Non-variceal gastrointestinal bleeding is the significant emergency problem to manage in the hospital. Transcatheter arterial embolization is minimally invasive treatment, which becomes an essential role in controlling bleeding, leading to lifesaving. To reach the goal, the interventional radiologist should have fundamental of vascular anatomy and choice of embolic material, which is the key to success.

Keywords: Anatomy; Embolization; Gastrointestinal bleeding

Introduction

Gastrointestinal (GI) bleeding is a typical scenario that can be present in an emergency situation which can be a life-threatening condition. Mortality rates as high as 10% to 14% have been reported. The estimated annual incidence is approximately 20 to 150 cases per 10,000 persons. Cause of GI bleeding can be classified into variceal and non-variceal bleeding. A multidisciplinary team consisting of members of the endoscopy, surgery, and radiology department are necessary for the initiation of the appropriate treatment strategy. Most of the time, conservative medical and endoscopic treatments are the primary treatment choices used to achieve hemostasis in GI bleeding patients. However, uncontrolled bleeding after a failure of endoscopic treatment can occur, especially in non-variceal GI bleeding. Nowadays, endovascular treatment is the preferred option comparing to surgical treatment due to the less invasive nature of the procedure and associated less morbidity and mortality rates. Adequate knowledge of the GI vascular anatomy is utmost necessary to perform angiography and transcatheter arterial embolization (TAE) successfully in treating GI bleeding patients.

Vascular Anatomy for GI Bleeding

Four major abdominal vessels that supply the GI tract are the celiac artery (CA), superior mesenteric artery (SMA), inferior mesenteric artery (IMA), and the internal iliac artery. The CA arises from the abdominal aorta at T12–L1 level. Trifurcation of the CA is found in the majority of the population (89%), composing of a left gastric artery (LGA), a common hepatic artery, and a splenic artery. A total of twelve variations of the CA was reported by Song et al. The SMA provides the primary blood supply to the small bowel, the ascending colon, and the transverse colon via the inferior pancreaticoduodenal artery, jejunal artery, ileal artery, ileocolic artery, and the middle colic artery (MCA). Sometimes, a replaced hepatic artery may arise from the proximal part of SMA. The IMA is a small artery arising anteriorly from the abdominal aorta at L3–L4 level. The IMA provides the left colic artery (LCA) which supplies the descending colon and anastomoses with the SMA at splenic flexure. The sigmoidal artery also originates from the IMA, and it supplies the sigmoid colon. The terminal branch of this artery is the superior rectal artery which supplies the upper rectum. Lastly, the anterior division of the internal iliac artery gives rise to the middle and inferior rectal arteries which supply the middle and lower rectum.

Stomach

The stomach is the largest alimentary tract organ. It has several vascular supplies which mainly arises from the CA. The...
gastric cardia and fundus are supplied by the LGA and short gastric artery (ShGA). The lesser curvature is supplied mainly by the LGA. The proximal greater curvature is supplied by the ShGA and left gastroepiploic artery (LGEA). The distal greater curvature of the stomach receives arterial supply from the right gastroepiploic arteries (RGEA) in 42% to 78% of cases while the rest is from the right gastric artery (RGA). The anterior wall of the antrum is supplied by the RGEA and the lower anterior branch of the LGA while the posterior wall is supplied by the RGA and the lower posterior branch of LGA. The RGEA and RGA supply pylorus.

The ShGA and LGEA arise from the splenic artery while the LGA arises directly from the CA in more than 90% of cases. An accessory LGA is reported in 1.8% to 20% of the European population. The RGA commonly arises from either the common hepatic artery or left hepatic artery. In a small portion of the population, it could arise from the gastroduodenal artery (GDA), the middle hepatic artery or the right hepatic artery. The RGEA arises from the GDA. The GDA arises from the common hepatic branch of the CA in 75% of cases. In the rest, it arises from the left or right hepatic artery or the SMA.

Duodenum

Duodenum is the first part of the small intestine, supplied mainly by the GDA. Ligament of Treitz, which is found in the duodenojejunal junction, divides the location of the GI bleeding into the upper and lower GI tract which is essential in bleeding management. The duodenal bulb is supplied by the supraduodenal artery, which is a proximal branch of GDA. The anterior and posterior pancreaticoduodenal arcades supply the anterior and posterior surface of the duodenum. The arcades are formed by the anterior superior pancreaticoduodenal artery and retroperitoneal artery and the inferior pancreaticoduodenal artery. Both anterior superior pancreaticoduodenal artery and retroperitoneal artery are branches of the GDA while the inferior pancreaticoduodenal is a right branch of SMA. The inferior pancreaticoduodenal artery arise as dual anterior and posterior branch in 60% of the population while the rest of the population will have a single artery.

Jejunum and ileum

Jejunum and ileum are supplied by the respective branches arising from the SMA. There are 4 to 6 jejunal branches and 9 to 13 ileal branches. Terminal ileum, cecum and inferior half of the ascending colon are supplied by the ileocolic artery arising as the terminal branch of SMA. The ileal and colic branches form the ileocolic loop. This loop gives rise to appendicular and anterior and posterior cecal arteries which supply appendix and cecum.

Colon

Main vascular supply of the colon is SMA and IMA. The ascending colon and the right half of the transverse colon are supplied by the right and middle colic arteries which arise from the right side of the SMA. Splenic flexure and descending colon are supplied by LCA which is an ascending branch of the IMA. The sigmoidal branch of the IMA supplies the sigmoid colon. The right and middle colic arteries arise as a common trunk in more than half of populations. In some case, MCA arises from the CA. The MCA is also reported to be absent in 2% to 22% of subjects, while the right colic artery, could be absent in up to 50% of the population. The MCA extends to supply the splenic flexure when the LCA is absent in about 7% of populations.

Rectum

Rectum receives blood supply from branches of the IMA and the internal iliac arteries. The superior rectal artery which arises from the IMA supplies the upper rectum. This artery forms an anastomosis with the middle rectal artery, inferior rectal artery and the marginal artery. Middle and inferior rectal arteries are branches of the internal iliac artery and internal pudendal artery, respectively. A dominant retrosigmoid collateral supply from the internal iliac has been reported previously.

Key Collateral Pathway

Extensive collateral blood flow is common, especially in the upper GI tract but it is rare in the colon. Collateral pathway has a role in preventing end-organ ischemia. However, in the case of GI bleeding, the collateral pathway can also be a risk factor for treatment failure. This phenomenon is commonly seen in the case of the duodenal bleeding, which has dual blood supply from both the GDA and the inferior pancreaticoduodenal artery. Embolization of only one of the arterial branches may result in treatment failure (Fig. 1). The collateral pathways could be formed between branches of the same trunk such as between LGA and RGA, or it could be between branches of two different trunks such as the anastomosis of SMA branches and CA branches in the pancreaticoduodenal arcade. The common pathways are as below.

Collateral between the branches of CA (Fig. 2)

1. The branch of the LGA anastomoses with ShGA at the level of the fundus.
2. The branch of the LGA and the RGA anastomose with each other at the level of the body and pylorus.
3. A right side branch of the dorsal pancreatic artery anastomoses with the branches from the anterior superior pancreaticoduodenal artery or the RGEA.
4. The epiploic branches of the RGEA and LGEA forms the posterior omental arcade of Barkow. Branches from this arcade forms anastomoses with the branches from the inferior pancreaticoduodenal artery, transverse pancreatic artery, MCA and the LCA.

Collateral between the branches of CA, SMA, IMA and internal iliac artery (Fig. 3)

1. The persistent embryonic anastomotic branch between CA and SMA is called the arc of Buhler.
2. Anterior and posterior gastroduodenal arcade formed by the anastomosis between the superior pancreaticoduodenal artery and retroperitoneal artery of the GDA with the inferior pancreaticoduodenal artery of the SMA.
3. The ascending branch of the LCA anastomoses with the branch of the MCA, creating the arc of Riolan (medial) and marginal artery of Drummond (lateral).
4. Superior rectal artery of the IMA forms an anastomosis with the middle rectal artery and inferior rectal artery which are the branches of the internal iliac artery and internal pudendal artery, respectively.
Fig. 1. A 30-year-old man had a motor vehicle accident. Computed tomography scan found a small pseudoaneurysm of gastroduodenal artery (GDA). (A) GDA angiogram found a small pseudoaneurysm (arrow). (B) Microcoil (arrow) embolization was performed at the proximal part of the parent artery. (C) Backflow filling into the pseudoaneurysm (arrow) was detected from inferior pancreaticoduodenal artery angiogram. (D) Further microcoil packing at the distal parent artery was done (arrowhead). (E) The celiac angiogram showed no demonstrable of pseudoaneurysm (arrow).

Fig. 2. Collateral between the branches of celiac artery. CA, celiac artery; LGA, left gastric artery; SPA, splenic artery; ShGA, short gastric artery; LGEA, left gastroepiploic artery; DPA, dorsal pancreatic artery; RGEA, right gastroepiploic artery; GDA, gastroduodenal artery; HA proper, hepatic artery proper; RGA, right gastric artery. Refer to “Collateral between the branches of CA” section in the main text for the definition of 1 to 4.

Fig. 3. Collateral between the branches of CA, SMA, IMA and internal iliac artery. LGA, left gastric artery; CA, celiac artery; SPA, splenic artery; GDA, gastroduodenal artery; SMA, superior mesenteric artery; MCA, middle colic artery; IMA, inferior mesenteric artery; LCA, left colic artery; SRA, superior rectal artery; IA, internal iliac artery. Refer to “Collateral between the branches of CA, SMA, IMA and internal iliac artery” section in the main text for the definition of 1 to 4.
Extra-alimentary Source of GI Bleeding

Hemobilia

Hemobilia is defined as bleeding into the biliary system which could be either bleeding into the intrahepatic or extrahepatic duct. It is an unusual source of GI bleeding in daily practice. The blood from the biliary system could pass into the bowel, and the patient can present with GI bleeding signs and symptoms. Over 50% of the etiology has iatrogenic cause such as secondary to biliary intervention procedure which accidentally created a fistulous communication between vessels and bile ducts. Pathologic vessels commonly from the artery however portal vein injury could be the cause of the hemobilia. Other known causes are biliary tumor or cholelithiasis but they are a less common occurrence. The most common presentation of hemobilia is melena. In a patient with a clinical presentation of GI bleeding and a history of prior biliary intervention or liver trauma, hemobilia should be considered. TAE is one of the good options to treat hemobilia. Hepatic artery and GDA pathology should be focused during angiography in case of iatrogenic bleeding (Fig. 4).

Hemosuccus pancreaticus

Hemosuccus pancreaticus is a rare source of GI bleeding. It is defined as bleeding from ampulla of Vater via the pancreatic duct. Possible causes of hemosuccus pancreaticus include acute or chronic pancreatitis, pancreatic trauma, vascular malformation and pancreatic tumor. Chronic pancreatitis is the most common cause. It occurs due to pancreatic enzyme induced peripancreatic vascular wall injury and leads to the development of pseudoaneurysm. The GI bleeding can occur from the splenic artery, GDA, pancreatic artery, and pancreaticoduodenal artery in this condition (Fig. 5). The endovascular intervention plays a significant role in treating this condition.

Imaging Evaluation for GI Bleeding

The site of bleeding identification is the key to success in either surgical or endovascular treatment. Multi-detector computed tomography (MDCT) is the non-invasive imaging modality of choice due to diagnostic ability and fast acquisition time. Newer generation MDCTs have increased temporal and spatial resolution which allows it to provide better details regarding the site and cause of bleeding. Such data helps interventionist in planning TAE approach. CT angiography (CTA) able to detect bleeding which is at the rate of 0.35 mL/min. Images are acquired in the arterial phase, venous phase, and delayed phase. Arterial phase imaging is done roughly 30 seconds after intravenous (IV) contrast infusion. This phase is crucial in mapping the mesenteric vasculature and identifying the site of bleeding. Cross-referencing the arterial phase with either the non-contrast or venous phase (acquired roughly 60 seconds post IV contrast injection) helps in differentiating hemorrhage with intrinsically hyperdense bowel contents (e.g., old ingested barium or suture). The important limitation of CTA is the inability to detect intermittent bleeding. However, in patients with lower GI tract bleeding with stable hemodynamic status, the risk of rebleeding is reported as low if the initial CTA is negative.

Tagged red blood cell scintigraphy can detect bleeding as
slow as 0.1 mL/min and have the ability to detect intermittent bleeding through sequential scans. However, it has a poor spatial resolution, and it is difficult to pinpoint the exact site of bleeding especially in the small bowel.\textsuperscript{18} It is also time-consuming and not appropriate in the acute setting.\textsuperscript{19}

Angiography meanwhile plays a dual role, both as a diagnostic tool as well as a therapeutic tool in dealing with GI bleeding. It has the sensitivity of detecting the bleeding rate of 0.5 to 1.0 mL/min.\textsuperscript{18} It should be considered in cases of recent ongoing GI bleeding even if the CTA is negative.\textsuperscript{19} The diagnostic accuracy of arteriography is reported as high if it is performed during the episode of active bleeding.\textsuperscript{6}

**Choice of Embolic Materials**

TAE is effective in controlling acute GI bleeding, especially in circumstances where an endoscopic or surgical approach is not suitable. TAE aims to stop bleeding without significant collateral damage. Interventionist should have a good knowledge of various embolic material used to achieve the goal of treatment. Optimal embolization depends on the vascular pathology and bleeding site. In general, embolization should be performed as close to the bleeding site as possible to reduce the risk of complications.

**Gelatin sponge**

Gelatin sponge (GS) is a widely available embolic material used by interventional radiologist especially in the management of hepatocellular carcinoma and acute arterial bleeding. GS is made from either the bovine or porcine collagen. It is a water-insoluble hemostatic agent. GS is a temporary embolic material as it resolves spontaneously over a period of 2 to 6 weeks. However, it can produce permanent embolization effect by inducing arteritis effect and intimal hyperplasia.\textsuperscript{20} The embolic effect of GS is dependent on the coagulation profile of the patient. Therefore, in a patient with severe coagulopathy, clinical failure of the hemo-
stasis can occur.\textsuperscript{21}

GS slurry can be prepared via two steps. Firstly, the GS is cut into small 1 mm cubes and mixed with contrast medium. It is followed by another step which is called the ‘pumping method’. It uses two syringes to pump the GS across a three-way stopcock valve to form the slurry consistency. The accurate size and concentration of GS are very challenging to be accurately estimated. During embolization, the catheter should be placed as close to the target vessels as possible. Careful monitoring of reflux is essential to prevent non-target embolization.

The advantages of GS are easy to use, widely available, inexpensive and has a temporary embolic effect. In the cases where the micro-catheter cannot reach to the target point, GS can be infused to reduce the blood flow and promote hemostasis. The GS particle can achieve a temporary embolic effect and disperse easily in case of massive extravasation (Fig. 6).

**Polyvinyl alcohol and microsphere**

Polyvinyl alcohol (PVA) or microsphere is a permanent embolic material, with particle sizes ranging from 40 to 1200 µm. The PVA is an old particulate embolic material which is a non-radioopaque material with an irregular surface. The PVA can be mixed with contrast medium to make it visible during injection. However, clumping of the PVA particle does occur commonly due to the irregular surface and obstructs the catheter.

Microsphere agents are made from acrylics, hydrogels, resins, polymers, or glass. Its major advantage is the uniform shape and smooth surface which reduces the clumping effect. It allows easier delivery through the small micro-catheters.

The use of permanent particle agent is to reduce the vascular supply of the bleeder. The size of the particulate agent chosen in GI bleeding should not be smaller than 500 µm to avoid ischemic complication.\textsuperscript{22} However, due to the risk of infarction, the operator must be cautious during embolization particularly in colonic bleeding.\textsuperscript{23}

**Coil**

The coil is considered as a large permanent embolic material. It is available in a variety of sizes, lengths, and shapes. It occludes the bleeding vessel by causing mechanical obstruction as well as promotes hemostasis at the pathologic vessels. The diameter of the coil ranges from 2 to 18 mm. Two delivery systems of the coil are available in the market which is the detachable and non-detachable type. The detachable coil is safer to be used during the coil packing. It prevents non-target embolization and misplacement of the coil. Two diameters of coil wire are available currently which is the 0.035 inch and 0.018 inch systems. Nowadays, the 0.018 inch microcoil systems are becoming more popular due to the ability to be used in a more distal embolization.

The main advantage of the coil is it could be placed at a pre-

![Fig. 6. A 70-year-old man with a history of advanced colonic cancer of descending colon. (A) Coronal computed tomography image showed circumferential colonic mass (arrow) at the descending colon. (B) The middle colic angiogram demonstrated a hypervascular mass (arrow) with no contrast extravasation at descending colon. (C) Gelatin sponge was used to embolize this mass, angiogram after embolization revealed marked decreased vascularization of the tumor (arrow).](image-url)
cise location. If a medium or large pathologic vessel is needed to embolize, such as GDA, the coil is the most suitable choice. A coil is also commonly used in the treatment of GI bleeding secondary to pseudoaneurysm. It is used to occlude the parent artery. The drawback is that the coagulation disorder may affect the efficacy of embolization. Post coiling recurrent hemorrhage rate of up to 20% was reported among GI bleeding patients with coagulopathy. A single coil is rarely enough to get total vascular occlusion; therefore most procedure requires the usage of a few coils. It leads to longer operation time and higher cost (Fig. 7).

In cases of patients with positive GI bleeding findings in either endoscopic or CTA but negative findings in the conventional angiography, the coil embolization can be used as an empirical treatment as it is safe and effective. Two vessels which are commonly embolized empirically are the LGA and GDA.

**N-butyl cyanoacrylate**

N-butyl cyanoacrylate (NBCA) is a liquid embolic material which has been used in the interventional radiology field for several years. There are many advantages of NBCA. Firstly, the NBCA can reach the pathology point via bloodstream even in cases where the microcatheter cannot reach the target especially due to the severe tortuosity of the vessel. Secondly, it helps to prevent the retrograde backfilling of the collateral vessel. Lastly, the NBCA can cause vascular blockage by polymerization, independent of coagulation status of the patient. The major drawback of NBCA is the difficulty to handle the rate and flow of the material and needed to be handled by an experienced interventional radiologist.

NBCA must be delivered mixed with lipiodol and under fluoroscopic guidance. Such a mixture has two significant roles; one it opacify the liquid to allow visualization during injection, and another one is it allows the control of the polymerization time. The lesser the concentration of NBCA in the mixture, the longer it takes to polymerize and therefore allows a more distal embolization. The operator could control the NBCA flow by adjusting the mixture concentration and injection rate. A forceful injection can make the NBCA go fast but also increases the risk of the reflux into the proximal non-target vessel. Before NBCA injection, flushing the delivery catheter with 5% dextrose solution is crucial to prevent premature polymerization within the catheter and thus occluding it. Immediately pull out of the catheter is also vital to prevent adherence of the catheter to vessel wall.

The critical complication that could occur during the NBCA embolization, particularly in the colon, is ischemia secondary to insufficient collateral flow. The animal studies had shown that the embolization of three or fewer vasa recta is safe and have a low risk of infarction. In a human study, it is reported that one vasa recta embolization is relatively safe but two or more branches may cause insignificant or self-limited ischemic damage. Risk of bowel ischemia evaluated by large meta-analysis states the complication rate secondary to NBCA embolization for upper GI bleeding and lower GI bleeding was 5.4% and 6.1%, respectively. This number is within the reported complication range of TAE for GI bleeding which ranges from 0% to 12% (Fig. 8).

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**Fig. 7.** A 70-year-old man, who had a history of chronic pancreatitis, presented with upper gastrointestinal bleeding. (A) Non-enhanced computed tomography (CT) scan found diffuse swelling of the pancreas (arrow) and small hematoma at distal common bile duct (arrowhead). (B) Arterial-phase CT scan showed a small pseudoaneurysm (arrowhead) at distal gastroduodenal artery (GDA) (arrow). (C) GDA angiogram revealed small pseudoaneurysm (arrowhead) at distal GDA. (D) Superselective angiogram found active contrast extravasation from an aneurysm (arrowhead) into the duodenum (arrow). (E) Then, four pieces of 2-mm interlocking coil were placed into the targeted vessel (arrow). Angiogram after embolization found absent of contrast extravasation.
Onyx

Onyx (polyethylene vinyl alcohol) is a liquid cohesive agent, widely used in the treatment of cerebral arteriovenous malformation. Its flow is more controllable compared to NBCA. Onyx has to be mixed with tantalum powder to provide a very high radiopacity. Slow injection without worrying about microcatheter adhesion into the vessel is possible with Onyx due to its non-adhesive effect. Before injection, preloading of DMSO (dimethyl sulfoxide) into the dead space of microcatheter is needed. The main disadvantage is that DMSO can cause irritation and induce vasospasm and pain during injection. The other disadvantage is a relatively high cost of Onyx. Urbano et al. reported a very high (93.5%) success rate in 31 patients by using Onyx in lower GI bleeding. Other disadvantages are:

1. Adhesive effect. Before injection, preloading of DMSO (dimethyl sulfoxide) into the dead space of microcatheter is needed. The adhesive effect. Before injection, preloading of DMSO (dimethyl sulfoxide) into the dead space of microcatheter is needed. The

2. High cost of Onyx. Urbano et al. reported a very high (93.5%) success rate in 31 patients by using Onyx in lower GI bleeding.

3. Vasospasm and pain during injection. The other disadvantage is that DMSO can cause irritation and induce vasospasm and pain during injection.

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5. Relatively high cost of Onyx. Urbano et al. reported a very high (93.5%) success rate in 31 patients by using Onyx in lower GI bleeding.

Conclusion

TAE play an essential role in the treatment of GI bleeding. The knowledge of the vascular anatomy of the GI tract and the collateral pathway of the visceral organs are required for successful treatment. The interventional radiologist should also be familiar with the characteristic, advantage and disadvantage of different embolic material which might affect the clinical outcome of the embolization.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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