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Pancreatic anastomosis training models: Current status and future directions

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A B S T R A C T

Postoperative pancreatic fistula (POPF) is a major cause of morbidity and mortality after pancreatoduodenectomy (PD), and previous research has focused on patient-related risk factors and comparisons between anastomotic techniques. However, it is recognized that surgeon experience is an important factor in POPF outcomes, and that there is a significant learning curve for the pancreatic anastomosis. The aim of this study was to review the current literature on training models for the pancreatic anastomosis, and to explore areas for future research. It is concluded that research is needed to understand the mechanical properties of the human pancreas in an effort to develop a synthetic model that closely mimics its mechanical properties. Virtual reality (VR) is an attractive alternative to synthetic models for surgical training, and further work is needed to develop a VR pancreatic anastomosis training module that provides both high fidelity and haptic feedback.

1. Introduction

Pancreatoduodenectomy (PD) is a complex surgical procedure and associated with significant perioperative morbidity (40–58%) and mortality (2–4%) [1–3]. Leakage of pancreatic enzymes from the pancreatoenteric anastomosis (postoperative pancreatic fistula, POPF) is a major source of the morbidity of PD and may lead to sepsis, bleeding, organ failure or death. The risk factors for POPF are well established and include body mass index, pancreatic duct width, and subjective intraoperative assessment of pancreatic texture ("hard" or "soft") [4–9] and several risk scores have been developed that can preoperatively stratify patients according to POPF risk [7]· [10].

The International Study Group of Pancreatic Surgery (ISGPS) has established a risk classification for postoperative pancreatic fistula (POPF) following pancreatoduodenectomy, based on pancreatic texture and duct size, with four categories: A (not-soft texture and duct >3 mm), B (not-soft texture and duct ≤3 mm), C (soft texture and duct >3 mm), and D (soft texture and duct ≤3 mm). This classification was validated using data from the Dutch Pancreatic Cancer Audit, with the model's performance evaluated by the area under the receiver operating curve [11]. Additionally, risk calculators like the Pancreatic Fistula Risk Score (FRS) have been developed to predict POPF risk, using various intraoperative and preoperative factors, and have been validated in multiple institutions [7]. A systematic review has also assessed multiple scoring systems for predicting POPF after pancreatoduodenectomy, highlighting the clinical applicability and study quality of these tools [12]. The ISGPS recommends using their classification system for reporting risk factors to enhance clinical decision-making and auditing [11,13].

Surgeon experience is also important but a less well-defined factor related to POPF. However, and importantly, this is a potentially modifiable risk factor for POPF and according to a recent study, the learning curve for the pancreatic anastomosis is in the region of 50 cases [14,15]. Given that pancreatic surgeons typically perform 15–20 PDs annually in high volume centres, it may take 2–3 years for a surgeon to ascend their learning curve. No single anastomotic method has been found to be superior in terms of POPF risk (e.g. invagination vs. duct-to-mucosa), although studies are conflicting and do not account for the learning curve [16–20]. Although pancreatoduodenectomy is a complex procedure with multiple steps that require structured training programs, there is an unmet need for a reliable pancreatic anastomosis training model

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that may shorten a pancreatic surgeon's learning curve and reduce the POPF rate. The aim of this review is to summarize the available literature relating to pancreatic anastomosis training models.

2. Pancreatic anastomosis training models

2.1. The ideal pancreatic anastomosis training model

The ideal training model for pancreatic anastomosis should be realistic, reproducible and affordable. The ideal model should have a similar appearance and dimensions compared to the human pancreatic remnant. The model should also resemble the texture of the normal (soft) human pancreas and therefore should have similar mechanical properties such as deformability, fragility, compressibility and elasticity. In engineering terms, these properties relate to Young's modulus, Poisson's ratio and strength. The ideal model should also be capable of differentiating between an experienced surgeon and a novice. To achieve this, the model should be capable of measuring outcome (i.e. POPF) and therefore should allow ‘leak testing’. Lastly, a reliable model should allow surgical trainees to learn and develop the technique for the pancreatic anastomosis that will ultimately shorten their learning curve. A pancreatic anastomosis training model must be ethical and reproducible and ideally it should also be reusable or recyclable. In order to facilitate widespread implementation, including into developing countries, the model must also be affordable. Ultimately, for a model to be impactful, it is necessary to demonstrate that its use shortens the learning curve.

2.2. Animal models

There is limited data on the use of animals for pancreatic anastomosis models. In one study of an in vivo porcine model of pancreatoduodenectomy, the pancreatic anastomosis was evaluated histologically ten days postoperatively [21]. Anastomotic bursting pressure was measured and the authors found that the anastomosis had healed in 6 out of 8 animals. The study concluded that quantitative measurement of collagen deposition at the pancreatic anastomosis provides objective assessment of healing of the pancreatic anastomosis [21]. In another animal study, the anatomical similarity between canine and human digestive tracts was used to simulate reconstruction after pancreatoduodenectomy [22]. A hepatobiliary surgeon performed simulated PD digestive reconstructions in six animals. The study showed that there was collagen integration in all bilioenteric and pancreatoenteric anastomoses and the study concluded that an animal model for digestive tract reconstruction after a simulated PD in canines is feasible [22].

There are several limitations with the use of in vivo animal models, including accessibility, cost and ethical considerations that are likely to prevent their routine use in surgical training models.

2.3. Human cadaveric models

Very few studies have evaluated the role of human cadaveric tissue as a training model for pancreatoduodenectomy. In one study, a perfused human cadaveric model was developed as a training model for robotic pancreatoduodenectomy, although it was primarily focussed on training the resection phase and bleeding control rather than the pancreatic anastomosis [23].

2.4. Synthetic models

Synthetic pancreatic anastomosis models are commercially available (e.g. Lifelike BioTisse, Ontario, Canada) or can be 3D-printed using a 3D model derived from CT images [24–27]. Four studies have evaluated the use of synthetic models to train the pancreatojejunostomy anastomosis [28–31] (Table 1). Each study utilised either commercially available or 3D-printed silicone models for either laparoscopic, robotic or open pancreatojejunostomy and compared techniques between experienced surgeons and trainees. Outcomes were subjectively evaluated by independent experts, but none of the models permitted leak testing. In a further study, surgeons were tasked to subjectively evaluate the appearance and tactile sensation of a 3D printed silicone model. Scored out of a maximum of 5, the model was rated 3.96 ± 0.55 (mean ± standard deviation) for overall appearance, 3.88 ± 0.45 for elasticity, and 3.83 ± 0.48 for suture breakthrough [31]. The physical properties of a synthetic pancreas model was objectively assessed in only one study [31], which reported that the stiffness of the model (measured by ultrasound elastography) was significantly higher than normal pancreas tissue (10.08 vs. 7.72 kPa; $p = 0.003$) [31,33]. There are no available studies that have evaluated the effect of training on synthetic models on the incidence/severity of POPF or on the learning curve for POPF (Table 2).

The Robotic Pancreatoduodenectomy Bio tissue Curriculum has been found to have validity and improve the technical performance of surgical oncology fellows [32]. A study conducted at the University of Pittsburgh Medical Centre demonstrated that the curriculum, which includes suture drills and various bio tissue drills, is feasible and leads to improved errors and technical performance. The purpose of this curriculum is to enhance the skills of novice surgeons outside of the operating room, ultimately reducing the learning curve for performing robotic pancreatoduodenectomies. The study concluded that this curriculum is a valid tool for teaching robotic pancreatoduodenectomies and has established milestones for achieving optimal performance [34].

2.5. Mechanical properties of pancreas

The pancreatoenteric anastomosis is technically challenging, particularly in patients with a non-dilated pancreatic duct and a soft pancreas. It is this subgroup of patients who have ‘high-risk’ anastomoses and are especially prone to developing POPF. Normal human pancreas tissue is soft and very fragile. All pancreatoenteric anastomoses are hand sewn with either absorbable or non-absorbable sutures according to surgeon preference. A wide range of pancreatic anastomotic methods have been described, and typically incorporate either a “duct-to-mucosa” or “invaginating” technique in one or two layers [35,36]. Irrespective of the method used, sutures may “cut through” or fracture a soft pancreas thereby precluding a water tight anastomosis and predisposing to POPF. It is not possible to determine exactly why experienced pancreatic surgeons have a lower POPF rate compared to junior colleagues, but it is likely that they have mastered precise suture placement and knot tying to maximise tissue apposition, whilst minimizing any stress or injury to the pancreatic parenchyma. Based on the fact that soft pancreas is an important risk factor for POPF, it follows that the ideal training model should have similar mechanical properties to a normal (soft) human pancreas.

The 3D printed model used by Yu et al. was found to have significantly higher stiffness compared to normal pancreas [31]. The operation procedures used in this study refer to the classic Cattell-Warren anastomosis method. The operation steps are detailed in Fig. 1.

In a study by Sugimoto et al., the Young's modulus (a measure of elasticity) of the resected cut end of pancreas was measured during pancreatoduodenectomy in 59 patients, and correlated with surgeon's assessment of pancreas texture, histological evidence of fibrosis as well as POPF. The Young's modulus was 1.4 ± 2.1 and

Table 1
Studies on synthetic pancreatic anastomosis models.

Author	Model	Type of anastomosis	Subjects	Leak test	Outcome assessment
Yang et al. (2022) [28]	3D-printed PJ silicone model	Laparoscopic PJ	16 surgeons 4 fellows 4 residents	No	Subjective assessment by expert
Wei et al. (2019) [29]	Commercially available silicone gel 3D printed PJ silicone model	Robotic PJ	3 surgeons	No	Subjective assessment by expert
Kang et al. (2022) [30]	Commercially available silicone model	Open PJ	5 residents	No	Subjective assessment by expert
Yu et al. (2022) [31]	3D-printed PJ silicone model	Open PJ	5 surgeons 5 fellows 5 residents	No	Subjective assessment by expert

Table 2
Summary table that outlines the role of simulation training using inanimate biotissue models in improving technical skills for pancreaticojejunostomy (PJ).

Author	Key Finding	Relevance to PJ Training Models
Hogg et al. (2019) [44]	A structured program for teaching PJ to surgical residents and fellows using an inanimate biotissue model improved technical proficiency, as assessed by the OSATS scale.	Supports the use of simulation training to enhance technical skills for PJ.
Sata et al. (2021) [45]	Demonstrates that a structured biotissue curriculum for robotic pancreatoduodenectomy improves technical performance among surgical oncology fellows	Supports the use of structured, simulation-based training modules for enhancing PJ anastomosis skills, particularly in robotic surgery contexts.
Saiura et al. (2021) [46]	The study demonstrated that simulation training using an inanimate biotissue model significantly improves the technical skills of hepatobiliary-pancreatic surgical fellows. Simulation training using an inanimate biotissue model is effective in improving the technical skills of hepatobiliary-pancreatic surgical fellows, as evidenced by improved OSATS scores. However, the time taken to complete the procedure did not change significantly.	Highlights the effectiveness of simulation training in enhancing the technical proficiency of surgical fellows for performing PJ, suggesting its potential to shorten the learning curve for this complex surgical procedure.

OSATS: Objective Structured Assessment of Technical Skills.

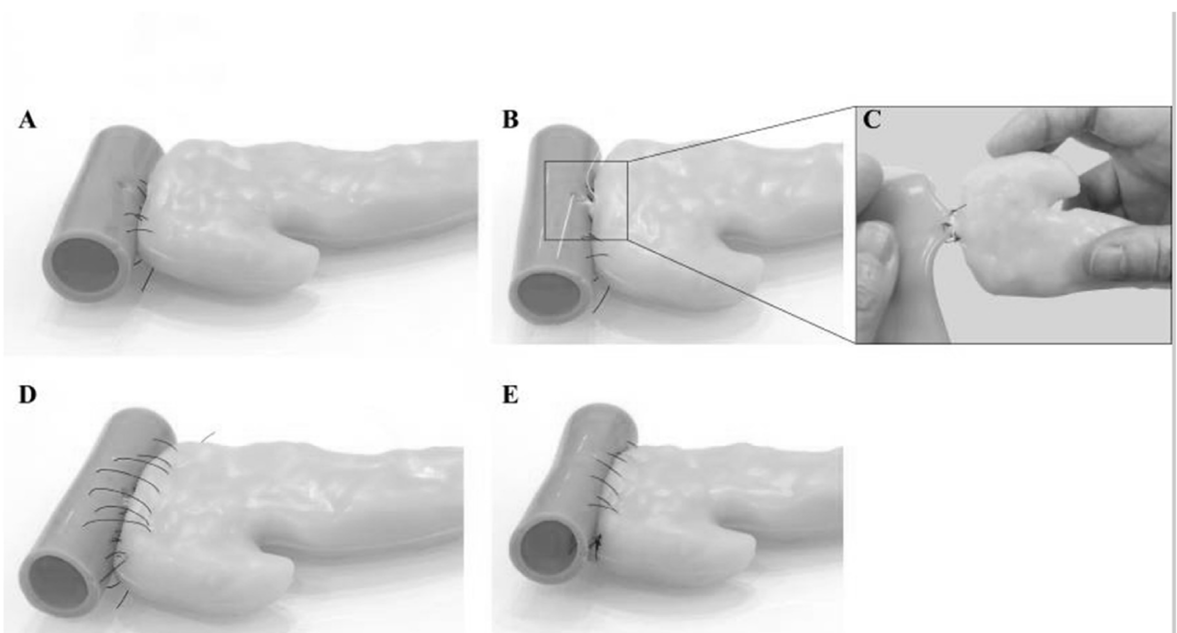

Fig. 1. 3D printed dry lab PJ model.

4.4 ± 5.1 kPa in soft and hard pancreas, respectively, and patients with a Young's modulus less than 3.0 kPa had a significantly higher incidence of POPF [37]. Wex et al. compared the shear mechanical properties of both porcine and human pancreas and concluded that pancreas was a nonlinear viscoelastic soft tissue [38]. However, they noted that porcine and human pancreas had different mechanical properties (complex shear modulus, storage and loss moduli) [38].

3. Virtual reality training models

The role of virtual reality (VR) in surgical training is gaining popularity, particularly in the field of minimally invasive surgery, and may become a viable alternative to synthetic training models in the future. VR training modules have been developed and validated for simple surgical tasks, as well as for more complex procedures such as colectomy, cholecystectomy or arthroplasty [39–41].

Table 3
Recommendations for future studies in the field of pancreatic anastomosis training models.

Area of Study	Current Limitations	Recommendations for Future Research
Mechanical Properties of the Human Pancreas	Lack of models that accurately mimic the mechanical properties of the human pancreas.	Develop synthetic models that closely replicate the mechanical properties (e.g., elasticity, compressibility) of the human pancreas.
Virtual Reality (VR) Training Models	VR models are expensive and lack widespread availability. Haptic feedback is limited in many VR systems.	Develop affordable VR pancreatic anastomosis training modules that provide high fidelity and haptic feedback.
Synthetic Models	Existing models do not permit leak testing. The stiffness of some models is higher than that of normal pancreas tissue	Create models that allow for leak testing and have mechanical properties more closely aligned with those of normal pancreas tissue.
Animal Models	Ethical considerations, accessibility, and cost limit the use of in vivo animal models	Explore the feasibility and ethics of using animal models more extensively, or develop alternative models that overcome these limitations.
Human Cadaveric Models	Limited studies on the use of human cadaveric tissue for pancreatoduodenectomy training.	Investigate the potential of human cadaveric models for more comprehensive training, focusing on both resection and anastomosis phases.
Effectiveness of Training Models	No studies evaluating the impact of training on synthetic models on POPF incidence or learning curve.	Conduct studies to assess whether training with synthetic models can reduce POPF rates and shorten the learning curve for surgeons.

VR: Virtual reality.

Table 4
Summary table that outlines the role of pancreatic texture and the pancreatic duct, as well as ways to objectively measure these factors to create a training module for pancreatojejunostomy (PJ).

Aspect	Description	Relevance to PJ Training Module
Pancreas Texture	The hardness and fibrosis of the pancreatic tissue are critical factors that influence surgical outcomes, such as the risk of post-operative pancreatic fistula (POPF)	Training modules should simulate the varying hardness of pancreatic tissue to prepare trainees for real-life scenarios.
Pancreatic Duct	The size and condition of the pancreatic duct are important considerations during PJ, as they can affect the complexity of the anastomosis.	Simulation models should include anatomically accurate representations of the pancreatic duct to enhance surgical planning and technique.
Objective Measurement	Durometers can measure pancreatic hardness, and secretin-enhanced MRCP (S-MRCP) can assess the pancreatic duct.	Trainees should learn how to use these objective measurement tools for preoperative planning and intraoperative decision-making.
Imaging Data	MRI and S-MRCP provide valuable information about the pancreatic tissue and duct that can guide surgical approach.	Integrating imaging data into the training module can help trainees interpret these images for better surgical planning.
Risk Assessment Tools	Predictive scores and tools that consider pancreatic texture and duct characteristics can estimate the risk of POPF.	Training should include the use of these tools to tailor the surgical approach to individual patient characteristics.
Feedback Mechanisms	Objective scoring systems can assess the trainee's proficiency in tissue handling, suture placement, and anastomosis completion.	Feedback mechanisms are essential for evaluating and improving the trainee's technical skills
Continuous Update	The training module should be regularly updated with the latest research and validated for effectiveness.	Ensuring the module reflects current best practices and is effective in improving surgical outcomes is crucial for ongoing education.

S-MRCP: Secretin-enhanced Magnetic Resonance Cholangiopancreatography.
PJ:Pancreato-jejunostomy

However, current VR training systems such as LapSim® (Surgical Science, Göteborg, Sweden) are expensive and not widely available. Lack of haptic feedback is another major limitation of many VR systems, although this issue is being addressed by emerging technology (e.g. FundamentalVR, London, UK). A VR simulation module has been developed for distal pancreatectomy [42], but there are currently no VR training modules for either pancreatoduodenectomy or pancreatic anastomosis.

4. Future development of training models for pancreatojejunostomy

Should consider the key characteristics of pancreatic tissue that have been identified through recent research. These characteristics include the hardness of the pancreatic tissue, which can be assessed by both palpation by experienced surgeons and more objectively using a durometer. Studies have shown that these two methods correlate well, with durometer offering a more precise measurement that could be beneficial for research and educational purposes [43,47]. To create effective training models for PJ, it is essential to integrate the knowledge of pancreatic tissue properties, such as hardness and fibrosis, into the design of simulation tools and curricula. Holomedicine, leveraging virtual reality and augmented reality technologies, can revolutionize medical education by providing immersive simulations and interactive learning modules for complex procedures like Pancreatojejunal Anastomosis. It offers opportunities for remote collaboration, personalized feedback, and continuing education for both students and practicing surgeons. However, careful consideration of ethical and safety implications is necessary for its integration into medical curricula. Table 3 summarises overview of recommendations for future studies in the field of pancreatic anastomosis training models. Table 4 outlines the role of pancreatic texture and the pancreatic duct,as well as ways to objectively measure these factors to create a training module for pancreatojejunostomy.

5. Conclusions

The ideal pancreatic anastomosis training model should replicate the biomechanical properties of the normal human pancreas. It should also be possible to leak test the completed anastomosis, in order to provide immediate feedback and to differentiate between experienced and novice surgeons. Unfortunately, currently available silicone models fulfil neither of these key objectives. Research is needed to understand the mechanical properties of the human pancreas in an effort to develop a synthetic model that closely mimics its fragility and elasticity. Virtual reality (VR) is an attractive alternative to synthetic models for surgical training, and further work is needed to develop a VR pancreatic anastomosis training module that provides both high fidelity and haptic feedback.

Material

Silicone material, Pancreas: Pink, Pancreatic Duct: White, Small intestine: Red.

Type of anastomosis

Cattell-Warren anastomosis.

Credit

Yu H, Yu T, Wang J, Wei F, Gong H, Dong H, He X, Wang Z, Yang J. Validation of a three-dimensional printed dry lab pancreaticojejunostomy model in surgical assessment: a cross-sectional study. BMJ Open. 2022 Feb 1; 12(2):e052295. https://doi.org/10.1136/bmjopen-2021-052295. PMID: 35105574; PMCID: PMC8808463.

Ethical approval and consent to participate

All methods were carried out in accordance with relevant guidelines, in accordance with the Helsinki Declaration. Due to the nature of this study (review article), ethical approval and consent were not sought.

Consent for publication

The authors hereby give *'Pancreatology'* the full rights to publish this manuscript. Due to the retrospective nature of this study, ethical approval and consent were not sought.

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Declaration of competing interest

"The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article."

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