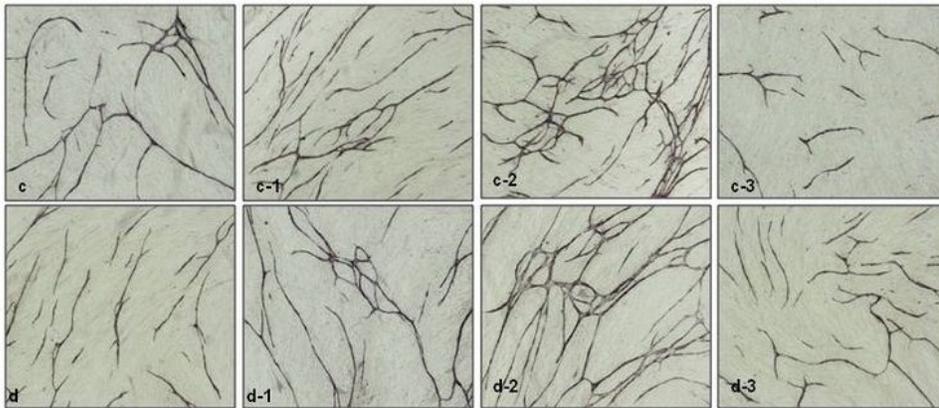


Figure 3

PLAC1 enhanced the invasiveness of colorectal cancers and HUVECs (A) The invasion of colorectal cancer cells treated with PLAC1 was assessed by the BD Bio-Coat Matrigel invasion assay. Colo320 cells were incubated for 24 h; the invading cells were fixed and stained with Diff-Quick stain. The invading cells were counted in five random microscopic fields ($\times 200$). The invasive ability of Colo320 cells was significantly promoted by PLAC1 compared with the control (** $P < 0.05$, * $P < 0.01$). A: 0 ng/ml of PLAC1; A-1: 1 ng/ml of PLAC1; A-2: 10 ng/ml of PLAC1; A-3: 100 ng/ml of PLAC1; A-4: 100 ng/ml of PLAC1+10 $\mu\text{g/ml}$ of anti PLAC1 antibody. Multiple comparisons used the method of one-way ANOVA followed by the SNK test. Columns, relative invading number. Bars indicate SD, * $P < 0.01$. (B) The invasive ability of HUVECs treated with PLAC1 was also measured by invasion assay. The invasiveness of HUVECs was significantly enhanced by PLAC1 compared with the control (* $P < 0.01$). B: 0 ng/ml of PLAC1; B-1: 1 ng/ml of PLAC1; B-2: 10 ng/ml of PLAC1; B-3: 100 ng/ml of PLAC1; B-4: 100 ng/ml of PLAC1+10 $\mu\text{g/ml}$ of anti-PLAC1 antibody. Multiple comparisons used the method of one-way ANOVA followed by the SNK test. Columns, relative invading number. Bars indicate SD, * $P < 0.01$.

Figure 4A**Figure 4B****Figure 4C****Figure 4**

The effect of PLAC1 and colorectal cancer cells on angiogenesis (A) Effect of PLAC1 pretreatment on tube formation. After incubation of HUVECs/fibroblasts in the presence of PLAC1 for 11 d, the tube formation was visualized with CD31 antibody staining. A: control; a-1: culture system treated with 1 ng/ml of PLAC1; a-2: culture system treated with 10 ng/ml PLAC1; a-3: culture system treated with 100 ng/ml PLAC1; GF (×200). The effect of PLAC1 on the tube formation area was measured quantitatively

using an image analyzer. Multiple comparisons were performed by one-way ANOVA followed by the Dunnett test. Bars indicate SD, * $P < 0.01$ compared with control. (B) Effect of different metastatic potentials of colorectal cancer cells on angiogenesis. HT-29 cells with higher liver metastatic potential or Colo320 cells with lower liver metastatic potential on angiogenesis and HUVEC/fibroblasts consisted of a coculture system using a double chamber. Angiogenesis was assessed after 11 d of coculture. The angiogenesis was visualized with CD31 antibody staining ($\times 200$). The angiogenesis was significantly enhanced by HT-29 cells compared with Colo320 cells. b: control; b-1: coculture with HT-29 cells; b-2: coculture with Colo320 cells. Multiple comparisons were performed by one-way ANOVA followed by an SNK test. Bars indicate SD, * $P < 0.01$ compared with control (coculture without colorectal cancer cells) and coculture with Colo320 cells. (C) The different metastatic potentials of colorectal cancer cells treated with PLAC1 or anti-PLAC1 antibody affected angiogenesis in the coculture system. HT-29 or Colo320 cells were pretreated with PLAC1 or anti-PLAC1 antibody and cocultured with HUVECs/fibroblasts. All cells were coincubated for 11 d, and angiogenesis was visualized with CD31 antibody staining ($\times 200$). PLAC1 enhanced angiogenesis in a dose-dependent manner in the Colo320 coculture system. However, anti-PLAC1 decreased angiogenesis in the HT-29 coculture system. c: coculture with HT-29 cells; c-1: coculture with HT-29 cells pretreated with 10 ng/ml PLAC1; c-2: coculture with HT-29 cells pretreated with 100 ng/ml PLAC1; c-3: coculture with HT-29 cells pretreated with 1 $\mu\text{g/ml}$ PLAC1; d: coculture with Colo320 cells; d-1: coculture with Colo320 cells pretreated with 10 ng/ml PLAC1; d-2: coculture with Colo320 cells pretreated with 100 ng/ml PLAC1; d-3: coculture with Colo320 cells pretreated with 1 $\mu\text{g/ml}$ PLAC1. Multiple comparisons were performed by the SNK test. * $P < 0.01$ compared with coculture colon cancer cells.

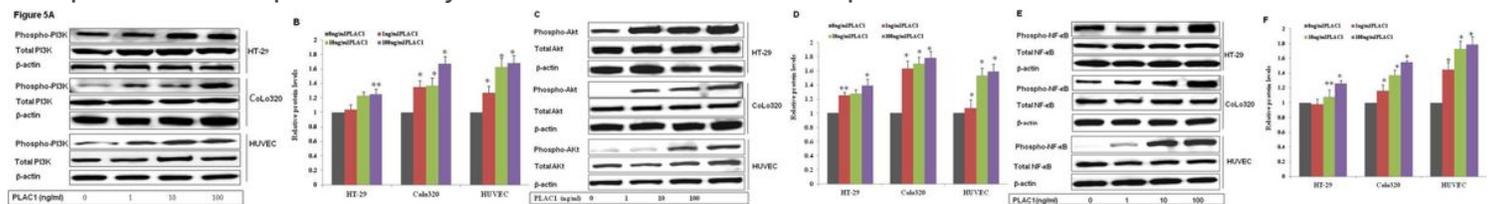
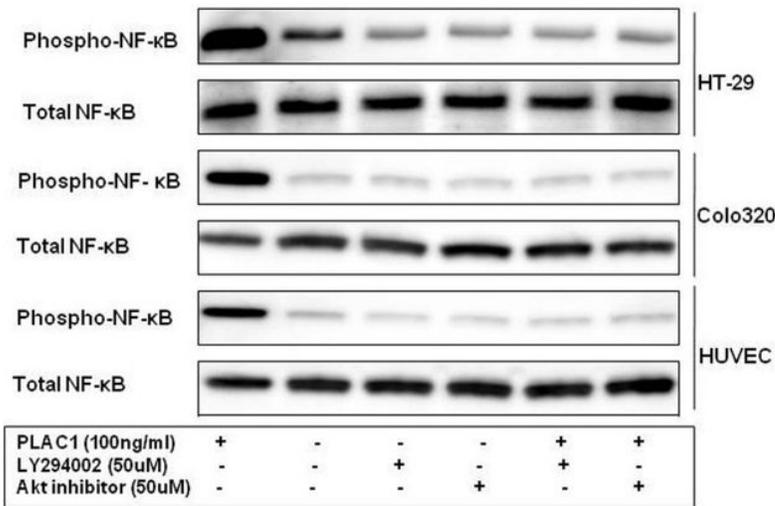


Figure 5

PLAC1-induced phosphorylation of PI3K, Akt and NF- κ B in human colorectal cancer cell lines and HUVECs HT-29, Colo320 cells and HUVECs were treated with different concentrations of PLAC1 (1 ng/ml, 10 ng/ml and 100 ng/ml) and cultured for 15 min. The cells were gathered and lysed by lysis buffer. Thirty micrograms of lysed protein was used for immunoblotting with a phospho-PI3K antibody (A, B), phospho-Akt antibody (C, D), and phospho-NF- κ B antibody (E, F). Detection of total PI3K levels served as a loading control.

Figure 6A



B

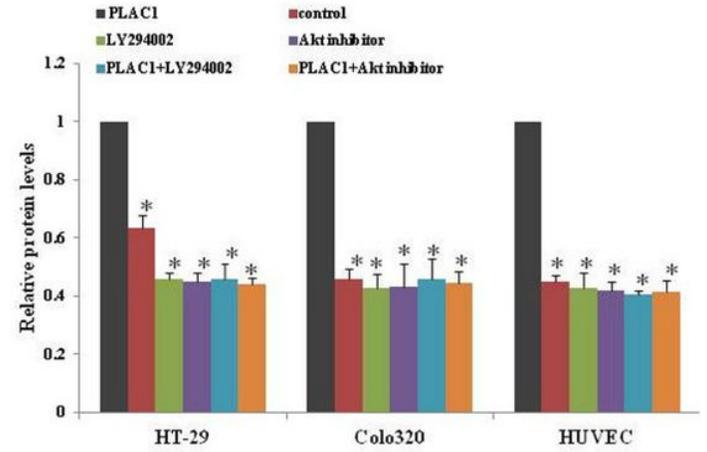


Figure 6

. Effect of Akt and PI3K inhibitor on PLAC1-induced phospho-NF-κB. HT-29, Colo320 cells and HUVECs, after being pretreated with 50 μM Akt inhibitor and 50 μM LY294002 for 1 hr, were incubated with 100 ng/ml PLAC1 for 30 mins. The cells were gathered and lysed by lysis buffer. Thirty micrograms of lysed protein was used for immunoblotting with a phospho-NF-κB antibody. Detection of total NF-κB levels served as a loading control.