SYD985, a Novel Duocarmycin-Based HER2-Targeting Antibody–Drug Conjugate, Shows Antitumor Activity in Uterine and Ovarian Carcinosarcoma with HER2/Neu Expression

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Abstract

Purpose: Carcinosarcomas (CS) are highly aggressive gynecologic malignancies containing both carcinomatous and sarcomatous elements with heterogeneous HER2/neu expression. We compared the efficacy of SYD985 (Synthon Biopharmaceuticals BV), a novel HER2-targeting antibody–drug conjugate (ADC), to trastuzumab emtansine (T-DM1, Genentech-Roche) against primary uterine and ovarian CS.

Experimental Design: Eight primary CS cell lines were evaluated for HER2/neu surface expression by IHC and gene amplification by FISH assays. The in vitro experiments included cytotoxicity, antibody-dependent cellular cytotoxicity (ADCC), proliferation, viability, and bystander killing. In vivo activity was studied in mouse xenograft and patient-derived xenograft (PDX) models.

Results: SYD985 and T-DM1 induced similar levels of ADCC in vitro. Eight primary CS cell lines were evaluated for HER2/neu expression and gene amplification by FISH. The in vitro experiments included cytotoxicity, antibody-dependent cellular cytotoxicity (ADCC), proliferation, viability, and bystander killing. In vivo activity was studied in mouse xenograft and patient-derived xenograft (PDX) models.

Conclusions: SYD985 may represent a novel and highly effective ADC against HER2-expressing CS. Clinical studies with SYD985 in patients harboring chemotherapy-resistant CS with low/moderate and high HER2 expression are warranted.

Cancer Therapy: Preclinical

Introduction

Carcinosarcomas (CS), also known as mixed malignant Mullerian tumors (MMMT), are rare but highly aggressive gynecologic malignancies accounting for less than 5% of all gynecologic cancers (1–3). CSs can arise in the ovary, cervix, or uterus. Previously published data from the SEER database suggest that the age-adjusted rate of CS development in the uterus is 0.6 of 100,000 and in the ovary 0.19 of 100,000 (4). Despite aggressive surgical and adjuvant therapy, 5-year survival rates for uterine CS are approximately 60% for early (stage I/II) disease and 9% to 22% for more advanced disease (5). Similarly, ovarian CSs account for less than 4% of all newly diagnosed ovarian carcinomas and carry a significantly worse prognosis than their epithelial ovarian carcinoma counterparts (6). Standard treatment for CS is aggressive surgical debulking followed by chemotherapy with or without radiation. The rarity of these tumors has made determination of the best adjuvant therapy difficult, and completing large prospective randomized trials remains challenging. As a result, a considerable amount of effort has been made by our group as well as others to better understand the biology of the disease, its developmental origins as well as common genetic alterations and activated molecular pathways in an attempt to improve treatments and ultimately survival (7).

CSs are composed of an epithelial component as well as a sarcomatous component. Many theories regarding the mechanism of development of this tumor, composed of two dissimilar cell populations, have been proposed (7). Importantly, recent comprehensive whole exome sequencing genetic studies from our research group have provided strong experimental evidence to suggest that ovarian and uterine CS originate as epithelial tumors and only subsequently may undergo mesenchymal transformation (8–11). These genetic landscape results are consistent with previous clinical/pathological studies showing that the epithelial component of the CS drives the growth and proliferation of these rare and biologically aggressive gynecologic cancers. Because of the reported overexpression and/or gene amplification of HER2 in over one third of uterine serous carcinoma (12, 13), which...
SYD985 Is a Novel ADC Active in Gynecologic Carcinosarcomas

Translational Relevance
Carcinosarcomas (CS) of the uterus and ovaries are uncommon but highly aggressive neoplasms characterized by a biphasic histology of carcinomatous and sarcomatous elements. In an effort to develop novel, active agents for these deadly gynecologic malignancies, we evaluated the efficacy of SYD985 (Synthon Biopharmaceuticals BV), a novel HER2-targeting antibody–drug conjugate (ADC) composed of the monoclonal antibody (mAb) trastuzumab linked to a highly potent DNA-alkylating agent (i.e., duocarmycin). Our results demonstrated that SYD985 is a novel ADC with remarkable and significantly more potent activity than T-DM1 against uterine and ovarian CS with strong (3+) as well as low (i.e., 1+) HER2/neu expression. Clinical studies with SYD985 in patients harboring chemotherapy-resistant uterine and ovarian CS with HER2 expression are warranted.

Syd985 represents the high-grade epithelial component of a large number of gynecologic CS (10), HER2 may represent an attractive target for anticancer therapy (4).

HER2-directed antibody antitumor activity is mainly due to inhibition of intracellular signaling via the phosphatidylinositol 3-kinase (PI3K) and the mitogen-activated protein kinase (MAPK) pathways, and activation of immune response through antibody-dependent cellular cytotoxicity (ADCC), and complement-dependent cytotoxicity (CDC; refs. 14, 15). Currently, the three monoclonal HER2-directed antibody drugs approved by the FDA as clinical therapies in tumors overexpressing HER2 include trastuzumab (approved in 1998; ref. 16), pertuzumab (approved in 2012), and trastuzumab emtansine (T-DM1; approved in 2013; refs. 17, 18). Antibody–drug conjugates (ADC) such as T-DM1 are considered to be sophisticated drug-delivery systems that provide one of the most promising approaches to improve the therapeutic window of existing cytotoxic agents such as tubulin-targeting agents (19–21). Trastuzumab emtansine (T-DM1), approved as a second-line monotherapy for the treatment of relapsed HER2-positive metastatic breast cancer, includes trastuzumab covalently linked with a noncleavable linker to the antimitotic agent emtansine (DM1; refs. 22, 23). Once the ADC is internalized into tumor cells by receptor-mediated endocytosis and processed, DM1 is linked with a noncleavable linker to the antimitotic agent emtansine (DM1; refs. 22, 23). Brieﬂy, vc-seco-DUBA is a well-deﬁned ADC predominantly consisting of 2.8 (28, 29).

SYD985 and T-DM1
T-DM1 (batch N0001B02; Roche) was purchased by Synthon Biopharmaceuticals BV. SYD985 was prepared as previously described (29). Brieﬂy, vc-seco-DUBA was coupled to a cysteine residue of trastuzumab after partial reduction of the interchain disulﬁdes. SYD985 was further puriﬁed to deliver a well-deﬁned ADC predominantly consisting of species with a drug-to-antibody ratio (DAR) of 2 and 4, yielding a mean DAR of 2.8 (28, 29).

Immunostaining of cell blocks of primary CS
Cell blocks from all eight CS cell lines described in Table 1 and tumor blocks from OM(M)98 (i.e., a freshly established CS-PDX1 used in the in vivo experiments described below) were reviewed by a gynecologic surgical pathologist to confirm the presence of CS cells. Brieﬂy, HER2 immunohistochemical staining was performed on paraﬁn-embedded 5-μm sections of cell blocks after

Materials and Methods
Establishment of cell lines
Study approval was obtained from the Institutional Review Board at Yale University, and all patients signed consent prior to tissue collection according to the institutional guidelines. Eight primary CS cell lines (cell line characteristics, epithelial/stromal components of each cell line, and tissue source are described in Table 1) were established from chemotherapy-naive patients at the time of primary staging surgery after sterile processing of fresh tumor biopsy samples, as described previously and evaluated in our study (10, 12). All revived cells were used within 50 passages and cultured for less than 6 months. Tumors were staged according to the International Federation of Gynecology and Obstetrics staging system. Patient characteristics are noted in Table 1. Primary uterine and ovarian CS cell lines with limited passages were used in the experiments listed below and corresponding cell blocks were analyzed for syd985 with different DAR in situ hybridization (ISH).

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Table 1. Characteristics and demographic data of CS cell lines used

<table>
<thead>
<tr>
<th>Cell line</th>
<th>Age</th>
<th>Race</th>
<th>FIGO stage</th>
<th>Primary site</th>
<th>Histology</th>
<th>IHC</th>
<th>FISH</th>
<th>Flow cytometry (MFI)</th>
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<tr>
<td>SARARK-1*</td>
<td>70</td>
<td>A</td>
<td>IC</td>
<td>Uterus</td>
<td>Homologous</td>
<td>ESS</td>
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<tr>
<td>SARARK-3</td>
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<td>W</td>
<td>IIIC</td>
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<td>ESS</td>
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<td>22.8</td>
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<tr>
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<td>W</td>
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<td>CDRS</td>
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</tr>
<tr>
<td>SARARK-6*</td>
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<td>W</td>
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<td>Ovary</td>
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<td>CDRS</td>
<td>3+</td>
<td>A</td>
</tr>
<tr>
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<td>55</td>
<td>W</td>
<td>IV</td>
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<td>Homologous</td>
<td>CDRS</td>
<td>1+</td>
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</tr>
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<td>IIIC2</td>
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<td>ESS</td>
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<td>A</td>
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<td>Homologous</td>
<td>ESS</td>
<td>1+</td>
<td>NT</td>
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</table>

Abbreviations: A, amplified; CC, clear cell; CDR, chondroid; CDRS, chondrosarcoma; EC, epithelial component; END, endometrioid; ESS, endometrial stromal sarcoma; FIGO, International Federation of Gynecology and Obstetrics; FISH, fluorescent in situ hybridization; IHC, immunohistochemistry; MFI, mean fluorescence intensity; NA, not amplified; NT, not tested; SC, sarcomatous component; SER, serous; UND, undifferentiated.

*Cell lines used in vitro and in vivo experiments.

deparaffinization and rehydration, using the c-erbB-2 antibody (Thermo Fisher Scientific) at 1:800 dilution. HER2 staining intensity was graded per the American Society of Clinical Oncology and the College of American Pathologists (ASCO/CAP) 2013 breast scoring criteria (20). Appropriate positive and negative controls were used with each case.

FISH of cell blocks from primary CS

FISH analysis was performed using the PathVysion HER2 DNA FISH Kit (Abbott Molecular Inc.) according to the manufacturer’s instructions. Cell block sections of 5 μm were deparaffinized and rehydrated, followed by acid pretreatment and proteinase K digestion. A probe mix containing an orange probe directed against the HER2 gene (Vysis, Inc., LSI HER2) and a green probe directed against the pericentromeric region of chromosome 17 (Vysis CEP 17) were added and specimens were denatured for 5 minutes at 73°C. Slides were then incubated overnight in a humidity chamber at 37°C and washed the day after when a fluorescence mounting medium, containing 4,6-diamidino-2-phenylindole (DAPI), was applied. Fluorescent signals in at least 30 nonoverlapping interphase nuclei with intact morphology were scored using a Zeiss Axiosplan 2 microscope (Carl Zeiss Meditec, Inc.) with a 100× planar objective, using a triple band-pass filter that permits simultaneous blue, green, and red colors. Tumor cells were scored for the number of orange (HER2) and green (chromosome 17) signals. A case was scored as amplified when the ratio of the number of fluorescent signals of HER2 to chromosome 17 was ≥2.

Tests for ADCC

Standard 4-hour chromium (⁵¹Cr) release assay was performed to measure the cytotoxic reactivity of Ficoll–Hiapycase-separated peripheral blood lymphocytes (PBL) from several healthy donors in combination with trastuzumab, T-DM1, and SYD985 against primary CS target cell lines at effector-to-target ratios (E:T) of 20:1 and 40:1. The release of ⁵¹Cr from target cells was measured as evidence of tumor cell lysis after exposure of the tumor cells to 2.5 μg/mL of trastuzumab or 2.5 μg/mL of T-DM1 and SYD985.

Dose–response experiments were performed in order to determine the optimal antibody dosing for ADCC experiments. The negative control condition was the incubation of target cells alone. As a positive control condition, 0.1% sodium dodecyl sulfate (SDS) was used to achieve complete lysis of target cells. Chimeric anti-CD20 mAb rituximab 2.5 μg/mL was used as the negative control for trastuzumab, T-DM1, and SYD985 in all bioassays. The percentage cytotoxicity of trastuzumab or T-DM1 was calculated by the following formula: % cytotoxicity = 100 × (E – S)/(T – S), where E is the experimental release, S is the spontaneous release by target cells, and T is the maximum release by target cells lysed with 0.1% SDS.

Cell viability assay

CS cell lines were plated at log phase of growth in 6-well tissue culture plates at a density of 20,000 to 40,000 cells in RPMI 1640 media (Life Technologies) supplemented with 10% fetal bovine serum, 1% penicillin/streptomycin (Mediatech), and 0.3% fungizone (Life Technologies). Cells were incubated at 37°C, 5% CO₂. After 24 hours of incubation, cells were treated with SYD985, T-DM1, trastuzumab, and isotype control ADC (i.e., rituximab conjugated to vc-seco-DIUA: SYD989). SYD985, T-DM1, and SYD989 were used at scalar concentrations of 0.005, 0.05, 0.5, 2 μg/mL, and 8 μg/mL. Trastuzumab was used at concentrations of 1, 5, 10, 40, and 100 μg/mL. Three days after drug treatment, cells were harvested in their entirety, centrifuged, and stained with propidium iodide (2 μL of 500 μg/mL stock solution in PBS). Analysis was performed using a flow cytometry–based assay to quantify percent viable cells as a mean ± SEM relative to untreated cells as 100% viable controls. A minimum of three independent experiments per cell line were performed.

Bystander killing

Briefly, a 1:1 ratio of HER2/neu 3+ positive CS cells (i.e., SARARK-6) and HER2/neu-negative USC cells (i.e., USC ARK-4) stably transfected with a Green Fluorescence Protein (GFP) plasmid (pCDH-CMV-MCSEF1-copGFP, a kind gift from Dr. Simona Colla, MDACC) were mixed (20,000 cells/well of each
cell type) and plated in 6-well plates (3 mL/well). After an overnight incubation, SYD985, T-DM1, or isotype control ADC at a concentration of 1 μg/mL or vehicle were added. After a 72-hour incubation, cells were harvested in their entirety, centrifuged, and stained with propidium iodide (2 μL of 500 μg/mL stock solution in PBS) to facilitate the identification of dead CS cells. Analysis was performed using flow cytometry–based assay to recognize to quantify percent viable cells as a mean ± SEM relative to untreated cells as 100% viable controls. A minimum of three independent experiments were performed.

**In vivo treatment**

The in vivo antitumor activity of SYD985 versus T-DM1 was tested in xenograft models with 3+ and 1+ HER2/neu expression established from primary CS cell lines and in freshly explanted PDXs with 3+ HER2/neu expression. Specimen collection and all animal experiments were approved by the institutional ethical committee (HIC) and Institutional Animal Care and Use Committee (IACUC) of Yale University. Briefly, 6- to 8-week-old CB-17/SCID mice were given a single subcutaneous injection of 7 × 10^6 CS SARARK-6 cells (HER2/neu 3+) in approximately 200 μL of a 1:1 solution of sterile PBS containing cells and Matrigel (BD Biosciences) while for the PDX experiments, the 3+ HER2/neu CS OM(M)98 (i.e., CS-PDX1) was obtained from a surgical specimen at the time of a staging procedure of a CS patient (stage IVB) and placed into a sterile Petri dish containing phosphate-buffered saline (PBS), then sliced into 5 × 5 × 2 mm fragments. Typically, one fragment was implanted into a subcutaneous area in the right or left flanks in combination with matrigel. The size of the implanted tumor was checked 1 to 3 times per week using Vernier calipers when the implanted tissue was palpable, and the volume was calculated as (length × width^2)/2. Once the tumor volume was approximately 0.2 cm^3 for the xenografted cell lines and about 0.4 cm^3 for the PDX, the mice were randomized into treatment groups (n = 5); those treated with SYD985 (3 mg/mg and 10 mg/kg), T-DM1 (10 mg/kg), isotype control ADC (SYD989; 3 mg/kg and 10 mg/kg), and PBS. Drug dosages were chosen according to previous studies conducted on different xenograft models (28, 29). All treatment drugs were given as a single intravenous (i.v.) injection based on prior literature (28, 29). Mice were observed for overall survival as the primary outcome measure. Tumor measurements were recorded twice weekly. Mice were sacrificed if tumor volume reached 1.5 cm^3 using the formula (width)^2/height/2. Animal care and euthanasia were carried out according to the rules and regulations as set forth by the IACUC.

**Statistical analysis**

Statistical analysis was performed using GraphPad Prism version 6 (GraphPad Software, Inc.). The differences in ADC levels by 4-hour chromium release assays as well as the inhibition of proliferation in the CS cell lines after exposure to SYD985 were evaluated by the two-tailed unpaired student *t*-test. Overall survival data were analyzed and plotted using the Kaplan–Meier method. Survival curves were compared using the log-rank test. Differences in all comparisons were considered statistically significant at *P* < 0.05.

**Results**

**HER2/neu expression in primary CS cell lines**

We evaluated erbB-2 gene amplification by FISH and surface HER2/neu protein expression by IHC in eight primary CS culture cell lines (Table 1) as well as the tumor blocks obtained from OM(M)98 (i.e., CS-PDX1). Gene amplification and high levels (3+ staining) of HER2 protein expression by IHC were detected in 25% of the CS cell lines (i.e., 2 out of 8) and in OM(M)98. Of interest, as described in Fig. 1, OM(M)98 CS was found to harbor a...
3+ HER2/neu serous carcinoma component while the homologous sarcomatous component was found HER2 negative by IHC. Two cell lines had low (1+) and four had negligible (0) HER2 expression on IHC, while there were no cell lines with 2+ expression (Table 1). On the basis of the HER2/neu results, we selected a total of 4 primary CS cell lines with similar growth rate and different HER2 expression and OM(M)98 (i.e., CS-PDX1) for the additional in vitro and in vivo experiments described below.

SYD985, T-DM1, and trastuzumab mediated ADCC against HER2-positive primary CS

Three representative primary CS cell lines were tested for their sensitivity to PBL-mediated cytotoxicity when challenged with heterologous PBLs collected from several healthy donors in standard 4-h 51Cr release assays. CS cell lines were consistently found to be resistant to PBL-mediated cytotoxicity when combined with PBLs and isotype control ADC (2.5 μg/mL) at E:T ratios of 20:1 and 40:1 (mean ± SEM cytotoxicity of 3.8% ± 0.40% with PBL alone and mean ± SEM cytotoxicity of 5.45% ± 0.15% in the presence of isotype control ADC + PBL, respectively; Fig. 2). We then investigated the sensitivity of CS cell lines to heterologous PBLs in the presence of trastuzumab, SYD985, and T-DM1 at 2.5 μg/mL (Fig. 2). SYD985, T-DM1, and trastuzumab (T) were similarly effective in inducing strong ADCC against primary CS cell lines expressing HER2/neu at high levels (i.e., SARARK-6, SARARK-9) with mean cytotoxicity ± SEM = 53.9% ± 7.08% for SYD985 versus 72.9% ± 10.55% for T-DM1 versus 56.7% ± 8.16% for Trastuzumab, P = 0.744. Similarly, no significant differences between SYD985, T-DM1, or trastuzumab in the induction of ADCC were detected against CS cell lines with low (1+) HER2 expression (P = 0.2455; Fig. 2).

Cytotoxicity of SYD985 versus T-DM1 in vitro

Next, we exposed four cell lines with different HER2/neu expression (Table 1) to scalar concentrations of ADC in the absence of PBL for a total of 3 days. As representatively demonstrated in Fig. 3, SYD985 was significantly more potent in inducing cell death than T-DM1 in all CS cell lines tested regardless of the level of HER2/neu expression (Fig. 3). In the HER2/neu 3+ cell lines, SYD985 exhibited a mean IC50 of 0.013 μg/mL while T-DM1 exhibited a mean IC50 = 0.096 μg/mL (P < 0.0001). In the HER2/neu 1+ cell lines, SYD985 exhibited a mean IC50 of 0.060 μg/mL while T-DM1 exhibited a mean IC50 = 3.221 μg/mL (P < 0.0001).

Bystander killing in vitro

Next, we evaluated the ability of SYD985 and T-DM1 to induce bystander cytotoxicity of CS cells with low/negligible HER2 expression (i.e., GFP-ARK-4) when admixed with SARARK-6 (HER2/neu 3+) cells for 96 hours. As shown in Fig. 4A for SYD985, while no increase in SARARK-6 killing was noted when SARARK-6 cells were cocultured with ARK-4 (P = 0.17), SARARK-6/ARK-4 cocultures yielded a significant increase (i.e., 42%, P = 0.01) in the amount of bystander killing of HER2-low/negligible ARK-4 cells when compared with controls. In contrast, minimal bystander cytotoxicity was detected when SARARK-6/ARK-4 cocultures were challenged with T-DM1 (i.e., 3%, P = 0.16) or isotype control ADC for 96 hours (Fig. 4B and C, respectively).

In vivo antitumor activity of SYD985 versus T-DM1

The in vivo effects of SYD985 and T-DM1 were determined by establishing xenografts from primary CS cell lines with 3+ and 1+ HER2/neu expression (i.e., SARARK-6 and SARARK-7, respectively) and PDXs with 3+ HER2/neu expression (i.e., OM(M)98). As described in Materials and Methods, after the tumors had reached the goal size, animals were randomized into treatment groups and treated as described previously (31). Tumors were assessed once weekly and mice were sacrificed if tumors became necrotic, reached a volume of 1.5 cm3, or mice appeared to be in poor health. Treatment with a single injection of SYD985 showed remarkable inhibition of tumor growth in mice harboring both xenografts and PDX with 3+ HER2/neu expression as well as against xenografts with 1+ HER2/neu expression (Fig. 5A, C and E). Specifically, in SARARK-6 (HER2/neu 3+) xenografts, we detected a significant difference in growth inhibition between animals treated with SYD985 3 mg/kg (P = 0.0006 at 29 days) and 10 mg/kg (P = 0.00001 at 29 days) when compared with T-DM1 at 10 mg/kg (Fig. 5A). Accordingly, a significant survival advantage was seen in SYD985-treated xenografts (Fig. 5B). Specifically, when comparing SYD985 10 mg/kg single injection to T-DM1 10 mg/kg single injection, there was a significant difference in mean overall survival of 85 days versus 43 days, respectively, (P = 0.0079). The significant survival difference was maintained when SYD985 3 mg/kg single injection was compared with T-DM1 10 mg/kg, with mean overall survival of 75 days versus 43 days, respectively (P = 0.0238). Notably, 5 out of 5 (100%) and 3 out of 5 (60%) of the mice were alive and disease-free at
SYD985 Is a Novel ADC Active in Gynecologic Carcinosarcomas

90 days after a single injection of SYD985 at a dose of 10 and 3 mg/kg, respectively. In contrast, there was no statistically significant difference in mean overall survival when comparing SYD989 10 mg/kg single injection to T-DM1 10 mg/kg single injection (mean overall survival of 37 days versus 43 days, respectively; $P = 0.5873$). Survival benefit in mice treated with 10 mg/kg of isotype control ADC was inferior to SYD985 dosed at both 3 and 10 mg/kg (Fig. 5B), indicating that SYD985-induced antitumor activity in these models is at least partly mediated through HER2. Importantly, SYD985 was also highly active against OM(M)98, a HER2/neu 3+ cell line (Fig. 5C). Specifcally, we detected a significant difference in growth inhibition between animals treated with SYD985 3 mg/kg ($P < 0.005$ at 7 days) and 10 mg/kg ($P < 0.005$ at 7 days) when compared with T-DM1 at 10 mg/kg (Fig. 5C). Accordingly, a significant survival advantage was seen in SYD985-treated PDX when compared with control treatments (Fig. 5D). Specifically, when comparing SYD985 10 mg/kg single injection to T-DM1 10 mg/kg single injection, there was a significant difference in the median overall survival of 108 days versus 17 days, respectively ($P = 0.02$). When comparing SYD985 3 mg/kg single injection to T-DM1 10 mg/kg single injection there was also a significant difference in median overall survival—42 days versus 17 days, respectively ($P < 0.005$).

To confirm the activity of SYD985 in vivo in low HER2/neu expressing tumors, additional experiments were performed by establishing xenografts from a primary CS cell line with 1+ HER2/neu expression (i.e., SARARK-7). Similarly to the in vivo results with the HER2/neu 3+ CS models, in SARARK-7 xenografts the difference in growth inhibition between animals treated with SYD985 3 and 10 mg/kg when compared with T-DM1 at 10 mg/kg was highly significant (i.e., $P = 0.0002$ at 25 days and $P = 0.00009$ at 22 days, respectively; Fig. 5F). Accordingly, a significant survival advantage was seen in SYD985-treated xenografts (Fig. 5F). Specifically, when comparing SYD985 10 mg/kg single injection to T-DM1 10 mg/kg single injection, there was a significant difference in the mean overall survival of undefined days versus 25 days, respectively ($P = 0.0018$).

Discussion

CSs are rare but highly aggressive gynecologic cancers composed of both an epithelial and sarcomatous component. Their rarity, aggressive biologic nature, and rapid development of chemotherapeutic resistance make these tumors difficult to cure and extremely difficult to study within clinical trials.

Our group has recently used whole exome sequencing (WES) to analyze the genetic landscape of a large number of uterine and ovarian CS as well as multiregion WES to resolve the evolutionary histories of the carcinomatous and sarcomatous elements (10). In this comprehensive report, in agreement with previously published clinical data (35), we demonstrated at molecular level that carcinomatous and sarcomatous elements derive from a common precursor having mutations typical of carcinomas (10). These results raised the possibility that treatments targeting genes and pathways within the carcinomatous elements such as HER2 may prove efficacious in treating both carcinomatous and sarcomatous elements (10).

As of April 2015, the FDA has approved five therapies for HER2-positive breast, gastric, and non–small cell lung cancer patients. The first class of drugs includes monoclonal antibodies against the extracellular domain of the HER2 receptor, including trastuzumab, ado-trastuzumab emtansine (T-DM1), and pertuzumab (27, 36, 37). In addition to these antibodies, two FDA-approved small-molecule tyrosine kinase inhibitors (TKI), lapatinib and afatinib, inhibit the intracellular kinase domain of the HER receptor to prevent signaling. In contrast to breast cancer, therapy with trastuzumab alone (i.e., GOG 181B; ref. 38) and lapatinib alone (i.e., GOG 229D; ref. 39) revealed no responses in women with recurrent HER2-overexpressing endometrial cancer. While there is disagreement regarding the reasons why trastuzumab and lapatinib failed to demonstrate any significant durable clinical benefit (40),
these clinical trials do suggest, as recently demonstrated by our research group (41, 42), that the limited benefit in endometrial cancer patients may be at least partially due to an innate or rapidly acquired resistance to drugs targeting the HER2/neu pathways.

In an effort to optimize the use of HER2 blockade in the next phase of CS treatment and meaningfully alter patient outcomes, multiple groups, including our own, have investigated the frequency of HER2 expression in uterine and ovarian CS with a reported range of overexpression of 25% to 56% (32–34, 43, 44). Along these lines, Nicoletti and colleagues recently compared the activity of T-DM1 and trastuzumab (T) against HER2-positive and -negative primary CS cell lines in vitro followed by developing a supportive CS in vivo model. In Nicoletti’s study, T-DM1 and T were similarly effective in inducing strong ADCC against CS-overexpressing HER2 at 3+ levels. In contrast, T-DM1 was dramatically more effective than T in inhibiting cell proliferation and, more importantly, in reducing tumor formation in CS xenografts overexpressing HER2 with a significantly longer survival when compared with T (44). Unfortunately, the activity of TDM-1 was evaluated in this study only against HER2/neu 3+ CS by IHC and c-erbB gene–amplified endometrial cancer cell lines.

Expanding the patient population who would benefit from HER2-targeted therapies to patients harboring tumors with low (1+) or moderate (2+) HER2/neu expression might significantly expand the number of treatment-eligible patients. Consistent with this view, Black and colleagues investigated the efficacy of SYD985 in USC and compared the antitumor activity of SYD985 to T-DM1 against multiple primary USC cell lines expressing different levels of HER2/neu both in vitro and in vivo (31). The data from Black and colleagues’ study demonstrated a remarkable antitumor activity of SYD985 against USC with not only strong (3+) but also with low to moderate (i.e., 1+/2+) HER2/neu expression (31). In agreement with Black’s results in USC, in the current study, we were able to demonstrate potent antitumor activity of SYD985 against both CSs with high (i.e., 3+) and low (i.e., 1+) HER2 expression. Importantly, our experiments demonstrated that SYD985 has consistently stronger cytotoxicity, more importantly, in reducing tumor formation in CS xenografts overexpressing HER2 with a significantly longer survival when compared with T (44). Unfortunately, the activity of TDM-1 was evaluated in this study only against HER2/neu 3+ CS by IHC and c-erbB gene–amplified endometrial cancer cell lines.

In vivo data in multiple animal models harboring CS xenografts with 3+ and 1+ HER2/neu expression. In this regard, while SYD985 and T-DM1 evoked similar levels of ADCC against HER2/neu-expressing CS cell lines in the presence of effector PBLs, SYD985 was significantly more cytotoxic against primary CS cell lines with HER2/neu expression of 1+ and 3+ in the absence of PBLs. Specifically, in HER2/neu 3+ cell lines, we found SYD985 to be more than 7 folds more potent than T-DM1 (P < 0.0001) in inducing cell death, while in HER2/neu 1+ cell lines, SYD985 was 54 folds more potent than T-DM1. In vivo data in multiple animal models harboring CS xenografts with 3+ and 1+ HER2/neu expression and PDx with 3+ HER2/neu expression were confirmatory of the in vitro results demonstrating high efficacy of SYD985. Indeed, one injection of SYD985 was enough to cure 100% and 60% of the mice harboring 3+ HER2/neu cells without any recurrence when treated with 10 and 3 mg/kg, respectively (45).

Cytotoxicity induced on HER2 3+ CS (SARARK-6), HER2 0/1+ USC (ARK-4), and SARARK-6/ARK-4 cocultures with 1 μg/mL of SYD985, T-DM1, and ADC-isotype control. A significant increase in the amount of killing of HER2 0/1+ USC cells was detected when compared with control (P = 0.01) after treatment with SYD985 Cell viability of ARK-4 decreased from 94% to 52% after coincubation of ARK-4 with SARARK-6, showing bystander killing effect of SYD985 in the presence of HER2 3+ cell line SARARK-6. B, Cytotoxicity induced on HER2 3+ CS (SARARK-6), HER2 0/1+ USC (ARK-4), and SARARK-6/ARK-4 cocultures with 1 μg/mL of SYD985 (T-DM1). No significant increase in the amount of killing of HER2 0/1+ USC cells was detected when compared with control (P = 0.29) after treatment with T-DM1. Cell viability of ARK-4 decreased from 98% to 95% after coincubation of ARK-4 with SARARK-6, which failed to show any bystander killing effect of T-DM1 in the presence of HER2 3+ cell line SARARK-6. C, Cytotoxicity induced on HER2 3+ CS (SARARK-6), HER2 0/1+ USC (ARK-4), and SARARK-6/ARK-4 cocultures with 1 μg/mL of SYD989 (isotype control ADC). No significant increase in the amount of killing of HER2 0/1+ USC cells was detected when compared with control (P = 0.51) after treatment with isotype control ADC.
view, we found SYD985 to be significantly more potent than T-DM1 in its ability to induce bystander killing of low/negative HER2/neu expressing tumor cells admixed with HER2/neu-positive tumor cells (31). Taken together, these results strongly suggest that SYD985 may represent a significantly more effective therapeutic tool when compared with T-DM1 or trastuzumab in HER2/neu-expressing CS. Indeed, SYD985 may be effective not only against CS with low to moderate HER2/neu expression in the epithelial component but also against the mesenchymal components of CS, which is commonly reported to have negligible HER2/neu expression. Consistent with this view, encouraging clinical results have recently been reported with SYD985 in phase I clinical trials in patients with locally advanced or metastatic solid tumors (NCT02277717; ref. 30).

In conclusion, we have demonstrated that SYD985 is a novel ADC active in gynecologic carcinosarcomas.
T-DM1 is significantly active against the epithelial CS component overexpressing HER2/neu but also, potentially, against sarcomatous CS components showing low to negligible HER2/neu expression (i.e., bystander killing). Clinical studies with SYD985 in CS patients harboring disease resistant to standard salvage chemotherapy are warranted.

Disclosure of Potential Conflicts of Interest
No potential conflicts of interest were disclosed.

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