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How-I-Do-It

Laparoscopic omentopexy as a spacer for carbon-ion radiotherapy in locally advanced pancreatic cancer

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Although half of the patients with pancreatic ductal adenocarcinoma (PDAC) are diagnosed at an advanced stage, surgical interventions needed at this stage are currently limited. Carbon-ion radiotherapy (CIRT) has emerged as a promising treatment modality for PDAC owing to its superior physical and radiobiological properties. However, a major challenge in this treatment is the proximity of the pancreas to radiosensitive organs including the stomach and duodenum, which limits dose escalation and increases the risk of severe complications, including ulceration and perforation. Herein, we report our experience with laparoscopic omentopexy as a spacer technique before CIRT in patients with locally advanced PDAC. A 55-year-old female with locally advanced PDAC, secondary to unreconstructible superior mesenteric vein involvement, who had planned to undergo CIRT. After 28 cycles of modified FOLFIRINOX, the tumor size demonstrated slight shrinkage. However, the tumor abutted the posterior wall of the stomach, raising concerns about ensuring a sufficient safety margin while delivering a curative dose of CIRT. Therefore, laparoscopic omentopexy was performed for spacer implantation between the pancreas and stomach. The patient was discharged on the postoperative day 2 without any complications. One month after the omentopexy, the patient completed all 12 fractions of the CIRT with no acute complications, except for grade 1 fatigue. After completing CIRT, the patient underwent regular follow-up evaluations. Laparoscopic omentopexy before CIRT in patients with locally advanced PDAC could enhance therapeutic efficacy.

Key Words: Heavy ion radiotherapy; Minimally invasive surgical procedures; Omentum; Pancreatic neoplasms; Radiation oncology

INTRODUCTION

Pancreatic ductal adenocarcinoma (PDAC) accounts for the majority (90%) of neoplasms arising from the pancreas. Moreover, the crude incidence and mortality rates of carcinoma are steadily increasing. Despite advanced surgical and medical modalities, the 5-year survival rate of PDAC is relatively low (10%) compared to that of other cancers [1]. One reason for this is the difficulty in making early diagnosis. Most patients are present with nonspecific symptoms at advanced stages. Therefore, only approximately 20% of the patients newly diagnosed with resectable PDAC undergo surgery [2].

Fortunately, advanced chemotherapeutic agents enable some patients with previously unresectable PDAC to be newly classified as borderline resectable, following neoadjuvant chemotherapy. However, half of the patients with PDAC are diagnosed at advanced stages. Although studies have explored conversion surgery for selected locally advanced PDAC, the conversion surgery rate remains at approximately 15% [3]. So, the role of surgical interventions is currently limited.

Carbon-ion radiotherapy (CIRT) has emerged as a promising treatment modality due to its superior physical and radiobi-

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ological properties, including the Bragg peak, which enables precise dose deposition with minimal exposure to surrounding healthy tissues and high linear energy transfer. These advantages make CIRT particularly effective for radioresistant tumors and malignancies at anatomically challenging locations. Several studies have demonstrated the efficacy and safety of CIRT in locally advanced PDAC [4-8]. However, survival outcomes remain suboptimal, highlighting the need for further treatment optimization. A major challenge in this treatment is the proximity of the pancreas to radiosensitive organs such as the stomach and duodenum, which limits dose escalation and increases the risk of severe complications, including ulceration and perforation.

To address this challenge, spacer implantation has been introduced as a technique to separate tumors from adjacent organs, enabling dose escalation while minimizing radiation-induced toxicity [9]. Although spacers have been widely employed in prostate cancer radiotherapy (RT) [10-12], including both conventional RT and CIRT, their application in intra-abdominal tumors presents unique anatomical challenges. In pancreatic cancer, few studies on spacer placement in RT have demonstrated its technical feasibility and safety [13,14]; however, most of them focused on dosimetric outcomes, with limited complications or clinical efficacy data. Notably, major centers in Japan have explored surgical spacer placement for CIRT, particularly in sarcoma [15] and rectal cancer [16,17], initially using nonabsorbable spacers, but more recently adopting absorbable spacers. Given the anatomical complexity and radiosensitivity of PDAC, bioabsorbable and biocompatible spacers may offer safe and effective alternatives for optimizing treatment outcomes. However, compared to other cancers, a more cautious approach is required in patients with PDAC to ensure both safety and efficacy.

Despite these considerations, no studies have evaluated the role of spacer placement in CIRT for locally advanced PDAC. Following the introduction of CIRT at the first center in Korea and the initiation of fixed-beam treatment for prostate cancer in April 2023 [18], we have actively applied CIRT to patients with pancreatic cancer starting in April 2024. Through multidisciplinary discussions, we considered marker and/or spacer implantation in selected cases to enhance safety and treatment accuracy. Herein, we report our experience with laparoscopic omentopexy as a spacer technique before CIRT for locally advanced PDAC. Moreover, we highlight the feasibility and potential clinical benefits of the modality.

CASE

Patient presentation and preoperative management

A 55-year-old female with no surgical or medical history, except for viral hepatitis B, visited the outpatient clinic due to epigastric pain. Imaging studies revealed a hypovascular mass, approximately 3 cm in size, in the neck of the pancreas. Endoscopic ultrasound-guided biopsy confirmed that the mass was a PDAC. Although no regional or distant metastasis was observed, the PDAC involved the long-segment superior mesenteric vein (SMV), causing occlusion and contact with the superior mesenteric artery (SMA). Given the unreconstructible SMV involvement, the tumor was classified as unresectable PDAC, and systemic chemotherapy was initiated (Fig. 1A).

After 28 cycles of modified FOLFIRINOX (mFOLFIRINOX; oxaliplatin, irinotecan, leucovorin, and fluorouracil) che-

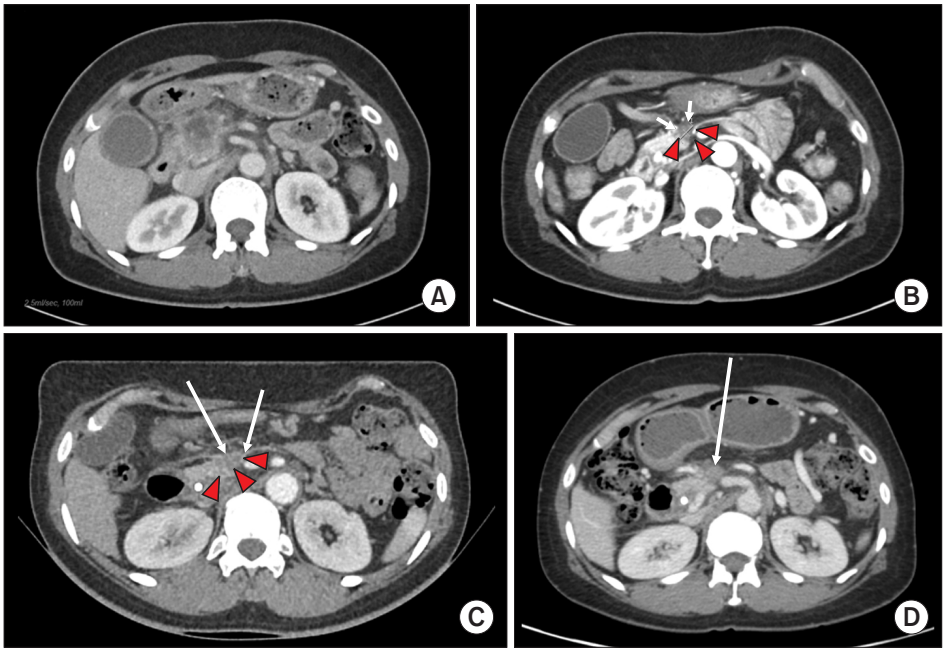

Fig. 1. Pre- and post-treatment computed tomography (CT) images of the patient. (A) Initial CT image at diagnosis displaying an approximately 3 cm hypovascular mass in the pancreatic head, with superior mesenteric vein (SMV) invasion and superior mesenteric artery (SMA) abutment, indicating an unresectable status. (B) Post-mFOLFIRINOX chemotherapy CT image demonstrating a reduction in tumor size; however, the tumor remains unresectable due to persistent SMV invasion and SMA abutment. The mass in the pancreatic head is abutting the posterior wall of the stomach. (C) Post-omentopexy CT image displaying approximately 3 cm separation between the tumor and the stomach wall, achieved through spacer placement. (D) CT image 1 month after carbon-ion radiotherapy, demonstrating a stable disease with no significant abnormalities in adjacent organs.

motherapy, the tumor slightly decreased in size and cancer antigen 19-9 (CA 19-9) levels normalized (from 3,433.9 to 21.9 U/mL). However, the tumor remained unresectable due to its continued invasion of the SMV and its persistent contact with the SMA (Fig. 1B). A multidisciplinary discussion concluded that the tumor was well controlled locally and that the patient could potentially benefit from CIRT. According to our institutional policy, CIRT is considered for PDAC in the absence of distant metastasis and other contraindications including gastrointestinal tract invasion. However, in the present case, the tumor abutted the posterior wall of the stomach (Fig. 1B), raising concerns about ensuring a sufficient safety margin while delivering a curative dose of CIRT. Therefore, laparoscopic omentopexy was performed for spacer implantation between the pancreas and stomach.

Two weeks after the 28th chemotherapy cycle, the patient was admitted for surgery. At the time of admission, her Eastern Cooperative Oncology Group performance status was 1. Preoperative laboratory tests revealed pancytopenia (absolute neutrophil count: 370/μL, hemoglobin: 9.6 g/dL, platelet: 28 K/μL). After administration of granulocyte-colony stimulating factor and platelet transfusion, laparoscopic omentopexy was performed on August 7, 2024.

Surgical procedure

Laparoscopic omentopexy was performed using a four-port system. The camera port was inserted at a supra-umbilical site, and three additional ports were placed on the left and right sides of the camera port and in the right upper quadrant.

The gastrocolic ligament was carefully divided, and the pancreatic surface was accessed. Sparing the omentum for pexy, the gastrocolic ligament division line was placed adjacent to the transverse colon. The omentum was prepared on the stomach side, taking care of preserving the gastroepiploic vessels. An assistant performed stomach traction to facilitate a clear operative view. Although the stomach was adherent to the pancreas, no evidence of stomach tumor invasion was noted. The surgical field for omentopexy was exposed after adhesiolysis between the stomach and pancreas (Fig. 2A). After suturing a single point of the omentum to the superior border of the pancreas, the omentum was positioned between the stomach and pancreas as a spacer. Two metal clips were placed on the pancreatic body and tail areas as markers to guide the CIRT procedure (Fig. 2B). To prevent omental migration, the omentum-adjacent gastroepiploic vessels were fixed with the tissue under the inferior pancreatic border (Fig. 2C). After the bleeding was controlled, the abdomen was closed using a routine maneuver without drain insertion (Supplementary Video).

The operative time was 104 minutes, and the estimated blood loss was minimal. Well-implanted metal clips in the pancreatic tail area are illustrated in the postoperative image (Fig. 2D). The patient was discharged on the postoperative day 2 without complications.

CIRT after the omentopexy and clinical course

Approximately 2 weeks following omentopexy, the patient underwent a 2-week preparation process for CIRT. The preparation process included immobilization device fabrication, respiratory training, and simulation imaging with computed tomography (CT) and magnetic resonance imaging (MRI). For CIRT in pancreatic cancer, the patients were placed in the prone position within a customized cradle and immobilized on a low-temperature thermoplastic sheet to ensure stable fixation. Four-dimensional (4D) simulation CT was performed to assess the patient's respiratory cycle and evaluate respiratory stability and periodicity. Following institutional policy, the gating window for treatment was determined based on an amplitude threshold, ensuring that the tumor center movement

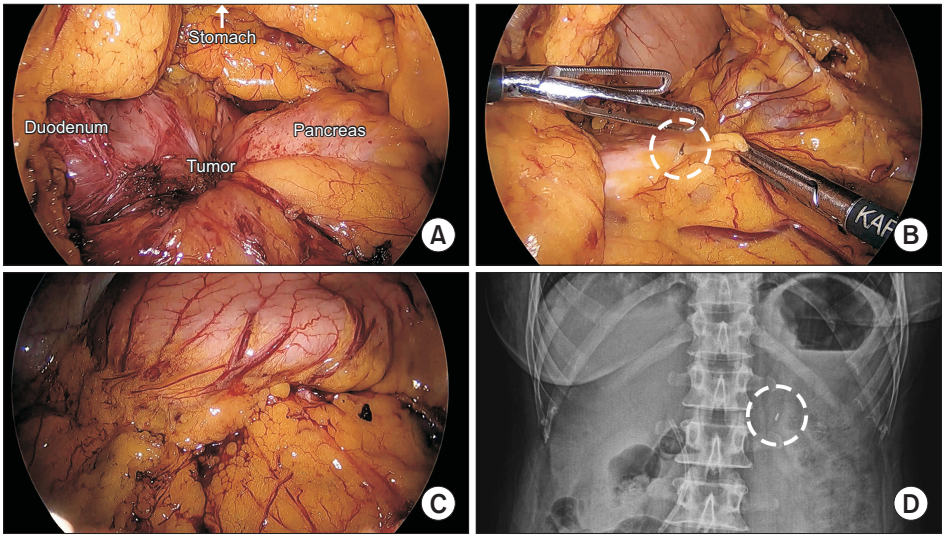

Fig. 2. Peri- and postoperative images of the patients. (A) The surgical field before omentopexy between the stomach and pancreas. (B) Metal clipping for marker during carbon-ion radiotherapy (white circle). (C) Surgical view after the omeotopexy. (D) Postoperative image illustrating the metal clips on the abdominal cavity (white circle).

remained within 2 mm.

The CIRT target volumes were defined as follows: the gross tumor volume (GTV) included the primary tumor delineated based on CT, MRI, and 18F-fluoro-deoxyglucose positron emission tomography (^{18}F-FDG-PET) imaging, whereas the clinical target volume (CTV) encompassed the GTV plus a 5-mm margin, including the neurovascular plexus and prophylactic nodal regions such as the celiac, superior mesenteric, peri-pancreatic, portal, and part of the para-aortic region. When the CTV was near an organ at risk (OAR), the OAR was prioritized and the CTV margin was reduced to maintain a minimum 3-mm separation between the structures. Additionally, robust planning was made to account for patient setup variations and density uncertainties, ensuring accurate dose delivery while maintaining OAR dose constraints based on the treatment phase selected through 4D CT scanning. A fractional dose of 4.6 Gy (relative biological effectiveness [RBE]), totaling 55.2 Gy (RBE), was prescribed to the CTV, with the treatment administered once daily, four times per week. In this patient, the following beam angles were used with a rotating gantry to maximize OAR sparing: posteroanterior (0°), right posterior oblique (30°), anteroposterior (180°), and left posterior oblique (300°) (Fig. 3). Spacer placement via omentopexy effectively increased the distance between the tumor and the stomach wall, allowing a high-dose delivery to be concentrated on the tumor while minimizing exposure to adjacent normal tissues (Fig. 1C).

For the daily treatment setup, orthogonal radiographic imaging at 0° and 45° was performed before beam delivery to confirm the patient positioning, bony landmarks, and marker placement. In this case, the radiation oncologist evaluated the positions of the endoscopic retrograde biliary drainage stent and surgical clips, using surgical clips as the primary reference for registration before initiating beam delivery. One beam was delivered per session, with a total daily treatment duration of approximately 30 minutes. During treatment, patients fasted for at least 6 hours prior to each session. In this patient, CT scans were performed every other day to monitor the tumor growth and internal organ changes. Additionally, an adaptive RT plan was implemented based on the assessment of the radiation oncologist.

The patient completed all 12 fractions of CIRT with no acute complications noted except for grade 1 fatigue. After completing CIRT, the patient underwent regular follow-up evaluations, including CT scans and tumor marker assessments, initially at 1-month intervals, followed by every 2 months thereafter. One month after CIRT, mFOLFIRINOX chemotherapy was resumed as a maintenance therapy, with the tumor exhibiting a stable disease status (Fig. 1D). As of 4 months post-CIRT, the patient maintained a stable disease status, with tumor markers and all laboratory results remaining within normal ranges. The patient remained in good condition without discomfort or treatment-related complications.

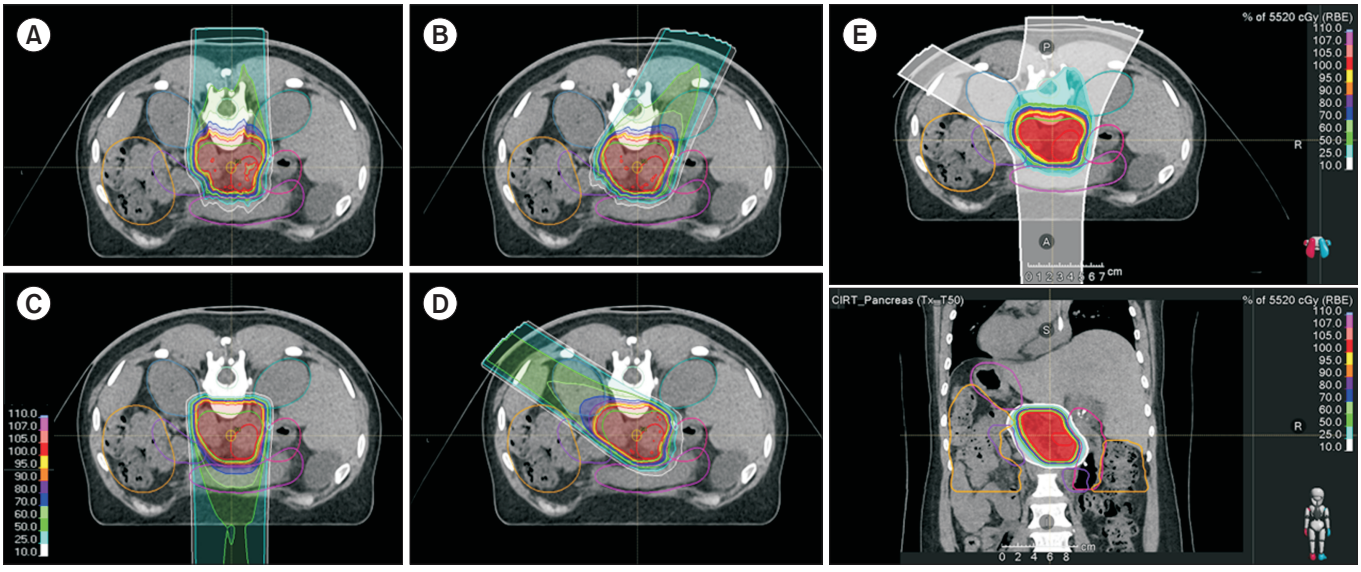

Fig. 3. Dose distribution of carbon-ion radiotherapy (CIRT) plan. (A) Posteroanterior beam (gantry 0°) dose distribution. (B) Right posterior oblique beam (gantry 30°) dose distribution. (C) Anteroposterior beam (gantry 180°) dose distribution. (D) Left posterior oblique beam (gantry 300°) dose distribution. (E) Composite dose distribution from all four beam angles, representing the final CIRT treatment plan. This figure presents the dose distribution of CIRT using a rotating gantry with four beam angles optimized to maximize tumor coverage while minimizing radiation exposure to adjacent organs at risk (OARs). The final treatment plan (e) Depicts the cumulative dose distribution, ensuring precise dose delivery to the tumor with effective OAR sparing.

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DISCUSSION

In CIRT for pancreatic cancer, 55.2 Gy (RBE) in 12 fractions is the most commonly used regimen, although dose prescriptions and biological effectiveness evaluations may vary slightly across institutions. To minimize toxicity, the maximum doses to the duodenum and stomach are generally limited to 44 to 46 Gy (RBE). Despite the Bragg peak effect, a steep dose fall-off requires at least 1 cm of separation to ensure ≥ 95% planning target volume coverage while maintaining OAR constraints. When a tumor abuts the stomach or duodenum, treatment options become limited, often necessitating dose reduction or partial tumor irradiation, which leads to suboptimal efficacy. This challenge is particularly pronounced in pancreatic head cancer, where surgical resection is often unfeasible and treatment outcomes remain poor.

To address this limitation, spacer placement has been introduced to increase the tumor-to-organ distance, enabling the safe and effective delivery of CIRT. Based on this rationale, we successfully performed laparoscopic omentopexy, before CIRT, for locally advanced pancreatic cancer. Following omentopexy, the patient underwent CIRT as planned without any significant complications, although further long-term follow-up is warranted.

Even though surgical spacers offer several advantages to patients undergoing CIRT, they have various limitations, particularly artificial spacers. One concern is potential adverse events associated with the use of artificial surgical spacers. Although the materials used for these spacers have been proven safe, they are foreign bodies and carry risks including abdominal discomfort, infection, and bowel perforation. To mitigate these risks, some physicians have designed abdominal spacers using surgical drains that can be easily removed without surgery [19]. However, this method also resulted in discomfort to the patients, as they had to keep the drain for approximately 6 weeks until they completed radiation therapy. In addition, some portions of the packed drain within the abdominal cavity were radiopaque and affected by radiation. Radiation oncologists should consider these factors during RT, as more complex plans are required to optimize treatment.

Another crucial problem is tumor progression during the interval until the initiation of CIRT. A previous study reported that approximately 1 month elapsed between space placement and the first irradiation [13]. Spacer insertion or omentopexy before CIRT is not a curative therapy but rather a supportive intervention designed to enhance its therapeutic efficacy. At our institution, CIRT is typically initiated 3 to 4 weeks after surgical spacer placement to ensure adequate stabilization of the CIRT treatment field and minimize the risk of wound complications. Although the relationship between this interval and the oncological outcomes has not been thoroughly studied, reducing the interval between surgery and CIRT remains a critical priority.

Reducing the interval between surgery and CIRT is essential for minimizing the risk of tumor progression. A potential strategy for achieving this involves a minimally invasive approach. Most patients undergoing CIRT have advanced disease and have already received multiple cycles of chemotherapy, making them vulnerable to complications that could potentially delay treatment. A minimally invasive approach could alleviate this risk by reducing wound-healing issues, which may prolong the treatment timeline. For instance, in prostate cancer, a rectal hydrogel spacer is placed between the anterior wall of the rectum and the posterior wall of the prostate via a percutaneous approach, avoiding the need for laparotomy [9,10,12]. However, in the case of pancreatic cancer, a percutaneous approach presents significant challenges due to the anatomical complexity of the pancreas and surrounding structures.

Omental packing or omentopexy is a technique used to cover a specific portion of the omentum. The technique has been selectively performed in cases of liver trauma for compression or gastric perforation to close defects [20]. Based on this concept, laparoscopic omentopexy using autologous biological tissue and a minimally invasive approach can solve the previously mentioned concerns. Using the omentum as a spacer addresses the issues originating from foreign bodies, with patients recovering quickly and experiencing relatively early discharge compared to those who underwent an open approach. Although this patient underwent CIRT 1 month after surgery, the approach indicates the potential for shortening the interval between surgery and CIRT.

Although laparoscopic omentopexy before CIRT demonstrates the possibility of providing a management option for locally advanced pancreatic cancer, this method has limitations. Similar to other cancers, pancreatic cancer induces cachexia, and the nutritional status of potential patients is often compromised due to their history of chemotherapy. Owing to these factors, some patients may have insufficient omental volume in the operative field. Surgeons should consider this and prepare alternative methods such as artificial spacer insertion. Nevertheless, this case suggests a foundation for broadening the current indications of CIRT for locally advanced PDAC and a novel role of hepatobiliary-pancreatic surgeons in the treatment of locally advanced PDAC. To our knowledge, this is the first case report of laparoscopic omentopexy before CIRT for locally advanced pancreatic cancer.

In conclusion, laparoscopic omentopexy for locally advanced PDAC before CIRT could be a viable option for improving therapeutic efficacy. Further studies with large populations are required to validate the aforementioned findings and provide statistical evidence.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.14701/ahbps.25-044.

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CONFLICT OF INTEREST

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

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Conceptualization: SHK, CMK. Data curation: SHK, SHC, MJJ, IJL, WSK. Methodology: SHK. Visualization: SHK. Writing - original draft: SHK, SHC. Writing - review & editing: MJJ, IJL, WSK, CMK.

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