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PICTORIAL ESSAY

# Stent Graft Placement for Injured Visceral Artery

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**Abstract:**
Injury of the visceral artery is a potentially fatal complication of iatrogenic procedures, trauma, and tumors. A stent graft can achieve rapid exclusion of the injured arterial portion and minimize the risk of ischemic complications by preserving arterial flow to organs. Although various types of stent grafts are available worldwide, Viabahn has only been approved for visceral arterial injury in Japan. The reported technical and clinical success rates, including cases with injured pelvic or thoracic arterial branches, are 80%-100% and 66.7%-100%, respectively. Severe ischemic complications are rare; however, fatal ischemia occurs when the stent graft is immediately occluded. The necessity of antiplatelet therapy is controversial, and a target artery diameter ≤ 4 mm is a significantly higher risk factor of stent-graft occlusion.

**Keywords:**
stent graft, visceral artery, active bleeding, pseudoaneurysm

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## Introduction

Injury of the visceral artery is a potentially fatal complication of various iatrogenic procedures, trauma, and tumors. Transarterial embolization with metallic coils, plugs, and/or glue (n-butyl cyanoacrylate) is an established endovascular treatment to achieve hemostasis [1]; however, it may frequently cause ischemic complications and be occasionally contraindicated when severe ischemic damage of organs is concerned by occlusion of the injured artery. It has been reported that 37% of patients who underwent coil embolization for hepatic artery hemorrhage developed hepatic infarction, and 27% experienced hepatic failure [2].

Because a stent graft (SG) can achieve rapid exclusion of the injured arterial portion and minimize the risk of ischemic complications by preserving arterial flow to organs [1-9], it is an ideal device for the treatment of active arterial bleeding and/or pseudoaneurysm, although the reintervention rate was significantly higher following SG placement compared with coil embolization (39.3% vs. 21.1%, respectively; $p$ = 0.012) [1]. Recent advancements of technologies have made it possible to deploy SGs in smaller arteries.

In this paper, we describe the indication, techniques, outcomes, and complications of SG placement for injured visceral arteries.

## Indication

SG placement is indicated for active bleeding and/or pseudoaneurysm located at the relatively large nontortuous visceral artery and involves a risk of ischemic damage of organs following coil embolization. Although sepsis is not an absolute contraindication, an intra-abdominal septic source is a significant risk factor for in-hospital mortality ($p$ = 0.010) [4] and SG occlusion ($p$ < 0.001) [6].

## Variations of SG

There are two types of commercially available SGs: balloon-expandable and self-expandable SGs [1-9]. Self-expandable SGs are generally considered more flexible and can fit the vascular configuration (**Fig. 1**) [3]. However, a

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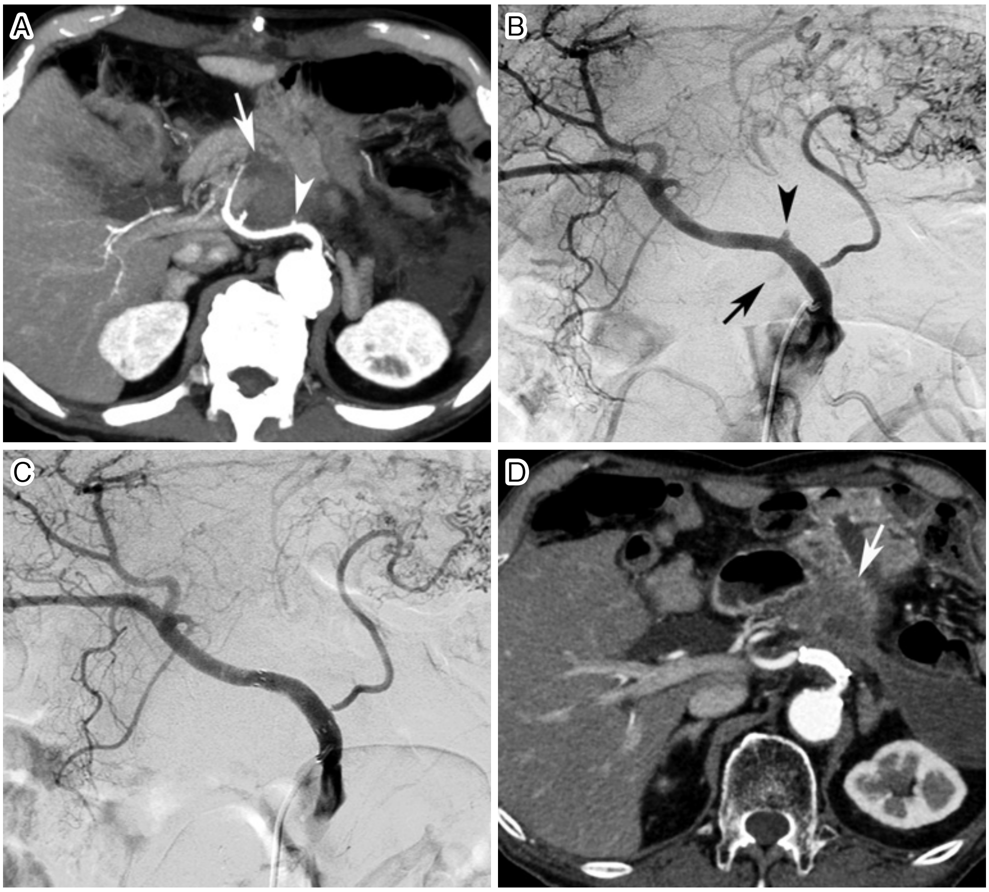


**Figure 1.** Bleeding from the splenic artery stump following dorsal pancreatectomy for pancreatic carcinoma.
A. The slab-maximum intensity projection image of arterial phase CT revealed a hematoma (arrow) in front of the splenic artery stump (arrowhead). B. Craniocaudal oblique celiac arteriogram revealed contrast extravasation (arrow) from the splenic artery stump (arrowhead). C. The splenic artery stump was sealed and contrast extravasation disappeared by deploying a 6 × 25-mm Viabahn. D. Arterial phase CT performed 1 year and 1 month after the procedure revealed that the stent graft was patent and fitted the vascular configuration, although recurrent tumor (arrow) was also observed.

relatively large guiding catheter/sheath is required to deploy them; therefore, it is difficult to place them in the peripheral vessels through a tortuous route [1]. Contrarily, some balloon-expandable SGs have a smaller profile than self-expandable ones. Therefore, they can be applied to peripheral arterial injuries, enabling more accurate localization, although the SG itself is more rigid (**Fig. 2 and 3**) [5]. In addition, balloon molding of SGs after deployment is possible to a greater extent, which is advantageous in cases of unintended undersizing and subsequent endoleak (**Fig. 4**) [3, 9], although excessive dilation may cause arterial injury and SG destruction.

Four kinds of balloon-expandable SGs are available in Japan, namely, GraftMaster (Abbott, Abbott Park, IL, USA) (**Fig. 2-4**), PK Papyrus (Biotronik, Berlin, Germany), Lifestream (BD, Franklin Lakes, NJ, USA), and Viabahn VBX (Gore, Newark, DE, USA); however, the former two SGs have only been approved for a ruptured coronary artery or coronary bypass graft during percutaneous angioplasty, and the latter two have been approved for symptomatic iliac artery occlusion or stricture. Thus, the use of these SGs in the visceral artery is off-label.

Regarding a self-expandable SG for injured arteries, Viabahn (Gore) is only available in Japan. A Niti-S ComVi stent (Taewoong Medical, Goyang-si, Korea) (**Fig. 5**) and Fluency Plus stent (BD) (**Fig. 6**), which are covered by expanded polytetrafluoroethylene (ePTFE) but only approved for the bile duct, were used before Viabahn was launched.

## Selection of SG

In Japan, placement of Viabahn is indicated for 4-12-mm-diameter injured arteries in the body trunk, excluding the aortic, coronary, brachiocephalic, carotid, vertebral, and pulmonary arteries [10], as well as symptomatic stricture ≥ 10 cm in the 4-7.5-mm-diameter superficial femoral artery and nonfunctional arteriovenous graft for hemodialysis. However, Viabahn cannot be used for patients with heparin-induced thrombocytopenia as it is covered with heparin-bonded ePTFE.

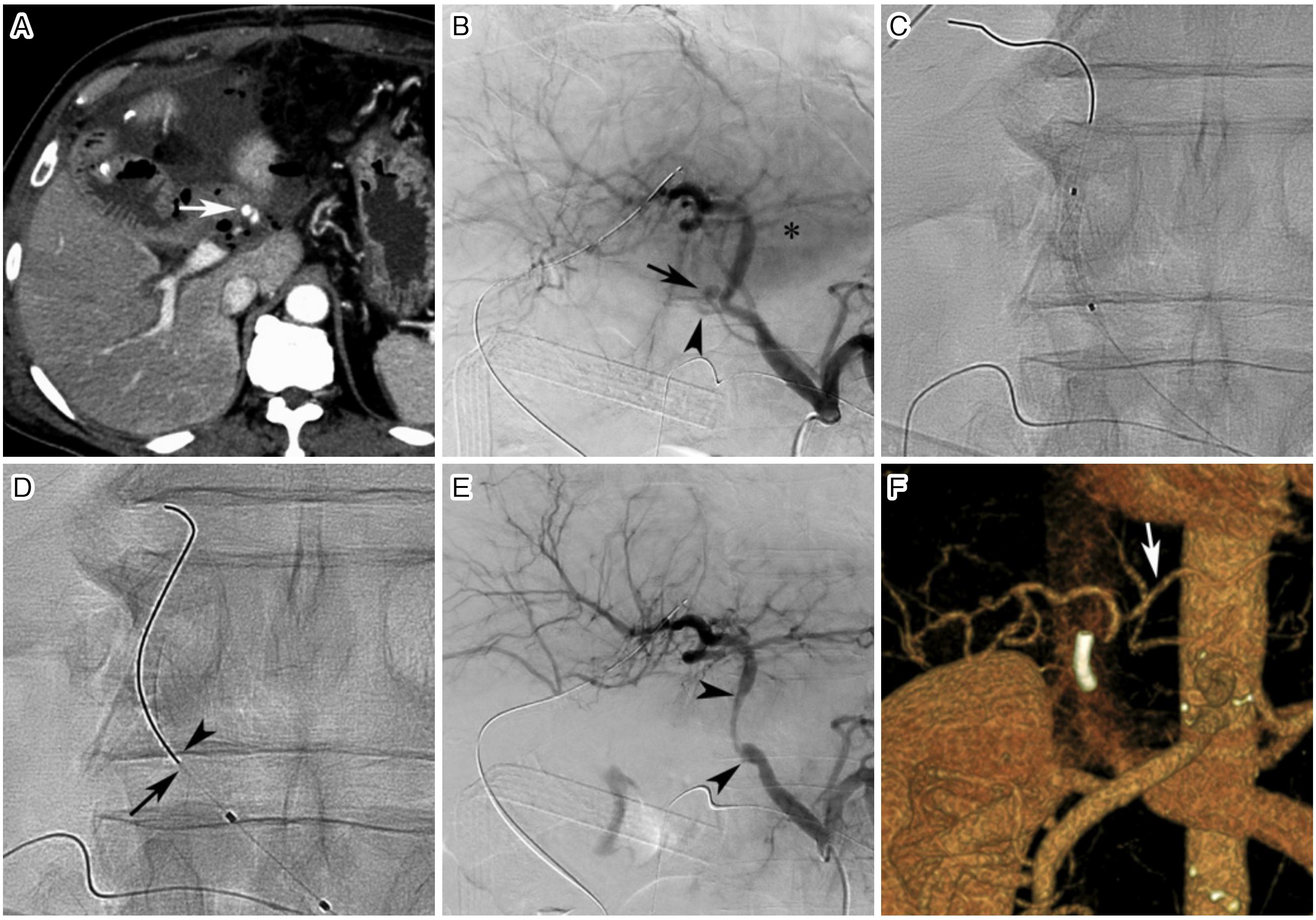


**Figure 2.** Bleeding from the left hepatic artery after pylorus-preserving pancreatoduodenectomy with portal vein resection and reconstruction for pancreatic carcinoma.

A. Arterial phase CT revealed a pseudoaneurysm (arrow) at the left hepatic artery (LHA). B. Celiac arteriogram revealed a pseudoaneurysm (arrow). The right hepatic artery (arrowhead) was sacrificed during the operation due to injury, and it was reconstructed through LHA *via* the communicating arcade. Accessory left gastric artery (ALGA) was also observed (asterisk). This suggested that coil embolization of LHA was safe because LHA might be reconstructed through ALGA. However, SG treatment was decided as there was a risk of inadvertent occlusion of ALGA during coil embolization of LHA. C. Although arterial bleeding stopped during the procedure, the hemodynamic condition of this patient was unstable. Therefore, placement of a 3 × 16-mm GraftMaster was decided because it was only stockpiled in our hospital for the treatment of coronary artery perforation, although the diameter of LHA and proper hepatic artery was 3.8 mm. D. Thereafter, postdilation of SG using a 4 × 20-mm angioplasty balloon catheter was attempted. However, the balloon catheter could not be advanced into the stented lumen due to friction between the tip of the balloon catheter and SG. The arrow and arrowhead indicate the tip of the balloon catheter and proximal end of the deployed SG, respectively. E. Celiac arteriogram obtained following SG placement revealed the disappearance of the pseudoaneurysm, although the stented lumen (arrows) was markedly narrow compared with the native LHA. F. Three-dimensional CT arteriography performed 263 days after the procedure revealed that the common hepatic artery was occluded and LHA was reconstructed through ALGA (arrow). This patient is still alive 6 years and 3 months after the procedure without tumor recurrence.

The diameter of Viabahn ranges from 5 to 13 mm, and the length variations are 2.5, 5, 10, and 15 cm for a 5-8-mm-diameter SG and 5 and 10 cm for a 9-13-mm-diameter SG. A 0.018-in guidewire is recommended for 5-8-mm-diameter SGs and 0.035-in for 9-13-mm-diameter SGs. The required sheath is 6-F for 5-6-mm-diameter SGs, 7-F for 7-8-mm-diameter SGs, 8-F for 9-10-mm-diameter SGs, and 10-F for 11-13-mm-diameter SGs.

The ideal diameter of SG is approximately 10% or 1 mm larger than the diameter of the injured artery [5, 6], and Viabahn oversized by >20% may cause frequent occlusion [6]. If CT performed before hemorrhage is available, it is useful to determine the SG diameter because vasoconstriction frequently occurs in a hypovolemic condition. Neck length is also critical to avoid rebleeding and type 1 endoleak. According to the guideline for the appropriate use of Viabahn, the minimal length of the landing zone is 20 mm [10]. However, securing a sufficient landing zone may be challenging, and Ueda et al. [6] reported that no type 1 endoleaks developed in patients with a mean neck length of 9.9 mm (range, 1-17 mm). At least, the entire injured segment should be covered by SG, and several SGs are also required for a long lesion [1-9].


**Figure 3.** Bleeding from the posterior segmental artery of the right hepatic artery after extended left hepatectomy with portal vein resection for hilar bile duct carcinoma.

A. Arterial phase CT revealed contrast extravasation at the hepatic hilum (arrow). The portal vein was also occluded (asterisk). The arrowheads indicate a drainage catheter in the bile duct placed during surgery. B. Celiac arteriogram revealed contrast extravasation from the stenosed posterior segmental artery (PSA) of the right hepatic artery (arrow). C. Portal phase of the superior mesenteric arteriography indicated that the portal vein (arrow) was occluded and intrahepatic portal veins (arrowheads) were faintly opacified through collaterals. D. A 1.7-F tip microcatheter was distally navigated beyond the injured segment by a 0.016-in guidewire through a 4-F guiding sheath placed in the common hepatic artery (CHA). Then, the guidewire was exchanged to a 0.014-in stiff guidewire, and the microcatheter was withdrawn (not shown). E. On performing deep cannulation of the 4-F guiding catheter into CHA to advance SG to the stenosed PSA, arterial flow of CHA was stalled. Thus, a bolus injection of 3,000 U of heparin was performed. However, it took several minutes to deploy SG because SG could not be easily passed through the stenosed segment. Finally, a 3 × 16-mm GraftMaster was successfully deployed. The arrow indicates contrast material in the stalled proper hepatic artery, and the arrowhead indicates extravasated contrast material. F. However, celiac arteriogram obtained immediately after SG placement revealed total occlusion of the proper hepatic artery. So, the microcatheter was advanced into PSA, and 240,000 IU of urokinase were infused (not shown). G. Common hepatic arteriogram obtained after infusion of urokinase showed that PSA was partially recanalized. The next day, the serum aspartate aminotransferase and alanine aminotransferase levels were elevated from 95 to 2,155 U/L and from 88 to 1,195 U/L, respectively, although anticoagulation therapy was continued. These values decreased to 54 and 86 U/L, respectively, 1 week later. H. Dynamic CT performed 13 days after the procedure revealed no hepatic infarctions. Extravasation disappeared and the artery (arrow) and portal vein (arrowhead) were also opacified in the liver remnant.

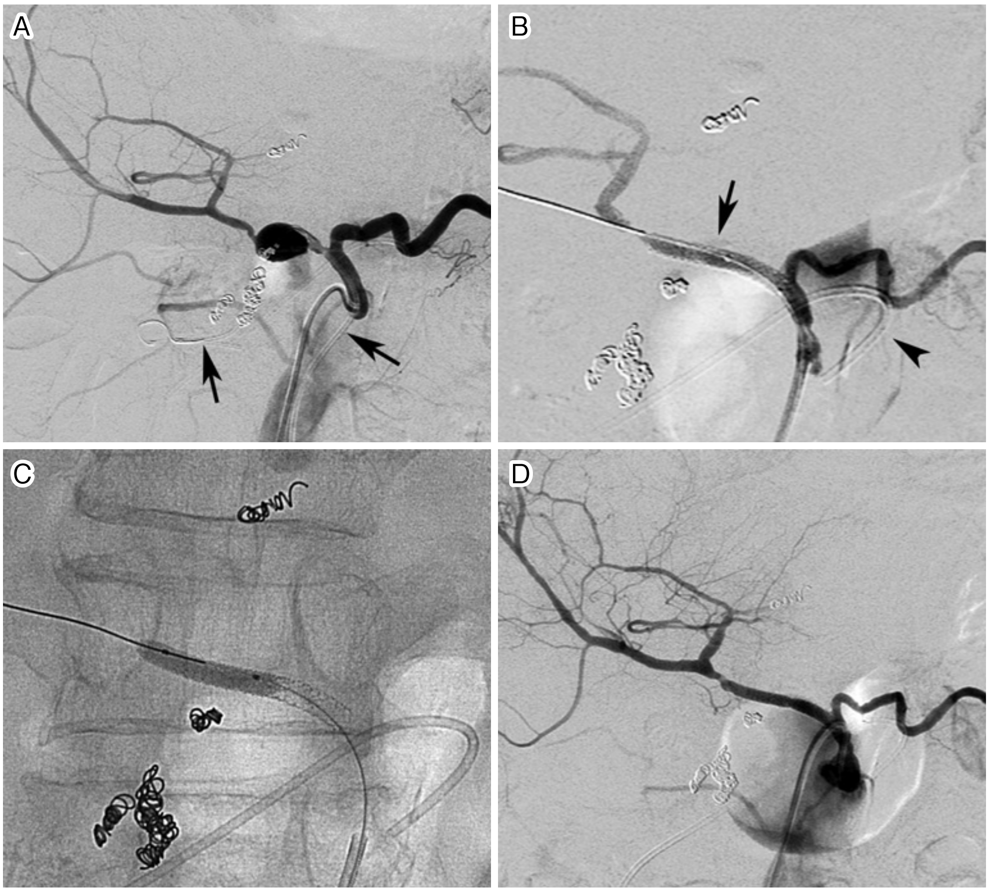


**Figure 4.** Pseudoaneurysm of the common hepatic artery during hepatic arterial infusion chemotherapy for hepatocellular carcinoma.
A. Celiac arteriogram revealed a large pseudoaneurysm at the common hepatic artery. The arrows indicate an indwelling catheter for hepatic arterial infusion chemotherapy for hepatocellular carcinoma placed 65 days ago. The diameters of the proper and common hepatic arteries were 3.0 and 3.2 mm, respectively. B. After removal of the indwelling catheter, two GraftMasters, 3 × 19 mm and 3.5 × 16 mm, were deployed by balloon inflation at 14 atm. Celiac arteriogram obtained immediately after SG placement showed type 1 endoleak (arrow). The arrowhead indicates a previously placed pancreatic stent due to chronic pancreatitis. C. Postdilation of SGs was performed using a 3.5 × 16 mm balloon catheter at 18 atm. D. Final celiac arteriogram revealed complete obliteration of the pseudoaneurysm. Figures 4A and 4B reprinted from Ref. (9) with permission.

## Procedure

After confirmation of contrast extravasation and/or a pseudoaneurysm on diagnostic angiography, a guiding catheter/sheath is advanced into the injured artery using a 0.035-in stiff guidewire *via* the femoral or axillary/brachial artery [1-9]. In some cases, it can also be advanced using a 0.014-/0.018-in stiff guidewire, following a slightly inflated angioplasty balloon catheter. The approach site is determined according to the branching direction of the parent artery of the injured artery on CT. The guiding catheter/sheath should be advanced as distally as possible, ideally beyond the distal side of the injured portion (**Fig. 7**) [6]. However, arterial flow of the catheterized artery is occasionally stalled by selective cannulation (**Fig. 3**). To prevent thromboembolic complications, 2,500-5,000 U of heparin are intravenously administered before placing the guiding catheter/sheath in hemodynamically stable patients [5, 7]. In cases with massive active bleeding, occlusion of the injured artery by a balloon catheter during SG preparation can provide temporary hemostasis and hemodynamic stability (**Fig. 8**) [8]. Heparin injection is also recommended when balloon occlusion is performed [8].

SG is advanced into the injured segment over a stiff guidewire and carefully deployed. When Viabahn placement is attempted in the severe tortuous artery, the bowstring phenomenon may cause unsuccessful deployment or jumping of SG. If there is a branch that may cause retrograde bleeding and/or aneurysm recanalization, a preventive coil or plug embolization should be performed before SG placement (**Fig. 9**). When traversing the injured portion by a stiff guidewire is dangerous, a catheter/microcatheter is navigated beyond the injured portion using a standard guidewire, and then the guidewire should be exchanged to a stiff one (**Fig. 3**). If SG is not fitted to the stented artery or type 1 or 2 endoleak is demonstrated on angiography following SG im-

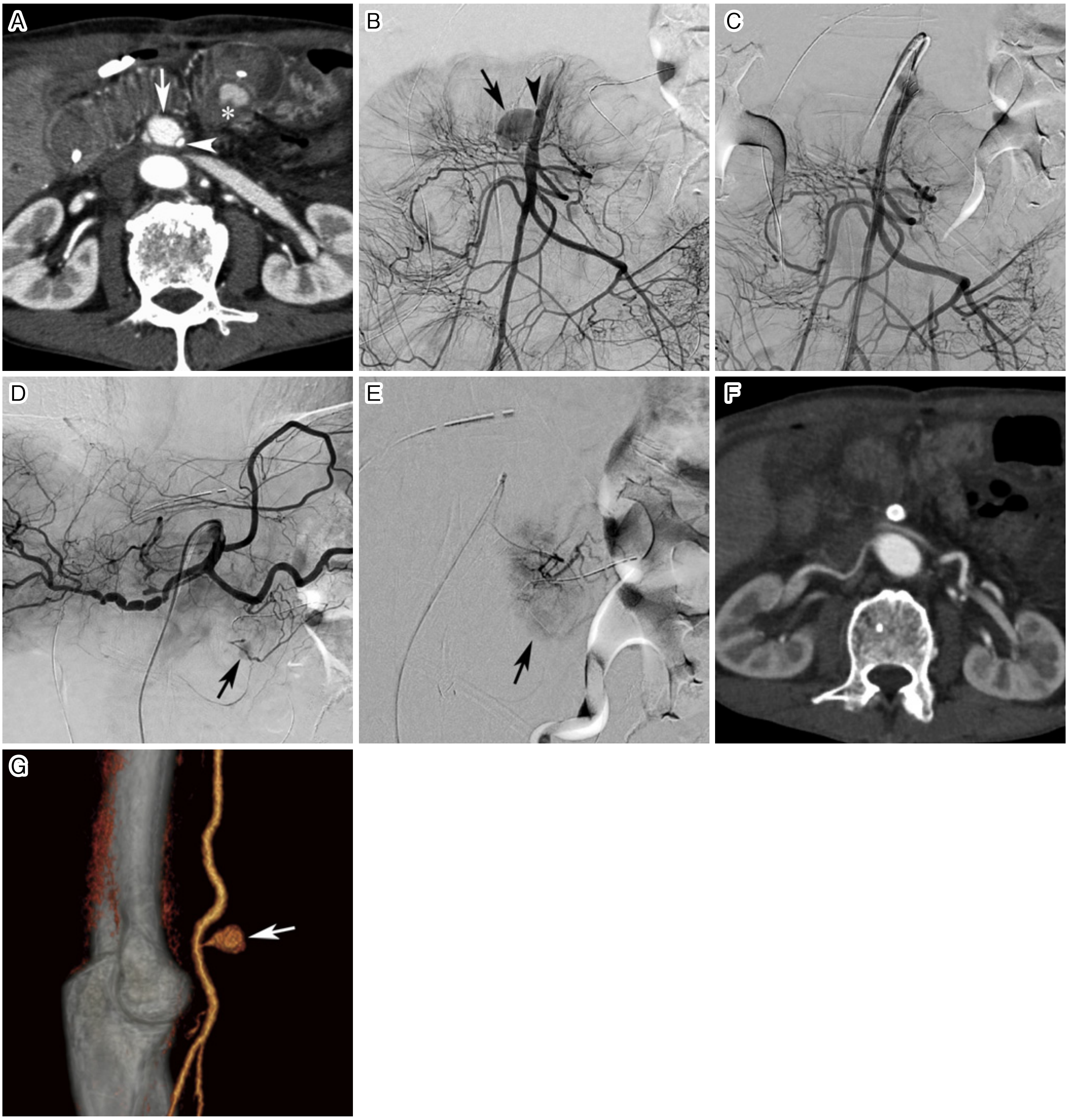


**Figure 5.** Pseudoaneurysms of the superior mesenteric and pancreatic magna arteries after pylorus-preserving pancreatoduodenectomy for pancreatic carcinoma.

A. Arterial phase CT revealed a large pseudoaneurysm (arrow) adjacent to the superior mesenteric artery (arrowhead). Another pseudoaneurysm was also observed at the pancreatic-jejunal anastomosis site (asterisk). B. Superior mesenteric arteriogram revealed the pseudoaneurysm (arrow). The arrowhead indicates the injured vessel portion. C. An 8 × 50-mm Niti-S ComVi stent was deployed *via* the left brachial access, and the pseudoaneurysm disappeared. No branches were also occluded by SG placement. D. Thereafter, celiac arteriogram was performed, and another pseudoaneurysm of the pancreatic magna artery (arrow) was demonstrated. Common hepatic artery was also serrated by the surgical procedure. E. A 1.7-F tip microcatheter could not be advanced near the pseudoaneurysm (arrow) as the route was very tortuous; therefore, embolization with gelatin sponge particles was performed, and it disappeared following embolization (not shown). F. Disappearance of pseudoaneurysms was confirmed on CT performed 10 days after the procedure (not shown). Arterial phase CT performed 2 months after the procedure revealed that SG was patent. G. However, a pseudoaneurysm of the left brachial artery at the insertion site of an 8-F sheath was revealed (arrow), and surgical repair was performed.

plantation, postdilation of SG with an angioplasty balloon catheter or additional SG placement is required (**Fig. 4**). However, the additional device occasionally cannot be advanced into the stented lumen due to friction between the devices (**Fig. 2**), and forceful advancement of these devices may cause SG migration.

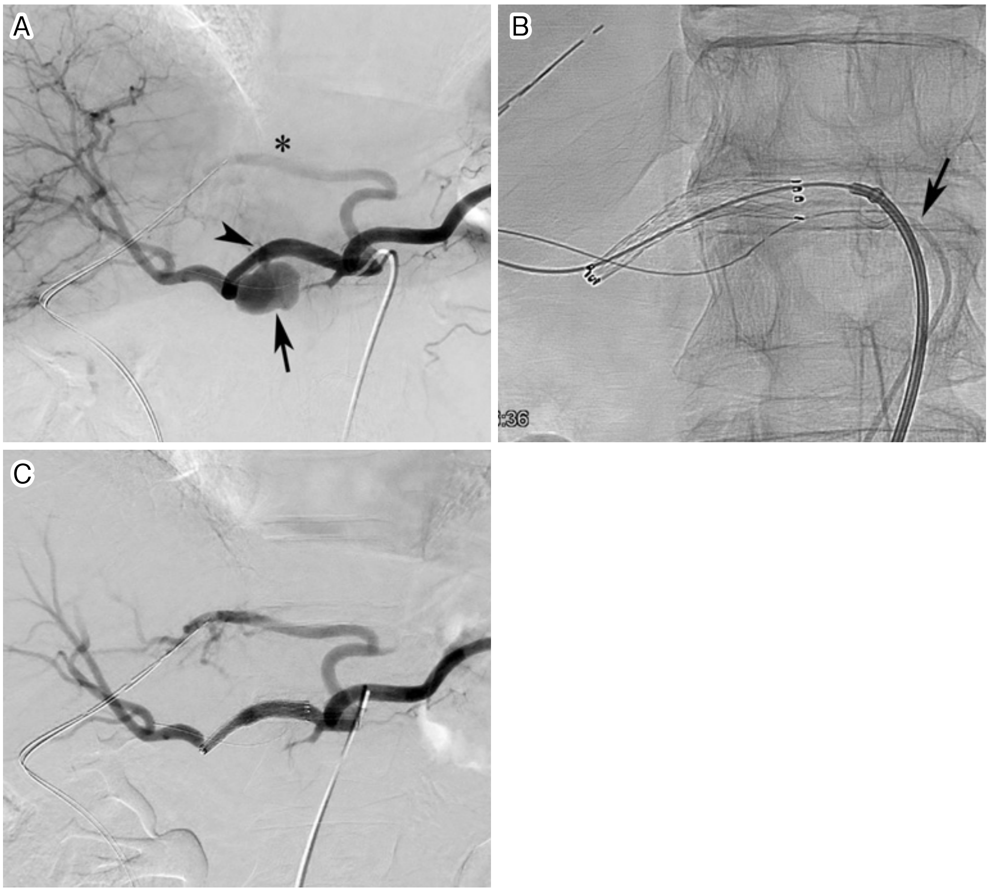


**Figure 6.** Pseudoaneurysm at the gastroduodenal artery stump following pancreatoduodenectomy for bile duct carcinoma.
A. Celiac arteriogram revealed a large pseudoaneurysm (arrow) at the gastroduodenal artery stump (arrowhead). Because the left hepatic artery (asterisk) arose from the left gastric artery, coil embolization of the common hepatic artery might have been safe. However, SG placement was selected to reduce the procedural time. B. An 8 × 40-mm Fluency Plus stent was advanced through a 9-F guiding sheath and placed to bridge the pseudoaneurysm. The arrow indicates another 4-F catheter placed in the celiac artery to visualize the pseudoaneurysm during SG placement. C. Celiac arteriogram obtained immediately after SG placement revealed the disappearance of the pseudoaneurysm.

## Technical Success

Technical success is defined as the disappearance of contrast extravasation and/or a pseudoaneurysm by SG placement. The reported technical success rate, including cases with injured pelvic or thoracic arterial branches, ranges from 80% to 100% [1-8]. However, SG placement is not initially attempted for patients with anatomical difficulties for this treatment (**Fig. 5**). Therefore, the technical success rate is significantly influenced by patient selection and possibly by the types of SG. Viabahn is mounted coverless on the delivery system and causes friction between the vessel walls; therefore, advancement of the guiding sheath beyond the injured portion can improve the technical success rate and reduce complications [6].

## Postprocedural Management

Vital signs are monitored after the procedure. In patients with a surgical drain, the volume and the nature of discharge from it are also monitored. Before and after the procedure, a broad-spectrum antibiotic is administered in cases of suspected infection [3, 5]. Disappearance of contrast extravasation or the pseudoaneurysm and patency of SG should be evaluated on dynamic CT. If ongoing or recurrent hemorrhage is demonstrated, additional treatment options should be determined depending on the CT findings. When fluid collection surrounding SG is demonstrated, percutaneous or surgical drainage should also be performed to maintain SG patency. After achieving successful hemostasis, imaging follow-up is performed according to the clinical symptoms and background disease of each patient.

Dual antiplatelet therapy (aspirin 100 mg/day and clopidogrel 75 mg/day) is generally recommended for at least 3-6 months after the procedure [1, 6]. However, the need for antiplatelet therapy is controversial in patients undergoing SG placement for an injured visceral artery. Wolk et al. [1] reported that the use of an antiplatelet agent was significantly correlated with a decrease in in-hospital mortality in univariate (11.5% vs. 25%, respectively, $p = 0.024$) and multivari-

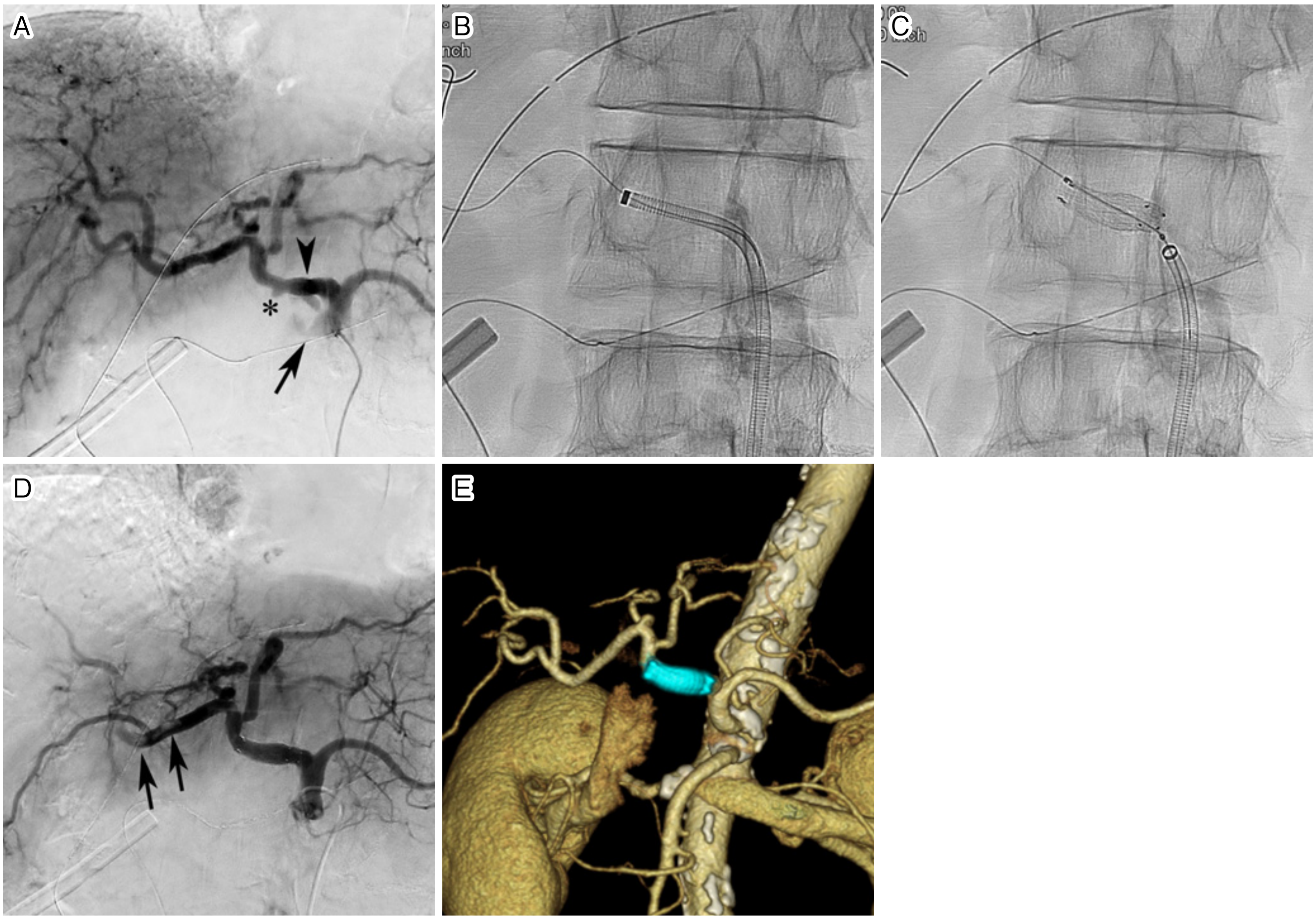


**Figure 7.** Bleeding from the common hepatic artery following pylorus-preserving pancreatoduodenectomy for pancreatic carcinoma.
A. Celiac arteriogram revealed contrast extravasation (arrow) from the pseudoaneurysm (arrowhead) at the common hepatic artery. The asterisk indicates the gastroduodenal stump. B. A 6-F guiding sheath was advanced beyond the injured portion. C. Then, a 6 × 25-mm Viabahn was deployed. D. Celiac arteriogram obtained immediately after SG placement revealed the disappearance of contrast extravasation. However, thromboembolic occlusion of the right hepatic artery developed (arrows). Heparinization was not performed during the procedure as active bleeding was demonstrated on arteriograms. The next day, the serum aspartate aminotransferase and alanine aminotransferase levels were elevated from 12 to 68 U/L and from 11 to 59 U/L, respectively, and these were normalized 5 days later without heparinization or antiplatelet therapy. E. Three-dimensional CT performed 2 days after the procedure revealed that the pseudoaneurysm was covered by SG and the right hepatic artery was recanalized.

ate analyses (hazard ratio: 3.1, 95% confidence interval: 1.1-9, $p$ = 0.034) without increasing the risk of rebleeding. In cases of postoperative hemorrhage, however, the risk of SG occlusion increases due to a persistent postoperative inflammatory environment and/or the damaged arterial lumen surrounded by unresolved complicated fluid collection or a hematoma [2, 4, 8]. In a study by Lim et al. [2], a target artery diameter < 4 mm was a significantly higher risk factor of SG occlusion ($p$ = 0.01), and the risk of SG occlusion decreased as the diameter of SG increased ($p$ = 0.01). Contrarily, the use of an antiplatelet agent did not significantly influence the patency of SGs ($p$ = 0.96). Furthermore, Ueda et al. [6] reported that anticoagulation therapy did not significantly influence SG patency ($p$ = 0.38), and patients with infection and target artery diameters ≤ 4 mm had a significantly higher risk of SG occlusion ($p$ < 0.01 and $p$ = 0.01, respectively). In addition, those with >20% oversized SG tended to have a higher risk of SG occlusion ($p$ = 0.06). Therefore, antiplatelet therapy should be performed based on the physician's decision according to achieving a good balance between the risk of rebleeding and necessity of maintaining the long-term patency of SG in each patient.

## Clinical Success

Clinical success is generally defined as no rebleeding and no repeated angiographic or surgical intervention at the treated site within 30 days or during the follow-up period. The reported clinical success rate, including nonvisceral arterial use, ranges from 66.7% to 100% [1-8], although it is strongly influenced by the background of each patient, such as the presence of local infection and/or leakage of pancreatic juice or bile from insufficient anastomoses. In a report by Öcal et al. [4], the need for intensive care before the procedure ($p$ = 0.013) and a smaller SG size (≤ 4 mm, $p$ = 0.032) were associated with clinical failure, and a trend to-

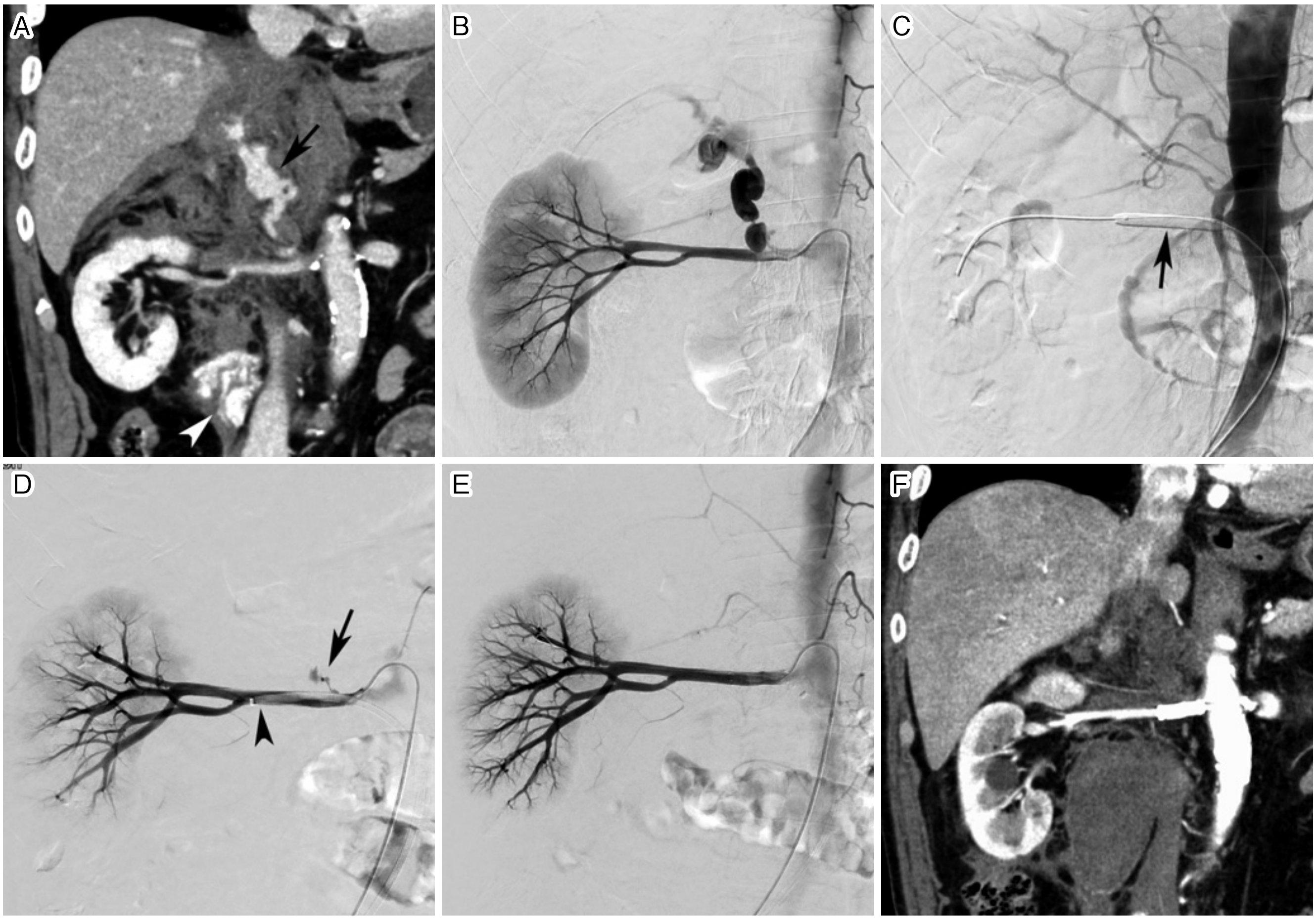


**Figure 8.** Bleeding from the right renal artery caused by trauma.
A. Coronal view of arterial phase CT revealed massive contrast extravasation (arrow) from the right renal artery. Contrast extravasation also extended beyond the lower pole of the right kidney (arrowhead). B. Arteriogram of the right renal artery revealed marked contrast extravasation from the right renal artery. C. A 5-F 5 × 40-mm angioplasty balloon catheter was inflated at the injured segment for 1 h until SG was delivered to our hospital. Aortography revealed that hemostasis could be achieved by balloon occlusion of the right renal artery. The arrow indicates the balloon. D. Arteriogram of the right renal artery obtained after 1-h balloon inflation revealed that contrast extravasation was significantly decreased (arrow). Heparinization was not performed during balloon inflation as the patient's hemodynamic condition was unstable. Arteriography was performed using another 4-F catheter, and a 7-F guiding sheath was placed into the right renal artery (arrowhead). E. A 7 × 25-mm Viabahn was deployed, and extravasation disappeared. The serum creatinine level was elevated from 1.0 to 1.7 mg/dL 2 days later, but it was normalized 5 days after the procedure. F. Coronal view of arterial phase CT performed 11 days after the procedure revealed that the SG was patent and the hematoma had decreased in size.

ward failure in patients with shock was observed ($p$ = 0.052).

## Long-term Patency of SG

The patency of SG reduces as the observation period becomes longer. The reported patency rates at 6 and 12 months after the procedure are 69.6%-100% and 42%-80%, respectively [1-8]. Regarding Viabahn placed in an injured visceral artery, it was 78.6%-100% at 6 months and 56.1%-80% at 12 months [5, 6].

Except for immediate SG occlusion, most SG occlusions during the observation period require no additional treatment because organ ischemia may not occur, probably due to the development of collateral circulation prior to SG occlusion (**Fig. 2**).

## Complications

Rupture of the pseudoaneurysm or disruption/dissection of the parent artery can occur during the procedure [3-5, 7]. If it is difficult to repair by placing an additional SG, conversion to coil embolization or surgical repair should be considered. Occlusion of the bleeding artery using a balloon catheter should also be attempted before transfer to the operating room [7]. Although the reported incidence of severe ischemic complications is low (range, 0%-3.8%) [1-8], thromboembolic complications occasionally occur (**Fig. 7**) despite heparinization (**Fig. 3**). Fatal ischemia, such as excessive hepatic infarction and mesenteric ischemia, may occur when acute occlusion of SG develops [2]. SG migration also develops infrequently [5]. Furthermore, incomplete hemostasis at the access site causes hematoma or pseudoaneurysm formation (**Fig. 3**) [4].

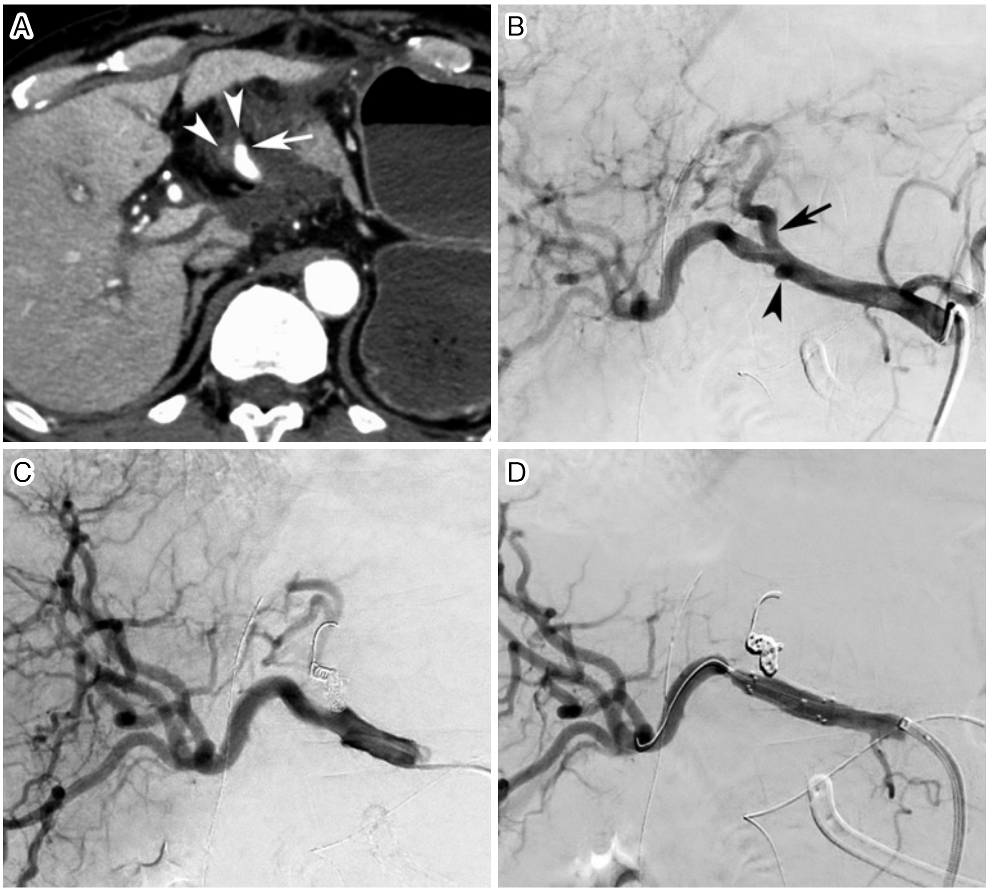


**Figure 9.** Bleeding from the gastroduodenal artery stump after pancreatoduodenectomy for duodenal carcinoma.
A. Arterial phase CT revealed contrast extravasation (arrows) from the gastroduodenal artery stump (arrowhead). B. Celiac arteriogram revealed that the left hepatic artery (LHA) (arrow) arose near the gastroduodenal stump (arrowhead). Bleeding from the gastroduodenal stump was stopped at that time. C. First, LHA was embolized with metallic coils. Common hepatic arteriogram obtained after coil embolization revealed that LHA was opacified through the communicating arcade. D. A 7 × 25-mm Viabahn was deployed to cover the orifice of the gastroduodenal stump and LHA.

## Conclusion

SG placement is an effective treatment option for injured visceral arteries. Interventional radiologists should be familiar with this procedure to rescue patients with an emergent condition.

**Conflict of Interest:** None
**Author Contribution:** S.M. was mainly involved in the drafting of the manuscript and creation of figures. S.M., M. Y., R.I., and A.Y. were involved in the interventional procedures. H.K. and N.S. were involved in image analysis. T.T. and H.Y. provided patient care. All authors reviewed the manuscript.
**IRB:** Our institutional review board approved the submission of this pictorial essay, and individual patient consent was waived. Written informed consent was obtained from each patient before stent graft placement.
**Disclaimer:** Shiro Miyayama is one of the Editorial Board members of Interventional Radiology. This author was not involved in the peer-review or decision-making process for this paper.

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