result of an occluded SEMS/PS, time to recurrent biliary obstruction is a robust estimation of stent outcomes because occlusion and migration are treated as a composite endpoint.

COMPLICATIONS OTHER THAN RECURRENT BILIARY OBSTRUCTION

COMPLICATIONS OTHER THAN recurrent biliary obstruction after SEMS/PS placement were not defined clearly in any of the five published fully randomized controlled trials. We decided on the definitions and severity of these complications, and these are shown in Table 2. Complications other than recurrent biliary obstruction can be categorized as follows: pancreatitis; cholangitis (non-occlusion cholangitis); cholecystitis; and others (bleeding, ulceration, penetration, perforation etc.).

These complications are categorized as early (within 30 days) and late (31 days or later). The severity of pancreatitis, cholangitis, cholecystitis, bleeding, and perforation was graded using the system proposed by Cotton *et al.*[23] The time point of complications is defined as the point when symptoms associated with these conditions are observed. The severity of pancreatitis was defined based on both Cotton's grading and the Atlanta classification 2012.[23,24]

Pancreatitis

A widely used consensus definition of post-ERCP pancreatitis is: (i) new or worsened abdominal pain; (ii) new or prolonged hospitalization for at least 2 days; and (iii) serum amylase ≥threefold the upper limit of normal, measured >24 h after the procedure.[25]

Cholangitis (non-occlusion cholangitis)

Cholangitis as a result of SEMS/PS occlusion is classified as 'stent occlusion'. Non-occlusion cholangitis is diagnosed when a fever >38°C continues >24 h with cholestasis observed, and when there is neither biliary dilation on imaging studies nor a definite finding of SEMS/PS occlusion or migration at the time of a reintervention.

Cholecystitis

Cholecystitis is diagnosed when a fever >38°C or right upper abdominal pain occurs with supportive imaging studies.

Other complications (bleeding, perforation etc.)

We recommend that bleeding after stent placement is defined as clinical evidence of bleeding with a hemoglobin drop of >3 g/dL. We recommend that perforation be defined as evidence of air or luminal contents outside the gastrointestinal tract. All other complications that are thought to be caused by SEMS/PS placement should also be documented.

Finally, we summarize the items that should be described in studies to evaluate stents used for malignant biliary obstruction (Table 3). We should evaluate endoscopic transpapillary biliary stenting in the same manner to compare clinical studies.

Table 3 Outcomes to be described in studies on stents for malignant biliary obstruction

Technical and functional success rates	
Recurrent biliary obstruction (RBO)	The incidence of RBO during the observed period (requiring the description of observational time). Median time to RBO (TRBO) estimated using the Kaplan–Meier method. Non-obstruction rates at 3, 6 and 12 months estimated using the Kaplan–Meier method. Comparison using the log–rank test.
Causes of recurrent biliary obstruction √ Rate of each cause √ Median time from placement √ Early (within 30 days) or late (≥31 days)	Occlusion √ Tumor ingrowth/mucosal hyperplasia √ Tumor overgrowth √ Sludge with/without stone √ Food impaction √ Hemobilia √ Kinking of bile duct √ Other Symptomatic migration (requiring any intervention) √ Proximal √ Distal
Complications other than recurrent biliary obstruction √ Rate of each cause √ Median time from placement √ Early (within 30 days) or late (≥31 days) √ Severity (Table 2)	√ Pancreatitis √ Cholecystitis √ Non-occlusion cholangitis √ Other (bleeding, ulceration, penetration, perforation etc.) √ Complications associated with stent placement procedure (perforation, bleeding with scope, desaturation of oxygen, aspiration pneumonia etc.)
Survival time	

Complications associated with stent placement procedure

We should evaluate all types of complication related to stent placement. The following complications were associated with scope or devices: peroration, bleeding, desaturation of oxygen, aspiration pneumonia etc.

CONCLUSIONS AND THE FUTURE

WE PROPOSE A standardized system, TOKYO criteria 2014, for reporting endoscopic transpapillary biliary stenting for biliary stricture. These consensus-based criteria include definitions of complications and appropriate evaluation of stent quality. For some time, we have used the term 'stent patency', but that did not include migration. Therefore, we adopted the term 'recurrent biliary obstruction' instead of 'stent occlusion'. Henceforth, we should use 'time to recurrent biliary obstruction' to evaluate stent quality. It is important to be able to compare biliary stent quality across studies using the TOKYO criteria 2014.

We can drain the bile duct using either transpapillary or EUS-guided transmural procedures. Therefore, we should also devise an evaluation method that includes transmural stenting in the near future.

CONFLICT OF INTERESTS

AUTHORS DECLARE NO conflict of interests for this article.

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Streptozocin chemotherapy for advanced/metastatic well-differentiated neuroendocrine tumors: an analysis of a multi-center survey in Japan

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Abstract

Background Neuroendocrine tumors (NETs) are believed to be relatively rare and to follow a generally indolent course. However, liver metastases are common in NET patients and the outcome of NET liver metastasis is poor. In Western countries, streptozocin (STZ) has been established as a first-line anticancer drug for unresectable NET; however, STZ cannot be used in daily practice in Japan. The aim of the present study was to determine the status of STZ usage in Japan and to evaluate the effectiveness and safety of STZ chemotherapy in Japanese NET patients.

Methods A retrospective multi-center survey was conducted. Five institutions with experience performing STZ chemotherapy participated in the study. The patient demographics, tumor characteristics, context of STZ chemotherapy, and patient outcome were collected and assessed.

Results Fifty-four patients were enrolled. The main recipients of STZ chemotherapy were middle-aged patients with pancreatic NET and unresectable liver metastases. The predominant regimen was the weekly/bi-weekly intravenous administration of STZ combined with other oral anticancer agents. STZ monotherapy was used in one-fourth of the patients. The median progression-free and overall survival periods were 11.8 and 38.7 months, respectively, and sustained stable disease was obtained in

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some selected patients. The adverse events profile was mild and tolerable.

Conclusions Our survey showed the clinical benefit and safety of STZ therapy for Japanese patients with unresectable NET. Therefore, we recommend that STZ, which is the only cytotoxic agent available against NET, should be used in daily practice in Japan.

Keywords Neuroendocrine tumors · Streptozocin · Multi-center survey · Tumor response · Progression-free survival rate

Introduction

Neuroendocrine tumors (NETs) have been regarded as relatively rare neoplasms, but the number of patients with NET is increasing in the US [1], Europe [2], and Japan [3, 4]. The epidemiological pattern of NET is highly heterogeneous; for example, the tumor location, biological behavior (functioning NET or non-functioning NET), and percentage of distant metastases differ extensively among databases. Therefore, the clinical outcomes of the various treatment modalities also differ according to the characteristics of the study cohort.

The clinical course of well-differentiated NET (NET G1 or NET G2) is believed to be generally indolent, but some previous studies have documented that 40–95 % of NET patients are metastatic at presentation, and the 5-year survival rate is 56–83 % for metastatic intestinal NETs and 40–60 % for metastatic pancreatic NETs. Thus, optimal management of metastatic lesions, especially of liver metastases, is key to improving the outcomes of NET patients [5].

Streptozocin (STZ) was first discovered as an antibiotic derived from *Streptomyces achromogenes*, and was approved in the US as a cytotoxic antitumor drug for symptomatic or advanced pancreatic NET in 1982. In Western countries, STZ combined with doxorubicin (DOX) or fluorouracil (5-FU) has been established as a first-line chemotherapy for both pancreatic and gastrointestinal NETs based on several clinical trails including randomized clinical trials [6–12]. However, STZ has not been covered by the Japanese insurance system, and Japanese oncologists/gastroenterologists cannot choose this powerful option for the treatment of advanced or metastatic NETs.

Because of these specific circumstances, STZ chemotherapy has only been used in clinical trials in Japan. Therefore, the aim of the study was to investigate the actual situations in which STZ is used in Japan and to evaluate the effectiveness and safety of STZ chemotherapy among Japanese NET patients.

Methods

This study was conducted as a retrospective multi-center survey. Five institutions (The University of Tokyo Hospital, Tokyo; Osaka Saiseikai Noe Hospital, Osaka; Kyoto University Hospital, Kyoto; Japanese Red Cross Medical Center, Tokyo; and Yamagata University Hospital, Yamagata) with experience performing STZ chemotherapy participated in the present study.

Patients who were treated with STZ between September 1995 and November 2011 were included as the study subjects. The following clinicopathological factors were investigated: (1) sex, age at the start of STZ chemotherapy, date at the start of STZ chemotherapy, and performance status at the start of STZ chemotherapy; (2) clinical diagnosis, site of the primary tumor, age of tumor presentation, behavior of the tumor (functioning or non-functioning), presence or absence of metastasis, and metastatic site(s); (3) STZ treatment regimen, period of treatment, total dose of administered STZ, antitumor drugs used in combination with STZ; and (4) efficacy of STZ chemotherapy, adverse events, progression-free survival period, and overall survival period. The tumor response to STZ therapy was evaluated using RECIST criteria [13], and adverse events were assessed according to the National Cancer Institute Common Terminology Criteria for Adverse Events (CTCAE version 4.0). The survival curves were generated using Kaplan–Meier methods [14], and the differences among the curves were evaluated using a log-rank test [15]. Differences were considered significant when $P < 0.05$.

The protocol was approved by the local ethical committee of each institution that participated in the study. The clinical data were summarized in a blinded manner.

Results

Patients

The data of 54 patients were collected. The patient cohort consisted of 24 male and 30 female patients, and the median age was 54.0 years (range 24–76 years) at the onset of the disease and 56.0 years (range 31–77 years) at the start of STZ administration (Table 1). Regarding the distribution of age at the onset of the disease, a peak occurred at between 50 and 59 years, followed by a second peak at 60–69 years (as shown in the Electronic supplementary material). The performance status of most of the patients was 0 or 1 (Table 1).

Tumor characteristics

The characteristics of the tumors are summarized in Table 1. Forty-two patients had pancreatic NET (P-NET),

Table 1 Patient demographics and tumor characteristics

Parameters	No. of patients	Percent (%)
Sex		
Male	24	44.4
Female	30	55.6
Age at onset		
Mean	52.5	
Median	54.0	
Range	24–76	
Age at the beginning of STZ administration		
Mean	56.0	
Median	56.0	
Range	31–77	
Performance status		
0	34	63.0
1	17	31.5
2	3	5.5
3–4	0	0.0
Primary site		
Pancreaticoduodenal NET	(46)	(85.2)
Pancreas head	12	26.1
Pancreas body	10	21.7
Pancreas tail	19	41.3
Head, body and tail	1	2.2
Duodenal	4	8.7
Gastrointestinal NET	(8)	(14.8)
Stomach	2	25.0
Small Intestine	1	12.5
Rectum	4	50.0
Others	1	12.5
Pathological diagnosis (WHO 2000)		
Well-differentiated endocrine tumor	0	0.0
Well-differentiated endocrine carcinoma	52	96.4
Poorly-differentiated endocrine carcinoma/ small cell carcinoma	1	1.8
Others	1	1.8
Functioning NET/non-functioning NET		
Functioning	(18)	(33.3)
Gastrinoma	9	16.7
Insulinoma	7	13.0
Glucagonoma	4	7.4
Somatostatinoma	1	1.9
Serotonin, tachykinins producing tumor	1	1.9
Non-functioning	(36)	(66.7)
Metastatic site(s)		
Liver	53	98.1
Lymph nodes	26	48.1
Peritoneum	3	5.6
Lung	2	3.7
Others	10	18.5

and the duodenum and gastrointestinal tract were the original sites in 4 and 8 patients, respectively. The pathological diagnosis based on the WHO Classification 2000 was well-differentiated endocrine carcinoma in 52 patients (96.4 %). One-third of the tumors ($n = 18$) were functioning, with 9 gastrinomas and 7 insulinomas; the other two-thirds were non-functioning NETs. All the patients had metastatic sites: all but one patient had liver metastasis, with lymph node metastasis being the second most common site ($n = 26$, 48.1 %).

STZ therapy

STZ chemotherapy was used as a first-line therapy in 39 patients, as a second-line therapy in 11 patients, and as a third-line therapy in 4 patients. The treatments used prior to STZ chemotherapy included transcatheter arterial chemoembolization (TACE), octreotide, 5FU, and gemcitabine.

STZ was administered intravenously in 35 patients (64.8 %) and intra-arterially in 3 patients. Both routes were used in 15 patients. The dosing regimen was daily [350–500 mg/m^2 of STZ administered for 5 consecutive days (days 1–5) every 6 weeks] in 14 patients and weekly or bi-weekly in 31 patients (350–1,000 mg/m^2 of STZ administered at each treatment).

Both regimens were used in 3 patients. Interestingly, the participating institutions in Eastern Japan applied a weekly or bi-weekly regimen, while the institutions in Western Japan applied a daily regimen.

Thirteen patients received STZ monotherapy, while a combination therapy was used in the other 41 patients. The combined antitumor agents included tegafur-uracil (UFT, $n = 26$), octreotide ($n = 20$), fluorouracil (5-FU, $n = 15$), and oral fluoropyrimidine (S-1, $n = 6$) (Table 2).

The dosing period ranged from 0 to 105 months, with a median of 12.4 months. The dosing period was within 20 months in most patients (Fig. 1a). The total amount of STZ administered ranged from 1.0 to 128.0 g (median 18.8 g) (Fig. 1b).

The tumor response as evaluated according to the RECIST criteria is shown in Table 3. The tumor response was CR in 2 patients, PR in 11 patients, SD in 9 patients, PD in 25 patients, and unknown in 7 patients, with a response rate of 27.7 %. The response to STZ monotherapy was CR in 1 patient, PR in 4 patients, SD in 1 patient, PD in 8 patients, and unknown in 4 patients, with a response rate of 35.7 %.

Documented adverse events included nausea ($n = 12$, 22.2 %), vomiting ($n = 7$, 13.0 %), and lethargy ($n = 4$, 7.4 %). Other adverse hematological, hepatobiliary, or nervous system events were observed in a few patients. Grade 3 adverse events were observed in 6 patients (3 nausea and 3 vomiting), but no grade 4 adverse events were documented (Table 4).New-onset diabetes mellitus was not

Table 2 STZ therapy

Parameters	No. of patients	Percent (%)
Dosing route		
Intravenous (IV)	35	64.8
Intra-arterial (IA)	3	5.6
IV/IA	15	27.8
Unknown	1	1.9
Dosing regimen		
Daily	14	25.9
Weekly/bi-weekly	31	57.4
Daily/weekly	3	5.6
Others	6	11.1
Antitumor agents combined with STZ		
Doxorubicin	1	1.9
Fluorouracil (5-FU)	15	27.8
Oral fluoropyrimidine (S-1)	6	11.1
Tegafur-uracil (UFT)	26	48.1
Octreotide	20	37.0
Mitomycin C	3	5.6
Interferon	1	1.9
Sunitinib	1	1.9
None (STZ monotherapy)	13	24.1

documented, but the control of the disease was impaired during STZ therapy in one patient who had been treated for diabetes mellitus.

STZ therapy was discontinued in 46 patients. The reasons for the discontinuation were tumor progression in 43 patients, conversion to other treatments in 2 patients, and a severe adverse event in 1 patient.

Patient outcome

Data regarding patient outcome were available for 38 patients. The progression-free and overall survival curves are shown in Figs. 2 and 3. The median progression-free period was 11.8 months in all of the patients (mean 23.0 ± 3.5 months), 7.6 months in the functioning NET patients, and 16.8 months in the non-functioning NET patients ($P = 0.14$). Meanwhile, the median survival period was 38.7 months in all of the patients (mean 28.7 ± 2.6 months), 23.6 months in the functioning NET patients, and 38.7 months in the non-functioning NET patients ($P = 0.32$).

The median amount of STZ administered was 18.8 g. When the patients were stratified according to the amount of STZ (≥18.8 or <18.8 g), both the overall survival rate and the progression-free survival rate were better in the patients who received ≥18.8 g STZ (see the Electronic supplementary material 2).

The overall and progression-free survival outcomes were similar among the patients who received a daily regimen and those receiving a weekly/bi-weekly regimen (data not shown). In addition, the outcomes did not differ between patients with pancreaticoduodenal NET ($n = 46$) and those with gastrointestinal NET ($n = 8$) (see the Electronic supplementary material 3).

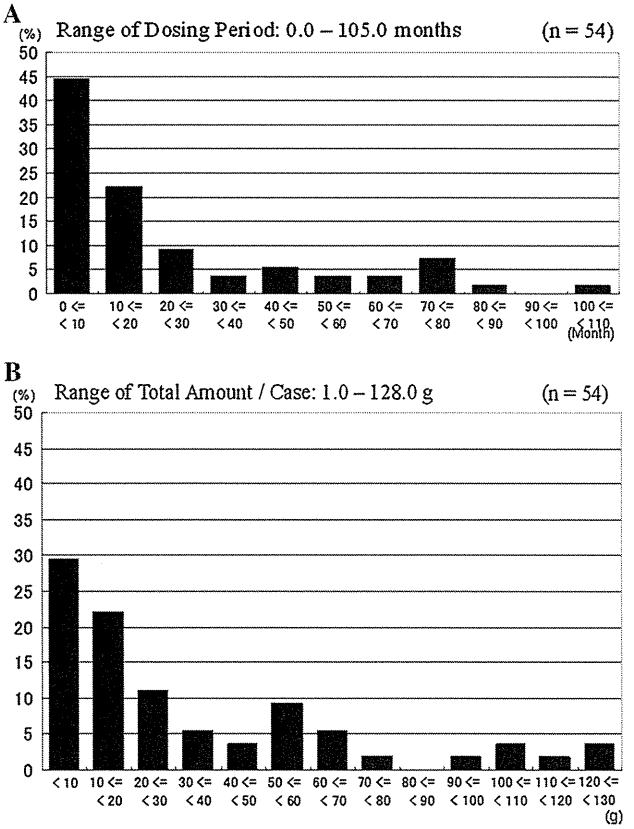

Fig. 1 Distribution of the dosing period (**a**) and the total amount of STZ administered (**b**) ($n = 54$)

Discussion

The present study was a retrospective multi-center cohort study in patients with unresectable NET receiving STZ chemotherapy. This is the first attempt to determine the circumstances surrounding chemotherapy for NET patients in Japan. The five participating centers were high-volume centers treating NET patients in Japan, and most of the patients who received STZ therapy before 2011 were thought to have been included in the study.

During the study period (from 1995 to 2011), octreotide was the only antitumor agent against NET available in Japan until everolimus and sunitinib began to be covered by the Japanese insurance system. STZ is not yet covered by the Japanese insurance system:, so STZ therapy had only been conducted on a clinical trial basis using imported

Table 3 Tumor response, evaluated according to the RECIST criteria

Tumor response according to RECIST criteria	All cases		Pancreaticoduodenal NET						Gastrointestinal NET					
			Subtotal		STZ monotherapy		Combination therapy		Subtotal		STZ monotherapy		Combination therapy	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
	54		46		14		32		8		4		4	
CR	2	4.3	2	5.3	1	11.1	1	3.4	0	0.0	0	0.0	0	0.0
PR	11	23.9	9	23.7	3	33.3	6	20.7	2	25.0	1	25.0	1	25.0
SD	9	19.6	8	21.1	1	11.1	7	24.1	1	12.5	0	0.0	1	25.0
PD	25	54.3	20	52.6	5	55.6	15	51.7	5	62.5	3	75.0	2	50.0
UK	7		7		4		3		0		0		0	

UK unknown

Table 4 Adverse events

Adverse events	*n*	%	CTCAE grade				
			G1	G2	G3	G4	Unknown
Gastointestinal disorder							
Abdominal pain	1	1.9	–	1	–	–	–
Diarrhea	2	3.7	1	1	–	–	–
Epigastric pain	1	1.9	1	–	–	–	–
Nausea	12	22.2	5	4	3	–	–
Acute pancreatitis	1	2.9	–	1	–	–	–
Vomiting	7	13.0	1	3	3	–	–
Hematolymphoid system disorder							
Leukopenia	1	1.9	1	–	–	–	–
Neutropenia	2	3.7	1	1	–	–	–
Thrombocytopenia	1	1.9	1	–	–	–	–
Ocular lesion							
Abnormal ocular sensation	1	1.9	–	–	–	–	1
Hepatobiliary system disorder							
Liver function abnormality	1	1.9	1	–	–	–	–
Nerve system disorder							
Syncope	1	1.9	–	–	1	–	–
Headache	1	1.9	–	–	–	–	1
Others							
Lethargy	4	7.4	3	1	–	–	–
Back pain	1	1.9	–	1	–	–	–

STZ at all of the institutions that participated in the present study. One of the aims of our study was to encourage the approval of STZ use in a daily clinical setting in Japan.

The results of the present study revealed that the main recipients of STZ chemotherapy were patients with P-NET (well-differentiated endocrine carcinoma based on the WHO Classification 2000) with liver metastases. The dosing routes and dosing regimens varied among the regions and institutions, but an intravenous weekly/bi-weekly regimen was popularly applied. The original regimen proposed by Moertel et al. [7] was a combination therapy of STZ with doxorubicin or STZ with fluorouracil (5-FU); however, in the present study, various antitumor agents were combined with STZ, and STZ monotherapy was applied in one-fourth of the patients. The reasons for this were likely twofold: first, the use of oral anticancer drugs, such as S-1 and UFT, is popular in Japan; second, the use of other cytotoxic anticancer drugs has not been approved.

Our results showed that the response rate was 27.7 % for all of the enrolled patients, and a subgroup analysis showed that the response rate was 28.2 % for pancreaticoduodenal NET patients and 25.0 % for gastrointestinal NET patients, respectively. In addition, STZ monotherapy was associated with a response rate of 35.7 % (40.0 % for pancreaticoduodenal NET and 25.0 % for gastrointestinal NET). These figures were comparable with those obtained in Western series in which radiological measurements were used to evaluate tumor response [10–12].

The dosing period was less than 10 months in 45 % of the patients, and 10–20 months in 22 % of the patients. As a result, the total amount of STZ adminstered was less than 20 g in over 50 % of the patients (Fig. 1b). These results corresponded to a median progression-free period of 11.8 months (Fig. 2). The figure of 11.8 months was similar to that obtained in studies examining everolimus and sunitinib [16, 17]. However, the progression-free survival curve in STZ therapy patients reached a plateau about 2 years after the start of the therapy (Fig. 2), showing a difference from the everolimus and sunitinib studies. This finding suggested that sustained stable disease can be expected in some selected patients receiving STZ, and that these patients can undergo STZ chemotherapy for a long period because of the mild adverse event profile. Actually, some patients in our study received STZ therapy for over 5 years. As expected, the

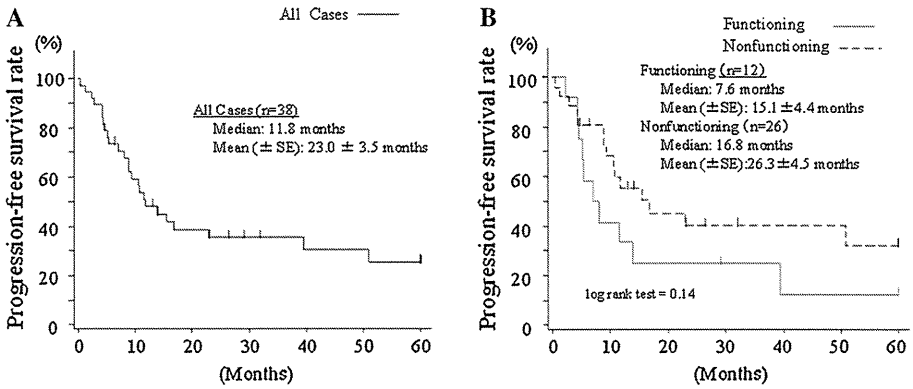

Fig. 2 Progression-free survival curves for all of the patients ($n = 38$) (**a**) and stratified according to functioning ($n = 12$) and non-functioning ($n = 26$) tumors (**b**)

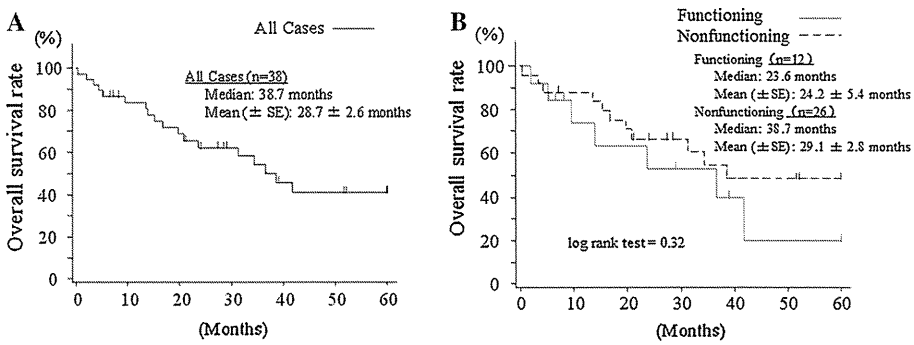

Fig. 3 Overall survival curves for all the patients ($n = 38$) (**a**) and curves stratified according to functioning ($n = 12$) and non-functioning ($n = 26$) tumors (**b**)

outcomes were better among the patients who received a larger dose of STZ (see the Electronic supplementary material 2). These results also support the idea that long-term STZ chemotherapy is associated with long-term SD maintenance. In our analyses, the progressions and overall survivals were comparable between the patients with functioning NET and those with non-functioning NET, suggesting that STZ is applicable to all NET patients with the same dosing regimen.

Our survey showed that the adverse events associated with STZ chemotherapy were acceptable. Studies using animal models showed that high-dose STZ administration induced impaired glucose tolerance, leading to diabetes mellitus. In the present survey, new-onset diabetes mellitus induced by STZ was not documented. In addition, STZ therapy was discontinued because of a severe adverse event in only one patient. This mild adverse event profile can likely be attributed to the relatively low-dose regimens performed in our series (350–500 mg/m^2 in the daily regimen, and 350–1,000 mg/m^2 regimen in the weekly/bi-weekly regimen).

In conclusion, our survey showed the clinical benefit and safety of STZ therapy for pancreaticoduodenal and gastrointestinal NET. Therefore, we recommend that STZ, the only cytotoxic agent available for NET, should be used in daily practice in Japan.

Acknowledgments This study was conducted by the NET Chemotherapy Investigation and Research Group in cooperation with NobelPharma Co. Ltd.

The context of the study was presented at the 49th Annual Meeting of the Japan Society of Clinical Oncology, November 2011, Nagoya.

Conflict of interest The authors declare that they have no conflict of interest.

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A targeting ligand enhances infectivity and cytotoxicity of an oncolytic adenovirus in human pancreatic cancer tissues

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ABSTRACT

The addition of a targeting strategy is necessary to enhance oncolysis and secure safety of a conditionally replicative adenovirus (CRAd). We have constructed an adenovirus library displaying random peptides on the fiber, and have successfully identified a pancreatic cancer-targeting ligand (SYENFSA). Here, the usefulness of cancer-targeted CRAd for pancreatic cancer was examined as a preclinical study. First, we constructed a survivin promoter-regulated CRAd expressing enhanced green fluorescent protein gene (EGFP), which displayed the identified targeting ligand (AdSur-SYE). The AdSur-SYE resulted in higher gene transduction efficiency and oncolytic potency than the untargeted CRAd (AdSur) in several pancreatic cancer cell lines. An intratumoral injection of AdSur-SYE significantly suppressed the growth of subcutaneous tumors, in which AdSur-SYE effectively proliferated and spread. An ectopic infection in adjacent tissues and organs of intratumorally injected AdSur-SYE was decreased compared with AdSur. Then, to examine whether the targeting ligand actually enhanced the infectivity of CRAd in human pancreatic cancer tissues, tumor cells prepared from surgical specimens were infected with viruses. The AdSur-SYE increased gene transduction efficiency 6.4-fold higher than did AdSur in single cells derived from human pancreatic cancer, whereas the infectivity of both vectors was almost the same in the pancreas and other cancers. Immunostaining showed that most $EGFP^+$ cells were cytokeratin-positive in the sliced tissues, indicating that pancreatic cancer cells but not stromal cells were injected with AdSur-SYE. AdSur-SYE resulted in a stronger oncolysis in the primary pancreatic cancer cells co-cultured with mouse embryonic fibroblasts than AdSur did. CRAd in combination with a tumor-targeting ligand is promising as a next-generation of oncolytic virotherapy for pancreatic cancer.

1. Introduction

Pancreatic cancer is the leading cause of cancer death, and it is considered one of the most lethal cancers in Japan as well as in the Western countries [1–3]. Despite the recent advances in therapeutic and diagnostic modalities [4,5], overcoming it remains one of the most formidable challenges in oncology today. Complete surgical resection has traditionally been considered the only curative treatment, but high rates of local and systemic failure persist in patients who undergo curative resections, and a 5-year survival rate is less than 5% [1]. This high mortality is due to the high incidence of metastatic disease at the time of diagnosis, a fulminant clinical course and the lack of adequate systemic therapies. In the locally advanced cases also, the development of strategies to strongly control local lesions and prevent distant metastases is an important issue. In spite of the fact that many studies have been tried to improve the outcomes, a novel approach is needed [3,5].

The conditionally replicative adenoviruses (CRAds), which are genetically programmed to replicate within tumor cells but not in normal cells and directly induce cytotoxic effects via cell lysis, are currently being explored in preclinical and clinical studies of various cancers such as head and neck cancer, pancreatic cancer, ovarian cancer, prostate cancer and malignant glioma [6–8]. Progress in the clinical studies of CRAds for solid cancers has been clarifying the need for two issues to be addressed [6,7,9]. First, tumor oncolytic activity should be enhanced to achieve any significant antitumor response. Since, in general, the oncolytic activity of CRAds is closely related with the infectious ability to the targets, the improvement of viral infectivity to tumors is necessary. However, an undesirable viral spread to adjacent tissues should be strictly limited around the virus-replicating tumors to reduce any adverse effect. In addition, CRAds leak from the tumors into systemic

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circulation often causes ectopic infection to vital organs such as the liver [10]. Therefore, suppression of naïve tropism for the reduction of unnecessary infection in non-target tissues and organs, and the reinforcement of a tumor-targeting potential in combination with the reduced tropism should solve the issues of conventional CRAds therapy [10,11].

Most of the presently used CRAds are based on serotype 5 (Ad5), whose entry into susceptible cells requires two distinct and sequential steps. The initial step is facilitated by an interaction of the fiber protein with its cellular receptor coxsackievirus and adenovirus receptor (CAR) [12]. Following attachment to CAR, internalization of the virus is promoted by the interaction of the penton base with αv integrins on the cell surface [12]. Retargeting has been achieved by direct genetic modifications of the capsid proteins: targeting ligands can be incorporated into the C-terminal and HI-loop of fiber proteins ablated for native tropism through the loss of binding with CAR and/or αv integrins [6,12]. However, the redirection of adenovirus vectors by engineering the capsid-coding region has shown limited success because proper targeting ligands are generally unknown. To overcome this limitation, we have developed a system for producing adenoviral libraries displaying a variety of peptides on the HI-loop of the fiber knob, and its screening has led to successful selections of several particular adenoviral vectors with high infectivity in target cells [13–17]. SYENFSA (SYE) is one of the selected sequences from the library by screening on the AsPC-1 pancreatic cancer cell line *in vitro*, and the adenovirus displaying the sequence showed higher infectivity in four of five pancreatic cancer cell lines [15].

To date, 2 types of CRAds have been developed. Type I is for introducing a mutation in the E1 region, and the function of these missing genes may be complemented by genetic mutation in tumor cells such as p53 mutation. Type II is for constructing viruses in which the transcription of E1 genes is restricted to tumor cells by either a tumor or tissue-specific promoter [6–8]. Survivin (Sur) is an anti-apoptotic protein involved in mitotic regulation during embryotic and fetal development, but its expression is generally undetectable in terminally differentiated adult tissue [18]. The promoter activity, largely silent in normal cells, is prominently expressed in tumor tissues including pancreatic cancer, and cells transfected with a reporter gene under the control of a Sur promoter exhibit cancer-specific activity *in vitro* and *in vivo* [19,20]. Therefore, CRAds, in which the transcription of E1 genes is restricted to tumor cells by the Sur promoter, were widely studied [21]. In this study, we constructed a Sur promoter-regulated CRAd displaying the pancreatic cancer-targeting sequence SYE (AdSur-SYE) to enhance oncolysis and secure safety. The therapeutic usefulness of AdSur-SYE was validated in surgical specimens of human pancreatic cancer as a preclinical study.

2. Materials and methods

2.1. Cell lines

Used in this study were a human embryonic kidney cell line (293), human pancreatic cancer cell lines (AsPC-1, BxPC-3, Panc-1 and MIAPaCa-2), a human prostate cancer cell line (PC3), a human dermal fibroblast and a mouse embryonic fibroblast (MEF). All the cancer cell lines were obtained from the American Tissue Culture Collection (ATCC; Rockville, MD, USA). Fibroblast was purchased from PromoCell GmbH (Heidelberg, Germany) and MEF was from ReproCell (Kanagawa, Japan). 293 cells, MIAPaCa-2 cells and MEFs were cultured in Dulbecco's modified eagle's medium (DMEM; Wako Pure Chemical Industries, Ltd., Osaka, Japan) with 10% fetal bovine serum (FBS); pancreatic cancer cell lines except for MIAPaCa-2 and PC3 were cultured in an RPMI-1640 medium (Nissui Pharmaceutical, Tokyo, Japan) with 10% FBS. Fibroblasts were cultured in the fibroblast growth medium (PromoCell GmbH). The 293–38 is a high-efficiency virus-producing clone of 293 cells [13].

2.2. Human surgical specimens

Surgical specimens (15 pancreatic ductal adenocarcinomas, 1 intraductal papillary mucinous neoplasm, 1 metastasis of renal cancer, 1 gallbladder cancer, 1 duodenal cancer, 6 pancreases and 1 liver) were obtained according to the Declaration of Helsinki Principles and the guideline of the Ethics Committee of the National Cancer Center (Tokyo, Japan). None of the patients had received any prior therapy. Tissues were processed into single cells or small pieces (1–4 mm in diameter), and were cultured in RPMI-1640 medium with 10% FBS.

2.3. Plasmids and recombinant adenovirus vectors

The 0.5-Kb survivin regulatory region [20] was inserted into the pGL3 basic vector (Promega, Madison, WI, USA) that contains the firefly luciferase gene, and designated as a pSur-Luc. A pRL-SV40 plasmid (Promega) expresses *Renilla* luciferase gene under the control of a SV40 promoter.

Adenovirus vectors were constructed as previously described [14,15,22]. The adenovirus vectors except for Ad-EGFP and AdΔE1-AP include 4 point mutations in the AB-loop of the fiber knob that reduces CAR binding. Ad-EGFP and AdΔE1-AP have a wild type of fiber. The AdSur-SYE and AdSur contain a 0.5-Kb survivin regulatory region upstream of the adenoviral E1 gene [20]. The AdΔCAR-SYE, AdΔCAR and Ad-EGFP contain a wild type of E1 region. The AdΔCAR-SYE, AdSur-SYE and AdLucEGFP-SYE have a SYE sequence in the HI-loop on the fiber knob [15,16]. The virus vectors contain a CMV promoter, the enhanced green fluorescent protein (EGFP) gene and a SV40 poly(A) signal in place of the E3 region, except for the AdΔE1-AP, AdLucEGFP and AdLucEGFP-SYE. In these viruses, the E1 gene is replaced with the CMV promoter-driven alkaline phosphatase or luciferase-EGFP fusion gene (LucEGFP), respectively (Fig. 1). The adenovirus vectors were expanded in the 293–38 cells. Physical particle concentration (viral particles (vp)/ml) of virus preparation was determined by optical absorbance (OD_{260}) [23].

2.4. Assay for luciferase activity

The cells were seeded at 1×10^5 per well in 24-well plates and transfected with both of pSur-Luc and pRL-SV40 by the lipofection method (Lipofectamine 2000 Reagent; Life Technologies Corp., Carlsbad, CA, USA). The cells were harvested with 100 μl of reporter lysis buffer (Promega) 48 h after the transfection. The light units of firefly and *Renilla* luciferase activities were assessed by dual luciferase reporter assay (Promega) using a luminometer (MiniLumat LB9506; EG&G Gerthold, Vilvoorde, Belgium). The sliced tissues prepared from surgical specimens of human pancreatic cancer (~1 mm in diameter) were infected with 3×10^9 vp of AdLucEGFP-SYE and AdLucEGFP. Twenty-four hours after the infection, the tissues were lysed with an equal volume of reporter lysis buffer. Twenty microliters of cell lysates were mixed with 100 μl of luciferase assay substrate (PicaGene; Toyo Ink CO., LTD., Tokyo, Japan). The light units of luciferase activity were measured using a luminometer (MiniLumat LB9506).

2.5. In vitro cell growth assay

The cells were seeded at 3×10^3 per well in 96-well plates and infected with viruses at 300, 1×10^3, 3×10^3, 1×10^4 and 3×10^4 vp/cell. The 1×10^4 of single cells prepared from surgical specimens of pancreatic cancers were co-cultured with 1×10^4 of MEF as feeder cells per well in 96-well plates and were infected with viruses at 1×10^3, 3×10^3, 1×10^4 and 3×10^4 vp/cell. The cell numbers were assessed by a colorimetric cell viability assay using a water-soluble tetrazolium salt (Tetracolor One; Seikagaku Corp., Tokyo, Japan). The absorbance was determined by spectrophotometry using a wavelength of 450 nm with 600 nm as a reference.

2.6. In vivo tumor growth

Five-week-old female BALB/c nude mice were purchased from Charles River Japan, Inc. (Kanagawa, Japan), and were housed under sterilized conditions. Animal studies were carried out according to the Guideline for Animal Experiments of the National Cancer Center Research Institute and approved by the Institutional Committee for Ethics in Animal Experimentation. BxPC-3 and PC3 cells (5×10^6) were injected subcutaneously into the nude mice. When tumor mass was established (~0.6 cm in diameter), 50 μl of a viral solution (0.5 or 2×10^{10} vp) was directly injected into the tumor. The short (r) and long (l) diameters of the tumors were measured and the tumor volume of each was calculated as $r^2 \times l \times 1/2$.

2.7. Detection of adenovirus DNA from cells

DNA was extracted from the cells 3 and 5 days after the virus infection using NucleoSpin Tissue (Macherey-Nagel, GmbH & Co., Duren, Germany). Adenoviral DNA was measured by SYBR Green real-time PCR using Eco™ Real-Time PCR system (Illumina Inc., San Diego, CA, USA). Briefly, 50 ng of extracted DNA was added to a final volume of 10 μl/reaction containing 1 × SYBR Green PCR Master Mix (Applied Biosystems Japan, Tokyo, Japan) and 100 nM of the primers; E4 upstream (5′-GGAGTGCGCCGAGACAAC-3′) and the downstream (5′-ACTACGTCCGGCGTTCCAT-3′), which detect a 68-bp region in E4 [16]. Thermal cycling conditions were as follows: initial denaturation at 95 °C for 10 min, and then 40 cycles at 95 °C for 10 s and at 60 °C for 30 s.

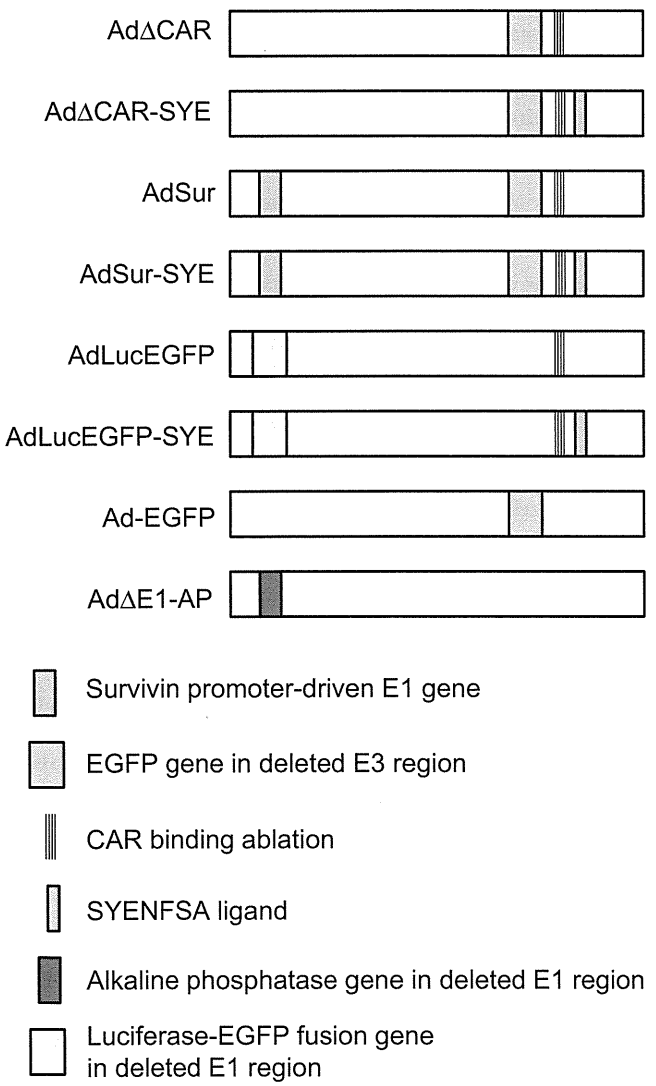


Fig. 1. Design of adenovirus constructs displaying a pancreatic-cancer targeting ligand. In adenovirus vectors except for Ad-EGFP and AdΔE1-AP, 4 point mutations were inserted in the AB-loop to reduce the CAR binding. In AdSur and AdSur-SYE, E1 gene is regulated by survivin promoter. In AdΔE1-AP, AdLucEGFP and AdLucEGFP-SYE, the E1 gene is replaced with CMV promoter-driven alkaline phosphatase or luciferase-EGFP fusion gene, respectively. The Ad-SYE, AdSur-SYE and AdLucEGFP-SYE display a pancreatic cancer targeting sequence SYENFSA on the fiber knob.

2.8. Detection of adenovirus genome from tumors and organs

DNA was extracted from the tumors and organs such as the liver, spleen, pancreas and lung 2 days after the intratumoral injection of an adenovirus solution (2×10^{10} vp) using Sepagene (Sanko Junyaku Co. Ltd., Tokyo, Japan). To quantitatively analyze the viral genome, SYBR Green real-time PCR was performed with the same E4 primers. A final volume of 10 μl/reaction containing 1 × SYBR Green Master Mix (Applied Biosystems Japan), 100 nM primers and 50 ng of extracted DNA was applied to the real-time PCR. For the standard curve to quantify the E4 copy numbers, E4 template DNA with a known copy number (2.4×10–2.4×10^6) was also analyzed. Thermal cycling conditions were as follows: initial denaturation at 95 °C for 10 min, and then 40 cycles at 95 °C for 10 s and at 60 °C for 30 s.

2.9. Flow-cytometry

Flow-cytometry was performed to assess the percentage of $EGFP^+$ cells. The cells were harvested 24 h after the viral infection, and were stained with LIVE/DEAD cell vitality assay kit (Life Technologies Corp.) for the selection of live cells followed by fixation with 4% paraformaldehyde (Wako Pure Chemical Industries, Ltd.) for 20 min at room temperature. For an epithelial cell marker MUC-1 staining, after the fixation, the cells were stained with monoclonal mouse α-human MUC-1 antibody (E29; Dako, Glostrup, Denmark) for 30 min at room temperature followed by staining with Alexa Fluor 647-goat anti mouse IgG (Life Technologies Corp.), and analyzed by FACS Calibur (BD Biosciences, San Jose, CA, USA).

2.10. Immunohistochemistry

The surgical specimens of human pancreatic cancer were processed into sliced pieces (~4 mm in diameter), and were infected with adenoviruses. Twenty-four hours later, the tissues were fixed in 4% paraformaldehyde at room temperature overnight. The cryostat tissue sections (4 μm) were mounted on glass slides and were subjected to immunohistochemistry to detect a cytokeratin. The sections were stained with monoclonal mouse α-human pancytokeratin antibody (AE1/AE3; Dako) and then with biotinylated anti-mouse IgG (Vector Laboratories, Burlingame, CA, USA) and streptavidin-conjugated Alexa Fluor 555 (Life Technologies Corp.). All the sections were counter-stained with DAPI (4′, 6-diamidino-2-phenylindole, dihydrochloride; Life Technologies Corp.).

2.11. Statistical analysis

Comparative analyses of the data were performed by the Student's *t*-test, using SPSS statistical software (SPSS Japan Inc., Tokyo, Japan). The differences were considered statistically significant when the P value was <0.05.

3. Results

3.1. High infectivity of AdΔCAR-SYE in human pancreatic cancer tissues

We previously reported that the replication-competent adenovirus with a wild type E1 region, which displayed a SYENFSA ligand (AdΔCAR-SYE), showed higher gene transduction efficiency in several other pancreatic cancer cell lines compared with the untargeted adenovirus (AdΔCAR) [15,16]. In this study, to examine whether the ligand-mediated high infectivity is recognized in the human pancreatic cancer tissues as well, the surgical specimens were first infected with AdΔCAR-SYE or AdΔCAR. Flow-cytometry showed that AdΔCAR-SYE increased the frequency of $EGFP^+$ cells 3.8-fold higher than AdΔCAR did in pancreatic cancer but not in the other types of cancer (Supplementary Fig. 1).

Next, the sliced tissues (~1 mm in diameter) were infected with luciferase-expressing adenoviruses. AdLucEGFP-SYE showed a higher luciferase activity than did the untargeted virus (AdLucEGFP) (Supplementary Fig. 2). The results confirmed the specific and high infectivity of an adenovirus vector displaying the SYE ligand not only in pancreatic cancer cell lines but also in human pancreatic cancer tissues.

3.2. Construction of a cancer-targeted adenovirus regulated by survivin promoter

Next, we constructed a CRAd displaying the targeting ligand SYE on the fiber knob. To address the relevance of a survivin promoter as the candidate tumor targeting promoter, the cancer cell lines and a primary culture of human dermal fibroblasts were transfected with pSur-Luc and pRL-SV40. The relative activity of survivin promoter to SV40 promoter was significantly higher in the pancreatic cancer cell lines than in PC3 cells and fibroblasts (Fig. 2A). Then, to examine the infectivity of CRAd displaying the SYE ligand, the cancer cell lines were infected with AdSur-SYE or AdSur. Flow-cytometry showed a higher infectivity in all 4 pancreatic cancer cell lines infected with AdSur-SYE than those infected with AdSur in a dose-dependent manner, whereas in the PC3 cells and fibroblasts, the frequencies of $EGFP^+$ cells in the AdSur-SYE-infected cells were comparable or less than that in the AdSur-infected cells (Fig. 2B and C). To confirm the virus replication in the cells infected with CRAds, we analyzed the copy number of the virus genome per cell by the real-time PCR method 3 and 5 days after the infection at 1×10^3 vp/cell. The adenovirus DNA rapidly increased in the AdSur-SYE-infected BxPC-3 cells, whereas it was not changed in the PC3 cells and fibroblasts (Fig. 2D).

3.3. Antitumor effect of a cancer-targeted conditionally replicative adenovirus

To examine whether the addition of targeting potential to CRAd results in an effective cell killing, cancer cell lines were infected with viruses. An *in vitro* cell growth assay showed that the AdSur-SYE markedly suppressed the growth of all 4 pancreatic cancer cell lines compared with AdSur, while the cytotoxic activity of AdSur-SYE was higher than that of Ad-EGFP. In PC3 cells and fibroblasts, the difference of cell growth inhibition between AdSur and AdSur-SYE was small (Fig. 3A).

Then, to investigate the *in vivo* efficacy of targeted CRAd, viruses were directly injected into BxPC-3 and PC3 subcutaneous tumors. The injection of AdSur-SYE effectively suppressed the BxPC-3 tumor growth more than AdSur did, and the higher dose of AdSur-SYE suppressed the tumor growth more efficiently than the Ad-EGFP, whereas the *in vivo* antitumor effect of AdSur was larger than that of AdSur-SYE in the PC3 tumors (Fig. 3B). The AdSur-SYE resulted in the central necrosis in the BxPC-3 tumors (Fig. 3C). To examine whether the viruses replicate and spread in the tumor tissues, the transgene expression was compared in AdΔE1-AP, AdSur and AdSur-SYE-injected tumors at day 2 and day 6 after injection. The expression in AdΔE1-AP- and AdSur-injected BxPC-3 tumors decreased at day 6 compared to day 2, whereas a marked EGFP expression was observed in AdSur-SYE-injected tumors at day 6 (Fig. 3D), indicating that AdSur-SYE more effectively proliferate and spread in the tumors. $EGFP^+$ cells were not detected in the adjacent skin and skeletal muscle (data not shown). In addition, the viral genome copy number in BxPC-3 tumors at days 2 and 6 was examined by the real-time PCR method, showing that the copy number of AdSur-SYE in the tumors significantly increased as compared with those of AdΔE1-AP and AdSur (Fig. 3E). All treated mice looked healthy during the course of the experiments, and blood chemistry showed no abnormal values in the treated mice at 4 weeks.

3.4. Ectopic infection of organs after intratumoral injection of adenoviruses

The replication of the adenovirus in the tumors results in an ectopic infection of organs through leakage into systemic circulation [10,15]. To evaluate the distribution of adenovirus genome in organs, various organs and subcutaneous tumors were subjected to real-time PCR 2 days after the intratumoral injection of viruses. The adenoviral genome copy number of AdSur-SYE in tumors was significantly elevated as compared with that of AdSur and was similar with Ad-EGFP, whereas the copy numbers of AdSur-SYE in organs were significantly less than those of AdSur and Ad-EGFP, indicating that the addition of SYE ligand decreased the ectopic undesirable infection of organs (Fig. 4).

3.5. Infectivity of AdSur-SYE in surgical specimens of human pancreatic cancer

To examine whether an addition of a targeting ligand in CRAd leads to high infectivity and oncolytic activity in the human pancreatic cancer tissues, the single cells prepared from surgical specimens were infected with AdSur-SYE or AdSur, and the percentage of $EGFP^+$ cells was analyzed by flow-cytometry 24 h after the infection. More than 60% of the single cells were MUC-1 positive, suggesting that a major population of live cells was pancreatic ductal adenocarcinoma cells (Fig. 5A). The infectivities of AdSur-SYE were 6.4-fold at 1×10^3 vp/cell and 6.2-fold at 1×10^4 vp/cell higher compared with those of AdSur in the pancreatic cancers, whereas the infectivities of AdSur-SYE and AdSur were almost the same in the other cancers, the pancreas and liver (Fig. 5B).

Next, the sliced tissues of pancreatic cancers were infected with AdSur-SYE or AdSur. $EGFP^+$ cells were detected on the surface of the AdSur-SYE-infected tissues, whereas the $EGFP^+$ cells were not detected in the AdSur-infected tissues. $EGFP^+$ cells in AdSur-SYE-infected tissue seemed to be pancreatic cancer cells in H&E staining of the same section (Fig. 5C). Since pancreatic cancer cells on the tissue slides were not clearly stained by the immunohistochemistry of MUC-1, cytokeratin was immunostained. The staining showed that most $EGFP^+$ cells in the AdSur-SYE-infected tissues were positive for cytokeratin, indicating that the cells infected with the virus were pancreatic cancer cells but not stromal cells such as endothelial cells and immune cells (Fig. 5D).

3.6. Oncolytic activity of AdSur-SYE in surgical specimens of human pancreatic cancer

Finally, to examine the oncolytic effect of AdSur-SYE, the single cells prepared from 4 patients with pancreatic cancer were co-cultured with MEFs, and were infected with viruses. Immunocytochemistry showed that several $MUC\text{-}1^+$ cells aggregated and grew as islands on the MEFs at day 6 (Fig. 6A), indicating that a significant population of cells prepared from surgical specimens was alive for at least 6 days. The number of $EGFP^+$ cells in AdSur-SYE-infected pancreatic cancer cells was significantly larger as compared with the AdSur-infected cells (Fig. 6B), and many $EGFP^+MUC\text{-}1^+$ cells were detected by ArrayScan VTI HCS Reader (Thermo Scientific, MA, USA) (Fig. 6C). An *in vitro* cell growth assay

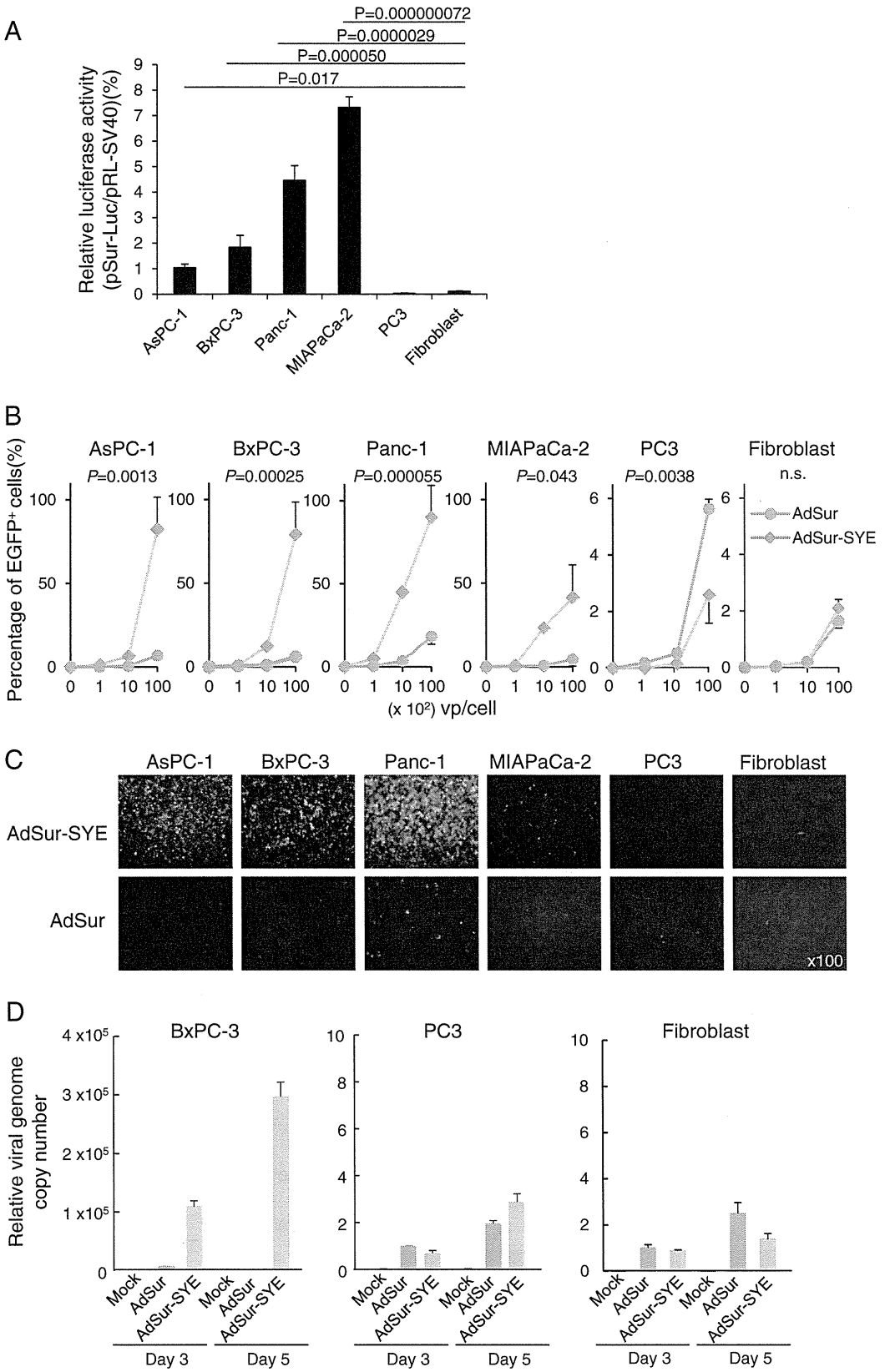
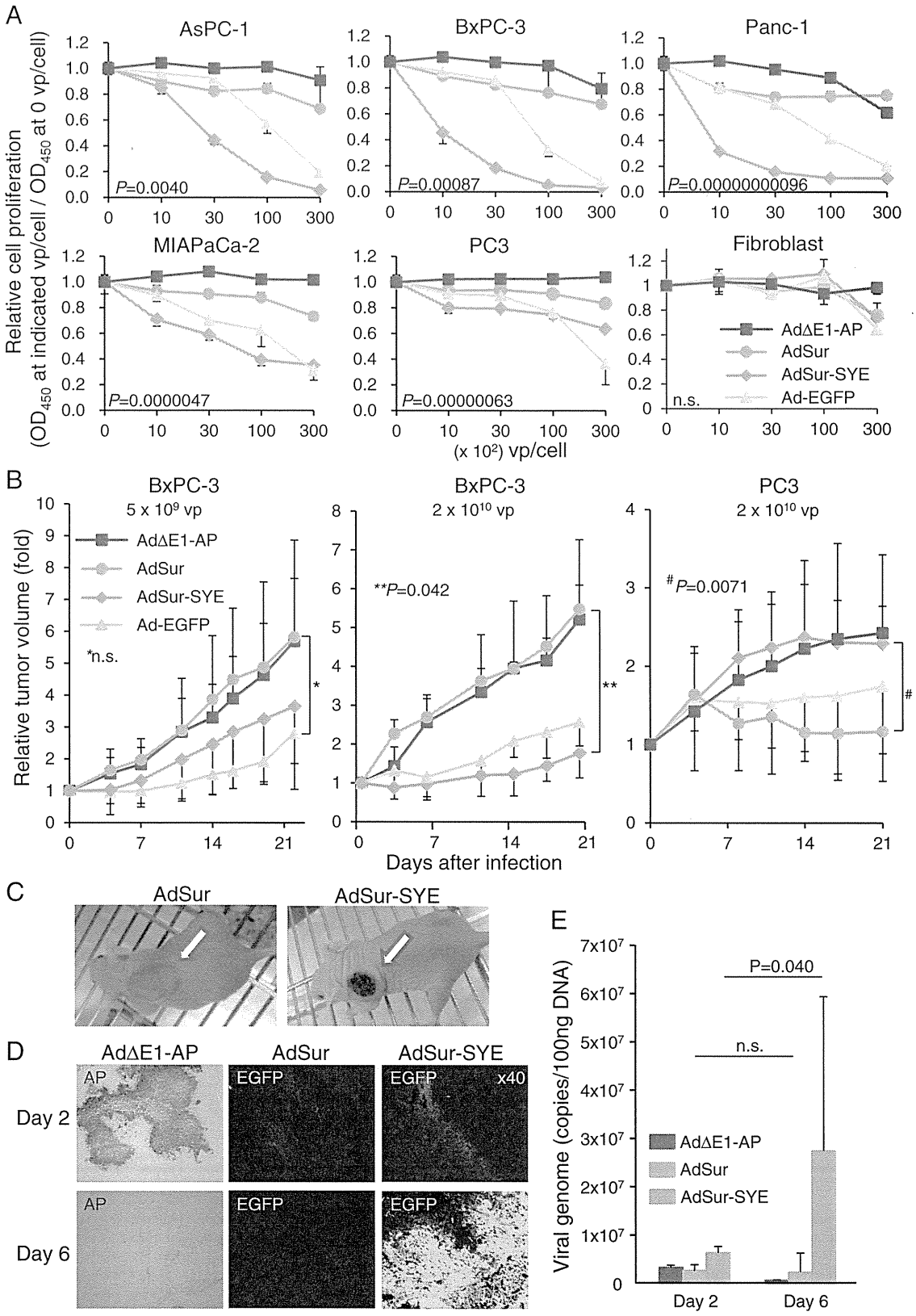


Fig. 2. Activity of survivin promoter and infectivity of AdSur-SYE in pancreatic cancer cell lines. A) The activity of survivin promoter in human pancreatic cancer cell lines. The cells were transfected with pSur-Luc and pRL-SV40, and 48 h later the luciferase activity was measured. The relative luciferase activity (the light unit of cells transfected with pSur-Luc/that with pRL-SV40) is presented. The assays (carried out in 5 wells) were repeated three times and the mean ± standard deviation was plotted. B) Infectivity of AdSur-SYE in pancreatic cancer cell lines. The cells were infected with AdSur-SYE or AdSur, and 24 h later the $EGFP^+$ cells were analyzed by flow-cytometry (n = 4). C) Photographs of cell lines infected with viruses at 1×10^4 vp/cell. D) The replication of adenoviral DNA in the cells. BxPC-3, PC3 cells and fibroblasts were infected with AdSur-SYE or AdSur at 1×10^3 vp/cell, and 3 and 5 days later the adenoviral DNA was analyzed by real-time PCR analysis (n = 3). The viral genome copy number was normalized to β-actin gene. The copy numbers at indicated viruses and days are shown as compared with that of AdSur at day 3.

showed that the proliferation was suppressed in cells infected with viruses in a dose-dependent manner, while the AdSur-SYE most effectively suppressed the growth of all 4 pancreatic cancer cells as compared with the AdSur, and that the cytotoxicity of AdSur-SYE was equal to or greater than that of Ad-EGFP (Fig. 6D). The results demonstrated that the pancreatic cancer-targeted CRAd showed a higher infectivity and oncolytic activity than untargeted CRAd in human pancreatic cancer tissues as well.



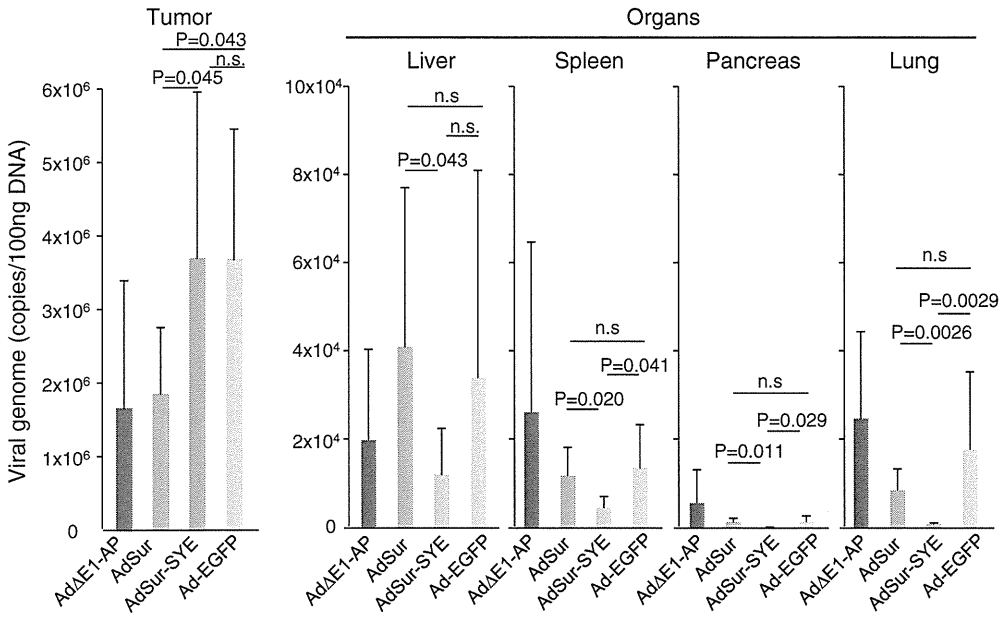


Fig. 4. Distribution of adenoviruses after intratumoral injection. DNA from the tumors and organs of AdΔE1-AP-, AdSur-, AdSur-SYE- or Ad-EGFP-injected mice was subjected to real-time PCR, and adenoviral genome copy numbers were analyzed (tumor; n = 6, liver; n = 6, spleen; n = 6, pancreas; n = 3, lung; n = 3).

4. Discussion

We previously reported that a replication-competent adenovirus displaying the SYE ligand exerted a potent cell killing in several pancreatic cancer cell lines [15]. However, the previous vectors contained a wild E1 region, which was not a typical CRAd, and it was not applicable in the clinical setting. In this study, we combined the pancreatic cancer-targeting ligand with CRAd, which is regulated by the survivin promoter, and demonstrated that CRAds equipped with a cancer-targetability showed a high infectivity and oncolytic activity in pancreatic cancer cell lines, mouse xenograft tumor models and human surgical specimens of pancreatic cancer.

The SYE sequence was selected by screening on the AsPC-1 pancreatic cancer cell line, and the infection of targeted vectors was considered to be mediated by specific receptors on target cells [15]. Since the expression levels and kinds of cell surface receptors may be substantially different between *in vitro* cell culture cells and *in vivo* tumor tissue, the infectivity in the human pancreatic cancer specimens may be different from those in the cell lines. The fact that the SYE ligand selected by *in vitro* cell line screening showed a high infectivity in human pancreatic cancer tissues also indicates that our screening strategy using cell lines is useful for identifying the ligand sequences, which are applicable in the clinical setting.

Since the SYE-mediated enhancement of gene transduction was observed in several pancreatic cancer cell lines (Fig. 2B and C), the cognate receptor for SYE sequence may be shared by these pancreatic cancer cell lines. Identification of the receptors is useful for understanding the molecular characteristics of the target cells and can be applied for diagnosis, such as the detection of a relapse of the disease. At present, we are developing a receptor identification system using microarray technology.

Although AdSur-SYE showed significantly stronger antitumor effects for pancreatic cancer cells, there were some discrepancies between *in vitro* culture and subcutaneous tumors. AdSur-SYE mediated more efficient tumor cell killing than Ad-EGFP in AsPC-3, BxPC-3 and Panc-1 cells, whereas tumor growth rates of subcutaneous BxPC-3 tumors were similar between AdSur-SYE and Ad-EGFP groups (Fig. 3A and B). The expression level of an unknown cognate receptor for SYE ligand in pancreatic cancer cell lines might be higher than that in BxPC-3 subcutaneous tumors. In addition, the AdSur-SYE showed a pancreatic cancer cell-specific infectivity, whereas the Ad-EGFP has a broad spectrum of infectivity due to the wild type of fiber. The pancreatic cancer cells as well as stromal cells such as fibroblasts and vascular endothelial cells may be infected with Ad-EGFP, which leads to the strong antitumor effect. Besides, AdSur effectively suppressed the growth of PC3 subcutaneous tumors than AdSur-SYE did (Fig. 3B). This antitumor effect of AdSur was confirmed in 2 independent experiments, and in our previous report also, a replication-competent adenovirus displaying no peptide (AdΔCAR) showed the stronger antitumor effect for PC3 tumors than the SYE-displaying adenovirus (AdΔCAR-SYE) [15]. Although the precise reason is unknown, PC3 tumors may be infected with AdSur via another unknown specific receptor, and the insertion of the SYENFSA sequence might disturb the AdSur infection due to the conformational change of a particular portion in fiber knob.

The key prerequisite for an efficient oncolytic virus is the restriction of virus replication in tumor cells. Although the replication and spreading of CRAds are restricted to tumor tissue in theory, several levels of additional safety devices are definitely required: the engineering of an adenovirus capsid to restrict infection for tumor cells being the first safety device, and E1 manipulation to limit replication in the tumors being the second one. In our vectors, CAR binding was ablated to reduce the naïve tropism, and, in fact, the intratumoral injection of AdSur-SYE

Fig. 3. Cytotoxic activity of AdSur-SYE in pancreatic cancer cells. A) Suppression of cell growth in pancreatic cancer cell lines. The cells were infected with viruses, and 5 days later a cell growth assay was performed. The relative cell growth (OD_{450} of cells at indicated vp/cell/that at 0 vp/cell) is shown. The assays (carried out in 4 wells) were repeated two times and the mean ± standard deviation was plotted. P value: AdSur-infected cells versus AdSur-SYE-infected cells at 3×10^4 vp/cell. B) Growth suppression of BxPC-3 subcutaneous tumors. Adenovirus vectors were injected into BxPC-3 and PC3 subcutaneous tumors inoculated in immune-incompetent mice. (Left) 5×10^9 vp of adenoviruses was injected into the BxPC-3 tumors (n = 8). (Middle) 2×10^{10} vp of adenoviruses was injected into the BxPC-3 tumors (n = 8). (Right) 2×10^{10} vp of adenoviruses was injected into the PC3 tumors (n = 7). C) Photographs of representative tumors 21 days after virus injection. BxPC-3 tumors were injected with 2×10^{10} vp of adenoviruses. D) Transgene expression in BxPC-3 subcutaneous tumors. Frozen sections of tumors were examined at days 2 and 6 after the injection of viruses (2×10^{10} vp) under fluorescence microscopy. The AdΔE1-AP-injected tumors were stained for AP activity (BCIP/NBT kit; Zymed Laboratories Inc., CA), and the sections were counterstained with methyl green. AP; alkaline phosphatase staining. E) The replication of adenovirus in tumors. Adenoviral genome copy numbers in tumors at days 2 and 6 after the injection were examined by the real-time PCR method.

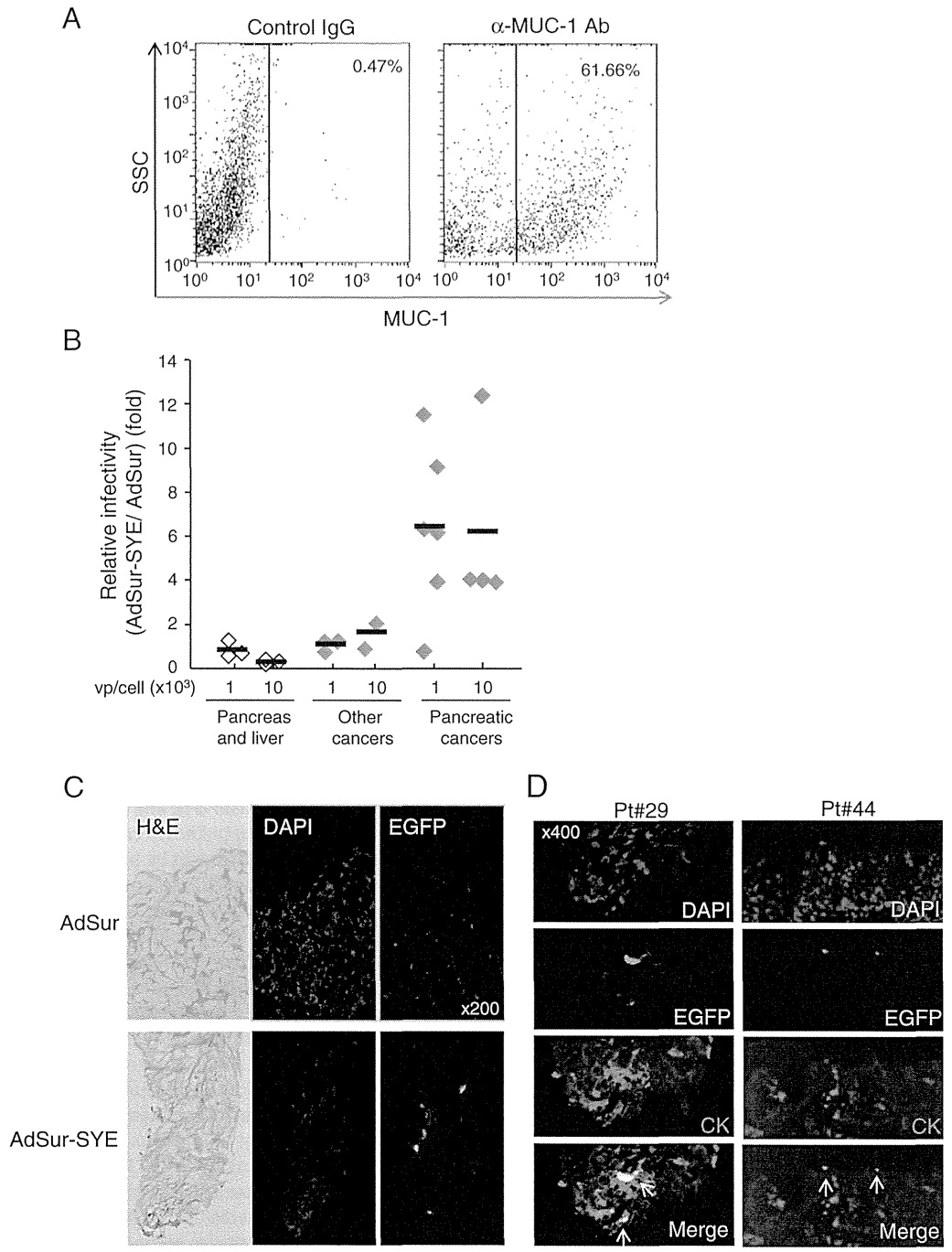


Fig. 5. Infectivity of AdSur-SYE in human pancreatic cancer tissues. Tumor cells were prepared from the surgical specimens of human pancreatic cancer. A) MUC-1$^+$ cells in the surgical specimens. Tumor cells were stained with α-MUC-1 antibody followed by Alexa Fluor 647. Ab: antibody. B) The detection of EGFP$^+$ cells by flow-cytometry. Tumor cells were infected with AdSur or AdSur-SYE at 1×10^3 and 1×10^4 vp/cell, and 24 h later EGFP$^+$ cells were analyzed by flow-cytometry. The relative frequency of EGFP$^+$ cells (the percentage of EGFP$^+$ cells infected with AdSur-SYE/that with AdSur) is presented. Pancreas; n = 2. Liver; n = 1. Other cancer; n = 2 (gallbladder cancer and duodenal cancer). Pancreatic cancer; n = 6 (pancreatic ductal adenocarcinoma). C) EGFP expression of sliced tissues infected with adenoviruses. The sliced tissues (Patient number: Pt# 29) were infected with 1×10^{10} vp of AdSur or AdSur-SYE, and 24 h later the tissues were fixed by 4% paraformaldehyde, and frozen sections were observed under fluorescent microscopy. D) Cytokeratin staining of sliced tissues infected with AdSur-SYE. The sliced tissues (Pt#29 and Pt#44) were infected with 1×10^{10} vp of AdSur-SYE, and after fixation, frozen sections were stained with α-pancytokeratin antibody. CK; cytokeratin Arrows; EGFP$^+$ cytokeratin$^+$ cells.

did not increase the infection of the adjacent tissues. In general, the additional ablation of binding sites with integrin and heparan sulfate proteoglycans from the adenoviral capsid may be useful to further reduce naïve tropism [24]. Although in this study an ectopic infection in distant organs of intratumorally injected AdSur-SYE was decreased compared with AdSur (Fig. 4), this decrease may be due to the reduced amount of viruses leaking from the tumor because of the enhanced transduction efficiency of AdSur-SYE in tumors. If the same amount of virus was intravenously injected, a level of ectopic infection in distant organs should be comparable between AdSur-SYE and AdSur as previously reported [15]. It was recently reported that coagulation factor (F) X binds the hypervariable regions (HVR) of the hexon in an adenovirus, leading to liver infection [25,26]. The factor X enhances liver transduction by adenovirus vectors due to the protection of adenovirus from attack by the classical complementary pathway [27]. Therefore, a targeted adenovirus constructed on a mutant hypervariable region backbone to

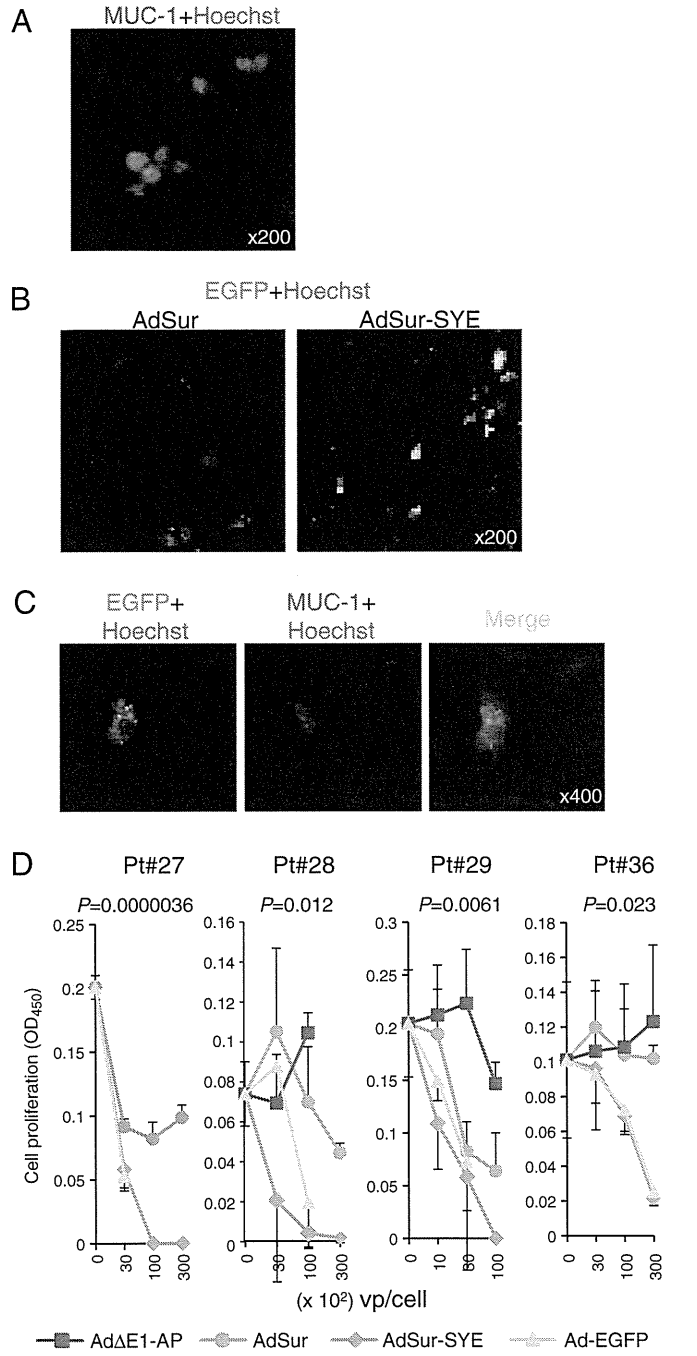


Fig. 6. Oncolytic activity of AdSur-SYE in human pancreatic cancer tissues. A) Co-culture of pancreatic cancer cells with MEFs. The pancreatic cancer cells were co-cultured with MEFs for 6 days. After the fixation with 4% paraformaldehyde, the cells were stained by monoclonal mouse α-human MUC-1 antibody (E29) followed by the 2nd antibody of Alexa Fluor 647 and hoechst33258. B) $EGFP^+$ cells in pancreatic cancer cells infected with viruses. The tumor cells co-cultured with MEFs were infected with viruses. The photographs were representatives of cells infected with AdSur-SYE and AdSur at 1×10^3 vp/cell at day 6, which were assessed by ArrayScan VTI HCS Reader. C) $EGFP^+MUC\text{-}1^+$ pancreatic cancer cells. The photographs are representatives of $EGFP^+$ and $MUC\text{-}1^+$ pancreatic cancer cells infected with AdSur-SYE at 1×10^3 vp/cell at day 6 by ArrayScan VTI HCS Reader. D) Cytotoxic activity of adenoviruses in pancreatic cancer cells co-cultured with MEFs. Tumor cells prepared from 4 surgical specimens of pancreatic cancer were co-cultured with MEFs and the cells were infected with adenoviruses. Six days after the infection, cell numbers were measured by an *in vitro* cell growth assay. The differences between the OD_{450} values of total pancreatic cancer cells and MEFs and those of MEFs alone were presented. The assays were carried out in 4 wells, and the mean ± standard deviation was plotted. P value: AdSur-infected cells versus AdSur-SYE-infected cells at 1×10^4 vp/cell.

suppress a liver transduction may effectively allow for the development of vectors to specifically transduce certain tumors even through systemic administration [28].

Pancreatic cancer is one of the most intractable cancers, and new therapeutic approaches that can effectively target its spread *in vivo* are urgently needed. In pancreatic cancer, a regional therapy is also particularly relevant, because locally advanced cases, which are surgically unresectable but can be accessible by ultrasound- or CT-guided percutaneous injection or endoscopic ultrasound-guided injection, require a strong local control strategy [1,5]. The selection of patients, whose cancer tissues are suitable to this targeting strategy, is one of the most important issues to achieve sure success in clinical trials. Since, in this study, the infection of AdSur-SYE is easily detected in the sliced tissues by EGFP expression under fluorescence microscopy (Fig. 5C), the selection of patients on biopsy samples may be feasible in the clinical setting. Although there is no metastasis in the locally advanced cancer at the time of diagnosis, distant metastases frequently appear in the process of disease progression. As a next step, a combination with other approaches such as immune therapies and systemic chemotherapies may contribute to mounting a systemic antitumor effect against pancreatic cancer.

In conclusion, we showed that a survivin promoter-regulated oncolytic adenovirus, which displays a pancreatic cancer-targeting ligand, resulted in an increased infectivity and stronger oncolytic potency than an untargeted adenovirus in pancreatic cancer tissues did. CRAds in combination with a targeting strategy are a promising candidate for the next generation of oncolytic virotherapy.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jconrel.2014.07.053.

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