Galanin Receptor Subtype 2 Suppresses Cell Proliferation and Induces Apoptosis in \( p53 \) Mutant Head and Neck Cancer Cells

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Abstract

Purpose: Galanin and its receptors (GALR1-3) are expressed in many normal tissues, but silenced in some tumors. Contradictory roles for galanin and its receptors in various tumors have been reported. To understand their function, investigations of individual galanin receptors are necessary. In head and neck squamous carcinoma cells (HNSCC) with silenced GALR1 and GALR2, we showed that reexpressed GALR1 suppresses tumor cell proliferation via Erk1/2-mediated effects on cdk inhibitors and cyclin D1. Others showed that GALR2 could induce apoptosis in neuroblastoma cells with wild-type \( p53 \), whereas GALR2 stimulated proliferation in small cell lung cancer. In this study, we investigated the role of GALR2 in HNSCC cells that have mutant \( p53 \) and do not express GALR1.

Experimental Design: UM-SCC-1, a human oral carcinoma cell line with a splice site mutation causing a 46-bp \( p53 \) off-frame deletion, was stably transfected to express GALR2 (UM-SCC-1-GALR2).

Results: Galanin treatment of UM-SCC-1-GALR2 caused morphologic changes and a marked decrease in cell number that were not observed in UM-SCC-1-mock cells. Galanin and GALR2 resulted in decreased bromodeoxyuridine incorporation, \( p27^{kip1} \) and \( p57^{kip2} \) up-regulation, and decrease in cell number that were not observed in UM-SCC-1-mock cells. Galanin and GALR2 also induced caspase-3-dependent apoptosis, which was confirmed by Annexin-V staining and DNA fragmentation analysis. These were not observed with GALR1.

Conclusion: This study shows that GALR2 reexpression can inhibit cell proliferation and induce apoptosis in HNSCC cells with mutant \( p53 \). GALR2 may be a feasible target for HNSCC therapy.

Patients with advanced head and neck squamous cell carcinoma (HNSCC) have poor prognosis even when aggressive treatments are used (1). Current progress in molecular biology should make it possible to create new strategies for cancer, such as molecular targeting therapy. Approximately 30% of all pharmaceuticals on the market today exert their therapeutic effect by interacting with a G-protein coupled receptor (GPCR). GPCRs control a wide array of signaling pathways in all tissues of the body, and we are only just beginning to understand the full range of their effects (2). Galanin, a 30-amino-acid peptide, and its receptors, GALR1, GALR2, and GALR3, are members of the GPCR superfamily and are variably expressed in many normal tissues, including squamous epithelium, and some tumors, such as glioblastoma, neuroblastoma, small cell lung cancer, and head and neck cancer (3–6). Reports of the effects of galanin signaling in tumors vary with tumor type. Seufferlein et al. (7) reported that galanin has mitogenic effects in small cell lung carcinoma, whereas, Ishii et al. (8) reported that galanin inhibits pancreatic carcinogenesis. One reason for these conflicting results is lack of knowledge about the effects of individual galanin receptors in cancer cells. To better understand galanin function, studies of individual galanin receptors are needed. Our previous findings indicated galanin and its receptors are likely to act as tumor suppressors in HNSCC because expression of the receptors is frequently silenced by loss of heterozygosity and promoter hypermethylation (9–11). Using cells that lack endogenous GALR1 expression, we showed that in cells expressing exogenous GALR1, galanin stimulation suppressed cell proliferation, consequent to the extracellular signal-regulated kinase (Erk) pathway, suggesting that this receptor is a likely tumor suppressor (6). Berger et al. (4) reported that exogenous expression of GALR2 inhibited cell proliferation and induced apoptosis in neuroblastoma. Furthermore, like GALR1, GALR2 is frequently silenced by methylation and deacetylation in HNSCC.5 To further explore

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Grant support: NIH NCI through the University of Michigan’s Cancer Center Support Grant (5P30 CA46592), Head and Neck SPORE grant (1 P50 CA97248), and a Grant-in-Aid for Scientific Research (No. 20592027) from the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

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how galanin and GALR2 function in HNSCC, we stably transfected hemagglutinin (HA)-tagged GALR2 into UM-SCC-1, a HNSCC cell line in which both GALR1 and GALR2 are silenced by methylation.5 In the present study, we showed that galanin and GALR2 induce apoptosis and inhibition of cell proliferation and incorporation of bromodeoxyuridine (BrdUrd) in HNSCC cells with mutant p53. These findings suggest that GALR2 is a potential target gene for molecular therapy in HNSCC.

Materials and Methods

Cell culture and proliferation assay. UM-SCC-1 was established from a human oral carcinoma of the retromolar trigone (12). UM-SCC-10B and UM-SCC-74B were established respectively from a lymph node metastasis of a laryngeal cancer and from a recurrent tongue cancer (13). Cell lines were cultured in DMEM (Gibco) supplemented with 10% heat-inactivated fetal bovine serum, 100 U/mL penicillin, and 100 μg/mL streptomycin (Irvine Scientific) at 37°C in 5% CO₂. The COOH-terminal HA-tagged GALR2 sequence was obtained from a human oral carcinoma of the retromolar trigone (12). UM-SCC-1 was established by transfecting pCMVGALR2IresGFP or pCMVIresGFP (Invitrogen) containing the internal ribosomal entry site (Ires) and human cDNA library (Invitrogen), subcloned into the pcDNA3 (BD Biosciences). To examine cell proliferation and morphology, photographs were taken using the Olympus IX71 Microscope (Olympus Corporation).

GALR2 Mediates Apoptosis Independent of p53

Translational Relevance

In this study, we investigated the role of GALR2 in head and neck squamous cell carcinoma (HNSCC), a tumor type that frequently contains mutated p53. Hemagglutinin-tagged GALR2 was stably expressed in a human oral carcinoma cell line UM-SCC-1 that contains mutant p53 and does not express GALR1. Galanin treatment of GALR2-transfected UM-SCC-1 cells caused distinct morphologic changes and a marked decrease in cell number. Galanin and GALR2 inhibited bromodeoxyuridine incorporation and induced p27Kip1 and p57Kip2 up-regulation and cyclin D1 down-regulation. These effects were similar to GALR1 signaling, but GALR2 also induced caspase-3-dependent apoptosis, which was not observed with GALR1. The results show that exogenous GALR2 expression can inhibit cell proliferation and induce apoptosis in HNSCC cells with mutant p53, and thus GALR2 may be a feasible target for HNSCC therapy.
Detection Kit 1 (BD Biosciences) according to the manufacturer’s instructions. Flow cytometric analysis was carried out using FACS Vantage SE and the data analyzed using CellQuest and ModFit LT software packages (Verity Software House Inc.). Genomic DNA was isolated using DNAeasy Tissue Kit (Qiagen, Inc.), and then loaded onto a 2% agarose gel. The DNA ladders stained with ethidium bromide were visualized under UV light.

Statistical analysis. Results were tested for statistical significance using two-way ANOVA or Student's t-test.

Results

Exogenous GALR2 expression. The extracted protein from UM-SCC-1-GALR2 and UM-SCC-1-mock cells pretreated with PNGase-F was assessed for exogenous GALR2 expression by immunoblotting using the monoclonal antibody for HA-tag. Digestion with PNGase-F, a glycosidase that removes N-linked sugars, and solubilization without boiling yielded the appropriate GALR2-HA band in UM-SCC-1-GALR2 but not in UM-SCC-1-mock cells (Fig. 1A). To assess the cellular localization of exogenous GALR2, cells grown on coverslips were stained with HA-tag antibody. Immunofluorescence revealed that all the GFP-positive cells show exogenous GALR2 expression localized to the cytoplasmic membrane as expected for a GPCR (Fig. 1B). The expression of GALR2 in the parent UM-SCC-1 cells was undetectable and less than that in normal human tissue (data not shown). Thus, the differences in the results that we obtained with the UM-SCC-1-GALR2 and UM-SCC-1-mock cells following galanin stimulation should reflect mainly the function of GALR2.

**UM-SCC-1 cells contain mutant p53.** As previous studies had shown that GALR2 signaling caused apoptosis in neuroblastoma cells with wild-type p53, we examined the p53 status of UM-SCC-1 cells to determine if the effects of galanin and GALR2 required p53-mediated signaling. UM-SCC-1 was previously reported by us to have wild-type p53 as assessed by sequencing exons 5-8 (13). Other experiments indicated, however, that UM-SCC-1 failed to respond to DNA damage with up-regulation of p21. Therefore, we sequenced the p53 transcript from UM-SCC-1, which revealed a splice site mutation that results in a 46-bp deletion and frame shift mutation beginning in exon 5 that leads to a nonsense sequence after the splice (Fig. 2A). UM-SCC-74B cells have wild-type p53 and were used as a control for transcript analysis (16). UM-SCC-10B contain a point mutation and overexpress p53 (17). These cells were used as a size marker for p53 protein expression. No p53 protein is detectable in UM-SCC-1 cells, suggesting that the truncated transcript fails to produce a protein or that it is degraded (Fig. 2B).

**GALR2-mediated galanin signaling inhibits cell proliferation and induces changes in cell morphology and adhesion.** To determine the role of GALR2 in cell proliferation, cells starved for 24 hours were treated with various concentrations of galanin, and counted with a Coulter counter. Figure 3A shows proliferation of UM-SCC-1-GALR2 and UM-SCC-1-mock cells after galanin treatment in dose-dependent and time-dependent assays. As the concentration of galanin increased, the proliferation of UM-SCC-1-GALR2 cells decreased significantly when

![Fig. 1.](image1.png) Exogenous GALR2 expression in transfected UM-SCC-1 cells. A, immunoblotting shows exogenous GALR2 expression in pCMVGALR2resGFP-transfected cells detected using antibody to HA-tag. Lanes labeled mock and GALR2HA contain protein lysates from mock-transfected and GALR2HA-transfected UM-SCC-1 cells (UM-SCC-1-GALR2). Lanes labeled mock+PNGase-F and GALR2HA+PNGase-F contain protein from cell lysates that were digested with N-glycosidase F. B, exogenous GALR2 localizes to the cell membrane in UM-SCC-1-GALR2 cells. UM-SCC-1-GALR2 cells were stained with mouse monoclonal anti-HA-tag antibody and Hoechst 33342. Photographs show cells stained with Hoechst 33342 (upper left), GFP (upper right), HA-tag (lower left), and the merged image (lower right); magnification >400.

![Fig. 2.](image2.png) p53 mutation analysis. A, direct cDNA sequencing of the reverse transcription-PCR products of control wild-type p53 expressed by UM-SCC-74B cells and mutant p53 expressed in UM-SCC-1 cells. B, p53 protein expressions in UM-SCC-1-mock, UM-SCC-1-GALR2, and UM-SCC-10B cells as positive control.
compared with the mock-transfected control cells. Proliferation was reduced by 58% compared with the control UM-SCC-1-mock cells when treated with 1 μmol/L of galanin (P < 0.01). Furthermore, UM-SCC-1-GALR2 cells treated with a fixed concentration of galanin (1 μmol/L) and counted at 24, 48, and 72 hours after galanin treatment, also exhibited a progressive decrease in cell number with time. Compared with galanin-treated UM-SCC-1-mock cells, galanin-treated UM-SCC-1-GALR2 cells showed almost no increase in cell number from control levels at 24 hours after galanin treatment. The inhibitory effect on galanin-treated UM-SCC-1-GALR2 cells increased in a time-dependent manner and was significantly different from UM-SCC-1-GALR2 cells without galanin treatment and UM-SCC-1-mock cells (Fig. 3A; P < 0.01). Obvious morphology changes also were seen in UM-SCC-1-mock cells after treatment with various concentrations of galanin. Within 24 hours after addition of 1 μmol/L of galanin, UM-SCC-1-GALR2 cells started to round up and exhibited decreased adhesion to the culture dishes. By 36 hours after treatment, 60% to 80% of cells had detached from the culture dishes and were floating in the medium (Fig. 3B). These results indicate that galanin and GALR2 affect cell adhesion in UM-SCC-1 cells.

GALR2 inhibits BrdUrd incorporation, and induces p27Kip1 and p57Kip2 up-regulation and cyclin D1 down-regulation. To clarify the mechanism of GALR1-induced inhibition of cell proliferation, we examined BrdUrd incorporation as an index of cell cycle arrest and inhibition of DNA synthesis. As compared with UM-SCC-1-mock cells, UM-SCC-1-GALR2 cells exhibited significantly lower BrdUrd incorporation after 1 μmol/L of galanin treatment (P < 0.01). However, this decrease of BrdUrd incorporation did not occur in UM-SCC-1-mock regardless of galanin treatment (Fig. 4A). These data indicate that GALR2-mediated inhibition of proliferation is associated with suppression of DNA biosynthesis. Deregulation of the cell cycle is a common feature of human cancers. Tumor-associated alterations in this process frequently affect cyclin-dependent kinases (Cdks) and their regulators such as p27Kip1, p57Kip2, and cyclin D1. To better understand the role of GALR2 in arrest of tumor cell proliferation, starved cells were treated with 1 μmol/L of galanin for 24 hours and the expression of these regulatory proteins was measured by immunoblotting using specific antibodies. As shown in Fig. 4B, p27Kip1 expression in UM-SCC-1-GALR2 was increased by galanin treatment, but this increase was not seen in UM-SCC-1-mock cells. Similarly, p27Kip1 and p57Kip2 expression in UM-SCC-1-GALR2 was obviously increased by galanin, but not in UM-SCC-1-mock cells. Densitometric measurements indicate that galanin significantly enhanced p27Kip1 expression by 1.8-fold and p57Kip2 by 1.7-fold (P < 0.05). In contrast, cyclin D1 expression decreased

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**Fig. 3.** Galanin-induced growth inhibition and cytotoxicity in UM-SCC-1-GALR2 cells. A, relative cell proliferation as a function of galanin concentration. The cells were serum-starved for 24 h and then cultured with various concentrations of galanin for 24 h (left) or with 1 μmol/L galanin for the indicated periods of time (right). Relative cell number is the ratio of cell number after treatment to that before treatment. Data were analyzed by two-way ANOVA (**P < 0.01). B, cell morphology changes induced by galanin in UM-SCC-1-mock and UM-SCC-1-GALR2 cells. The photographs show cells that were cultured with various concentrations of galanin for 24 h (magnification ×200).
in UM-SCC-1-GALR2, but not in UM-SCC-1-mock cells. Densitometric measurements indicate that galanin significantly suppressed cyclin D1 expression by 0.28-fold ($P < 0.01$). These data suggest that galanin and GALR2-induced arrest of proliferation is associated with regulation of $p27^{kip1}$, $p57^{kip2}$, and cyclin D1.

**GALR2 activation leads to apoptosis.** To investigate whether UM-SCC-1-GALR2 cells die through apoptosis, galanin-treated cells were treated and stained with BrdUrd and annexin-V, which indicates apoptosis. Annexin-V-positive cells were detected by flow cytometry. The annexin-V-positive rate in the galanin-treated group was significantly higher than in the control group ($P < 0.01$).

**GALR2 regulation of cell cycle control genes.** Serum-starved cells were treated with galanin, and the expressions of $p27^{kip1}$, $p57^{kip2}$, and cyclin D1 were assessed by immunoblotting. The band intensities were determined by densitometry and normalized to GAPDH ($**P < 0.01$).

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**Fig. 4.** Galanin and GALR2 are associated with arrest of cell proliferation. A. BrdUrd incorporation after galanin treatment. The BrdUrd-positive cells (left) were detected as described in Materials and Methods (magnification ×200). The BrdUrd incorporation rate is the ratio of BrdUrd-positive cell number to the total cell number. Closed bars, galanin treatment; open bars, no treatment (right; $**P < 0.01$). B, galanin and GALR2 regulate cell cycle control genes. Serum-starved cells were treated with 100 nmol/L galanin for 24 h, and the expressions of $p27^{kip1}$ (upper left), $p57^{kip2}$ (upper right), and cyclin D1 (lower) were assessed by immunoblotting. The band intensities were determined by densitometry and normalized to GAPDH ($**P < 0.01$).
cells were assessed for Annexin-V expression by flow cytometry. Annexin-V-positive cells increased with galanin concentration in UM-SCC-1-GALR2 but not in UM-SCC-1-mock cells (Fig. 5A; \( P < 0.01 \)). Furthermore, galanin and GALR2 induced DNA ladder formation, a characteristic of apoptosis. Cells were treated with 100 nmol/L galanin for 24 hours, then genomic DNA was extracted and loaded onto a 2% agarose gel. As shown in Fig. 5B, galanin-treated UM-SCC-1-GALR2 cells exhibited obvious DNA ladder formation. These results provide the evidence that galanin and GALR2 induce apoptosis in UM-SCC-1 cells.

**Activation of caspase-3 in GALR2-mediated apoptosis.** Caspases are a family of cysteine-proteases, which upon activation will cleave cellular protein targets, leading to the biochemical and morphologic alterations typical of apoptosis (18). To examine the contribution of caspase-3 to galanin-stimulated GALR2-mediated apoptosis, we counted active caspase-3–positive cells by flow cytometry in galanin-treated UM-SCC-1-mock and UM-SCC-1-GALR2 cells. Active caspase-3–positive cells were significantly increased in a galanin concentration-dependent manner in UM-SCC-1-GALR2 (Fig. 6A; \( P < 0.01 \)). Furthermore, preincubation of cells with 50 \( \mu \)mol/L DEVD prior to 0.1 \( \mu \)mol/L galanin treatment could prevent the apoptotic effect of galanin and GALR2 (Fig. 6B). Thus, these results pointed to the activation of caspase-3 by galanin as a critical step in the process of apoptotic cell death occurring in UM-SCC-1-GALR2 cells.

**Discussion**

In this study, we showed that reintroduction of GALR2 into HNSCC cells makes the tumor cells susceptible to...
galanin-induced growth inhibition and apoptosis. These results suggest that the galanin-GALR2 pathway has significant growth regulatory activity and that loss of this pathway could be an important factor in tumor development and progression. Furthermore, because GALR2 can induce apoptosis in p53 mutant HNSCC cells, the loss or inactivation of the galanin-GALR2 signaling cascade provides tumor cells with another mechanism of avoiding cell death. Our results also suggest the possibility that reactivation of the galanin receptor(s) pathway could be a therapeutic strategy in HNSCC. In fact, our recent data show that the galanin receptors are frequently silenced by hypermethylation in HNSCC (11), and that galanin and GALR1 can inhibit cell proliferation (6).

It was reported earlier that GALR2 can initiate a complex signaling cascade by coupling to Gq, Gi, and G12 proteins (5), but that in small cell lung cancer, galanin activated mitogen-activated protein kinase and had mitogenic effects (7). Recently, it was reported that in neuroblastoma cells, exogenous expression of GALR2 inhibited cell proliferation by inducing apoptosis (4). It is known that some kinds of GPCRs, including the N-formyl peptide receptor, and the V2 vasopressin, angiotensin II, and CXCR2 receptors are capable of initiating apoptosis upon stimulation (19). Although the mechanism by which the GALR2 pathway induces antiproliferative effects is not completely understood, a few studies about other GPCRs have been reported. Angiotensin II–induced apoptosis is mediated via its receptors through the induction of transforming growth factor-β production, which is followed by increased transcription of cell death genes such as Fas, Fasl, Bax and caspase-3 (20). The N-formyl peptide receptor also induces apoptosis by the activation of several signaling proteins, such as p38, MEK, and caspases (21). Recently, Tofghi et al. showed exogenous GALR2-transfected pheochromocytoma cells induced apoptosis, by decrease in the phosphorylated Bad level followed by suppression of the phosphoinositide 3-kinase/Akt pathway (22). In our preliminary data, galanin induced activation of Erk pathway activation in UM-SCC-1-GALR2 cells (data not shown), and Erk pathway and phosphoinositide

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**Fig. 6.** GALR2-induced apoptosis through caspase-3 activation. A, active caspase-3 staining. The active caspase-3–positive cells were stained and counted by flow cytometry (left). Percent positive is the ratio of active caspase-3–positive cells to total cell number (right; *P < 0.01). B, effects of galanin and caspase-3 inhibition on GALR2-induced cell death. Serum-starved UM-SCC-1-GALR2 cells were pretreated with 50 μmol/L DEVD before galanin treatment. Relative cell number is the ratio of the cell number after treatment to that before treatment (*P < 0.01).
3-kinase/Akt pathway could cross-talk in cancer cells (23), but their roles for GALR2-induced apoptosis in HNSCC cells are unclear.

In our study, GALR2 up-regulated p27Kip1 and p53Kip2 while down-regulating cyclin D1, p27Kip1, p53Kip2, and p21cip1 belong to the Cip/Kip family of inhibitors of cyclin-dependent kinases. Their roles are not fully understood but many studies have been reported. One recent finding has shown that p21cip1 is implicated in the antiapoptotic response to chemotherapy (24). As a negative regulator of apoptosis, p21cip1 interacts with several caspases, such as caspase-3, caspase-8, and caspase-10 (24). We could not detect p21cip1 expression in either UM-SCC-1 or UM-SCC-1-mock cells (data not shown), but its absence is consistent with the fact that UM-SCC-1 cells have mutated p53. Meanwhile, it has been reported that p27Kip1 positively regulates the apoptotic response (25, 26). Actually, galanin and GALR2 mediated p27Kip1 up-regulation and caspase-3-dependent apoptosis in our experimental models, but the role of p27Kip1 for GALR2-mediated apoptosis is unclear. Clinically, p27Kip1 and p53Kip2 are known to be tumor suppressor genes, and their expression levels are related to prognosis in many different tumors, including non–small cell lung carcinoma, gastric carcinoma, and HNSCC (27–30). Overexpression of cyclin D1 occurs at a high frequency in a variety of carcinomas, including those arising in the breast, colorectum, and head and neck, and is associated with poor prognosis (31–33). The fact that galanin and GALR2 can regulate these genes suggests GALR2 is a tumor suppressor in head and neck cancer cells.

It is significant that GALR2 can mediate this potent antiproliferative effect in the absence of p53 function. Most studies have focused on the involvement of p53 in regulating apoptosis, because the therapeutic action of many antineoplastic agents depends on p53-induced apoptosis. However, p53 is frequently mutated in HNSCC, and thus it would be valuable to find a molecule that can kill tumor cells in a p53-independent manner. Although the p53-independent mechanism activated by GALR2 has not yet been clearly defined, it is known that some kinds of receptors and signaling proteins, such as adenosine A1, E2F1, and p73, induce apoptosis independent of p53 (34–37). Conflicting results have been reported regarding GPCR-induced apoptosis and p53 status. Wang et al. reported a potential role for GPCR signaling in the modulation of p53-mediated apoptosis and indicated that β-arrestin 2 may serve as a signaling linker between the GPCR and p53 pathways via sequestration of murine double minute (21). On the other hand, the somatostatin analogue AN-238 and its GPCR receptor induce apoptosis though a p53-independent pathway (38). The orexin receptor was also reported to induce p53 transcription–independent apoptosis though p38 activation (39). Until now, it had not been determined whether GALR2 needs p53 function to induce apoptosis, because GALR2-mediated apoptosis was shown in the neuroblastoma cell line SH-SY5Y (4). In general, p53 is wild-type in human neuroblastoma cell lines (40). SH-SY5Y cells are known to have wild-type p53 and were used as a typical model to study the mechanism of p53-induction of apoptosis (41). In the present study, GALR2 induced antiproliferative and apoptotic effects in UM-SCC-1, a cell line that expresses only a truncated p53 message that lacks the COOH-terminal sequence encoding the nuclear localization signal and lacks detectable p53 protein. Our results showed that GALR2 can induce apoptosis and cell cycle arrest though a p53-independent but caspase-3-dependent pathway. These results suggest that GALR2 might act through a novel apoptotic pathway that is not yet well-defined.

In conclusion, we have shown that galanin and GALR2 induce apoptosis and cell cycle arrest independent of p53. These results suggest that GALR2 probably controls normal cell proliferation and survival in the epithelium and that its loss may facilitate tumor development and progression. Furthermore, this pathway is a possible target in head and neck cancer.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

References


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