Targeting Galectin-1 in Carcinoma-Associated Fibroblasts Inhibits Oral Squamous Cell Carcinoma Metastasis by Downregulating MCP-1/CCL2 Expression

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Abstract

Purpose: Carcinoma-associated fibroblasts (CAFs) in tumor stroma play an important role in tumor progression and have been associated with a poor prognosis in oral squamous cell carcinoma (OSCC). However, how CAFs influence OSCC malignancy and whether normalizing CAFs inhibits cancer progression remain unclear.

Experimental Design: The relationship between the expression of Galectin-1 (Gal-1) and alpha-smooth muscle actin (α-SMA, a CAF marker) in OSCC patient samples and primary cultured CAFs was examined by quantitative real-time PCR, Western blotting, and immunofluorescence. To examine the effect of Gal-1 on CAF activation and CAF-mediated tumor invasion and migration in vitro, Gal-1 expression was knocked down by small hairpin RNA. Finally, cancer cells and CAFs were coimplanted into SCID mice to evaluate the effect of Gal-1 on CAF-modulated tumor progression in vivo.

Results: Gal-1 expression is positively associated with α-SMA in the stroma of OSCC specimens. Gal-1 knockdown decreases activated CAF characteristics, resulting in a decrease in α-SMA expression and extracellular matrix protein production. Notably, blocking Gal-1 expression significantly inhibits CAF-conditioned medium-induced tumor cell migration and invasion, possibly by reducing the production of monocyte chemotactic protein-1 (MCP-1/CCL2). MCP-1 induces the migration of OSCC cells by binding to the receptor CCR2; adding an MCP-1 antibody to CAF-conditioned medium that inhibits the interaction between MCP-1 and CCR2 abolishes migration. Finally, we found that Gal-1 knockdown in CAFs significantly reduces CAF-augmented tumor growth and metastasis in vivo.

Conclusions: Our findings demonstrate that Gal-1 regulates CAF activation and indicate that targeting Gal-1 in CAFs inhibits OSCC metastasis by modulating MCP-1 expression.

Introduction

Among carcinoma-associated stromal cells, fibroblasts are a critical component of tumor stroma (1). Fibroblasts that contribute to tumor stroma are also called carcinoma-associated fibroblasts (CAFs), myofibroblasts, or activated fibroblasts (2, 3). Myofibroblasts are differentiated fibroblasts that express alpha-smooth muscle actin (α-SMA) and produce extracellular matrix (ECM) proteins such as fibronectin and collagen, which promote wound healing (4). Clinical observations (1, 5) have documented that the accumulation of large amounts of myofibroblasts in tumor-associated stroma accelerates tumor progression and metastasis. Because current therapeutic approaches for advanced cancer are limited and often fail, targeting stromal cells may be an adjuvant therapy that can improve disease outcome.

Head and neck squamous cell carcinoma (HNSCC) is the 6th most common cancer in the world; it has a poor prognosis because of local metastasis and a high rate of recurrence (6). The presence of myofibroblasts in oral squamous cell carcinoma (OSCC) patients is correlated with tumor stage, metastasis, and a poor prognosis (7), suggesting that CAFs may be important in the progression of OSCC. Evidence also shows that the conditioned medium of CAFs increases cancer cell proliferation and invasion compared to normal fibroblasts in breast carcinoma and...
colon cancer (8, 9), suggesting that targeting CAFs could provide a feasible therapy for OSCC. Developing approaches to destroy or normalize CAFs has become an important issue in cancer therapy. For example, the genetic knockout of fibroblast-activated protein (FAP), a protein specifically expressed in myofibroblasts, significantly suppressed lung and colon tumor growth in mice (10). The monoclonal antibody against FAP, sibrotuzumab, has been investigated in a Phase I clinical trial (11). In addition, an inhibitor of collagen I synthesis, halofuginone, prevents fibroblast differentiation to myofibroblasts and significantly reduces tumor progression when combined with low-dose chemotherapy (12).

Galectin-1 (Gal-1) belongs to the β-galactoside-binding lectin family and behaves as a monomer of 14.5 kD that can dimerize under certain circumstances. Each monomer is composed of a carbohydrate-recognition domain that recognizes a wide range of glycoproteins and glycolipids (13). Gal-1 expression in cancer-associated stroma is correlated with poor survival in several types of cancer including breast, prostate, and head and neck cancers (14–17). We previously reported (18) that increased Gal-1 expression in cancer-associated stroma and the tumor-invasive front is significantly correlated with a poor prognosis in OSCC. However, whether Gal-1 affects tumor stroma cell homeostasis, especially in fibroblasts, is still unknown. In this study, we investigated whether Gal-1 affects CAF activation and whether targeting Gal-1 in CAFs could provide a feasible therapy for OSCC.

Materials and Methods

Patients and cell lines

Eighty-two OSCC patients from Chi-Mei Medical Center and National Cheng Kung University Medical Center, Tainan, Taiwan, participated in the study; all signed an informed consent form. The study protocols were approved by the institutional review boards of both hospitals. All patients were staged according to the American Joint Committee on Cancer (5th AJCC) 1997 cancer staging guidelines. The information of the 82 patients was listed in Supplementary Table S1. The cell lines (OC-2, OEC-M1, and HSC-3) information was described in our previous paper (19).

Primary culture of HGFs and CAFs

CAFs and normal human gingival fibroblasts (HGFs) were isolated from OSCC tumor tissues and their normal counterparts, as previously described (20). The normal counterparts were defined by the noncancerous region of oral tissue at least 2 cm away from the outer tumor margin. The isolated HGFs and CAFs were further characterized using Western blotting (Fig. 1C). Vimentin was strongly expressed in HGFs and CAFs, cytokeratin was not expressed, and α-SMA was strongly expressed in CAFs but not in HGFs. All HGFs and CAFs used in the experiments were less than 10 passages.

Cell invasion and migration assay

Cell invasion and migration assays were done in 24-well Transwell polycarbonate filters (pore size, 8 μm; Corning Costar) coated with or without Matrigel (BD Biosciences) as previously described (19). Briefly, OSCC cells were plated in the upper chamber, and the conditioned media of HGFs, CAFs, CAF sh-Luc cells, or CAF sh-Gal-1 cells were added to the lower chamber. The invaded and migrated cells were counted after the cells had been individually incubated for 24 and 8 hours. Nonpenetrating cells were removed from the upper surface of the filter with a cotton swab. Penetrating cells were fixed and stained with a DiffQuick stain kit (Dade Behring, Inc.) according to the manufacturer's instructions. For quantification, all of the cells invaded or migrated into the lower surface were stained and counted under a light microscope. All of the experiments were performed in triplicate. Results show the mean ± SD of 3 independent assays.

Quantitative real-time PCR

Total RNA was isolated using a Trizol reagent (Invitrogen Corp.), and then 1 μg was reverse transcribed (ImProm-II Reverse Transcriptase; Promega). Quantitative real-time PCR (qRT-PCR) was used to analyze the expression of different mRNAs, as previously described (21, 22). Briefly, PCR amplifications were performed with SYBR Green PCR Master Mix on a LightCycler 480 real-time PCR detection system (Roche Applied Science). The qRT-PCR was performed as follows: initial denaturation at 95°C for 10 minutes, and 45 cycles of denaturation at 95°C for 15 seconds, annealing at 60°C for 10 seconds, and extension at 72°C for 10 seconds. Delta-cycle threshold (ΔCt) values were calculated by subtracting the CT value from the corresponding β2-microglobulin CT (internal control) value for each sample. The relative expression level of individual genes was calculated by comparing the ACT values of Gal-1 knockdown cells to those of the control groups and were shown in folds changed.

shRNA lentivirus production

Lentiviral vectors containing luciferase, Gal-1, and CCR2 small hairpin (sh) RNA were obtained from the National RNAi Core Facility (Academia Sinica) and prepared in accordance with standard protocols. Briefly, 3 × 10⁶ 293T cells were seeded in a 10-cm dish. After 24-hour incubation, cells were cotransfected with 5 μg pLKO.1.shRNA, 5 μg pCMVΔR8.91, and 0.5 μg pMD.G plasmids by Lipofectamine 2000 (Invitrogen). After transfection, we changed the medium to remove transfection reagents and virus was collected 48 hours later and filtered through 0.45 μm filters. Cells were infected with lentivirus (multiplicity of infection 5) in the presence of polybrene (8 μg/ml). Forty-eight hours postinfection, the cells were treated with 1 μg/ml of puromycin to select puromycin-resistant clones. The shRNA target sequences were: for CCR2: 5′-GCT GCA AAT GAG TGG GTC TTT-3′, and for Gal-1: G1: 5′-GCT GCC AGA TGG ATA CTA AT-3′ and G2: 5′-CGC TAA GAG CTT CGT GCT GAA-3′.
Immunohistochemical analysis
The immunohistochemical analysis was performed as previous described (21).

Immunofluorescence staining
Cells were seeded on the cover slides, incubated for 24 hours, washed twice with PBS, and then fixed on ice in 3.7% paraformaldehyde for 20 minutes. After they had been washed 3 more times with PBS, the cells were permeabilized on ice in 0.05% Triton X-100 for 5 minutes, washed once more with PBS, and then incubated with α-SMA antibody (MCA1906; Serotec) for 2 hours at room temperature. The cells were then washed and incubated with fluorescein isothiocyanate (FITC)-conjugated secondary antibodies. The α-SMA expression was visualized using a fluorescence microscopy.

Coinjecting mice with OSCC cells and CAFs to measure tumor progression
The animal experiment protocols were approved by the National Cheng Kung University Animal Center ethical committee. Briefly, $1 \times 10^5$ OC-2 (an OSCC cell line) cells and $3 \times 10^5$ CAFsh-Luc cells or CAFsh-Gal-1 cells were mixed with Matrigel and subcutaneously (s.c.) coinjected into SCID mice. Tumor size was measured using calipers, and the tumor volume was calculated using the following equation: $\text{tumor volume} = \frac{\text{length} \times \text{width} \times \text{width}}{2} \times 0.45$. Tumor metastasis was quantitatively determined by measuring the cancer cells in circulation, as previously described (20). For the detecting circulating cancer cells in mice, peripheral blood samples from mice were collected in heparinized microhematocrit tubes (Assistent). The genomic DNA was extracted using a kit (QIAamp Mini DNA kit; Qiagen). PCR was used to measure the level of circulating tumor cells for the human Alu sequence (23). The PCR results were quantified using ImageJ software, and the relative amount of circulating tumor cells was calculated by dividing the PCR results by those from control mice that had not been implanted with tumor cells.

Cytokine array analysis
The cytokines secreted from HGFs, CAFs, CAFsh-Luc cells, and CAFsh-Gal-1 cells were analyzed using a kit.
Gal-1 overexpression is associated with fibroblast activation

To determine whether Gal-1 expression is associated with CAFs, we first investigated the localization of Gal-1 and α-SMA in clinical OSCC samples. Gal-1 colocalizes with fibronectin, α-SMA, and Gal-1 expression. C, collagen I, fibroblast activation protein (FAP), α-SMA, and fibronectin (FN) mRNA expression is reduced in sh-Gal-1 CAFs compared with sh-Luc CAFs. Gene expression was analyzed by qRT-PCR. The relative expression levels of individual genes were calculated by comparing the ΔCT values of sh-Gal-1 CAFs to those of sh-Luc CAFs and are shown in folds changed. D (top), silencing Gal-1 disrupts stress-fiber formation of α-SMA in CAFs. Left, sh-Luc lentivirus stably transduced CAFs. Right, sh-Gal-1 lentivirus stably transduced CAFs. Cells were seeded on slides coated with poly-l-lysine, and immunofluorescence staining was used to visualize the distribution of α-SMA, as described in the Materials and Methods (α-SMA antibody: Cat. MCA1906; Serotec, Oxford, UK). Bottom, Gal-1 knockdown in CAFs reduces the number of α-SMA-positive cells. We counted α-SMA-positive cells and DAPI-positive cells in 9 different fields from sh-Luc and sh-Gal-1 groups. The data were calculated by dividing the number of α-SMA-positive cells by the number of DAPI-stained cells and shown in percentage of α-SMA-stained cells. ***, P < 0.001.

Statistical analysis

The association between Gal-1 and α-SMA expression was analyzed using Fisher’s exact test (Prism 5; Graphpad Software, Inc.). The other experiments were assessed using an unpaired Student’s t test or 1-way ANOVA, and shown as mean ± SD. Statistical significance was set at P < 0.05.
Fig. 2A), which indicates a dominant role for Gal-1 in CAFs. The data in Figure 1 show that Gal-1 expression closely correlates with CAF activation and suggests that Gal-1 may regulate CAF homeostasis.

**Gal-1 modulates fibroblasts transdifferentiation to myofibroblasts**

Because CAFs promote tumor invasion and migration through paracrine stimulation (1), we investigated whether silencing Gal-1 inhibits CAF-augmented tumor cell invasion and migration. HGFs and CAFs were infected with lentivirus carrying luciferase shRNA (shLuc) or Gal-1 shRNA (shGal-1). The conditioned medium was collected as a chemoattractant. Cell migration and invasion assays were performed as described in the Materials and Methods. All of the experiments were performed in triplicate. Results show the mean ± SD of 3 independent assays. *P < 0.05, **P < 0.01, and ***P < 0.001.

with α-SMA in spindle-like cells (Figs. 1A and S1), suggesting that Gal-1 overexpression might be associated with CAF activation. To verify the correlation of Gal-1 and α-SMA expression, we used qRT-PCR. Eighty percent of the tumors with high Gal-1 expression had high α-SMA expression, and 63% of the tumors with low Gal-1 expression had low α-SMA expression (Fig. 1B, P < 0.0001). To further examine this correlation, we directly isolated CAFs and HGFs from 2 OSCC tissue samples. The absence of Pan-CK expression in HGFs and CAFs indicated that the samples were not contaminated by epithelial cells. Vimentin (a fibroblast marker) is strongly expressed in HGFs and CAFs. Both Gal-1 and α-SMA expression are higher in CAFs than in paired HGFs (Fig. 1C), which is consistent with the results shown in Figure 1B. To rule out the possibility that Gal-1 and α-SMA were expressed in cancer cells, we analyzed Gal-1 and α-SMA mRNA expression both in the OSCC cell lines and in CAFs. Both Gal-1 and α-SMA expression levels in CAFs were at least 10 times higher than in OSCC cells (Fig. S2), which indicates a dominant role for Gal-1 in CAFs. The data in Figure 1 show that Gal-1 expression closely correlates with CAF activation and suggests that Gal-1 may regulate CAF homeostasis.

**Targeting Gal-1 suppresses CAF-augmented cancer cell invasion and migration**

Because CAFs promote tumor invasion and migration through paracrine stimulation (1), we investigated whether silencing Gal-1 inhibits CAF-augmented tumor cell invasion and migration. HGFs and CAFs were infected with lentivirus containing luciferase- or Gal-1-shRNA. The conditioned media were collected as chemoattractants for the migration and invasion chamber assays. CAF-conditioned medium (CAF-CM) induced more OEC-M1 cell migration and invasion than HGF-CM (Fig. 3A and B, lane 1 vs. lane 2); however, Gal-1 knockdown almost abolished CAF-CM–induced cancer cell invasion and migration (Fig. 3A and B, lane 2 vs. lane 3). Furthermore, the same assays performed in HSC-3 cells, another OSCC cell line, yielded similar results (Fig. 3C and D). These data imply that Gal-1 might regulate CAF-induced OSCC cell invasion and migration by affecting the secretion and production of chemotactic proteins.

**Gal-1 regulates CAF-augmented tumor cell invasion and migration by increasing MCP-1/CCL2 expression**

Because cytokines secreted from stromal cells influence cancer cell invasion and migration in many types of cancer (1), we examined the secretion of cytokines in the conditioned media of HGFs and CAFs (CAF-CM and HGF-CM) using cytokine array analyses. The secretion levels of several cytokines are higher in CAF-CM than in HGF-CM (Fig. 4A); in particular, MCP-1 expression is 14 times higher (Fig. 4A). Surprisingly, when we compared cytokine
expression in the conditioned media of CAFs with and without Gal-1 expression, MCP-1 expression was strongly down-regulated in CAF sh-Gal-1 CM than in CAF sh-Luc CM (Fig. 4B), which was confirmed by Western blotting and ELISA assays in other primary culture CAFs (Figs. 4C and S3). These results suggest that MCP-1 may be a critical regulator in CAF-mediated tumor invasion and metastasis and that it is an important target of Gal-1.

MCP-1 was originally identified as a chemotactic protein for monocytes and macrophages, but its effect on OSCC cell migration and invasion is not clear. Therefore, we determined whether MCP-1 induces OSCC cell migration
by treating cells with recombinant MCP-1 protein. MCP-1 treatment significantly increased tumor cell migration in a dose-dependent manner (Fig. 5A). We next examined whether MCP-1 is a critical regulator in CAF-mediated tumor invasion and metastasis. Adding an anti-MCP-1 inhibitory antibody in CAF-CM inhibited cancer cell migration but not in HGF-CM (Fig. 5B), suggesting a pivotal role for MCP-1 in tumor–stroma interaction.

To determine whether Gal-1 regulates CAF-CM–induced cell migration by modulating MCP-1 expression, we treated CAF sh-Luc CM and CAF sh-Gal-1 CM with MCP-1 inhibitory antibody. This treatment reduced CAF sh-Luc CM-induced cell migration but had no effect on sh-Gal-1 CM-induced cell migration (Fig. 5C). Because MCP-1 induces signal transduction primarily by binding to CCR2, we investigated the effect of MCP-1 on cancer cell migration by knocking down CCR2. The knockdown efficiency in OEC-M1 cells was about 80% (Fig. S4). Down-regulating CCR2 inhibited CAF sh-Luc CM-induced cell migration but did not affect CAF sh-Gal-1 CM-induced cell migration (Fig. 5D). These results show that Gal-1 modulates MCP-1 expression in CAFs, which promotes cancer cell migration by interacting with CCR2.

Gal-1 knockdown in CAFs inhibits OSCC progression in vivo

To determine whether targeting Gal-1 in CAFs efficiently inhibits cancer progression and metastasis in vivo, we mixed the CAFs (infected with sh-Luc or sh-Gal-1 shRNA lentivirus) and OC-2 cells in a 3:1 ratio and injected (s.c.) the mixtures into SCID mice as previously reported (8). Tumors were visible as early as 20 days postinjection in the CAFs (sh-Luc) mixed with OC-2 cells; however, it took 30 days for injections of OC-2 cells alone to generate tumors (Fig. 6A). CAFs (sh-Luc) mixed with OC-2 cells also generated larger tumors than OC-2 cells alone (Fig. 6A). Notably, we found that Gal-1 knockdown in CAFs significantly inhibited CAF-promoted tumor growth (Fig. 6A). Circulating tumor cells have been reported as a prognostic factor for distant metastases and survival in
cancer patients (24, 25). In this study, we found that OC-2 cells mixed with sh-Gal-1-transduced CAFs resulted in fewer cancer cells in circulation than OC-2 cells mixed with CAFs (sh-Luc), and Group-3 mice were injected with OC-2 mixed with CAFs (sh-Gal-1). Tumor size was measured as described in the Materials and Methods; **, P < 0.01. B, Group-3 (n = 4) and Group-1 (n = 5) mice had fewer circulating cancer cells than did Group-2 mice (n = 5). The index shows the relative amount of circulating tumor cells measured 42 days after tumor inoculation and was calculated as described in the Materials and Methods; *, P < 0.05.

C, Group-2 mice died earlier than Group-1 and -3 mice. The survival curve was computed using the Kaplan-Meier product-limit method. The log-rank test was used to compare the survival curves. D, a summary of how Gal-1 activates stromal fibroblasts and promotes cancer metastasis.

Discussion

In this study, we demonstrated that Gal-1 plays a critical role in stimulating the transdifferentiation of fibroblasts to myofibroblasts and increases MCP-1 secretion, which promotes tumor progression and metastasis by interacting with CCR2 on cancer cells (Fig. 6D). Silencing Gal-1 in CAFs suppresses CAF-augmented tumor cell migration and invasion in vitro as well as tumor formation and intravasation in vivo, which suggests that targeting Gal-1 in CAFs may provide a viable antimetastasis strategy. Our findings also suggest that targeting Gal-1 in CAFs may be more efficient in advanced-stage cancer because myofibroblast accumulation in tumor stroma is often associated with late-stage cancer (7).

There are no published studies on the role of Gal-1 in CAFs extracted from clinical tissues. Our results show that the knockdown of Gal-1 reverses activated CAFs to quiescent fibroblasts and highlight the role of Gal-1 in CAF homeostasis. Notably, we found that Gal-1 expression is...
Closely correlated with CAF activation in clinical oral cancers, Gal-1 overexpression has also been shown to correlate with hepatic and pancreatic stellate cell (a quiescent fibroblast) activation (26, 27) in fibrosis tissues, which indicates that the level of Gal-1 expression in fibroblasts controls the progression of fibrosis and cancer. A recent study showed that targeting lysyl oxidase-like-2 (LOXL2), an enzyme that promotes the cross-linking of fibrillar collagen I, inhibited liver and lung fibrosis as well as cancer metastasis (28), suggesting that targeting Gal-1 may be effective both in the diseases of fibrosis and cancer metastasis. Although it remains unclear whether myofibroblasts in cancer-associated stroma are similar to those in fibrosis tissue, the data suggest that agents targeting fibrosis may inhibit cancer metastasis.

It is not clear how Gal-1 regulates myofibroblast activation, but significant evidence has shown that reactive oxygen species (ROS)-induced oxidative stress is related to myofibroblast transdifferentiation (29–31); the superoxide-producing enzyme, NADPH oxidase-4 (NOX4), is up-regulated in myofibroblasts, and the knockout of NOX4 in mice attenuates bleomycin-induced pulmonary fibrosis (30, 32). It has also been shown that Gal-1 activates neutrophil NADPH oxidase (33), suggesting that Gal-1 may control myofibroblast activation by modulating NOX4 expression. Conversely, Gal-1 could be the downstream mediator of factors that induce myofibroblast transdifferentiation such as transforming growth factor (TGF-β1; ref. 34), endothelin-1 (ET-1; ref. 35), and platelet-derived growth factor (PDGF; ref. 34). However, we did not observe a change in Gal-1 expression upon TGF-β1 or endothelin-1 treatment (Fig. S5), indicating that Gal-1 may be regulated by other factors. For example, PDGF-induced myofibroblast transdifferentiation was associated with Gal-1 upregulation (34).

It has been reported that MCP-1 promotes cancer progression by indirectly recruiting monocytes or macrophages to tumor sites (36, 37); however, its direct function in cancer cell invasion and migration is not clear in OSCC. We found that MCP-1 secreted by CAFs promoted OSCC cell invasion and migration by binding to its receptor, CCR2, indicating a direct effect of MCP-1 on tumor malignancy. Recent studies (38, 39) showing that MCP-1, which is up-regulated in the stroma of prostate cancer (16–18); (c) the downstream target gene, MCP-1, which is up-regulated in the stroma of prostate and breast cancer, is associated with more advanced cancer stages and poor disease survival (36, 44, 45); (d) it has been reported that Gal-1 directly induces MCP-1 production in pancreatic stellate cells (27, 46).

Taken together, these facts support the hypothesis that targeting Gal-1 in CAFs inhibits tumor progression and metastasis by downregulating MCP-1 expression. Therefore, developing agents, such as siRNAs or anginex (47), that target Gal-1 in CAFs may open a new avenue in cancer therapy.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Acknowledgments

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References


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