Introduction: This study aimed to compare the perioperative outcomes of patients who underwent minimally invasive spleen-preserving distal pancreatectomy (MI-SPDP) versus open surgery SPDP (O-SPDP). It also aimed to determine the long-term vascular patency after spleen-saving vessel-preserving distal pancreatectomies (SSVDPs).

Methods: A retrospective review of 74 patients who underwent successful SPDP and met the study criteria was performed. Of these, 67 (90.5%) patients underwent SSVDP, of which 38 patients (21 open, 17 MIS) had adequate long-term post-operative follow-up imaging to determine vascular patency.

Results: Fifty-one patients underwent open SPDP, whereas 23 patients underwent minimally invasive SPDP, out of which 10 (43.5%) were laparoscopic and 13 (56.5%) were robotic. Patients who underwent MI-SPDP had significantly longer operative time (307.5 vs. 162.5 min, \( P = 0.001 \)) but shorter hospital stay (5 vs. 7 days, \( P = 0.021 \)) and lower median blood loss (100 vs. 200 cc, \( P = 0.046 \)) compared to that of O-SPDP. Minimally-invasive spleen-saving vessel-preserving distal pancreatectomy (MI-SSVDP) was associated with poorer long-term splenic vein patency rates compared to O-SSVDP (\( P = 0.048 \)). This was particularly with respect to partial occlusion of the splenic vein, and there was no significant difference between the complete splenic vein occlusion rates between the MIS group and open group (29.4% vs. 28.6%, \( P = 0.954 \)). The operative time was statistically significantly longer in patients who underwent robotic surgery versus laparoscopic surgery (330 vs. 173 min, \( P = 0.008 \)).

Conclusion: Adoption of MI-spleen-preserving distal pancreatectomy (SPDP) is safe and feasible. MI-SPDP is associated with a shorter hospital stay, lower blood loss but longer operation time compared to O-SPDP. In the present study, MI-SSVDP was associated with poorer long-term splenic vein patency rates compared to O-SSVDP.

Keywords: Laparoscopic pancreatectomy, patency, robotic pancreatectomy, spleen-saving pancreatectomy, splenic vessels

INTRODUCTION

Laparoscopic distal pancreatectomy (LDP) is currently widely accepted as being a safe and feasible procedure for the management of benign or borderline malignant pancreatic lesions in the body or tail of pancreas, given its...
benefits including decreased post-operative pain, shorter hospital stay and earlier recovery.\textsuperscript{[12‑16]} The important function of the spleen has been emphasised in recent years, not only in preventing infectious and haematological complications but also in providing a potentially longer survival time with malignancies.\textsuperscript{[6‑9]} Spleen-preserving distal pancreatectomy (SPDP) has also been shown to be safe with low morbidity.\textsuperscript{[10,11]} As such, many pancreatic surgeons today advocate splenic preservation during distal pancreatectomy especially when performed for non-malignant conditions.

There are two main surgical techniques described for SPDP: spleen-saving vessel-preserving distal pancreatectomies (SSVDP) which preserves the main splenic artery and vein, and the Warshaw technique where the splenic vessels are ligated and the spleen is perfused by preserved short gastric vessels and collaterals. Often, surgeons try to adopt the former approach to preserve the splenic vessels, due to the significantly increased risks of splenic infarction and gastric varices when the splenic vessels are sacrificed.\textsuperscript{[12‑16]} Multiple studies have compared laparoscopic SPDP versus open SPDP with conflicting results, with some describing poorer splenic vein patency in laparoscopic SPDP as compared to open SPDP\textsuperscript{[17]} and yet others describing high patency rates and low splenic infarction rates with laparoscopic SPDP.\textsuperscript{[18,19]} Numerous studies have also compared robotic versus laparoscopic approaches for distal pancreatectomy, showing that the robotic approach is a safe and feasible alternative approach with comparable perioperative and oncological outcomes compared to that of the laparoscopic approach,\textsuperscript{[20‑24]} and may even have better spleen and vessel preservation rates.\textsuperscript{[25,26]}

This study aims to review and compare the perioperative outcomes of patients who underwent minimally-invasive spleen-preserving distal pancreatectomy (MI-SPDP) versus those who underwent O-SPDP. It also aims to determine the long term splenic vessel preservation and patency rates after SSVDP.

**METHODS**

A retrospective review of all consecutive patients who underwent SPDP at our institution from 2005 to 2019 was carried out. This study was approved by our institutional review board. Patients were included if they had underwent distal pancreatectomy with splenic preservation. Patients with removal of the spleen or any other concomitant major organs apart from the distal pancreas during the index operation were excluded from the study. In total, 74 patients who met the study inclusion criteria underwent successful SPDP. This was a per-protocol analysis whereby only patients who had successful preservation of the spleen were included. Patients who had a planned spleen-preserving procedure which was converted to a splenectomy were excluded from the study.

Data of all patients were collected retrospectively from the patients’ clinical, radiological and pathological records. The choice of surgical approach was based on multiple factors such as surgeon’s and patient’s preference, patient’s overall fitness and lesion characteristics. Ultimately, the final decision for a particular treatment approach was made after extensive discussions between the managing clinician and the patient.

All laparoscopic and robotic SSVDP procedures were performed or supervised by two surgeons (Goh, \(n = 12\); Chan, \(n = 4\); others, \(n = 7\)) who completed advanced hepatopancreatobiliary fellowship training in 2011 and 2009, respectively. The MIS procedures included cases performed during the surgeons’ learning curves, starting from the very first MIS case performed in 2011 onwards. The open procedures were in general performed by more experienced senior surgeons who completed fellowships between 2000 and 2005.

**Surgical approach**

The operative technique at our institution has been described in detail previously.\textsuperscript{[21‑24,27‑28]} Briefly, robotic distal pancreatectomy was performed using three robotic arms (two left, one right) and a robotic camera system (Da Vinci Si, Intuitive Surgical, Sunnyvale, California, USA). The robotic instruments used included a combination of some of the following instruments: harmonic scalpel, Cadiere forceps, fenestrated bipolar, Hem-o-lok clip\textsuperscript{®} applicator and a large needle driver. The bedside assistant used conventional laparoscopic suckers, bowel graspers and endostaplers through a 12-mm assistant port placed in the left iliac fossa.

LDP was performed using various laparoscopic energy devices over the study period depending on the individual surgeon preference including the harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, OH, USA), ENSEAL (Ethicon Endo-Surgery, Cincinnati, OH, USA), LigaSure (Covidien, Boulder, CO, USA) or Thunderbeat (Olympus, Tokyo, Japan). In general, dissection of the pancreas proceeded from the medial to the lateral position in most cases except for distal lesions in the pancreatic tail. Endoscopic staplers were used to transect the pancreas and in selected cases, these were reinforced with sutures.

**Definitions**

We defined subtotal pancreatectomy as when the transection of the pancreas was at the neck either at...
or to the right of the portal vein/splenic vein junction. Distal pancreatectomy was defined as the resection of the pancreas to the left side of the superior mesenteric vein.

The latest 2016 ISGPS classification system for Pancreatic Fistula system\(^{(29)}\) was used to define and grade pancreatic fistulae. A clinically relevant post-operative pancreatic fistula (POPF) is defined as a drain output of any measurable volume of fluid with amylase level > three times the upper institutional normal serum amylase level, associated with a clinically relevant development/condition related directly to the POPF. The post-operative complications were graded according to the Clavien–Dindo grading system.\(^{(180)}\) All postoperative morbidities were recorded and included if they occurred within 30 days from surgery, or within the same hospital stay regardless of the length of stay. 30- and 90-day mortalities were also recorded.

The patency of the splenic vessels was classified into three grades according to the degree of stenosis, as follows: Grade 0, intact; Grade 1, partial occlusion and Grade 2, complete occlusion, as described previously by various other studies. Splenic perfusion was classified into four grades according to the extent of the splenic infarction as a percentage of the total splenic volume: Grade 0, intact; Grade 1, <50% infarction; Grade 2, ≥50% infarction and Grade 3, 100% infarction.\(^{(17,31)}\) All post-operative computed tomography images were compared with pre-operative images to evaluate post-operative changes in vascular patency.

**Statistical analysis**

All statistical analyses were performed using the computer program Statistical Package for the Social Sciences for Windows, version 20.0 (SPSS Inc., Chicago, IL, USA). Analyses were performed using the Mann–Whitney U-test, Chi-squared tests or Fisher’s exact test as appropriate. All statistical tests were two sided, and \(P < 0.05\) was considered statistically significant.

**RESULTS**

**Demographics**

During the study period, a total of 74 patients who met the study criteria underwent SPDP at our institution. Fifty-one (68.9%) patients underwent open SPDP and 23 (31.1%) patients underwent minimally invasive SPDP, out of which 10 (43.5%) were laparoscopic and 13 (56.5%) were robotic. Sixty-seven (90.5%) patients underwent SSVDP, out of which 38 patients (21 open, 17 MIS) had adequate post-operative follow-up imaging and were included for the analysis of long-term vascular patency.

**Comparison between open and MI-SPDP**

The comparison between the baseline demographics, clinicopathological features and outcomes of these patients are summarised in Tables 1 and 2. There were no significant differences in the demographics and clinicopathological features between both groups.

Patients who underwent MI-SPDP had a significantly longer operative time (307.5 vs. 162.5 min, \(P = 0.001\)) but shorter hospital stay (5 vs. 7 days, \(P = 0.021\)) and lower median blood loss (100 vs. 200 cc, \(P = 0.046\)) compared to that of O-SPDP. MIS tended to be associated with a statistically non-significant increased use of the Warshaw technique, that is lower splenic vessel preservation rate (82.6% vs. 94.1%, \(P = 0.117\)) and higher readmission

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**Table 1: Patient profile (n=75)**

| Variable                          | Open (n=51) | MIS (n=23 [10 lap, 13 robotic]) | \(P\) | Lap (n=10) | Robotic (n=13) | \(P\) |
|-----------------------------------|------------|---------------------------------|-------|-----------|---------------|------|
| Median age (IQR), years           | 53 (32)    | 54 (26)                         | 0.727 | 43.5 (42) | 62 (22)       | 0.252|
| Male, n (%)                       | 17 (33.3)  | 10 (43.5)                       | 0.563 | 4 (40)    | 5 (38.5)      | 0.677|
| BMI (IQR)                         | 23.8 (6.7) | 23.1 (6.2)                      | 0.283 | 22.4 (5.3) | 24.4 (6.2)    | 0.509|
| DM (%)                            | 4 (7.8)    | 2 (8.7)                         | 0.901 | 1 (10)    | 1 (7.7)       | 0.846|
| Previous abdominal surgery, n (%) | 3 (5.9)    | 0 (0)                           | 0.225 | 0 (0)     | 0 (0)         |      |
| ASA score, n (%)                  | 18 (35.3)  | 9 (39.1)                        | 0.830 | 3 (30)    | 6 (46.2)      | 0.734|
| 2                                 | 30 (58.8)  | 12 (56.5)                       | 0.660 | 6 (60)    | 6 (46.2)      |      |
| 3                                 | 35 (6.9)   | 1 (8.7)                         | 1 (10) | 1 (7.7)  |              |      |
| Median tumour size (IQR), mm      | 25 (23)    | 20 (23)                         | 0.389 | 22.5 (18) | 20 (33)       | 0.857|
| Tumour type                       |            |                                 |       |           |               |      |
| Neuroendocrine                    | 11 (21.6)  | 6 (26.1)                        | 0.076 | 2 (20)    | 4 (30.8)      | 0.504|
| Solid pseudopapillary neoplasm    | 3 (5.9)    | 6 (26.1)                        | 4 (40) | 2 (15.4) |              |      |
| Mucinous cystic neoplasm          | 6 (10.8)   | 1 (4.3)                         | 0 (0)  | 1 (7.7)   |              |      |
| Intraductal papillary mucinous neoplasm | 5 (9.8) | 4 (17.4)                      | 1 (10) | 3 (23.1) |              |      |
| Others                            | 26 (51.0)  | 6 (26.1)                        | 3 (30) | 3 (23.1) |              |      |

BMI: Body mass index, IQR: Interquartile range, DM: Diabetes mellitus, ASA: American Society of Anesthesiologists, MIS: Minimally invasive surgery
Comparison between laparoscopic and robotic spleen-preserving distal pancreatectomy

The outcomes are presented in Tables 1 and 2. Comparison between patients who underwent laparoscopic and robotic SPDP demonstrated that the operative time was noted to be significantly longer in patients who underwent robotic surgery as compared to those who underwent laparoscopic surgery (330 vs. 173 min, \( P = 0.008 \)). Nonetheless, there were no significant differences in the duration of post-operative hospital stay (6 vs. 5 days, \( P = 0.141 \)), development of pancreatic fistula (\( P = 0.261 \)) or post-operative morbidity (15.4 vs. 18.2%, \( P = 0.574 \)) between both groups. There was a nonsignificant higher splenic vessel preservation rate in the robotic compared to the laparoscopic group.

Comparison between long-term patency of open and MI-SSVDP

Sixty-seven patients underwent SSVDP, of which 38 had long-term follow-up imaging to determine vascular patency (21 open and 17 MIS). Patients who underwent open SSVDP had a significantly longer follow-up duration with imaging as compared to those who underwent MIS SSVDP (70 vs. 18.5 months, \( P = 0.023 \)). Patients who underwent open surgery were operated between 2005 and 2019, whereas those who underwent MIS were operated between 2011 and 2019. The outcomes are presented in Table 3. The post-operative patency of the splenic artery between open and MIS SSVDP groups did not differ significantly. However, those who underwent MI-SSVDP had significantly poorer long-term splenic vein patency rates on follow-up imaging overall as compared to those who underwent open SSVDP (\( P = 0.048 \)). Of note, there was no significant difference between the complete splenic vein occlusion rates between the MIS group and open group (29.4% vs. 28.6%, \( P = 0.954 \)). There was no significant difference in splenic perfusion between open and MI-SSVDP groups (\( P = 0.167 \)).

Comparison between laparoscopic and robotic spleen-saving vessel-preserving distal pancreatectomies [Table 4]

In terms of long-term vessel patency, there were also no significant differences in the splenic artery patency rates and splenic perfusion between both groups. The splenic

| Variable | Open (n=51) | MIS (n=23 [10 lap, 13 robotic]) | P | Lap (n=10) | Robotic (n=13) | P |
|----------|-------------|---------------------------------|---|------------|---------------|---|
| Concomitant other surgery, n (%) | 8 (15.7) | 1 (4.3) | 0.698 | 1 (10) | 0 (0) | 0.241 |
| Subtotal pancreatectomy, n (%) | 15 (30.0) | 4 (17.4) | 0.254 | 1 (10) | 3 (23.1) | 0.404 |
| Splenic vessels ligated, n (%) | 3 (5.9) | 4 (17.4) | 0.117 | 3 (30) | 1 (7.7) | 0.162 |
| Median operative time (IQR), min | 162.5 (62.5) | 307.5 (164) | 0.001 | 173 (167.5) | 330 (155) | 0.008 |
| Median blood loss (IQR), cc | 200 (300) | 100 (225) | 0.046 | 75 (400) | 200 (250) | 0.090 |
| Blood transfusion, n (%) | 7 (13.7) | 0 (0) | 0.074 | 0 (0) | 0 (0) | NA |
| Open conversion, n (%) | NA | 0 | NA | 0 (0) | 0 (0) | NA |
| Post-operative hospital stay (IQR), (days) | 7 (4) | 5 (3) | 0.021 | 5 (2) | 6 (3) | 0.141 |
| Post-operative morbidity, n (%) | 16 (31.3) | 7 (30.4) | 0.936 | 3 (30) | 4 (30.8) | 0.968 |
| Major morbidity (> Grade 2), n (%) | 8 (15.6) | 4 (17.4) | 0.854 | 3 (30) | 1 (7.7) | 0.162 |
| Pancreatic fistula (B), n (%) | 6 (11.7) | 5 (21.7) | 0.264 | 3 (30) | 2 (15.4) | 0.400 |
| Reoperation, n (%) | 3 (5.9) | 0 (0) | 0.548 | 0 (0) | 0 (0) | NA |
| Readmission, n (%) | 5 (9.8) | 6 (26.1) | 0.068 | 3 (30) | 3 (23.1) | 0.708 |
| 30-day mortality, n (%) | 1 (2.0) | 0 (0) | 1.00 | 0 (0) | 0 (0) | NA |

There were no Grade C fistulas. NA: Not applicable, IQR: Interquartile range, MIS: Minimally invasive surgery

| Variable | Open (n=21) | MIS (n=17 [6 lap, 11 robotic]) | P |
|----------|-------------|---------------------------------|---|
| Median CT follow-up time (IQR) (months) | 70 (69.8) | 18.5 (58.5) | 0.023 |
| Splenic artery patency, n (%) | 19 (95.2) | 13 (76.5) | 0.204 |
| Grade 0 | 0 (0) | 2 (11.8) | |
| Grade 1 | 1 (7.1) | 2 (11.8) | |
| Splenic vein patency, n (%) | 15 (71.4) | 8 (47.1) | 0.048 |
| Grade 0 | 0 (0) | 4 (23.5) | |
| Grade 1 | 6 (28.6) | 5 (29.4) | |
| Splenic vein occlusion, n (%) | 6 (28.6) | 5 (29.4) | 0.954 |
| Splenic perfusion, n (%) | 21 (100) | 15 (88.2) | 0.167 |
| Grade 0 | 0 (0) | 2 (11.8) | |
| Grade 2/3 | 0 (0) | 0 (0) | |

CT: Computed tomography, IQR: Interquartile range, MIS: Minimally invasive surgery
Several studies have compared laparoscopic SPDP versus open SPDP with conflicting results, with some describing poorer splenic vein patency in laparoscopic SPDP as compared to open SPDP,[17] whereas others have reported higher patency rates and lower splenic infarction rates with laparoscopic SPDP.[18,19] Several authors have also compared robotic versus laparoscopic approaches for distal pancreatectomy and have reported that the robotic approach is a safe and feasible alternative approach with comparable perioperative and oncological outcomes compared to that of the laparoscopic approach.[20‑24] The robotic approach has also been reported to be associated with superior spleen and splenic-vessel preservation rates compared to that of conventional laparoscopy.[25‑27]

In this study, we found that patients who underwent MIS surgery had a significantly shorter hospital stay and decreased blood loss but at the expense of a longer operative time compared to that of open surgery. There was also a higher frequency with the use of the Warshaw technique with MIS surgery, in particular via conventional laparoscopy. There was no difference in post-operative morbidity or mortality between both procedures. We also found that there were no significant differences in long-term splenic artery patency rates and splenic perfusion between the open and MIS groups.

In agreement with the literature, our study showed that the splenic vein patency tended to be more likely to be compromised as compared to splenic artery patency. Moreover, patients who underwent MI-SSVDP had significantly poorer splenic vein patency in the long term as compared to those who underwent O-SSVDP. However, it is important to note that the lower splenic vein patency rate in MI-SSVDP was mainly due to partial occlusion of the splenic vein, and the complete occlusion rates between both groups were similar. Comparison between robotic and laparoscopic SSVDP demonstrated that the post-operative splenic vein patency tended to be higher in the robotic group, although this was not statistically significant.

A major factor which may contribute to the lower incidence of splenic vein patency after MIS versus open surgery is the dissection technique. The method of dissection adopted in both surgical approaches tends to differ. In

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**Table 4: Post-operative splenic vessel patency and perfusion between laparoscopic and robotic SSVDP groups**

| Variable                                      | Lap (n=6) | Robotic (n=11) | P  |
|-----------------------------------------------|-----------|----------------|----|
| Median CT follow-up time (IQR) (months)       | 6.5 (60.3)| 2.45 (51)      | 0.661 |
| Pancreatic fistula, n (%) (A, B or C)         | 5 (83.3)  | 6 (54.5)       | 0.261 |
| Splenic artery patency, n (%)                 |           |                |     |
| Grade 0                                       | 4 (66.7)  | 9 (81.8)       | 0.893 |
| Grade 1                                       | 1 (16.7)  | 1 (9.1)        |     |
| Grade 2                                       | 1 (16.7)  | 1 (9.1)        |     |
| Splenic vein patency, n (%)                   |           |                |     |
| Grade 0                                       | 2 (33.3)  | 6 (54.5)       | 0.225 |
| Grade 1                                       | 3 (50)    | 1 (9.1)        |     |
| Grade 2                                       | 1 (16.7)  | 4 (36.4)       |     |
| Splenic vein occlusion, n (%)                 |           |                |     |
| Grade 0                                       | 4 (66.7)  | 5 (45.5)       | 0.667 |
| Grade 1                                       | 2 (33.3)  | 0 (0)          |     |
| Grade 2/3                                      | 0 (0)     | 0 (0)          |     |

CT: Computed tomography, IQR: Interquartile range

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vein preservation rate tended to be higher in the robotic group, with 54.4% in the robotic group maintaining complete splenic vein patency as compared to 33.3% in the laparoscopic group, although this did not reach statistical significance.

**DISCUSSION**

At present, two main surgical techniques have been described for SPDP: splenic vessel preservation which preserves the main splenic artery and vein, popularised by Kimura et al. (1996), and the Warshaw technique, where the splenic vessels are ligated and the spleen is perfused by preserved short gastric vessels and collaterals. The former tends to be favoured by some surgeons, given its reportedly lower incidence of complications including lower post-operative splenic infarction rates and gastric varices.[12‑16] More recently, some authors have also proposed the use of autogenic splenic implantation after distal pancreatectomy as an alternative to SPDP to preserve immunologic splenic function although the efficacy of this procedure is still subject to ongoing investigation.[31]

Nonetheless, it has been well reported in the literature that despite successful completion of SSVDP, the patency of the splenic vessels regardless of approach may not always be maintained. This is especially with regard to splenic vein patency.[7,32] There are several possible reasons for this: first, given the anatomical course of the splenic vein that frequently runs closely adherent to the pancreas, greater manipulation and dissection of the splenic vein is often required, with multiple small branches often encountered as well. This frequently results in tearing of these tributaries and even the main splenic vein itself resulting in bleeding. Attempts to control this bleeding such as by suturing may result in narrowing of the splenic vein, predisposing it to thrombosis. Moreover, veins are typically more susceptible to thrombosis and inflammation compared to arteries, given their thinner walls and lower velocity of blood flow.[7,32]
open surgery, sharp dissection is typically employed, and any small branches encountered are usually ligated with ties, whereas laparoscopic energy devices such as ultrasonic shears or advanced bipolar are usually used in MIS for dissection of structures including vessels. These energy devices have been shown to generate extreme temperature gradients with collateral thermal damage that can result in significant histologic injury extending to the walls of large vessels, which may subsequently lead to thrombosis or vascular stricture.[5,34] Nevertheless, in the present study, despite compromise in the splenic vessel patencies, splenic perfusion was well maintained in most patients in both open and MIS groups, with long-term preservation of splenic perfusion for all patients in the open group and in 15 out of 17 patients in the MIS group.

The present study has several limitations. First, it is a single-centre retrospective study, with a relatively small number of patients included, which may have resulted in statistical type 1 or 2 errors. Second, the study spanned a period of 14 years whereby changes in surgical technique and patient management over time may have confounded the outcomes. Historical bias may also have affected the outcomes observed as patients who underwent MIS were more likely to be operated more recently (2011–2019) as opposed to those who underwent open surgery (2005–2019). This also resulted in a significantly longer duration of follow-up associated with open surgery compared to that of MIS. Selection bias was also likely a major confounder influencing the study results in this non-randomised study. Finally, many of the MIS cases included were performed during the institution’s learning curve, which likely contributed to the longer operation times. Further prospective studies with a larger patient cohort and more standardised follow-up duration with radiological evaluation at more consistent time points may be useful to compare and confirm the significance of post-operative outcomes in open versus minimally invasive spleen-saving distal pancreatectomies, particularly the effects on long-term splenic vessel patency rates, if any.

**CONCLUSION**

Adoption of the MIS approach (laparoscopic or robotic) for SPDP is a safe and feasible option. It is associated with a shorter hospital stay, lower blood loss but longer operation time and higher readmission rate. MI-SSVDP was associated with a poorer long-term splenic vein patency rates compared to O-SSVDP. Further studies with larger patient cohorts and long-term follow-up would be useful to draw a more definitive conclusion on the comparison of vessel patency rates between the various approaches used in SSVDP.

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**Conflicts of interest**

Dr Goh BK has received travel grants and speaker fees from Transmedic, the distributor for Da Vinci Robot, Johnson and Johnson and Medtronic. None of the other authors have any disclosure or conflicts of interest to declare.

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