YM155 Reverses Cisplatin Resistance in Head and Neck Cancer by Decreasing Cytoplasmic Survivin Levels

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Abstract

Cisplatin is one of the commonly used chemotherapeutic drugs for the treatment of head and neck squamous cell carcinoma (HNSCC). However, acquisition of cisplatin resistance is common in patients with HNSCC, and it often leads to local and distant failure. In this study, we showed that survivin expression is significantly upregulated in HNSCC primary tumors and cell lines. In addition, survivin levels were significantly higher in human papilloma virus–negative patients that normally respond poorly to cisplatin treatment. Survivin expression was further increased in cisplatin-resistant cells (CAL27-CisR) as compared with its parent cells (CAL27). Therefore, we hypothesized that targeting of survivin in HNSCC could reverse the resistant phenotype in tumor cells, thereby enhancing the therapeutic efficacy of cisplatin. We used both in vitro and in vivo models to test the efficacy of YM155, a small molecule survivin inhibitor, either as a single agent or in combination with cisplatin. YM155 significantly decreased survivin levels and cell proliferation in a dose-dependent manner. In addition, YM155 pretreatment significantly reversed cisplatin resistance in cancer cells. Interestingly, YM155 treatment altered the dynamic localization of survivin in cells by inducing a rapid reduction in cytoplasmic survivin, which plays a critical role in its antiapoptotic function. In a severe combined immunodeficient mouse xenograft model, YM155 significantly enhanced the antitumor and antiangiogenic effects of cisplatin, with no added systemic toxicity. Taken together, our results suggest a potentially novel strategy to use YM155 to overcome the resistance in tumor cells, thereby enhancing the effectiveness of the chemotherapy in HNSCC. Mol Cancer Ther; 11(9); 1988–98. ©2012 AACR.

Introduction

Head and neck cancer is the sixth leading cancer by incidence worldwide and approximately 600,000 cases are diagnosed every year. In the United States, an estimated 40,250 new cases of head and neck cancer were expected in 2012 (1). Although advancements in the techniques for surgery, radiation, and chemotherapy have increased the local control of head and neck squamous cell carcinoma (HNSCC), the overall survival rates have not improved significantly over the last 3 decades. This poor outcome becomes even worse (20% 5-year survival rate) for advanced stage HNSCC patients whose tumors are not amenable for surgery (2). Cisplatin is one of the most commonly used chemotherapeutic agents used for the treatment of head and neck cancers (3). However, many patients acquire resistance to chemotherapeutic agents leading to treatment failures. Prognosis of such patients who have to undergo late salvage surgery is very poor (4). Therefore, it is important to understand the molecular mechanisms that contribute to drug resistance to identify novel therapeutic targets for head and neck cancer.

One such protein that has been identified to be deregulated in a number of human tumors is survivin. It is a bifunctional protein that acts as a suppressor of apoptosis and has an essential role in mitosis (5). It is a nuclear and cytoplasmic shuttling protein that is predominantly cytoplasmic, in part, because of an active nuclear export signal in its linker region (6). Cytoplasmic survivin predominantly mediates the antiapoptotic function, whereas nuclear survivin mediates the mitotic function and is significantly less stable (6–8). Survivin is largely undetected or expressed at very low levels in normal tissues (9), whereas it is overexpressed in many malignancies, including breast, lung, colon, pancreas, liver, and head and neck cancer and has also been linked to poor patient survival (10, 11). In addition, growing evidence suggest that survivin expression is associated with drug resistance in cancer cells and cancer-associated endothelial cells...
in a preclinical cells, in a dose-dependent manner, in vitro regulated survivin expression in head and neck cancer combination with cisplatin, in preclinical head and neck nation strategy for clinical trials. A scientific rationale to evaluate this or a similar combination for patients that are resistant to cisplatin, and provides results showed that YM155 could be a useful adjuvant growth and tumor angiogenesis. Taken together, our YM155 and cisplatin combination regimen was very line (CAL27-CisR), with acquired cisplatin resistance. (UM-SCC-74A) as well as in a cisplatin-resistant cancer xenografts (19–22). In addition, phase I and phase II trials with YM155 have shown its safety and tolerability in patients with unresectable melanoma and advanced refractory non–small cell lung carcinoma (23, 24).

The objective of this study was to determine the in vitro and in vivo efficacy of YM155, alone or in combination with cisplatin, in preclinical head and neck cancer models. YM155 treatment significantly down-regulated survivin expression in head and neck cancer cells, in a dose-dependent manner, in vitro as well as in a preclinical in vivo model. In addition, YM155 treatment was able to reverse cisplatin resistance in a naturally occurring cisplatin-resistant HNSCC cell line (UM-SCC-74A) as well as in a cisplatin-resistant cell line (CAL27-CisR), with acquired cisplatin resistance. YM155 and cisplatin combination regimen was very well tolerated in vivo and significantly inhibited tumor growth and tumor angiogenesis. Taken together, our results showed that YM155 could be a useful adjuvant for the treatment of head and neck cancer, particularly for patients that are resistant to cisplatin, and provides a scientific rationale to evaluate this or a similar combination strategy for clinical trials.

Materials and Methods

Patient samples, cell culture, and reagents
We used 2 patient sample groups for this study. Use of patient samples was approved by the Ohio State University Institutional Review Board. A board-certified pathologist diagnosed all tumor tissue as HNSCC. For group 1, tumor and adjacent normal tissue samples were collected from head and neck cancer patients undergoing surgical resection at the James Comprehensive Cancer Center at The Ohio State University, Columbus, OH. Normal samples were collected from areas adjacent to the tumor but outside the tumor margins (patient tumor characteristics are presented in Supplementary Table S1). Group 2 consisted of 225 patients with oropharyngeal SCC treated at our institution from 2002 to 2009. Patients underwent complete resection or had a biopsy and neck dissection with or without adjuvant chemotherapy/radiation therapy (patient tumor characteristics are presented in Supplementary Table S2). HNSCC cell lines (UM-SCC-38, UM-SCC-74A, UM-SCC-49, UM-SCC-47, UM-SCC-11B, and UM-SCC-25) were obtained from Dr. Thomas E. Carey (University of Michigan, Ann Arbor, MI). CAL27 was purchased from American Type Culture Collection. The identity of all cell lines was confirmed by short tandem repeat genotyping (Identifier Kit, Applied Biosystems). The characteristic of cell lines [origin, p53 status, human papilloma virus [HPV status (refs. 25, 26)]] are presented in Supplementary Table S3. Normal human oral keratinocytes were purchased from ScienCell. Human epidermal keratinocytes, adult (HEKa) and human epidermal keratinocytes, neonatal (HEKn) were purchased from (Invitrogen). All HNSCC cell lines were cultured in Dulbecco’s Modified Eagle’s Medium (DMEM) supplemented with 10% FBS. Human oral keratinocytes, HEKa, and HEKn were grown in keratinocyte growth medium (Invitrogen). YM155 was obtained from Selleck Chemicals. Cisplatin was purchased from Sigma-Aldrich. Antibodies against survivin, β-catenin, lamin A/C, and glyceraldehyde-3-phosphate dehydrogenase (GAPDH) were obtained from Cell Signaling Technology. Survivin antibody for immunofluorescence was purchased from Novus Biologicals. CD31 antibody was from Dianova.

Induction of cisplatin resistance in a head and neck cancer cell line
CAL27 cells were initially cultured in DMEM containing 0.2 μmol/L cisplatin, and the cells that proliferated were repeatedly subcultured in DMEM containing increasing concentrations of cisplatin over a 6-month period. Cells that grew in 20 μmol/L cisplatin were designated as CAL27-CisR. They were maintained in DMEM containing 3 μmol/L cisplatin.

Quantitative real-time PCR analysis
RNA from the HNSCC tumors, adjacent normal controls, HNSCC cell lines was extracted using TRizol reagent (Invitrogen). RNA from paraffin-embedded xenograft tumors was extracted using the RecoverAll Mammalian RNA Extraction Kit (Ambion). Survivin RNA was transcribed into cDNA and amplified with TaqMan primer/probe Hs03043576_m1. Survivin mRNA expression was normalized to RNU48 and OAZ1, respectively, using the 2δΔCt method (27).

Cell proliferation assay
Cell proliferation was measured using the MTT proliferation kit (Roche Applied Science) as described previously (28). Cells were treated with cisplatin or YM155 for 72 hours. For combination treatment, cells were pretreated with YM155 for 6 hours and then treated with cisplatin for additional 72 hours. The percentage cell growth inhibition for each treatment group was calculated by adjusting the untreated control group to 100%.
Apoptosis assay

Cells were plated in 6-cm dishes and treated with YM155, cisplatin, or in combination. Seventy-two hours after treatment, cells were stained with Annexin V (Molecular Probes) and propidium iodide (Sigma-Aldrich) and analyzed by flow cytometry (BD Biosciences).

Nuclear and cytoplasmic protein extraction

Cells were cultured in 6-cm plates and treated with YM155 for different time points. At the end of each treatment, cells were harvested and nuclear and cytoplasmic protein fractions were separated by NE-PER Nuclear and Cytoplasmic Extraction Kit (Pierce Biotechnology), according to manufacturer’s instructions.

Western blot analysis

Whole-cell lysates or nuclear and cytoplasmic fractions were separated by 4% to 12% NuPAGE Bis-Tris gels (Invitrogen) as described previously (28). Protein loading in all the experiments was normalized by stripping the blots and then reprobing with anti-GAPDH antibody.

Colony formation assay

Tumor cells were plated in 6-cm dishes and treated with cisplatin, YM155, or a combination of both. After 72 hours, 4 × 10^5 viable cells from each group were plated in 6-cm dishes and cultured for additional 10 days. The colonies were fixed with methanol and stained with crystal violet. Photomicrographs were taken and the number of colonies was counted by Alpha Innotech imaging software.

Immunofluorescent staining

CAL27-CisR cells were cultured in 4-well labtech chambers. CAL27-CisR cells were treated with YM155 (10 nmol/L) for different time points. At the end of incubation, survivin localization was analyzed by immunofluorescent staining, as described previously (29). The fluorescent images were captured using Nikon Eclipse 80i microscope with DS-Ri1 camera at ×600 magnification and overlaid using NIS-Elements-Basic Research software (Nikon).

Matrigel in vitro endothelial tube formation assay

Endothelial tube formation was assayed using Matrigel-coated 8-well chamber slides as described previously (30). Each chamber was photographed (Nikon Eclipse Ti microscope with DS-Fi1 camera) at ×100 magnification, and total area occupied by endothelial cell-derived tubes in each chamber was calculated using software (NIS-Elements-Basic Research; Nikon) and expressed as an angiogenic score.

Severe combined immunodeficient mouse xenograft model

Six- to 8-week-old severe combined immunodeficient (SCID) mice (National Cancer Institute) were used in all the in vitro experiments (31). Tumor cells (1 × 10^6) were mixed with 100 μL of Matrigel and injected in the flanks of SCID mice. After 8 days, mice were stratified into different groups (n = 5), so that the mean tumor volume in each group was comparable. At days 8, 11, 14, 17, 21, 24, and 28, animals were treated with YM155 (3 mg/kg) or cisplatin (5 mg/kg) via intraperitoneal injections. Tumor volume measurements [volume (mm^3) = L × W^2/2 (length L, mm; width W, mm)] began on day 6 and continued twice a week until the end of the study. After 36 days, primary tumors were carefully removed, photographed, and analyzed for survivin expression and tumor angiogenesis.

Tissue microarrays and immunohistochemistry

Paraffin-embedded tissue sections from patients in group 2 were represented on tissue microarrays (TMA). The slides were stained with survivin and p16, an established surrogate marker for HPV status (Roche mtm AG) as described previously (32). HPV16 status was determined using in situ HPV DNA Probe (Dako; ref. 33). Survivin intensity was scored as 1: none; 2: low; 3: moderate or 4: high. p16 expression was scored as positive if 50% or more of tumor cells showed positive staining. A tumor was scored as HPV16 positive when specific staining was observed in tumor cell nuclei. Xenograft tumor sections were stained for angiogenesis (CD31) as described previously (28). Microvessel density was calculated by counting 5 random high power fields (×200).

Statistical analysis

Data from all the in vitro experiments are expressed as mean ± SEM from a minimum of 3 independent experiments. The survivin expression in patient samples from group 1 and HNSCC cell lines was analyzed by Mann–Whitney test. To assess survivin stain intensity in patient samples from group 2, core samples were averaged across each patient to create one survivin stain intensity score. The rest of the data was statistically analyzed by 2-way ANOVA, or Student t test, and a Bonferroni adjustment were carried out. All statistical analyses for TMA data were conducted in SAS version 9.2. The rest of the data was statistically analyzed by 2-way ANOVA or Student t test, and a P value of less than 0.05 was considered significant.

Results

Survivin expression is significantly higher in primary tumor samples and cancer cell lines from head and neck cancer patients

Our results showed that survivin expression was significantly higher (Mann–Whitney test; P = 0.028) in...
HNSCC tumor samples (group 1, Supplementary Table S1) as compared with adjacent normal tissue (Fig. 1A). Analysis of group 2 patients showed that patients whose tumors were p16 negative had a significantly higher survivin stain intensity as compared with patients with p16-positive tumors ($P < 0.0001$; Fig. 1B). Similar results were obtained when HPV16 status was taken into consideration ($P < 0.021$, Supplementary Table S2). Tumors from patients who smoked more than 10 pack-years had higher survivin stain intensity as compared with those with 10 pack-years or less smoking history ($P < 0.004$, Fig. 1C). In addition, patients with T4 stage tumors had significantly higher mean survivin stain intensity than those with T1 stage ($P < 0.01$). We next examined whether survivin expression is also elevated in head and neck tumor cell lines. Indeed, both survivin mRNA and protein levels were significantly higher in all the head and neck cancer cell lines as compared with normal keratinocytes (Mann–Whitney test; $P = 0.009$ for RT-PCR data, Fig. 1D and E).

**Figure 1.** Survivin expression is upregulated in HNSCC cell lines and patient’s primary tumor samples. A, survivin expression in primary tumor samples ($n = 10$) and in adjacent normal mucosa ($n = 10$) of head and neck cancer patients. B, survivin stain intensity was analyzed in p16-negative ($n = 56$) and p16-positive primary tumor samples ($n = 169$). C, survivin stain intensity was analyzed in tumors from patients with 10 pack (pk)-years or less smoking history ($n = 58$) and compared with survivin stain intensity in tumors from patients with more than 10 pack-years smoking history ($n = 157$). Gray box, interquartile range (25th to 75th percentile); black diamond, mean; black horizontal bar, median; top and bottom whiskers, maximum and minimum values, respectively. D and E, survivin expression was analyzed in normal keratinocytes and head and neck cancer cell lines by RT-PCR (D) and Western blotting (E). For survivin Western blot, equal protein loading was verified by stripping the blots and reprobing with GAPDH antibody.

Survivin expression is markedly elevated in cisplatin-resistant head and neck cancer cell line and treatment with YM155 significantly downregulates survivin expression in a dose-dependent manner

To examine the role of survivin in the acquisition of cisplatin resistance, we took a head and neck cancer cell line (CAL27) that is sensitive to cisplatin treatment ($IC_{50}$, 3 μmol/L) and induced cisplatin resistance by culturing this cell line in increasing doses of cisplatin over an extended period of time. This new cell line, designated CAL27-CisR ($IC_{50}$, 28 μmol/L), was found to be significantly more resistant to cisplatin treatment (>7 folds) as compared with its parental cell line (Fig. 2A). Interestingly, CAL27-CisR cells also showed a significant increase in survivin levels as compared with CAL27 cells (Fig. 2B and C). Survivin knockdown in CAL27-CisR cells significantly reversed cisplatin resistance in these cells (Fig. 2D and E).

Recently, a novel small molecule inhibitor of survivin (YM155, Fig. 2G) was identified by cell-based high-throughput screening (19). We next examined whether YM155 is effective in inhibiting survivin protein expression in head and neck cancer cell lines. We selected 2 cisplatin-resistant cell lines UM-SCC-74A (naturally cisplatin resistant) and CAL27-CisR (generated in our laboratory) for our in vitro and in vivo work. YM155 significantly downregulated survivin expression in both the cell lines in a dose-dependent manner (Fig. 2H and I). In addition, YM155 was very effective in inhibiting tumor cell proliferation (nanomolar concentrations) in HNSCC cell lines (Supplementary Fig. S1). For all the subsequent in vitro experiments using UM-SCC-74A and CAL27-CisR, we used the respective $IC_{50}$ doses of YM155 (15 and 10 nmol/L for UM-SCC-74A and CAL27-CisR, respectively) and cisplatin (10 and 28 μmol/L for UM-SCC-74A and CAL27-CisR, respectively) as a single agent or in combination.
YM155 significantly reverses cisplatin resistance in head and neck cancer cells by rapidly decreasing cytoplasmic survivin levels

Recent studies have highlighted the role of survivin in the acquisition of drug resistance in cancer cells (12, 15, 16). We next examined whether YM155 could reverse the cisplatin resistance in head and neck cancer cells and enhance its antitumor effects. Treatment of CAL27-CisR cells with cisplatin showed 51% inhibition of cell proliferation, whereas it completely inhibited cell proliferation in CAL27 cells (Fig. 3A). Interestingly, pre-treatment of CAL27-CisR cells with YM155 (10 nmol/L) significantly reversed cisplatin resistance (90%) in CAL27-CisR cells (Fig. 3A). Similarly, treatment with YM155 significantly reversed cisplatin resistance in naturally cisplatin-resistant UM-SCC-74A cells (Supplementary Fig. S2). We next investigated the effect of YM155 alone or in combination with cisplatin on tumor cell colony formation. As observed with cell proliferation assay, YM155 and cisplatin combination treatment was very effective showing 96% inhibition of tumor cell colony formation, whereas YM155 and cisplatin alone showed 64% and 47% inhibition of tumor cell colony formation, respectively (Fig. 3C and D). In the next set of experiments, we examined whether YM155-induced inhibition of cell proliferation and colony formation is mediated via tumor cell apoptosis. Indeed, YM155 treatment in combination with cisplatin showed significantly higher tumor cell apoptosis (Fig. 3B). In addition, YM155 and cisplatin combination treatment markedly reduced survivin levels in both UM-SCC-74A and CAL27-CisR cells (Fig. 3E and F). Recent studies have highlighted the role of cytoplasmic survivin in mediating the antiapoptotic function (7). We further carried out immunofluorescence and subcellular fractionation studies to examine whether YM155 treatment decreases cytoplasmic survivin levels in cancer cells. Our results clearly showed that YM155 treatment rapidly decreases (within 1 hour) survivin levels in both UM-SCC-74A and CAL27-CisR cells (Fig. 3G and H and Supplementary Fig. S3).

YM155 inhibits tumor growth in a dose-dependent manner

To confirm the antitumor effects of YM155 in vivo, we used a SCID mouse xenograft model. Animals
bearing UM-SCC-74A tumors were treated with different doses of YM155. Animals treated with YM155 at 10 mg/kg dose showed the maximal tumor growth inhibition (65% at day 36), whereas YM155 at 3 and 1 mg/kg showed 31% and 10% tumor growth inhibition, respectively, at day 36 (Fig. 4A and B). We next examined the effectiveness of different YM155 doses in downregulating survivin expression in vivo. Survivin expression in tumor samples at the end of the in vivo study (day 36) was examined by quantitative RT-PCR. Similar to tumor growth inhibition results, YM155 treatment at 1 mg/kg did not significantly decrease survivin levels. However, YM155 treatment at 3 and 10 mg/kg doses significantly decreased survivin expression in UM-SCC-74A tumors (Fig. 4C).
YM155 significantly enhances the therapeutic efficacy of cisplatin in cisplatin-resistant head and neck cancers

Our in vitro data suggested that YM155 significantly reverses cisplatin resistance in head and neck cancer cells. To further validate our in vitro results, we carried out YM155 and cisplatin combination treatment study in a SCID mouse xenograft model. Animals bearing cisplatin-resistant cells (CAL27-CisR) as well as its parental cisplatin-sensitive cells (CAL27) showed a similar tumor growth profile (Fig. 5A and B). As observed in our in vitro studies, cisplatin treatment (5 mg/kg) of animal bearing CAL27-
YM155 and cisplatin combination treatment significantly inhibits tumor angiogenesis

We have previously shown that VEGF, a key angiogenic factor, upregulated Bcl-2 proteins in endothelial cells via the PI3K/Akt pathway (35), and Bcl-2, in turn, protected endothelial cells by upregulating survivin via the Raf–MEK–ERK signaling cascade (36). Recently, Virrey and colleagues, have also shown that increased survivin expression confers chemoresistance to tumor-associated endothelial cells (37). We therefore examined whether YM155 treatment alone or in combination with cisplatin inhibits tumor angiogenesis. YM155 and cisplatin treatment alone showed 40% and 24% inhibition of tumor angiogenesis in UM-SCC-74A (Fig. 6A and B) and 38% and 29% inhibition in CAL27-CisR, respectively (Fig. 6C), whereas YM155 and cisplatin combination treatment showed 86% and 83% inhibition of tumor angiogenesis in UM-SCC-74A and CAL27-CisR tumors, respectively.

We next examined whether YM155 combination treatment mediates its antiangiogenesis effects by inhibiting VEGF-mediated angiogenesis. VEGF treatment of endothelial cells significantly enhanced the tube formation on growth factor–reduced Matrigel (Fig. 6D and E). Low dose combination of YM155 (10 nmol/L) and cisplatin (5 μmol/L) significantly inhibited (92%) VEGF-mediated tube formation (Fig. 6D and E), whereas YM155 and cisplatin treatment alone showed 45% and 34% inhibition of endothelial cell tube formation, respectively. VEGF treatment of endothelial cells markedly upregulated survivin levels, whereas YM155 treatment alone or in combination with cisplatin significantly inhibited survivin levels (Fig. 6F).

Discussion

HNSCC remains a challenging clinical problem because of the persistent high rate of local and distant failure, which is, in turn, due to the acquisition of chemo and radioresistance (38). Therefore, there is an urgent need to identify new therapeutic targets so that novel treatment regimens can be developed to improve the therapeutic efficacy while minimizing the toxic side effects. One such target molecule for head and neck cancer is survivin protein. Recent studies have shown that survivin is largely undetectable in normal mucosa, but it is highly expressed in most head and neck cancers correlating with poor survival and resistance against chemotherapy and radiotherapy (10, 39, 40). In our study, we also observed significantly higher levels of survivin in primary tumors from head and neck cancer patients as compared with surrounding normal tissue. In addition, survivin expression was also significantly upregulated in all head and neck cancer cell lines, both at the mRNA and protein level as compared with normal keratinocytes. More importantly, survivin levels were further elevated in cisplatin-resistant cells, as compared with their parental cisplatin sensitive cells. Therefore, we hypothesized that targeting of survivin in advanced HNSCC could reverse the resistant phenotype in tumor cells, thereby enhancing the therapeutic efficacy of cisplatin.

Patients with head and neck cancer encompass a heterogeneous group and can be further subdivided into 2 distinct tumor subtypes; HPV-negative and HPV-positive tumors. Interestingly, majority of the head and neck cancer patients with HPV-positive tumors respond very well to traditional chemotherapy with cisplatin and show significantly favorable clinical outcome (32, 38). It is the patients with HPV-negative tumors that show markedly poor clinical outcome and often develop resistance to chemotherapy. These HPV-negative HNSCC patients are usually smokers, have more aggressive disease, are older in age, and unable to tolerate the comorbidities normally associated with toxic chemotherapeutic agents. Therefore, this non–HPV–associated patient population could tremendously benefit from the addition of targeted therapies to currently used treatment regimens. In this study, we found that tumors from HPV-negative patients express significantly higher levels of survivin as compared with tumors from HPV-positive patients. We also found that survivin expression is higher in patients with a more than 10 pack-years of tobacco smoking history. This data gave us a strong rationale to test the antitumor effects of a novel survivin inhibitor YM155 in HNSCC. In this study, we have used 2 HPV-negative HNSCC cell lines (UM-SCC-74A and CAL27-CisR). UM-SCC-74A cell line is derived from a head and neck cancer patient with base of tongue tumor and is highly resistant to both chemotherapy and radiation treatment (41, 42). In addition, we generated a cisplatin-resistant cell line (CAL27-CisR, IC_{50} 28 μmol/L) in our laboratory by culturing a cisplatin-sensitive tongue SCC cell line CAL27 (IC_{50} 3 μmol/L) in increasing doses of cisplatin over a period of time.

YM155 treatment was very effective in inhibiting tumor cell proliferation in nanomolar concentrations in all HNSCC cell lines that we tested. In addition, YM155 pretreatment significantly reversed cisplatin resistance in CisR tumors did not significantly affect tumor growth (11% inhibition at day 36), whereas cisplatin treatment of CAL27 markedly decreased tumor growth (55% inhibition at day 36). YM155 (3 mg/kg) treatment of CAL27-CisR tumors was significantly more effective in reducing tumor burden (38% inhibition at day 36). YM155 in combination with cisplatin was most effective in inhibiting tumor growth of CAL27-CisR (66% inhibition at day 36).

We next tested the efficacy of YM155 and cisplatin combination treatment in a naturally cisplatin-resistant head and neck cell line (UM-SCC-74A). Cisplatin (5 mg/kg) and YM155 (3 mg/kg) treatment alone showed 19% and 31% tumor growth inhibition (Fig. 5C and D), in which YM155 and cisplatin in combination showed significantly higher tumor growth inhibition (64%). In addition, the combination treatment was very well tolerated, and it did not cause any animal mortality or induce significant decrease in body weight (Supplementary Fig. S5).

YM155 Inhibits HNSCC Growth
a naturally resistant head and neck cell line (UM-SCC-74A) as well as in cell line with acquired cisplatin resistance (CAL27-CisR). YM155 treatment also significantly downregulated survivin expression in both of these cisplatin-resistant cell lines in a dose-dependent manner. Survivin has been shown to mediate its cytoprotective function predominantly at the initiation of mitochondrial apoptosis to prevent caspase-9 activation by forming a survivin–caspase-9 complex and preventing caspase-9 incorporation in a functional apoptosome complex (43, 44). Interestingly, YM155 treatment induced a rapid reduction of cytoplasmic survivin levels in cancer cells. These results suggest that YM155 is not only able to downregulate survivin expression at the transcriptional level, but it may also be able to reduce cytoplasmic survivin levels by shuttling survivin from cytoplasm to nucleus and mediating its degradation (7, 45, 46). This assumption is supported by recent studies showing that only export-competent survivin was able to efficiently inhibit chemo- and radiotherapy-induced cell death.

Figure 6. YM155 and cisplatin combination treatment significantly inhibits tumor angiogenesis and VEGF-mediated endothelial cell tube formation. A, representative photomicrographs of tumor blood vessel staining for untreated, cisplatin (CDDP), or YM155 alone or combination groups for UM-SCC-74A tumors. B and C, microvessel density in the tumor samples was calculated by counting 5 random fields (>200) and expressed as vessel density ± SE. *, significant difference (P < 0.05) as compared with no treatment group; **, significant difference (P < 0.05) as compared with single treatment groups. D, representative photomicrographs of in vitro tube formation assay for untreated, VEGF, VEGF + cisplatin (V + CDDP), VEGF + YM155 (V + YM155), and VEGF + CDDP + YM155. E, quantitative data for tube formation expressed as angiogenic score ± SE from 3 independent experiments. F, endothelial cells were treated with VEGF and cisplatin (5 μmol/L) or YM155 (10 nmol/L) alone or in combination for 48 hours. Whole-cell lysates from each group were Western blotted and probed for survivin. Equal sample loading was verified by stripping the blots and reprobing with anti-GAPDH antibody.
YM155 Inhibits HNSCC Growth

(5, 47). In line with this hypothesis, Engels and colleagues showed that in patients with oral squamous cell carcinoma, increased cytoplasmic survivin levels were associated with significantly shorter disease-free survival (8). Therefore, these results highlight the importance of regulating not only the total levels but also the localization of survivin in cancer cells.

To determine whether the observed in vitro synergy between YM155 and cisplatin extends to the in vivo setting, we used a SCID mouse model to study the effect of combination treatment on tumor growth and tumor angiogenesis. Indeed, low dose combination of YM155 (3 mg/kg) and cisplatin (5 mg/kg) induced significant reduction in tumor burden. This marked inhibition of tumor growth by combination therapy, particularly in chemoresistant cell line, could be because of YM155-mediated downregulation of survivin levels, notably cytoplasmic survivin (7), as well as reduction in the formation of new blood vessels by inhibiting VEGF function (28), as observed in tube formation assay. YM155 and cisplatin combination treatment was very well tolerated in the animals. It did not cause any animal mortality, induce significant weight loss, or cause any major systemic toxicity, such as dry scaly skin or respiratory distress, which has been reported in animals treated with high doses of chemoradiation treatment with other small molecular weight inhibitors (48).

In conclusion, we have shown that YM155 significantly enhances the therapeutic efficacy of cisplatin treatment by inhibiting tumor growth and tumor angiogenesis. These results suggest a potentially novel strategy to reverse cisplatin resistance in head and neck cancers. Moreover, this strategy of using a combination of low doses of YM155 and cisplatin has the potential of significantly decreasing side effects associated with the concurrent chemoradiation treatment while maintaining the therapeutic efficacy.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Authors’ Contributions

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