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The learning curve for a surgeon in robot-assisted laparoscopic pancreaticoduodenectomy: a retrospective study in a high-volume pancreatic center

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Abstract

Background Pancreaticoduodenectomy (PD) is one of the most technically difficult abdominal operations. Recent advances have allowed surgeons to attempt PD using minimally invasive surgery techniques. This retrospective study aimed to analyze the learning curve of a single surgeon who had carried out his first 100 robot-assisted laparoscopic pancreaticoduodenectomy (RPD) in a high-volume pancreatic center.

Methods The data on consecutive patients who underwent RPD for malignant or benign pathologies were prospectively collected and retrospectively analyzed. The data included the demographic data, operative time, estimated blood loss, post-operative length of hospital stay, morbidity rate, mortality rate, and final pathological results. The cumulative sum (CUSUM) analysis was used to identify the inflexion points which corresponded to the learning curve.

Results Between 2012 and 2016, 100 patients underwent RPD by a single surgeon. From the CUSUM operation time (CUSUM OT) learning curve, two distinct phases of the learning process were identified (early 40 patients and late 60 patients). The operation time (mean, 418 min vs. 317 min), hospital stay (mean, 22 days vs. 15 days), and estimated blood loss (mean, 227 ml vs. 134 ml) were significantly lower after the first 40 patients ($P<0.05$). The pancreatic fistula, postoperative hemorrhage, delayed gastric emptying, and reoperation rates also decreased in the late 60 patients group ($P<0.05$). Non-significant reductions were observed in the incidences of major (Clavien–Dindo Grade II or higher) morbidity, postoperative death, bile leakage, gastric fistula, wound infection, and open conversion.

Conclusions RPD was technically feasible and safe in selected patients. The learning curve was completed after 40 RPD. Further studies are required to confirm the long-term oncological outcomes of RPD.

Keywords Pancreaticoduodenectomy · Robotic surgery · Da Vinci · Learning curve

Pancreaticoduodenectomy (PD) is one of the most technically difficult abdominal operations and it involves extensive dissection, resection, and reconstruction of the digestive system. In the past, surgeons can only perform open pancreaticoduodenectomy (OPD) through a long abdominal incision. The first successful laparoscopic pancreaticoduodenectomy (LPD) was reported in 1994 [1]. Subsequently, more reports on pancreaticoduodenectomy using the minimally invasive approach appeared and showed that this operation was technically feasible and safe in appropriately selected patients [2–5].

Robotic surgery has several advantages over laparoscopic and open surgery. The robotic surgical system eliminates surgeon's tremor, increases flexibility of the manipulator's arm, and improves three-dimensional vision [6–8]. Robotic surgery has been reported to decrease postoperative complications, shorten hospital stay, and result in fast recovery of patients when compared to open procedures. It has now

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been widely adopted in many abdominal operations. Robot-assisted laparoscopic pancreaticoduodenectomy (RPD) has also been reported to be efficient and safe in well-selected patients [9, 10].

Surgeons are particularly concerned about the learning curve of RPD as this operation is technically complicated and involves extensive dissection with a lot of intracorporeal suturing and knot-tying. Studies comparing minimally invasive PD with OPD showed better postoperative outcomes using the minimally invasive approach [11, 12]. There have only been very few reports on the learning curves for LPD [13, 14 ,14] and RPD [15]. A study on the operative mortality rates for the learning curves of PD from 143 hospitals on 1210 patients showed that the mortality rate for the first 10 patients was 11.3%. It improved for the subsequent patients, falling to 7.1% for the 21st to 30th patients and then to 0% by the 61st to 70th patients [16]. If we take this lesson from open surgery, we should look at the learning curve for RPD only after we have accumulated enough experience on RPD.

In this study, we analyzed the surgical outcomes and our learning curve for the first 100 consecutive RPDs performed by a single surgeon from a high-volume pancreatic center (defined as hospitals with a case load of > 16 pancreatic resections per year [17]).

Methods

Patient population and study design

Data from consecutive patients who underwent RPD for malignant or benign pathologies at the Department of Hepatobiliary and Pancreatic Surgical Oncology, the Chinese PLA General Hospital between February 2012 and July 2016 were prospectively collected and retrospectively analyzed. These data included demographic data, operative time, estimated blood loss, postoperative length of hospital stay, morbidity rate, mortality rate, and pathological results. This study was approved by the Institutional Review Board.

After a detailed history taking and physical examination, all patients underwent routine investigations which included blood tests, serum tumor markers, computerized tomography (CT) scans, magnetic resonance imaging, and positron emission tomography–computed tomography. The inclusion criteria were as follows: (1) resectable tumors confined to the pancreatic head or periampullary region without vascular invasion; (2) complied with the American Society of Anesthesiologists score (ASA) of < 3; (3) good general health with no serious co-morbid diseases; and (4) no previous treatment to the tumor. The exclusion criteria were: as follows (1) prior abdominal surgeries with severe abdominal adhesion; (2) body mass index > 40; (3) locally advanced or metastatic tumors; and (4) intolerance of prolonged anesthesia. All patients gave written informed consents for the operation. The da Vinci S Surgical System (Intuitive Surgical Inc., Sunnyvale, CA) was used for RPD. All the operations were performed by a single surgeon and supported by surgeons who were experienced with advanced laparoscopic and open pancreatic surgery.

Operative technique

The RPD technique used in this institution had been published [18]. A supine and reverse Trendelenburg position was used in all the operations. After the robotic system was docked over the head of the patient, the assistant surgeon operated between the patient's legs. An extended Kocher's maneuver was performed to mobilize the transverse duodenum from the ligament of Treitz. The bile duct was transected superior to the cystic duct junction. The regional lymph nodes were harvested. The distal stomach was transected with a 75-mm cartridge endostapler (blue load) (Ethicon Endo-Surgery, Cincinnati, OH). The retropancreatic tunnel was created between the pancreas and the portal vein, and the tunneled pancreas was transected along the lateral border of the SMV-portal vein. The proximal jejunum was transected at the right margin of the superior mesenteric vessels by using a 45-mm cartridge endostapler (blue load). A two-layer end-to-side duct-to-mucosal pancreaticojejunostomy was performed with 4–0 Prolene sutures. An internal pancreatic ductal stent was used. An end-to-side hepaticojejunostomy and a side-to-side gastrojejunostomy were performed for digestive tract reconstruction. The specimen, placed into an endoscopic bag, was retracted through the enlarged umbilical port site. Two closed suction drains were placed near the pancreaticojejunostomy and hepaticojejunostomy at the end of the operation.

Cumulative sum analysis to define the learning curve

The cumulative sum (CUSUM) analysis was used to define the learning curve. CUSUM is the accumulated total difference between each data point and the mean of all the data points, which is widely used in the assessment of new technical skills. The patients were categorized in a chronological order. The difference between the operative time (OT) of each patient and the mean OT was calculated chronologically. The CUSUM OT was obtained by adding up all the difference from the first patient to the next cumulatively. This same method was used for each patient until the last one, and the CUSUM OT was calculated as zero ultimately. A graphical representation of the learning curve was depicted to detect the different phases of the learning process.

Statistical analysis

The SPSS 17.0 statistics software was used. Continuous variables were expressed as mean ± standard deviation, and the Student's *t* test was used to compare the data between the two groups. Categorical variables were compared using the χ^2 test or Fisher's exact test. The differences were considered statistically significant when *P* values were < 0.05.

Results

The preoperative parameters for all the patients are shown in Table 1. The mean age of the patients was 55 years with 47.0% being female. The indications for RPD included pancreatic adenocarcinoma (*n* = 28 28%), cholangiocarcinoma (*n* = 11 11%), cancer of ampulla (*n* = 39 39%), neuroendocrine tumor (*n* = 6 6%), solid pseudopapillary neoplasm (*n* = 5 5%), IPMN (*n* = 4 4%), and chronic pancreatitis (*n* = 7 7%). The intraoperative and postoperative outcomes are displayed in Table 2. The mean OT was 357 min and the average estimated blood loss (EBL) was 171 ml. There were 58 patients with complications, which included pancreatic fistula (*n* = 24 24%), bile leakage (*n* = 11 11%), postoperative hemorrhage (*n* = 22 22%), gastric fistula (*n* = 2 2%), delayed gastric emptying (*n* = 15 15%), wound infection (*n* = 2 2%), reoperation (*n* = 6 6%), and postoperative death (*n* = 3 3%).

Grade B postoperative pancreas fistula occurred in nine patients who responded to management with percutaneous or endoscopic drainage of intraabdominal collections or angiographic procedures for bleeding. Reoperation was needed for the patients with a Grade C pancreas fistula.

In this study, we analyzed all the perioperative outcomes. A graph of operative times was plotted for each of the patients arranged in a chronological order which demonstrated decreasing operative times and variances with increasing experience (Fig. 1). The CUSUM OT learning curve is illustrated in Fig. 2. The result indicated a significant reduction in OT after the first 40 patients (from 418 to 317 min; *P* = 0.001). From the CUSUM OT learning curve, two distinct phases of the learning process were identified. The upward slope ($y = 74.32 + 276.17x - 10.71x^2$ $R^2 = 0.96$ and $y = 2856.76 - 152.93x + 6.44x^2 - 0.07x^3$ $R^2 = 0.92$) during the first 40 patients showed longer operative times while the downward slope ($y = 287.56 + 81.50x - 0.85x^2$ $R^2 = 0.95$) during the second phase indicated gradual improvement in operative time once the learning curve had been attained.

The operative and postoperative outcomes of the two phases, which were based on the OT learning curve, are summarized in Table 2. A comparison of the perioperative outcomes between the two groups (early 40 patients and late 60 patients) was then performed. As shown in Table 1, the two groups were comparable in all the baseline characteristics. The operation time (mean, 418 min vs. 317 min), hospital stay (mean, 22 days vs. 15 days), and estimated blood loss (mean, 227 ml vs. 134 ml) were significantly lower after the first 40 patients (*P* < 0.05). The pancreatic fistula, postoperative hemorrhage, delayed gastric emptying, and reoperation rates were also decreased in the late 60 patients group (*P* < 0.05). Non-significant reductions were observed in the

Table 1 Details of patients and pathology

Variables (*n*)	Total	Early (*n* = 40)	Late (*n* = 60)	*P*-value
Age	55.05 ± 14.22	54.68 ± 11.59	55.3 ± 15.72	0.83
Gender (male/female)	53/47	22/18	31/29	0.74
ASA score				0.73
1	63 (63%)	26 (65%)	37 (61.7%)	
2	37 (37%)	14 (35%)	23 (38.3%)	
3	0	0	0	
Pathologic parameters and outcomes				0.48
Ca pancreas	28 (28%)	7 (17.5%)	21 (35%)	
Cholangiocarcinoma	11 (11%)	4 (10%)	7 (11.7%)	
Ca ampulla	39 (39%)	19 (47.5%)	20 (33.3%)	
Neuroendocrine tumor	6 (6%)	3 (7.5%)	3 (5%)	
Solid pseudopapillary neoplasm	5 (5%)	3 (7.5%)	2 (3.3%)	
IPMN	4 (4%)	2 (5%)	2 (3.3%)	
Chronic pancreatitis	7 (7%)	2 (5%)	5 (8.3%)	
Tumor size (cm)	2.7 ± 1.5	2.4 ± 1.4	2.9 ± 1.6	0.11
Mean lymph node harvested	7.02 ± 4.30	6.42 ± 3.75	7.39 ± 4.56	0.27
Positive margin	0	0	0	
BMI	23.82 ± 3.63	23.05 ± 3.09	24.34 ± 3.87	0.08
Preoperative albumin	44.96 ± 12.59	48.15 ± 13.14	42.82 ± 11.74	0.04

Table 2 Intraoperative and postoperative outcome

Variables (n)	Total	Early (n = 40)	Late (n = 60)	P-value
Operating time (min)	357.87 ± 93.28	418.43 ± 95.02	317.5 ± 66.40	0.001
Estimated blood loss (ml)	171.13 ± 144.46	227.63 ± 221.20	134.75 ± 100.53	0.005
Open conversion	5 (5%)	4 (10%)	1 (1.7%)	0.16
Number of patients with complication	58 (58%)	26 (65%)	34 (56.7)	0.40
Complications, Clavien Grade > II	22 (22%)	12 (30%)	10 (16.7%)	0.11
Overall complication				
Pancreatic fistula	24 (24%)	14 (35%)	10 (16.7%)	0.036
Grade A	13 (13%)	7 (17.5%)	6 (10%)	0.27
Grade B	8 (8%)	5 (12.5%)	4 (6.7%)	0.52
Grade C	3 (3%)	2 (5%)	0	0.31
Bile leakage	11 (11%)	5 (12.5%)	6 (10%)	0.70
Postoperative hemorrhage	22 (22%)	14 (35%)	8 (13.3%)	0.01
Gastric fistula	2 (2%)	2 (5%)	0	0.16
Delayed gastric emptying	15 (15%)	10 (25%)	5 (8.3%)	0.02
Wound infection	2 (2%)	2 (5%)	0	0.16
Reoperation rate	6 (6%)	6 (15%)	0	0.007
Postoperative death	3 (3%)	3 (7.5%)	0	0.12
Mean postoperative hospital stay (days)	18 ± 13.46	22 ± 16	15 ± 10.71	0.01
Readmission (90-day)	7 (7%)	3 (7.5%)	4 (6.7%)	0.81

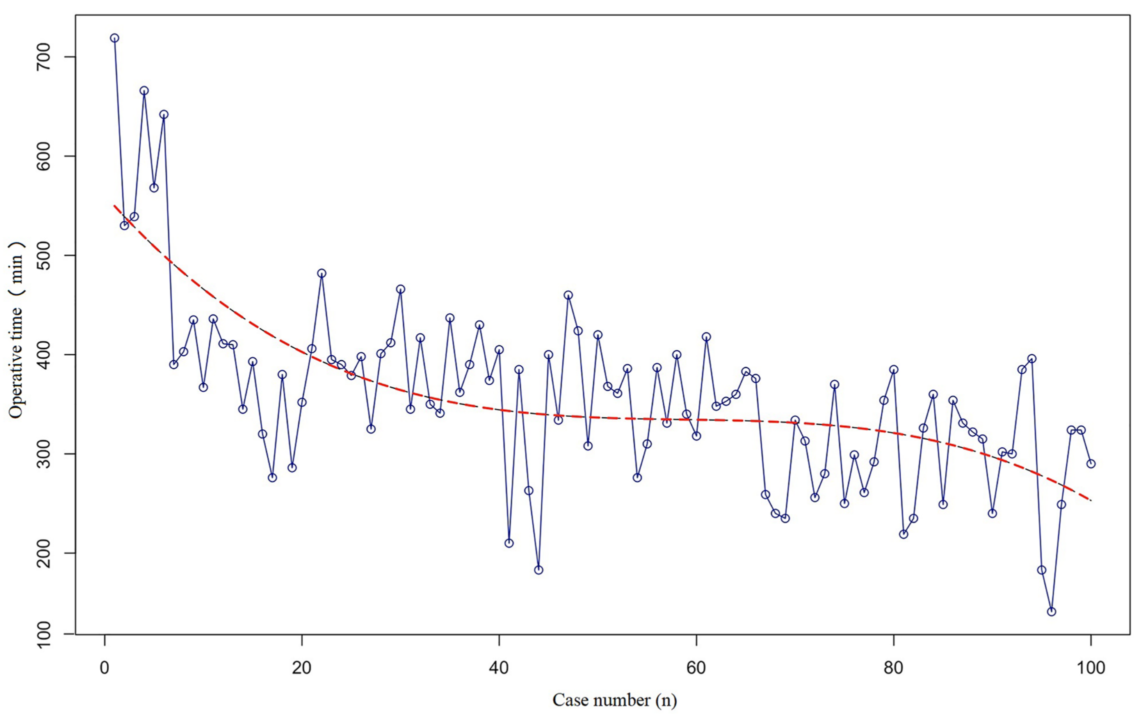

Fig. 1 Graph of operative times plotted for each of the 100 consecutive patients demonstrating decreasing variance with increasing experience

incidences of major (Clavien–Dindo Grade > II) morbidity, postoperative death, bile leakage, gastric fistula, wound infection, hospital readmission, and open conversion. Four patients in the early 40 patients group required conversion to laparotomy for significant adhesions (3 patients, 7.5%) and intraperitoneal hemorrhage (1 patient, 2.5%), while one patient in the late 60 patients group required conversion to open surgery because of severe adhesions. There were 3 (7.5%) postoperative deaths in the early 40 patients group. One patient suffered from pulmonary embolism leading to

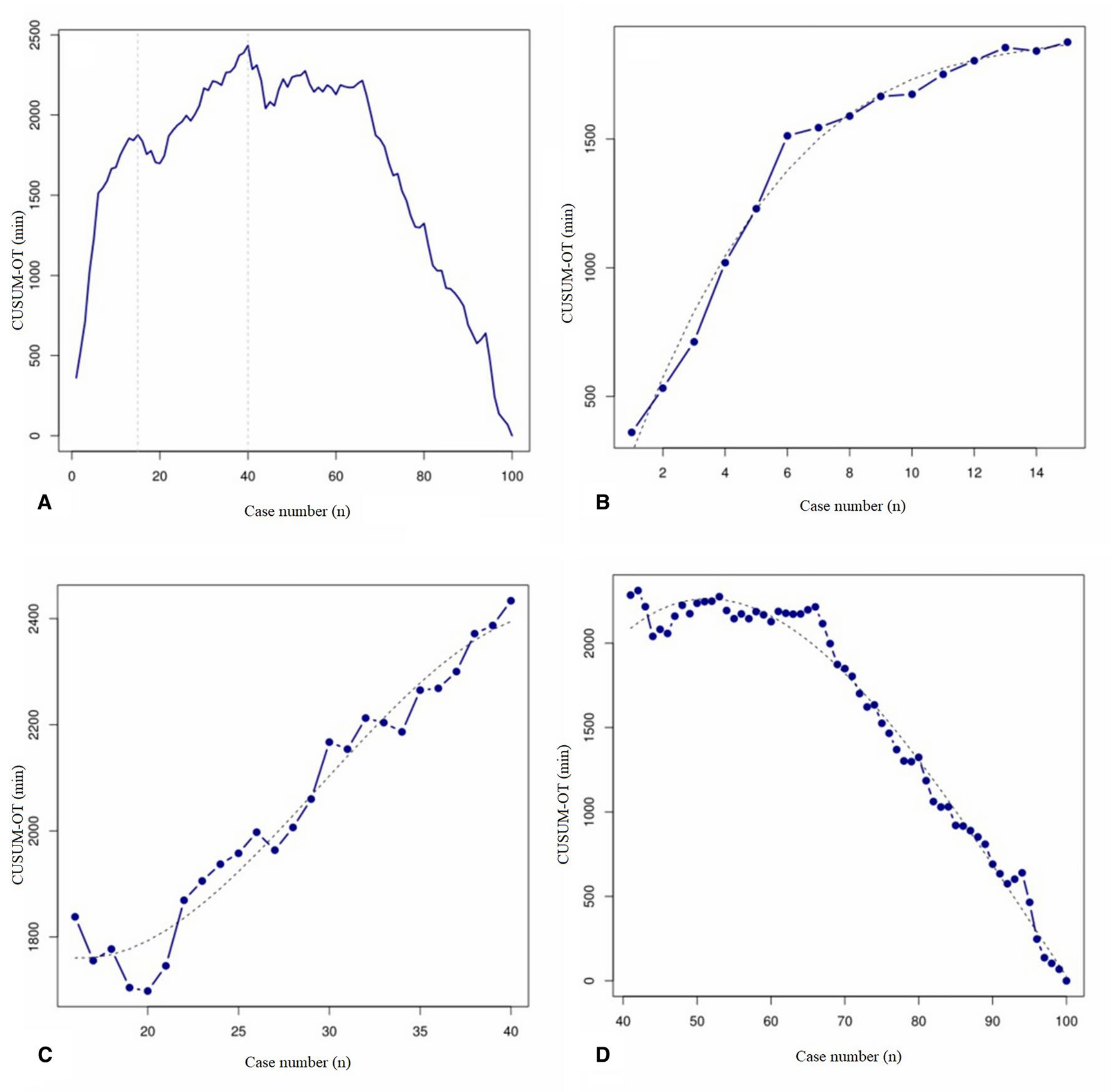

Fig. 2 **A** CUSUM-OT curve identifies three learning phases for RPD. **B, C** The first phase present an upwards slope. **D** The second phase indicates a downwards slope

respiratory failure, and the other two patients suffered from uncontrollable postoperative hemorrhage.

Discussion

PD is known for its technical complexity and difficulty in abdominal surgery. Extensive digestive organ dissection and multiple anastomoses make this surgical procedure difficult even with the open approach. No significant progress was made in pancreatic surgery with the MIS approach until the introduction of the surgical robot and endoscopic equipments. The advantages in intracorporeal anastomosis in the robotic surgery system gradually lead to the growing interest in robot-assisted surgery [19–21]. Published meta-analyses comparing minimally invasive pancreaticoduodenectomy (MIPD, which combined RPD with LPD) with OPD demonstrated that MIPD was a reasonable alternative to OPD, with advantages of a shorter hospital stay and less estimated blood loss [22–24]. However, the surgical approaches between laparoscopic and robotic are quite different [25] and they should lead to different operative and postoperative outcomes. We recently conducted a study to evaluate the surgical outcomes of RPD versus LPD, and found that the robotic approach resulted in significantly a shorter operative time, shorter hospital stay, and less blood loss [18]. Previously published articles also supported better results with RPD than LPD [13, 15, 26]. To our knowledge, there was only one report on the learning curve for RPD. This study by

Napoli et al. showed the operation time dropped after the first 33 operations and was associated with less delayed gastric emptying. The readmission rate dropped after 40 operations [15]. All the surgeons in our study had advanced open and laparoscopic skills in pancreatic surgery. Between July 2014 and November 2015, 120 OPD, 18 LPD and 45 robotic distal pancreatectomy had been performed by the single chief operating surgeon before the first robotic PD. This analysis suggested that the operative time dropped significantly after the first 20, and then after the 40 operations ($P < 0.01$). The hospital stay and the rates in reoperation, delayed gastric emptying, estimated blood loss and pancreatic fistula were significantly lower after the first 40 operations ($P = 0.01$). For patients who underwent RPD, extended lengths of hospital stay happened in some patients because of postoperative complications, especially at the steep initial learning curve. With increase in experience with RPD, there were less postoperative complications with a corresponding decrease in the length of hospital stay. Non-significant reductions were observed after 40 operations in incidences of major (Clavien–Dindo Grade II or higher) morbidity, postoperative death, bile leakage, and open conversion.

The main disadvantage of RPD which increased the operative time in our study was the docking time of the robotic surgical system [27–29]. However, our results showed the decrease in the operative time for RPD after 40 operations was so significant that the operative time of our RPD patients compared favorably with open PD, and was shorter than that reported by Buch et al. [19]. There are several reasons for the relatively short operation time of RPD in our study: (1) the ease in accessing and exposing the pancreas; and (2) the superiority of suture and knot tying in the robotic surgical system. We also analyzed the R0 resection rate [30, 31] the number of lymph nodes harvested [32, 33] and the overall complication rates in our first 40 operations compared with the subsequent operations, as these factors are known to affect the short- and long-term outcomes after PD. Our analysis showed that there was a similar R0 resection rate, a similar rate of patients with Clavien Grade > II postoperative complication and more lymph nodes were harvested in the later 60 operations compared with the early 40 operations. However, the rates of delayed gastric emptying, pancreatic fistula, postoperative hemorrhage, and reoperation were significantly less and there was also a significantly shorter hospital stay in the later 60 operations. This demonstrated the learning curve was achieved after 40 operations.

Our analysis has several limitations. First, the most important one is the learning curve may actually be shorter than 40 operations for surgeons who have experienced in robotic surgery. Similarly, surgeons with experience in laparoscopic and open PD may also have a shorter learning curve for RPD. Second, this is a retrospective study which has its inherent defects. Third, the strict inclusion/exclusion criteria used in this study can hinder the generalization of our results.

In conclusion, RPD in well-selected patients was safe and efficacious. The learning curve was completed after the first 40 operations. RPD is a feasible alternative to open surgery. Further studies are required to determine the long-term outcomes of RPD.

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Compliance with ethical standards

Disclosures Tao Zhang, Zhi-Ming Zhao, Yuan-Xing Gao, Wan Yee Lau, Rong Liu declare no conflicts of interest or financial ties to disclose.

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