

Targeting S100P Inhibits Colon Cancer Growth and Metastasis by Lentivirus-Mediated RNA Interference and Proteomic Analysis

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S100P was recently found to be overexpressed in a variety of cancers and is considered a potential target for cancer therapy, but the functional role or mechanism of action of S100P in colon cancer is not fully understood. In the present study, we knocked down the gene expression of S100P in colon cancer cells using lentivirus-mediated RNA interference. This step resulted in significant inhibition of cancer cell growth, migration and invasion *in vitro* and tumor growth and liver metastasis *in vivo*. Moreover, S100P downstream target proteins were identified by proteomic analysis in colon cancer DLD-1 cells with deletion of S100P. Knockdown of S100P led to downregulation of thioredoxin 1 and β -tubulin and upregulation of Rho guanosine diphosphate (GDP) dissociation inhibitor α (RhoGDI α), all potential therapeutic targets in cancer. Taken together, these findings suggest that S100P plays an important role in colon tumorigenesis and metastasis, and the comprehensive and comparative analyses of proteins associated with S100P could contribute to understanding the downstream signal cascade of S100P, leading to tumorigenesis and metastasis.

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INTRODUCTION

Colorectal cancer is one of the most common malignancies worldwide. Despite the improvement in its prognosis and therapy in the last few decades, nearly one-half of colorectal cancers relapse from metastasis after curative surgery (1). It is essential to develop new targets and therapeutic approaches, and therapeutic target development requires identification of novel functional molecules, their mechanisms of action and strategies for intervention (2). S100P is a 95-amino acid residue protein that is a member of the S100 family. The protein was first purified from placenta with a restricted cellular distribution (3). S100 proteins consist of Ca²⁺ binding proteins of

the elongation factor (EF)-hand type that mediate Ca²⁺-dependent signal transduction pathways involved in the regulation of a number of cellular processes such as cell cycle progression and differentiation (4). Overexpression of S100P was observed in various cancers, including pancreatic (5), breast (6), colon (7), prostate (8) and lung carcinomas (9). S100P was also reported to correlate with tumor growth and metastasis in breast (6,10,11), colon (12) and pancreatic (3) cancer. S100P ectopic expression in a non-metastatic rat mammary cell line caused a notable increase in local muscle invasion and a significant induction of metastasis in tumor-bearing animals (10). Gene transfer or extracellular addition of S100P

increased tumor growth and metastasis, and silencing of S100P resulted in the reduction of the tumor growth and secondary metastatic volume in models of pancreatic cancer (3). Extracellular S100P interacts with the receptor of advanced glycation end products (RAGE), which is associated with various cancers and stimulates Erk and nuclear factor (NF)- κ B activity (13). Overexpression of S100P in pancreatic cancer Panc-1 cells protects cancer cells against cell death induced by chemotherapeutic 5-fluorouracil (5-FU) (3) and leads to increased S100A6 and cathepsin D expression, both of which are involved in cellular invasion (14). S100P also appears to function to increase gastric cancer growth and invasion of the cancer cells (15). Despite recent advances in understanding the biology of S100P, the functional role or mechanism of action of S100P in colon cancer is poorly understood. Fuentes *et al.* (12) showed that S100P is specifically expressed in human colon cancer tissue but not in nor-

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mal colon tissue, and exogenous S100P increases colon cancer SW480 cell proliferation and cell migration *in vitro* and up-regulates Erk phosphorylation and NFκB activation. Thus, it appears that S100P is a potential therapeutic target for colon cancer.

In the present study, we investigated the functional role and molecular mechanisms of S100P activity in colon cancer. We found that knockdown of S100P expression by lentiviral vector-mediated RNA interference (RNAi) inhibited colon cancer cell growth, migration and invasion *in vitro*, as well as tumor growth and liver metastasis *in vivo*. Furthermore, thioredoxin 1 (trx-1), β-tubulin and Rho GDP dissociation inhibitor α (RhoGDIA) were identified as S100P downstream target proteins in colon cancer cells by proteomic analysis.

MATERIALS AND METHODS

Cell Culture

Colon cancer cell lines DLD-1 and SW620 were used for the present study. All cells were cultured in Dulbecco’s modified Eagle’s medium (DMEM) with 10% fetal bovine serum (Invitrogen, Carlsbad, CA, USA) supplemented with 100 U/mL penicillin and 100 μg/mL streptomycin at 37°C in a humidified 5% CO₂ incubator.

Lentiviral shRNA Vector Construction, Production and Transduction

Lenti-shRNA vector construction was done as previously described (16). Briefly, we synthesized DNA fragments containing GAC AGC ACA as the loop for short-hairpin RNA (shRNA) and cloned the shRNA targeting human S100P (5’-AAC TCA CTG AAG TCC ACC TGG GCA TCT CC-3’) into human U6 promoter-containing pBluescript SK(+) plasmid (pU6) after annealing. Then we subcloned the U6-shRNA cassettes into the lentiviral vector (16). A lentivirus carrying shRNA-targeting firefly luciferase (shLuc: 5’-TGC GCT GCT GGT GCC AAC CCT ATT CT-3’) was used as the control. Lentiviral packaging

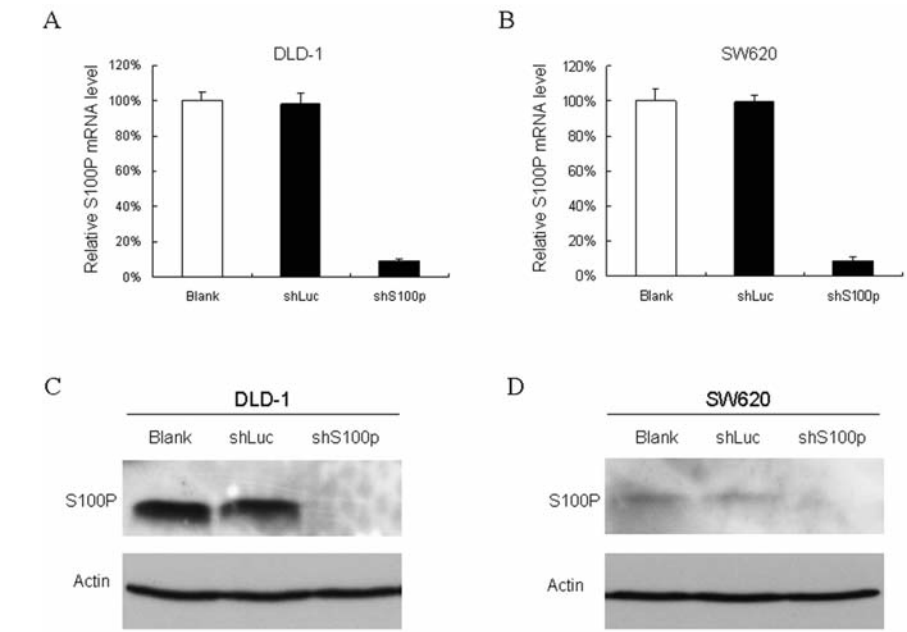


Figure 1. Efficient knockdown of S100P expression by lentiviral vector-mediated RNAi in DLD-1 and SW620 colon cancer cells lines. (A, B) Decreases in S100P mRNA level in DLD-1 and SW620 cells transduced with lenti-shS100P revealed by real-time RT-PCR. (C, D) Decreases in S100P protein levels in DLD-1 and SW620 cells transduced with lenti-shS100P revealed by Western blotting. shLuc, colon cancer cells transduced with lenti-shLuc; shS100P, colon cancer cells transduced with lenti-shS100P.

and transduction were carried out as previously described (16).

Reverse Transcription and Quantitative Real-Time Polymerase Chain Reaction

Total RNA was isolated using Trizol (Invitrogen), and cDNA synthesis was performed using a Superscript First-Strand Synthesis Kit (Promega, Madison, WI, USA) (17). The quantification of mRNA levels was carried out using SYBR® Green PCR Master Mix (Applied Biosystems, Warrington, UK; PCR, polymerase chain reaction) and an ABI 7500 Real-Time PCR System (Applied Biosystems). The following forward and reverse primers were used: S100P, 5’-ATG ACG GAA CTA GAG ACA GCC ATG GGC-3’ and 5’-GGA ATC TGT GAC ATC TCC AGG GCA TCA-3’ (12); GAPDH, 5’-CCA GCC GAG CCA CAT CGC TC-3’ and 5’-ATG AGC CCC AGC CTT CTC CAT-3’. The relative expression of S100P was normalized to that of GAPDH, an endogenous housekeeping gene.

Western Blot

The SDS-PAGE and Western blot analysis was performed as described (17). The primary antibodies used were polyclonal antibodies against S100P, β-tubulin, thioredoxin, RhoGDIA and actin (Santa Cruz Biotechnology, Santa Cruz, CA, USA).

Cell Proliferation and Colony Formation Assays

Cell proliferation was measured using a methylthiazolotetrazolium (MTT) assay (17). For colony formation assay, 5,000 cells in complete DMEM were seeded onto 10-cm culture dish and allowed to grow for 14 d to form colonies, which were then stained with coomassie blue. The rate of colony formation was calculated with the following equation: colony formation rate = (number of colonies/ number of seeded cells) × 100%.

Culture of Colon Cancer Cells in Three-Dimensional Collagen Gels

A total of 5,000 cells were collected and resuspended in a 2-mL solution

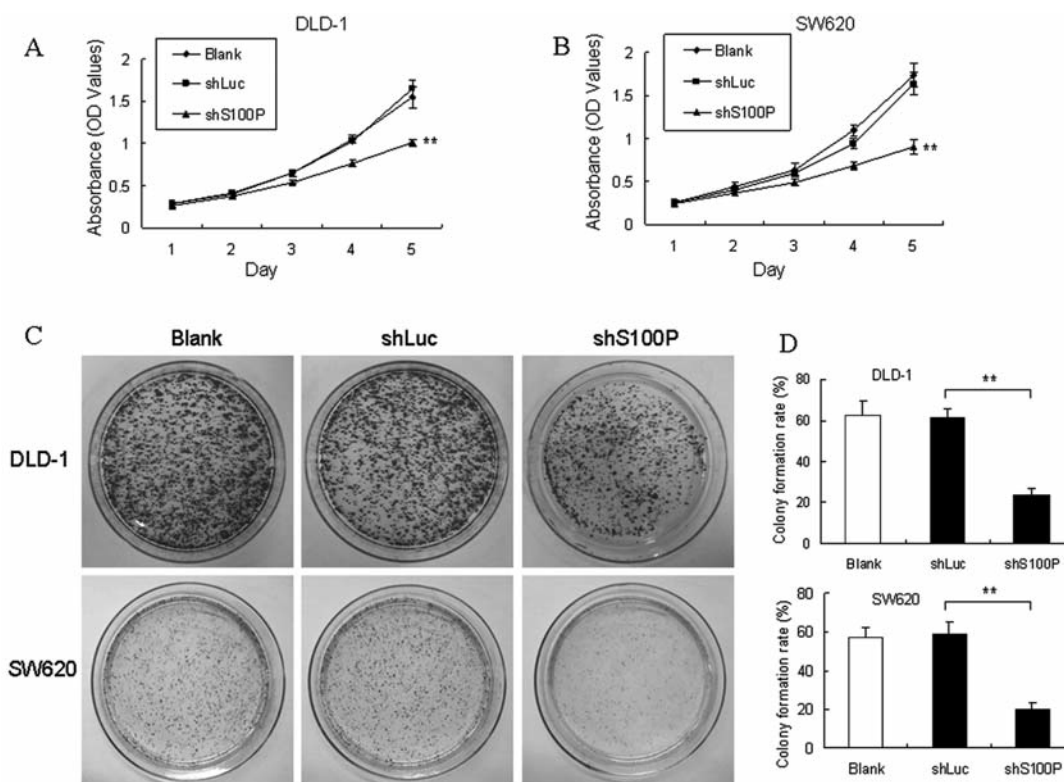


Figure 2. Knockdown of S100P by lentiviral vector-mediated RNAi inhibited colon cancer cell growth and colony formation. (A, B) S100P knockdown caused a significant growth inhibition of colon cancer cells as revealed by MTT assay. (C, D) S100P knockdown inhibited cancer cell colony formation; representative images from triplicate experiments were shown. shLuc versus blank: $P > 0.05$; shS100P versus shLuc: $**P < 0.01$. OD, optical density.

containing complete DMEM, rat tail collagen I (BD Biosciences, Franklin Lakes, NJ, USA), to support the growth of cells in a three-dimensional matrix (18). The solution was added into six-well plates and incubated for 30 min at 37°C until a homogenous gel was formed. The culture medium was added to the space surrounding collagen I gel embedded with cells and replenished every 2 d. After 14 d, results were observed and photographed. The number of spheroids was counted at 20 random fields with magnification of 40 \times .

Wound Healing and Cell Invasion Assays

A wound-healing assay was performed as described (14). Assayed cells (1×10^6) were seeded on a six-well plate and cultured for 24 h. A scratch was made on the cell monolayer with a

200- μ L pipette tip. The photographs were taken immediately and at 72 h after wounding. A 48-well Boyden chamber and polycarbonate membrane precoated with matrigel (BD Biosciences) with 10- μ m pores (Neuro Probe, Gaithersburg, MD, USA) was used to evaluate the cancer cell invasion ability (19). DMEM with 10% fetal bovine serum was added to the lower compartment as a chemoattractant. DLD-1 or SW620 (4×10^4) suspended in 50 μ L DMEM with 0.5% BSA was loaded onto the upper compartment of each chamber. After incubation in a humidified atmosphere of 5% CO₂ at 37°C for 13 h (DLD-1 cells) or 38 h (SW620 cells), the cells on the upper surface of the membrane were gently scraped off, and the cells on the bottom surface of the membrane were fixed with 4% paraformaldehyde and stained with hematoxylin. Images were captured using a microscope at a $\times 100$ magnification, and

invasion cells were counted in 10 random selected fields. All experiments were done in triplicate.

Tumor Growth and Liver Metastasis Model in Nude Mice

Six-week-old male athymic nude mice were purchased from the Animal House, Chinese University of Hong Kong. All experiments were approved by the Animal Experimental Ethics Committee of the Chinese University of Hong Kong. Nude mice were injected subcutaneously with 1×10^6 DLD-1 cells transduced with lenti-shLuc or lenti-shS100P. The volumes of tumors were monitored at the indicated times and calculated according to the formula: $0.5 \times \text{length} \times \text{width}^2$. *In vivo* liver metastatic capability of colorectal cancer cells was evaluated in athymic nude mice ($n = 10$ /each group) as described previously (20). Briefly, a small left ab-

dominal incision was made under sterile conditions and spleen was exteriorized. Control or S100P knockdown DLD-1 cells (1×10^6) in 0.1 mL PBS were injected into the spleen by means of a sterile tuberculin syringe and a 27-gauge needle. Ten minutes after the injection, a splenectomy was performed. The abdomen was closed with nylon sutures. After 6 wks, the animals were euthanized and liver metastases were examined.

Proteomic Analysis

The procedures were carried out as described previously (16,19). Briefly, for the first dimension, immobilized pH gradient (IPG) strips (13 cm, pH 4–7, nonlinear [NL]) were used according to the manufacturer’s instructions. The second dimension was run in 12.5% uniform sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE) gel for protein separation. Thereafter, the protein spots were visualized by silver staining. All gel images were digitalized using a scanner (GS-800 calibrated densitometer; Bio-Rad, Hercules, CA, USA) with the Quantity One software (Bio-Rad). All images were analyzed using PDQuest (version 8.0, Bio-Rad) for spot detection and quantification. Spots of interest were selected and excised from the gels for identification. Protein identification was achieved by matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) using a 4700 Proteomics Analyzer (TOF/TOF) (Applied Biosystems). Peptide mass mapping was carried out using the program MASCOT (Matrix Science, London, UK) against an NCBI nr database with a GPS explorer software (Applied Biosystems). Tryptic autolytic fragments and notable contamination were excluded from the peak lists before the database search.

Statistical Analysis

Data are expressed as mean \pm SD in this study. Statistical analysis was performed by using the independent samples *t* test (SPSS Inc., Chicago, IL, USA).

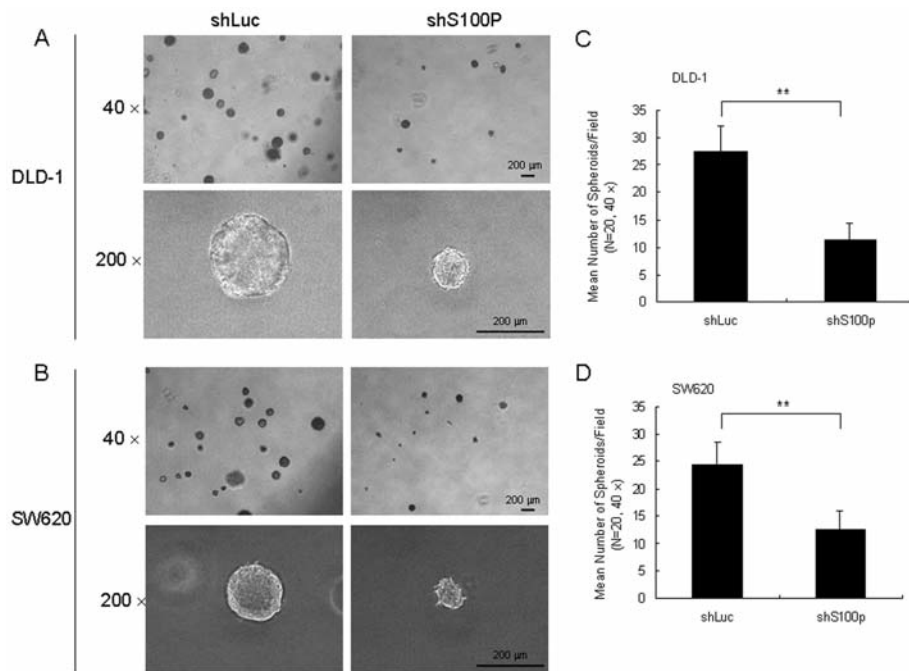


Figure 3. Knockdown of S100P inhibited colon cancer DLD-1 and SW620 cell growth in a three-dimensional culture model. (A, B) Phase contrast micrographs of DLD-1 and SW620 cell growth in a three-dimensional culture at a magnification of 40 or 200, scale bar = 200 μ m. Typical photographs were shown. (C, D) Mean number of spheroids/field was calculated (n = 20, 40x). Values are mean \pm SD. ***P* < 0.01.

P values <0.05 were considered statistically significant.

RESULTS

Efficient Knockdown of S100P Expression by Lentiviral Vector-Mediated RNAi in Colon Cancer Cells

To examine the effect of blocking S100P expression by lentiviral vector-mediated RNAi, real-time PCR and Western blot analysis were performed on DLD-1 and SW620 colon cancer cells. As shown in Figure 1A, S100P mRNA expression was reduced by 90% after lenti-shS100P infection in DLD-1 cells, but control lenti-shLuc did not alter S100P expression. The protein expression diminished to barely detectable levels in the DLD-1 cells infected with lenti-shS100P, compared with the cells infected with the control lenti-shLuc or the uninfected blank cells (Figure 1C). Similar data were achieved in SW620

cells after lenti-shS100P infection (Figure 1B, D).

RNAi-Mediated Knockdown of S100P Suppressed Colon Cancer Cell Proliferation In Vitro

As revealed by MTT assay, S100P knockdown significantly reduced cell proliferation of colon cancer DLD-1 and SW620 cells (Figure 2A, B). As shown in Figure 2C and D, DLD-1 and SW620 cells infected with lenti-shS100P showed significant reduction in the colony formation. No apparent difference was found between the parental cells and the control cells (which were infected with lenti-shLuc). Moreover, Figure 3A and B showed the images of colon cancer DLD-1 and SW620 cell growth in a three-dimensional culture model. There was a clear decrease in both the size and number of spheroids (Figure 3A and Figure 4D) in cells with lenti-shS100P compared with the control cells. These results indicate a positive correlation between

the expression of S100P and the rate of colon cancer cell growth.

Knockdown of S100P Inhibited Colon Cancer Cell Migration and Invasion *In Vitro*

The effect of S100P on colon cancer cell migration and invasion was investigated by using a monolayer wound healing and chamber assays. As shown in Figure 4A, DLD-1–shS100P cells after a wound scratch significantly inhibited the ratio of wound sealing compared with the control DLD-1–shLuc cells. In addition, knockdown of S100P inhibited colon cancer cell invasion through matrigel-coated membranes (Figure 4B).

RNAi Targeting S100P Inhibited Tumor Growth and Liver Metastasis of Colon Cancer *In Vivo*

Tumor formation was compared between DLD-1–shLuc and DLD-1–shS100P cells in nude mice. Cells were inoculated in nude mice, and tumor growth was measured after 6 wks. As shown in Figure 5A and B, tumor formation was observed in all mice inoculated with DLD-1–shLuc or DLD-1–shS100P cells, while knockdown of S100P in DLD-1 cells showed a decrease in the size of tumors when compared with its control counterpart (Figure 5A). Moreover, Figure 5C shows the macroscopic appearance of liver metastasis after intrasplenic injection of colon cancer DLD-1 cells into the athymic nude mice spleen. Some macroscopic nodules (that is, metastasis) were found at the liver surface 6 wks after injection with DLD-1–shLuc cells and in 5 of 10 mice with macroscopic nodules (50% liver metastasis), whereas no macroscopic nodule was found at the liver surface after injection with DLD-1–shS100P cells in spleen.

Proteomic Analysis of S100P Downstream Target Proteins in Colon Cancer Cells

Image analysis using the PDQuest two-dimensional software identified 30 protein spots that displayed differential expression among DLD-1 transduced

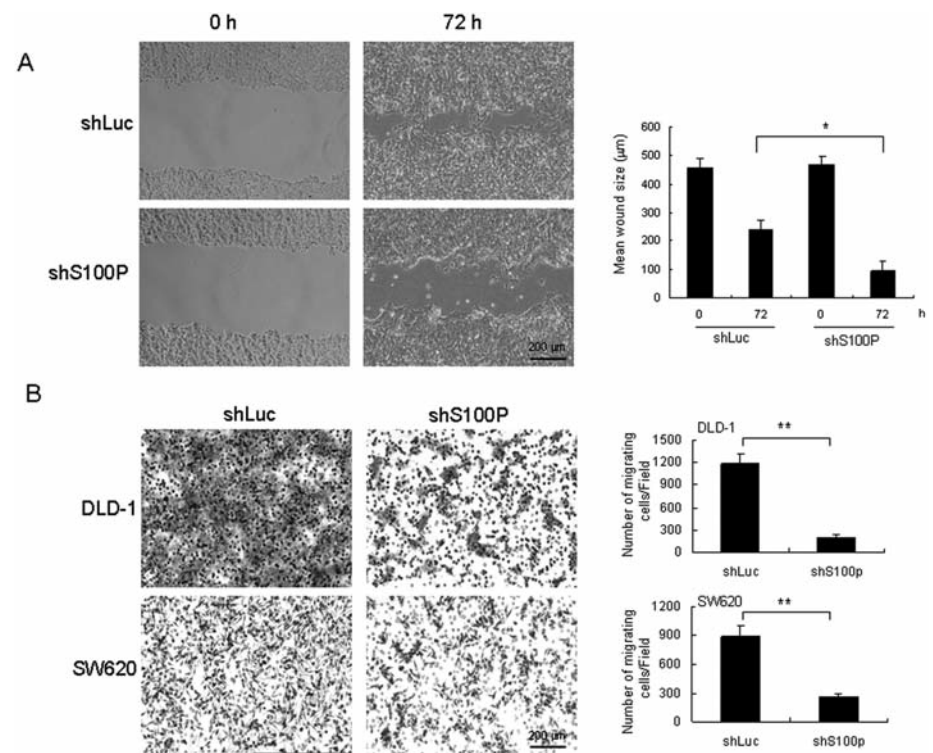


Figure 4. Knockdown of S100P by RNAi inhibited colon cancer cell migration and invasion *in vitro*. (A) Wound-healing assay showed DLD-1 cells transduced with lenti-shLuc or lenti-shS100P at 0 and 72 h after wounding. Bar chart showing the size of the wound at 0 and 72 h. (B) S100P knockdown inhibited cancer cell invasion in DLD-1 and SW620 cell lines. Representative images from triplicate experiments were shown. * $P < 0.05$, ** $P < 0.01$.

with lenti-shLuc and lenti-shS100P (Figure 6). Subsequently, each spot was analyzed and 24 S100P-associated proteins were identified by MALDI-TOF MS (Table 1). These proteins were all differentially expressed at least two-fold (either increased or decreased) when the comparison between the control and the S100P knockdown colon cancer DLD-1 cells was made. Of these, 15 were upregulated and 9 were downregulated. Among the 24 proteins, 3 with the most significant differential expression identified above were selected and further analyzed by Western blotting (Figure 6A, B). Consistent with two-dimensional gel electrophoresis (2-DE) and MALDI-TOF MS results, thioredoxin 1 and β -tubulin protein were significantly downregulated upon S100P-knockdown cancer cells. Additionally, higher expression protein level of RhoGDI A was found in the S100P-knockdown cells.

DISCUSSION

Recently, S100P proteins have become a major interest in cancer because they are overexpressed in a variety of tumors and their putative involvement in the metastatic process (2–4,21). An earlier report indicated that exogenous S100P increased colon cancer SW480 cell proliferation and cell migration *in vitro* (12). However, the role of S100P in tumorigenesis and metastasis of colon cancer *in vivo* and its molecular mechanisms have never been elucidated. In the current study, we suppressed S100P expression in colon cancer cells using lentiviral vector-mediated RNAi to determine its exact role in colon tumorigenesis and metastasis. Our group developed an efficient and convenient lenti-shRNA system that provided shRNA and fluorescent marker protein coexpression and allowed for easily identified transduced cells (16). Lentiviral infection has advan-

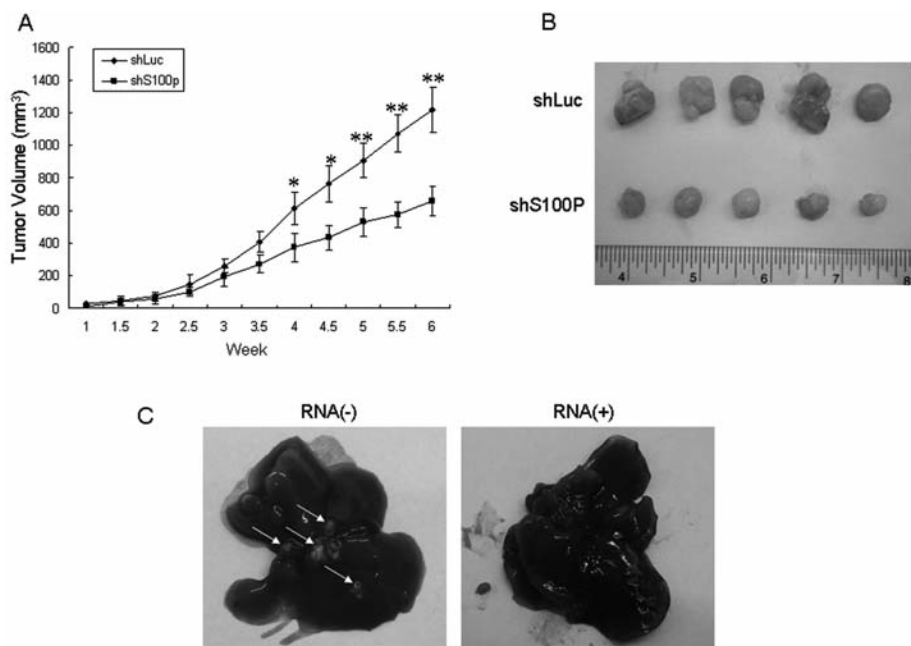


Figure 5. RNAi targeting S100P inhibited tumor growth and liver metastasis of colon cancer *in vivo*. (A) Knockdown of S100P inhibited tumor growth *in vivo*. * $P < 0.05$, ** $P < 0.01$. (B) Photographs of nude mice at 6 wks after inoculation with DLD-1 cells ($n = 5$). (C) Macroscopic appearances of liver metastasis. Suppression of S100P reduced liver metastases of colon cancer cells in the intrasplenic injection mice model ($n = 10$). Metastatic tumor nodules were identified as whitish and patchy areas (indicated by arrows). shLuc, DLD-1 colon cancer cells transduced with lenti-shLuc; shS100P, DLD-1 colon cancer cells transduced with lenti-shS100P.

tages over other gene-therapy methods. Lentivirus can infect both dividing and nondividing cells with high efficiency, achieve long-term stable expression of the transgene and have low immunogenicity. Lenti-shS100P was used to effectively knock down the expression of S100P in colon cancer cells. We observed a significant inhibition of cell growth by MTT, colony formation assay and the three-dimensional culture model *in vitro* when the expression of S100P was suppressed by RNAi in DLD-1 and SW620 cells. Also, knockdown of S100P drastically inhibited colon cancer cell migration and invasion *in vitro*, which is similar to its suggested role in pancreatic cancer (3). Furthermore, we used an *in vivo* animal model to explore the exact role of S100P in colon cancer tumorigenesis and liver metastasis. We observed a marked inhibition of colon cancer tumorigenicity and liver metastasis through knockdown of S100P expression in a nude mice model *in vivo*. These results indicated that S100P played a crucial role in the tumorigenesis and metastasis of colon cancer.

It is known that S100 proteins affect cell function by both intracellular and extracellular mechanisms (22). S100 proteins are also implicated in promoting cancer progression through specific roles in cell survival and apoptosis pathways (22). Recent studies have demonstrated that the actions of S100P are mediated by activation of RAGE in pancreatic and colon cancer cells (2,12,13). In the present study, proteomic analysis was used to identify S100P-associated downstream proteins in colon cancer cells. Among 24 differentially expressed spots, down-regulation of two proteins (trx-1 and β -tubulin) and upregulation of RhoGDIA were confirmed to be valid after Western blot analysis of DLD-1 cells with deletion of S100P.

Trx-1 is a ubiquitously expressed small redox protein that is a key regulator of cellular redox balance. Trx-1 acts as an antioxidant, growth-promoting, antiapoptotic and inflammation-modulating protein that provides reduc-

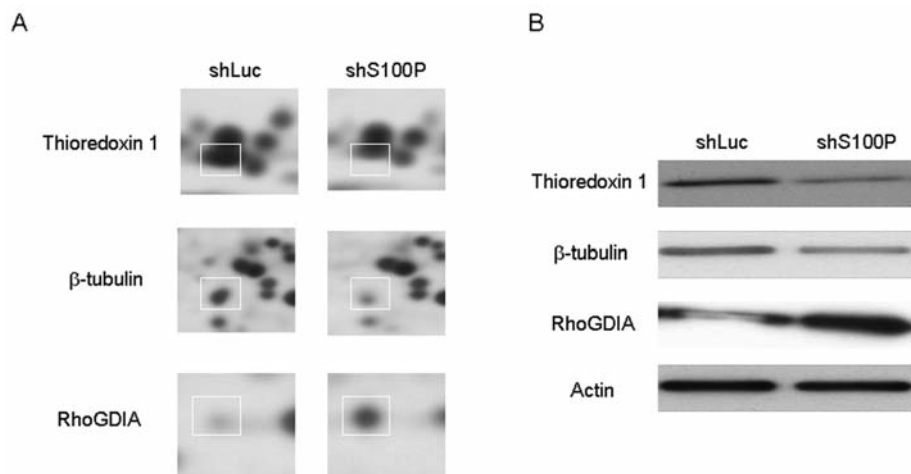


Figure 6. Differentially expressed protein spots among DLD-1 transduced with lenti-shLuc or lenti-shS100P. (A) Selected regions of 2-DE gels illustrate differentially expressed proteins among DLD-1 transduced with lenti-shLuc or lenti-shS100P. Enlarged images of interest spots were shown. (B) Confirmation of differential expression of thioredoxin 1, β -tubulin and RhoGDIA. Western blot analysis showed that thioredoxin 1, β -tubulin and RhoGDIA proteins were differentially expressed among DLD-1 transduced with lenti-shLuc or lenti-shS100P. Actin was used as an internal control.

Table 1. Differentially expressed proteins between control and S100P knockdown colon cancer cells were identified by MALDI-TOF MS.

Protein	Accession number	M_r/pI^a	Protein score
Laminin-binding protein	Gi 34234	31773.9/4.84	375
67-kDa laminin receptor	Gi 250127	32746.4/4.83	374
Thioredoxin	Gi 50592994	11729.7/4.82	167
Catechol-O-methyltransferase isoform S-COMT	Gi 6466450	24433.4/5.15	101
Eukaryotic translation elongation factor 1 delta isoform 2	Gi 25453472	31102.8/4.9	140
ATP synthase, H + transporting, mitochondrial F1 complex, β subunit precursor	Gi 32189394	56524.6/5.26	271
Ubiquilin 1 isoform 2	Gi 16753205	59182.8/5.01	181
Tubulin-specific chaperone α	Gi 4759212	12846.7/5.25	157
Tubulin, β	Gi 18088719	49639.9/4.75	231
Triosephosphate isomerase 1	Gi 4507645	26652.7/6.45	257
Tumor necrosis factor type 1 receptor-associated protein TRAP-1-human	Gi 1082886	75294.9/8.43	335
Phosphoglycerate mutase 1 (brain)	Gi 4505753	28785.8/6.67	242
Tumor protein, translationally controlled 1	Gi 4507669	19582.6/4.84	178
Rho GDP dissociation inhibitor (GDI) α	Gi 4757768	23192.7/5.02	97
Tumor protein, translationally controlled 1	Gi 4507669	19582.6/4.84	74
ATP synthase, H + transporting, mitochondrial F1 complex, α subunit 1, cardiac muscle	Gi 15030240	59771.6/9.07	190
Heterogeneous nuclear ribonucleoprotein K isoform α	Gi 14165437	50996.4/5.19	188
Chaperonin containing TCP1, subunit 5 (epsilon)	Gi 24307939	59632.8/5.45	511
NADH dehydrogenase (ubiquinone) Fe-S protein 1, 75 kDa (NADH-coenzyme Q reductase)	Gi 21411235	79388.5/5.8	351
RuvB-like 2	Gi 5730023	51124.6/5.49	328
T-complex protein 1 isoform α	Gi 57863257	60305.6/5.8	261
Aldehyde dehydrogenase 1B1 precursor	Gi 25777730	57213.2/6.55	375
SFN protein	Gi 16306737	24321.0/4.77	147
Protein disulfide isomerase-related protein 5	Gi 1710248	46170.2/4.95	345

^aMolecular mass/isoelectric point (M_r/pI).

ing equivalents and a transcriptional regulator (23). Trx-1 expression was reported to be increased in several human cancers, including lung (24,25), liver (26), pancreatic (27), colorectal (28,29) and gastric carcinoma (30). Increased trx-1 levels are associated with increased proliferation of tumor cells, inhibition of apoptosis, aggressive tumor growth and decreased patient survival (23). In human colorectal cancer, trx-1 overexpression is related to a poor prognosis in patients with liver metastases (28,29). Tubulin is the basic subunit of microtubules and the α,β tubulin dimer assembles forming microtubules. Microtubules are important cellular targets for anticancer therapy because of their key role in cell division, intracellular transport, maintenance of cell shape and cellular motility (31). Microtubule-targeting drugs such as taxanes and vinca alkaloids have been used successfully to treat a variety of cancers in the clinic

(32). Tubulin as an antitumor target continues to attract the attention of significant drug discovery and development (33). RhoGDIA is a small family of proteins that includes RhoGDIA, RhoGDIB and RhoGDIG. RhoGDIs regulate Rho subfamily GTPases including Rho, Rac and Cdc42, which are important molecular switches involved in the regulation of cytoskeletal structures that affect or enable the regulation of cell morphology, movement, attachment, phagocytosis and cytokinesis. Deregulation of RhoGDIA was observed in human lung (34), breast (35) and liver cancer (36). Also, RhoGDIA was considered a candidate metastasis suppressor for human hepatocellular carcinoma (HCC) (36), siRNA against RhoGDIA increased the motility and invasion of HCC cells and ectopic expression of RhoGDIA inhibited HCC cell migration and invasion.

In summary, the results of this study showed that suppression of S100P using

a lentivirus RNAi expression system could significantly inhibit colon cancer cell growth and metastasis *in vitro* and *in vivo*. In addition, knockdown of S100P decreased the level of trx-1 and β -tubulin and increased RhoGDIA expression, which might indicate the importance of these proteins in colon carcinogenesis via the S100P downstream pathway. These findings provided information that suggested new therapeutic targets for the treatment of colon cancer. However, further studies would be necessary to clarify their exact role in colon carcinogenesis and their applications in treating colon cancer.

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DISCLOSURE

The authors declare that they have no competing interests as defined by *Molecular Medicine*, or other interests that might be perceived to influence the results and discussion reported in this paper.

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