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Serial Radiographic Imaging for Real-Time Evaluation of Blood Flow During Low Anterior Resection: Initial Study in a Porcine Model

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To determine whether real-time intraoperative serial radiographic imaging of the marginal artery and vasa recta is feasible in patients undergoing low anterior resection, we attempted such imaging in a porcine model using a specialized fluoroscopic digital X-ray system and thin flat panel detector. Of the possible complications after low anterior resection, anastomotic dehiscence is one of the most serious, with poor blood supply in the anastomotic region being a chief contributor. General anesthesia was induced in a male domestic pig, and a midline incision was made from the xiphoid process to just above the bladder. The rectum was transected at the peritoneal reflection and then mobilized by dissection of the right leaf of the sigmoid mesocolon from the inferior mesenteric artery to the superior rectal artery. The rectal stump was pulled out and placed directly on the detector. Noniodine contrast agent was injected, and blood flow to and from the area surrounding the rectum was evaluated. Serial radiographs depicting the superior rectal artery, colonic, rectal, surrounding mesenteric tissue, and the vasa recta were obtained. The region where the marginal artery ran along the distal portion of the rectal stump was poorly poor imaged in all 3 imaging phases. Diameters of arteries were easily determined. The success we had in radiographically observing blood flow in tissues that would be involved in low anastomosis convinced us that such intraoperative evaluation is clinically feasible.

Key words: Low anterior resection – Real-time imaging – Serial radiography – Vasa recta

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Anterior rectal resection is the standard surgical treatment for high or middle rectal carcinoma. Of the possible postoperative complications, anastomotic dehiscence is one of the most serious, with poor blood supply in the anastomotic region being a chief contributor to its development.[1] The incidence of anastomotic dehiscence began to rise with recognition of the importance of total mesenteric excision (TME) in cases of colorectal cancer,[2–5] and the reported incidence in cases of anterior resection requiring intestinal anastomosis has ranged from 9% to 12%.[6–8] The anastomotic leakage that results often leads to prolonged hospitalization for radiologically guided drainage and creation of a stoma. In many cases, the patient's quality of life is affected[8] and in some cases, complications of anastomotic leakage lead to death. Anastomotic dehiscence often occurs in association with anastomosis within 5.0 cm of the anal dentate line, and several investigators have recommended preventive use of a diverting stoma.[9–11]

The risk of anastomotic dehiscence is decreased when hemodynamics is monitored intraoperatively. After low anterior resection in particular, altered hemodynamics across the anastomosis can lead to anastomotic dehiscence or stenosis.

Fluorescence imaging and computed tomography (CT) are often performed for intraoperative navigation, tumor localization, and sentinel lymph-node diagnosis, and three-dimensional reconstruction CT images obtained preoperatively are useful for intraoperative verification of the anatomy and blood vessels. When surgical resection plus lymph node dissection is performed in cases of gastrointestinal carcinoma, it is important to determine, intraoperatively, the hemodynamic status of the reconstructed organs; any disruption in blood flow can be an indicator of postoperative complications.

Although angiographic imaging of blood flow within the arteries and veins of organs within the body cavities is possible, no modality by which we can intraoperatively image arteries and veins entering and leaving the intestinal tract and thus predict ischemia has been reported. We tested, in a large animal model, use of a mobile fluoroscopic X-ray unit designed for serial intraoperative contrast imaging of the marginal artery and vasa recta. The test was conducted to determine whether real-time serial radiographic imaging of these vessels during low anterior resection and anastomotic reconstruction is clinically feasible.

Materials and Methods

Mobile fluoroscopic digital X-ray system

The fluoroscopic digital X-ray system, shown in Fig. 1A, is comprised of 2 components: a mobile X-ray cart manufactured by Canon (referred to as the Digital Mobile X-Ray System, Table 1) and a Canon CXDI-50RF flat panel detector, which at 26 mm is the thinnest commercially available flat panel detector. The pixel pitch of the detector is 160 μm. The Digital Mobile X-Ray System was designed for pulsed fluoroscopic (i.e., serial), imaging, and especially for use with the CXDI-50RF flat panel detector. This detector is truly portable because it is lightweight, easy to install, and can be freely positioned. The imaging area is large at 350 mm × 430 mm and is suitable for viewing moving images.

Testing use of the Digital Mobile X-Ray System for real-time depiction of blood flow at the low anterior anastomosis

Our test was conducted under approval of and according to the guidelines of the Chiba University Ethics Committee (Animal Experiment Plan: Approval No. Animal 26-84). The test involved use of a male domestic pig that weighed 30 kg. The pig was sedated by intramuscular injection of 1.5 mg/kg midazolam and 40 μg/kg medetomidine, a 27-Fr catheter was inserted into the right ear vein, and anesthesia was induced with 1.5 mg/kg thiopental. A tracheal interpolation tube was inserted, and a 6-Fr endotracheal tube was used to maintain a patent airway. Anesthesia was maintained by inhalation of isoflurane. Once anesthesia was established, a midline incision was made from the xiphoid process to just above the bladder. The rectum was transected at the peritoneal reflection and then mobilized by dissection of the right leaf of the sigmoid mesocolon from the inferior mesenteric artery (IMA) to the superior rectal artery for preservation of these arteries.

At this point, the X-ray cart was wheeled over to the surgery table (Fig. 1B), and the remnant sigmoid colon and rectal stump were pulled out of the abdominal cavity and placed on the flat panel detector (Fig. 1C). Although the panel is small, it is not small enough to insert into the abdominal cavity. We palpated the vessels, from the IMA to the peripheral arteries, to confirm that they pulsed as normal, and we examined distribution of the

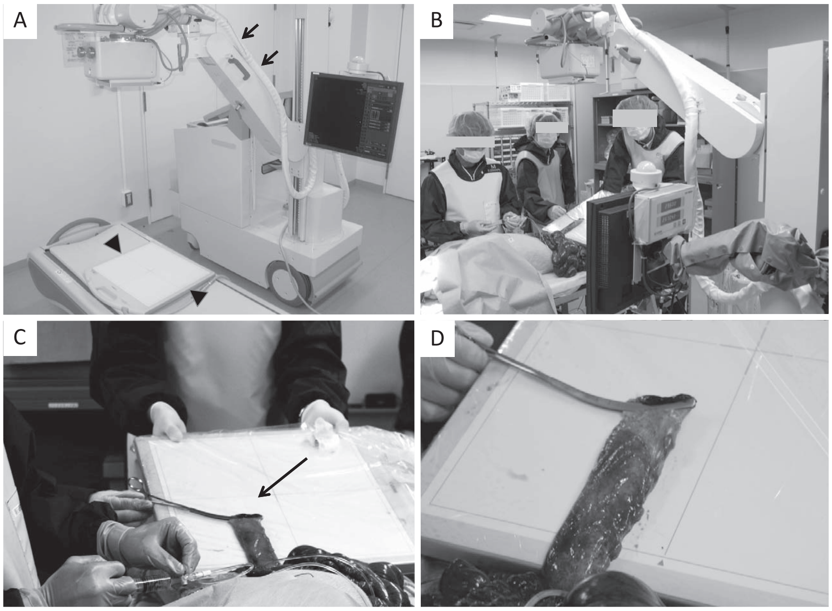

Fig. 1 Overview of the animal experiment. (A) Mobile radiography cart (arrows) and flat panel detector (arrowheads) were positioned near the surgery table. (B) Photograph obtained during the experiment shows the procedural setup. (C) The rectal stump and remnant sigmoid colon (dashed arrow) were placed on the flat panel detector and imaging was begun. (D) Blood flow to the rectal stump and remnant sigmoid colon is clearly depicted.

peripheral branches of the IMA. To achieve this, we cannulated the IMA near the rectal stump.

We then, in real time, imaged blood flow from the marginal artery and vasa recta to the rectal stump. We inserted a 20-Fr angiocatheter into the marginal artery via the IMA, ligated the IMA at the insertion site, and injected iohexol at 2 mL/second (Omnipaque 300, Daiichi Sankyo Co Ltd, Tokyo, Japan) for 3 seconds for a total dose of 6 mL. We then began the X-ray imaging (Fig. 1C), which was performed in serial radiography mode under the following settings: tube voltage of 50 kV; tube current of 0.5 mAs/frame, and pulse rate of 2 frames per second.

For objective assessment of the local circulation both before transection of the rectum and after the anastomotic suturing, we measured the luminal diameter of the arteries around the rectum, the branches of the IMA, and the first and second branches of the vasa recta on the contrast images.

Table 1 Digital Mobile X-Ray System specifications for serial radiography mode

Maximum rated tube voltage	125 kV
Maximum rated tube current-time product	4.0 mAs
Maximum rated tube current	100 mA
X-ray tube voltage	40~125 kV
X-ray amount	0.04~4.0 mAs/frame
Continuous imaging time	1~300 s
Pulse rate	0.25~5 fps

Results

The sigmoid colon and rectal stump were easily pulled out of the pelvic cavity and placed on the flat panel detector. The organs were inspected macroscopically, and normal blood flow was observed. The X-ray examination was performed without difficulty, and blood flow remained stable throughout (Fig. 1D).

We obtained serial radiographs of the region around the rectal stump, and these images are shown in Fig. 2. In the arterial phase, the marginal artery and vasa recta were imaged sequentially. The vasa recta longa, (Fig. 2B, solid arrow) and vasa recta brevia, (Fig. 2B, dashed arrow) were shown to run alternately. In the equilibrium phase, the arteries and the veins were visualized simultaneously, and uptake of the contrast medium into the colonic tissue was also seen (Fig. 2C). In the venous phase, reflux of the contrast medium into the straight venules was seen, the enhancement decreased, and the branching vessels on the rectal wall were clearly visualized (Fig. 2D). The region where the marginal artery ran along the distal portion of the rectal stump was poorly imaged throughout the arterial, venous, and equilibrium phases. The marginal vein was shown to run parallel to the marginal artery, and its luminal diameter was greater than that of the marginal artery (Fig. 2B–D). As shown in Fig. 3, the diameter of the marginal artery was 1.12 mm, the diameter of the first branch (vasa recta brevia) was

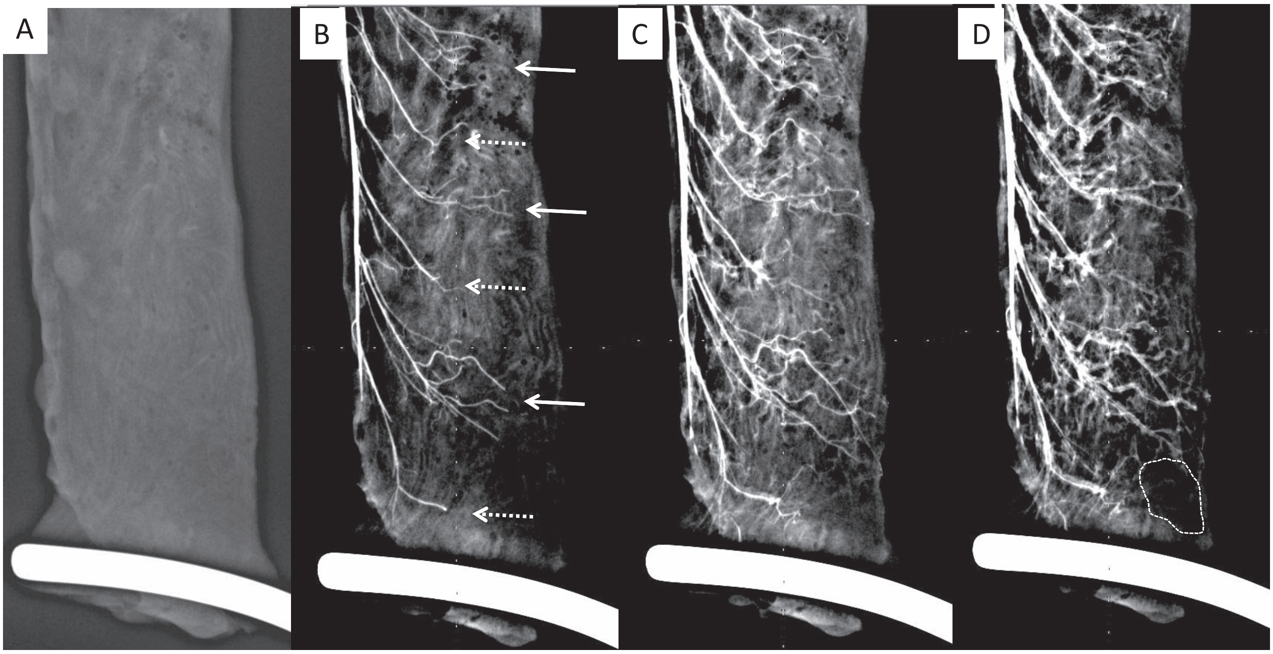

Fig. 2 Serial radiographs of the region around the rectal stump. (A) Control. (B) Arterial phase image. The vasa recta longa (solid arrow) and vasa recta brevia (dashed arrow) were shown to run alternately. (C) Equilibrium phase image. The arteries and the veins were visualized simultaneously, and uptake of the contrast medium into the colonic tissue was seen. (D) Venous phase image. Reflux of the contrast medium into the straight venules was seen, the enhancement decreased, and the marginal vein was clearly identified. The region where the marginal artery ran along the distal portion of the rectal stump (region indicated by a dashed line) was poorly imaged in all 3 phases.

0.58 mm, and that of the second branch (vasa recta longa) was 0.32 mm.

Discussion

Anastomotic leakage after laparoscopic low anterior resection is a serious complication that leads to prolonged hospitalization. A diverting colostomy or drainage procedure must be performed, and patient quality of life is compromised. In a reported retrospective study of rectal resection, a long operation time was shown to be significantly associated with anastomotic leakage,[12] and in a prospective study, rectal resection lasting longer than 4 hours was shown to predict anastomotic leakage.[13] The results of these studies imply that the occurrence of anastomotic leakage is related to increased difficulty of the colorectal surgery, which is the case in obese patients and in patients with a contracted pelvis, for example.[14] In the case of low anastomosis, the risk of anastomotic leakage could be reduced if blood flow at the rectal stump or to the anastomotic site could be assessed during surgery. Such assessment would facilitate appropriate deci-

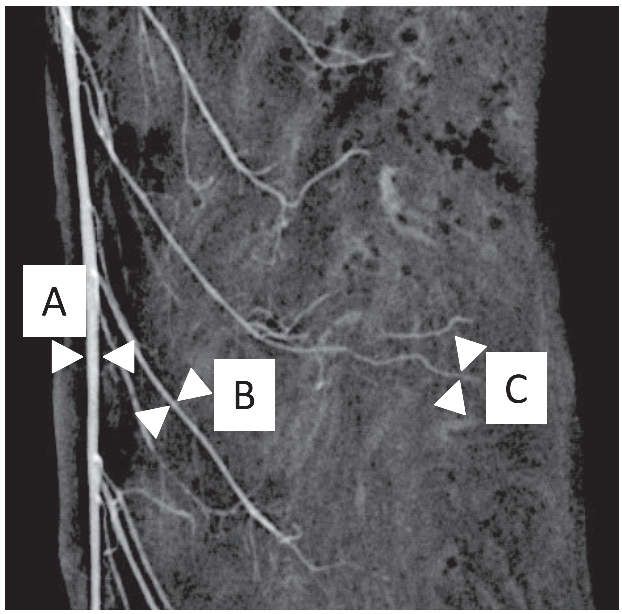

Fig. 3 Diameters of the marginal artery and first and section branches of the vasa recta seen on a magnified arterial phase image. (A) the marginal artery for the rectum, 1.12-mm diameter. (B) First branch of the vasa recta brevia, 0.58 mm diameter. (C) Second branch of the vasa recta longa, 0.32 mm diameter.

sion-making (i.e., whether a temporary diverting colostomy should be created).

Although there is no established method for objective evaluation of hemodynamics on the cut end of the colon used for low anastomosis, there have been reports of laser Doppler assessment of blood flow to the anastomotic site.[15,16] Boyle *et al*[15] showed, by means of scanning laser Doppler flowmetry, that blood flow decreased by 32% on the cut end of the rectal stump and by 51% at the anastomotic site.[15] Vignali *et al*[16] used laser-Doppler flowmetry in patients undergoing low anterior resection and reported positive correlation between decreased blood flow on both cut ends to be used for anastomosis and the incidence of postoperative anastomotic leakage.[16] Both groups of investigators concluded that a decrease in blood flow at the colon or the rectal stump to be used for anastomosis is a risk factor for anastomotic leakage.

Jimenez *et al*[17] used contrast-enhanced sonography for intraoperative evaluation of hemodynamics of the colon in a canine model of abdominal surgery performed under general anesthesia and reported that intravenous injection of a perflutren lipid microsphere preparation allowed measurement of blood flow over time in a region of interest on the wall of the jejunum.[17] They noted that in clinical practice, measuring methods would depend on factors such as the patient's age and disease.[17] Swift *et al*[18] tested contrast-enhanced sonographic evaluation of blood flow in patients undergoing colorectal surgery and reported that the technique, which was particularly effective when the bowel was submerged in sterile water, was both clinically feasible and practical. In a review of colonic anastomotic leakage, Kingham and Pacher[14] stressed that checking blood flow on the oral side is essential in confirming appropriate collateral flow and preventing such complications as anastomotic leakage and anastomotic stenosis. Blood flow within the marginal artery around the rectal stump can be evaluated by palpation for a pulse or by contrast Doppler ultrasonography, but blood flow within the more distal vasa recta is difficult to evaluate ultrasonographically.[19] At present, there seems to be no means of imaging the vasa recta for observation of hemodynamics.

In the animal model described herein, we tested whether contrast-enhanced X-ray imaging can be used for evaluation of blood flow in the marginal artery and vasa recta during low anterior resection. The flat panel detector we used was only 26-mm thick, making it the thinnest in the world, and use of this detector in conjunction with an X-ray system designed specifically for use with this portable detector made it possible for us to observe the hemodynamics of the vasa recta in real time and convinced us that such evaluation is clinically feasible.

The flat panel detectors currently marketed are thick, and previous studies that involved use of flat panel detectors required use of excised organs. Although informative, none of the methods used allowed study of the circulation in real time. In a screening angiography study designed to examine the anatomy of the small arteries and their collaterals in colorectal resections, Allison *et al*[20] showed that the spacing of the small arteries and the number of collaterals vary depending on their position in relation to the colon. Ours was the only study of blood flow from the IMA to the inferior mesenteric vein to the marginal artery and to the small arteries in real time. We believe our study results accurately reflect the physiologic hemodynamic changes that occur during low anterior resection. We also believe, judging from the poor imaging of the region on the oral side of the rectum, that the risk of anastomotic leakage is increased when tissue with poor circulation is used for the anastomosis.

We attribute the detailed observation we achieved to several factors, an important one being the fact that the flat panel detector was positioned directly under the resected rectum; adjacent organs did not get in the way. Our study stands as the first reported study of live, serial radiographic imaging of blood flow within the marginal artery at the resected rectal stump and sigmoid colon and the first and second branches of the vasa recta. Our animal model of low anterior resection can be considered a good representation of low anterior resection in humans, and the serial radiographic imaging performed in our animal model can also be considered a good representation of what can be achieved clinically. Studies performed even in cadavers are not capable of showing what we observed. The clinical limitation we will face in the immediate future is that the contrast imaging will require cannulation of the IMA, the dominant vessel supplying the colon; but as time passes, we expect it will become possible to use peripheral vessels to facilitate the contrast imaging. In either case, objective, real-time, X-ray-based clinical evaluation of blood flow or quantification of hemodynamics of tissue to be involved in the anastomosis in patients undergoing low anterior resection and of blood flow in the reconstructed organs will be possible.

Acknowledgments

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