Since its introduction in the 1980s, minimally invasive surgery and its advancements have drastically changed the landscape of surgery and how it is practiced (1). In the course of three decades, laparoscopy has become the gold-standard approach for many general surgical operations, including cholecystectomies and bariatric surgery. Laparoscopic surgery has been shown to have lower rates of surgical site infections, less post-operative pain and an overall shorter hospital stay as compared to the conventional open technique (2).

In 1994, Cuschieri reported the first laparoscopic pancreatic surgery (3). Although minimally invasive pancreatic surgery was initially slow in gaining acceptance among hepatobiliary and pancreatic surgeons, it is fast becoming a widely accepted approach (4). This is especially so for distal pancreatic resections. As compared to other pancreatic surgeries such as pancreaticoduodenectomy, the lack of anastomoses in distal pancreatectomy make it an especially feasible operation to carry out via a minimally invasive approach (5). A systematic review and meta-analysis by Venkat et al. in 2012 showed that there was a decrease in blood loss, reduced length of hospital stay, and lower overall risk of postoperative complications and wound infections for patients who underwent laparoscopic distal pancreatectomy as compared to open. Furthermore, there was no significant increase in operative time, and oncological outcomes were not inferior to the conventional open technique (6).

Distal pancreatectomy can either be performed with or without splenic preservation. As more evidence surfaces of the important role that the spleen plays in host immunological defenses, an increasing number of spleen-preserving distal pancreatectomies have been attempted, especially for non-malignant tumours of the left pancreas (7). Warshaw described his technique in 1988, where the spleen is preserved but the main splenic artery and vein are resected, leaving the short gastric vessels for splenic perfusion (8). In 1996, Kimura et al. described a technique to preserve both the splenic vessels and the spleen (9). Kimura’s technique describes a very careful dissection of the pancreas off the splenic vessels, with extra caution taken in ligating the many small tributaries of the splenic vein, making it technically more challenging than the Warshaw technique.
technique. However, with an increased risk of splenic infarction and gastric varices in the Warshaw technique (5), spleen and vessel preservation should be attempted whenever possible. The most recent meta-analysis by Yongfei et al. supports both the laparoscopic Warshaw and Kimura technique as safe spleen-preserving techniques. While the Kimura technique has a longer operative time and blood loss, this is offset by the lower rates of splenic infarction and gastric varices development compared to the Warshaw technique. Significantly, while there are regional variations between surgical techniques preferred for spleen preservation between Western and Eastern centres, there are no significant differences in outcomes between these techniques (10).

The first series of robotic pancreatic resections was published by Giulianotti et al. in 2003 with a series of five distal pancreatectomies of which two were spleen-preserving (11). The robotic platform could offer an advantage over conventional laparoscopy in spleen and vessel preserving distal pancreatectomy (Table 1). The laparoscopic technique has been shown to have a significant rate of conversion to open (12), possibly owing to the inherent limitations of the laparoscopic platform. These limitations were challenged by the introduction of the robotic system, which offered a three-dimensional and magnified view, instruments that allowed for greater freedom of movement, and elimination of hand tremor, resulting in better stabilization of the camera and working instruments. Waters et al. demonstrated a higher spleen preservation rate in robotic distal pancreatectomy as compared to laparoscopic and open techniques (65%, 29% and 12% respectively) (13). Hwang et al. described successfully performing 21 out of 22 planned spleen-preserving robot-assisted distal pancreatectomies, where the splenic vessels were conserved in 17 of them (81%) (14). In a review discussing the impact of robotic technology on pancreatic minimally invasive surgery, Joyce et al. even suggested that robotic pancreatic surgery, since its introduction, has been more eagerly adopted as compared to the traditional laparoscopic approach, and that robotic assistance seemed to enable surgeons to overcome limitations they felt with the laparoscopic system (15).

There have been several systematic reviews published in recent years comparing robotic versus laparoscopic distal

<table>
<thead>
<tr>
<th>Reference</th>
<th>No. of cases</th>
<th>Conversion to open (%)</th>
<th>Percentage done with spleen preservation (%)</th>
<th>Operative time (mins)</th>
<th>LOS (days)</th>
<th>Cost (USD)</th>
<th>No significant difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giulianotti, 2003</td>
<td>5 robotic</td>
<td>–</td>
<td>40 spleen-preserving</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Hwang, 2013</td>
<td>22 robotic</td>
<td>0</td>
<td>95.5 (81% splenic vessel preservation)</td>
<td>398</td>
<td>7</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Waters, 2010</td>
<td>17 robotic</td>
<td>–</td>
<td>65</td>
<td>298</td>
<td>4</td>
<td>10,588</td>
<td>Blood loss, morbidity</td>
</tr>
<tr>
<td></td>
<td>28 laparoscopic</td>
<td></td>
<td>29</td>
<td>222</td>
<td>6</td>
<td>12,986</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32 open</td>
<td></td>
<td></td>
<td>245</td>
<td>8</td>
<td>16,059</td>
<td></td>
</tr>
<tr>
<td>Liu, 2017</td>
<td>102 robotic</td>
<td>2.9</td>
<td>60 (malignant); 95.5 (benign)</td>
<td>NSD</td>
<td>7.6</td>
<td>–</td>
<td>Blood loss, morbidity, operative time</td>
</tr>
<tr>
<td></td>
<td>102 laparoscopic</td>
<td>9.8</td>
<td>35.5 (malignant); 52.4 (benign)</td>
<td>8.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zhou, 2015 (meta-analysis of 7 studies)</td>
<td>211 robotic</td>
<td>NSD</td>
<td>44.3</td>
<td>247.8</td>
<td>6.9</td>
<td>NSD</td>
<td>Major morbidity, peri-op mortality</td>
</tr>
<tr>
<td></td>
<td>357 laparoscopic</td>
<td></td>
<td>26.5</td>
<td>229.9</td>
<td>8.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gavriilidis, 2016 (meta-analysis of 9 studies)</td>
<td>246 robotic</td>
<td>NSD</td>
<td>NSD</td>
<td>NSD</td>
<td>8.2</td>
<td>–</td>
<td>Major morbidity, peri-op mortality</td>
</tr>
<tr>
<td></td>
<td>391 laparoscopic</td>
<td></td>
<td></td>
<td></td>
<td>10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wright, 2016 (systematic review of 37 articles)</td>
<td>195 robotic</td>
<td>10.8</td>
<td>–</td>
<td>NSD</td>
<td>NSD</td>
<td>–</td>
<td>Major morbidity, peri-op mortality</td>
</tr>
<tr>
<td></td>
<td>349 laparoscopic</td>
<td>21.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

LOS, length of stay; NSD, no significant difference.
pancreatectomy. Gavriilidis et al. performed the first meta-analysis including 9 studies and 637 patients (246 robotic and 391 laparoscopic). Their findings showed that the robotic approach showed a shorter hospital length of stay of 1 day. Early results also showed a significant increased readmission rate for the robotic approach although this was based on only three studies. There were no significant differences in conversion rate, post-operative pancreatic fistula, major morbidity and spleen preservation rate (16). The Pittsburgh group did a similar review but only included studies with >40 patients with minimally invasive distal pancreatectomy in their analysis of comparative studies. This showed lower conversion rates to laparotomy and reduced blood loss but similar operative time, length of stay, morbidity and mortality (17). Limitations to these studies include the retrospective nature of these studies with small sample sizes, likely selection bias for simpler cases for the robotic approach and early learning curve of most surgeons in their early experience with robotic surgery.

In the largest comparative minimally invasive distal pancreatectomy series to date, Liu et al. compared the robotic vs. laparoscopic distal pancreatectomy using propensity score matching of 102 patients in each arm. This showed a reduction in rate of conversion to laparotomy especially in patients with large tumours (>5 cm), improved splenic and splenic vessel preservation rates in moderate tumours (3–5 cm) and a reduction in post-operative hospital stay. There were no differences in operative time, blood loss, transfusion rate and rates of overall morbidity and pancreatic fistula (18). These results suggest that in expert hands, after overcoming the learning curve, the robotic approach may allow for greater rates of completion in “difficult” resections with the reduced need for conversion either to splenic vessel and splenic resection or to laparotomy. Further studies from large centers are awaited to confirm these findings as experience with robotic pancreatic surgery accumulates.

The robotic platform however, is not without its drawbacks. Lack of tactile feedback may result in excessive force when manipulating delicate tissue, leading to unnecessary trauma (19). Cost has also been an impediment to the widespread usage of the robotic platform. With a high base cost ranging in the millions, expensive maintenance and the need for additional consumables in the form of single-use instruments, robotic surgery has not been adequately shown to be more cost-effective despite its monetary savings with regards to shorter length of hospital stay and productivity gains (20) (Table 1). This evidence is conflicting however, as the use of the robotic approach can be shown to be profitable in some hospital settings (21). Furthermore, as some authors suggest, with the wider adoption of the robotic system, market pressures and increased competition from other players may eventually drive the cost of instrumentation and robotic utilization lower (17).

Another drawback is the learning curve needed to become even adept with the robotic surgical system, let alone translating that new expertise into better clinical outcomes for patients. Most studies use the number of cases needed to achieve a plateau in operative time as a variable to examine the learning curve, and current evidence shows a very wide range of results, with little examination of clinical outcomes (Table 2). Pernar et al. reviewed the literature on robotic surgery learning curves where colorectal cases were shown to have a range of 25–75 cases, 10–95 cases for foregut or bariatric surgery, and 10–80 for solid organ surgery (22).

At this time, insufficient evidence exists to draw a significant conclusion regarding the learning curve for robotic distal pancreatectomy. Napoli et al. was able to describe a relatively gentle learning curve of 10 cases, based on reductions in operative time, but was unable to demonstrate any improvement in clinical outcome (23). Shakir et al. analyzed the first 100 consecutive robotic distal pancreatectomy cases at a high-volume center. He described a learning curve of 40 cases, and also performed

<table>
<thead>
<tr>
<th>Author, year</th>
<th>No. of cases</th>
<th>Robotic system</th>
<th>No. of surgeons</th>
<th>Method</th>
<th>Learning curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Napoli, 2015</td>
<td>55 consecutive</td>
<td>–</td>
<td>–</td>
<td>Cumulative sum analysis of operative time</td>
<td>10 cases</td>
</tr>
<tr>
<td>Shakir, 2015</td>
<td>100 consecutive</td>
<td>Da Vinci S or Si</td>
<td>3, extensive experience with LDP, no substantial robotic experience</td>
<td>Cumulative sum analysis of operative time</td>
<td>40 cases</td>
</tr>
</tbody>
</table>

LDP, laparoscopic distal pancreatectomy.
further analysis of perioperative outcomes comparing the pre-learning curve and post-learning curve cohorts, which showed significant reductions in complication and readmission rates after the learning curve had been reached (24).

In conclusion, current evidence demonstrates clear benefits of minimally invasive distal pancreatectomy over the open technique for indicated cases. There is also data to support robotic distal pancreatectomy over the laparoscopic technique especially when there is a role for spleen and vessel preservation. More high-quality studies on learning curves and the comparison of outcomes of pre- and post-learning curve cohorts could definitely contribute to the ongoing debate of the cost-benefit ratio of the robotic platform as compared to the conventional laparoscopic technique.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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