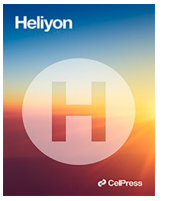
Heliyon 10 (2024) e27500

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Review article

Application of the superior mesenteric artery-first approach in laparoscopic pancreatoduodenectomy: A literature review

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ARTICLE INFO

Keywords:
Artery-first approach
Laparoscopic pancreatoduodenectomy
Minimally invasive
Superior mesenteric artery
Pancreatoduodenectomy

ABSTRACT

Background: Laparoscopic pancreaticoduodenectomy (LPD) is a complicated surgical procedure that has recently been performed safely. A superior mesenteric artery (SMA)-first approach can allow complete mesopancreas resection, maximizing surgical margins and R0 resection rates. Therefore, the SMA-first approach is recommended. This review is a literature summary of recent updates of the SMA approaches for LPD and informs clinical practice of the advantages of its various approach.
Methods: A systematic literature search was performed on the PubMed (MEDLINE) database using truncated word searches and medical subject headings to identify all pertinent published studies.
Results: After searching PubMed, 303 studies were identified and reviewed, of which 25 described the SMA-first approach, including the anterior, posterior, right, and left approaches, fully described in 5, 6, 13, and 6 articles, respectively.
Conclusions: The SMA-first approach is the standard surgical technique for LPD. This review summarized each SMA-first approach's distinct advantages and indications.

1. Introduction

The safety and efficacy of laparoscopic pancreaticoduodenectomy (LPD) are comparable to those of open surgery, with the advantages of faster recovery and minimal scarring [1]. LPD has gradually become a common strategy in clinical practice due to innovations in laparoscopic technology and advancements in surgical approaches. The conventional approach of LPD follows the superior mesenteric vein (SMV)-portal vein (PV) axis that could still result in achieving R0 resection under certain conditions such as early-stage lesions or good anatomy locations, despite difficulties and risks. Tumor invasion of these veins has previously been considered to render them unresectable [2]. However, the development of venous resection, novel reconstruction technologies, and the superior mesenteric artery (SMA)-first approach, which has become increasingly more popular addressed this issue, providing that negative resection margins can be easily obtained [3]. Therefore, the focus has shifted to SMA and whether the involvement of the SMA determines the resectability [4]. Moreover, careful preoperative examination cannot be ignored; studies on using multidetector

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https://doi.org/10.1016/j.heliyon.2024.e27500
Received 13 April 2023; Received in revised form 29 February 2024; Accepted 29 February 2024
Available online 11 March 2024

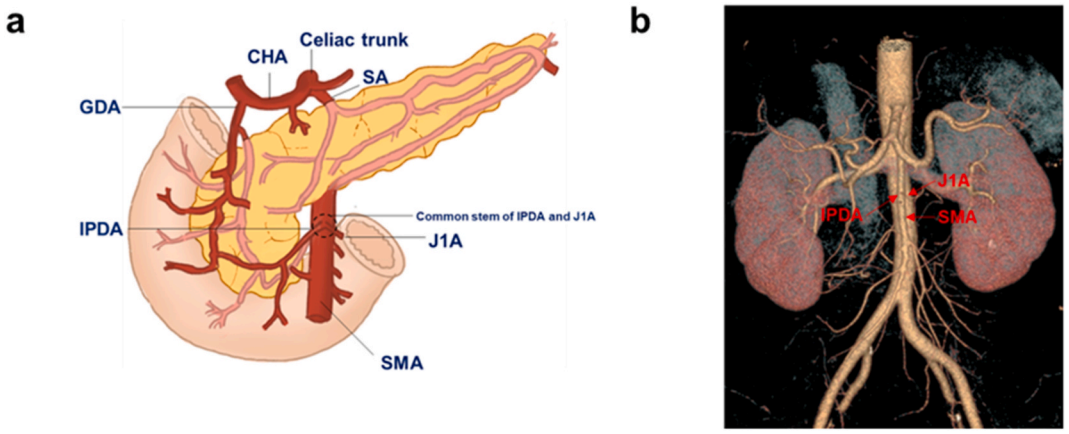

Fig. 1. a, The anatomy of the SMA; b, Three-dimensional reconstruction of the SMA. SMA, superior mesenteric artery; CHA, common hepatic artery; GDA, gastroduodenal artery; IPDA, inferior pancreaticoduodenal artery; J1A, first jejunal artery; SA, spleen artery.

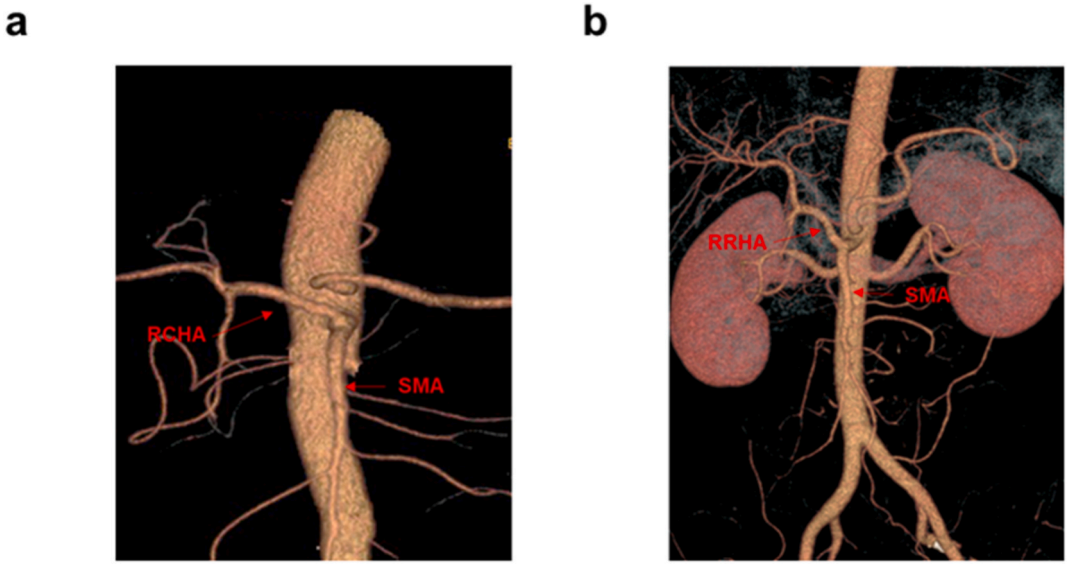

Fig. 2. a, Three-dimensional reconstruction of the RCHA from the SMA; b, three-dimensional reconstruction of the RRHA, replaced right hepatic artery of the SMA. RCHA, replaced common hepatic artery; SMA, superior mesenteric artery; RRHA, replaced right hepatic artery.

computed tomography for determining resectability have reported a positive predictive value to be as high as 89% [5]. As a result, the resectability via LPD has been significantly improved.

The basic critical aspect of successful SMA-first approach implementation is proficiency regarding anatomical knowledge of the SMA (Fig. 1a and b). In brief, the SMA arises from the anterior wall of the abdominal aorta with the location at the level of the first lumbar spine. Its branches mainly include the inferior pancreaticoduodenal arteries (IPDAs), jejunoileal arteries (JAs), middle colic arteries, right colic artery, and ileocolic arteries [6]. Studies have revealed that the IPDA that should be cut off during the LPD procedure has a common trunk originating from the SMA with the first jejunal artery (J1A) in over 70% of cases [7]. Moreover, other aberrant vascular variants arising from the SMA such as replaced common hepatic artery (RCHA) and replaced right hepatic artery (RRHA) are relatively common and can be extremely easily damaged if surgeons were not aware of their presence (Fig. 2a and b). Hence, the anatomy of the SMA continues to present great technical challenges, especially in LPD, due to its deep location, lack of identifiability, and numerous fragile branches [8]. Furthermore, the retropancreatic tissue surrounding the SMA, the "mesopancreas," [9] is attached to the SMA and must be resected intact to promote R0 resection.

Nevertheless, studies summarizing each SMA-first approach's advantages and indications in LPD remain rare [8]. This review is a summary of recent updates of the literature describing the SMA approach for LPD to inform clinicians about the advantages of each approach so that the most appropriate method can be applied flexibly in clinical practice.

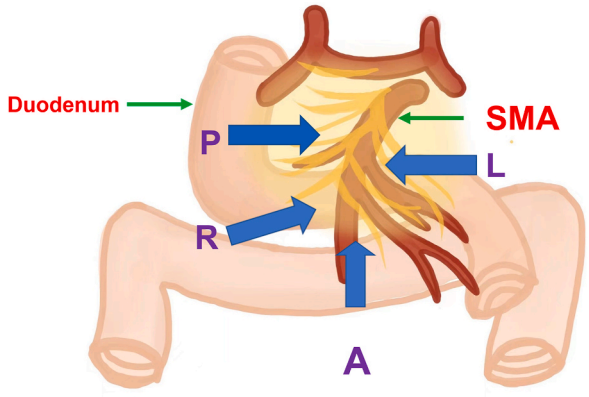

Fig. 3. Surgical approaches to the superior mesenteric artery. A, anterior approach; L, left approach; P, posterior approach; R, right medial uncinate approach.

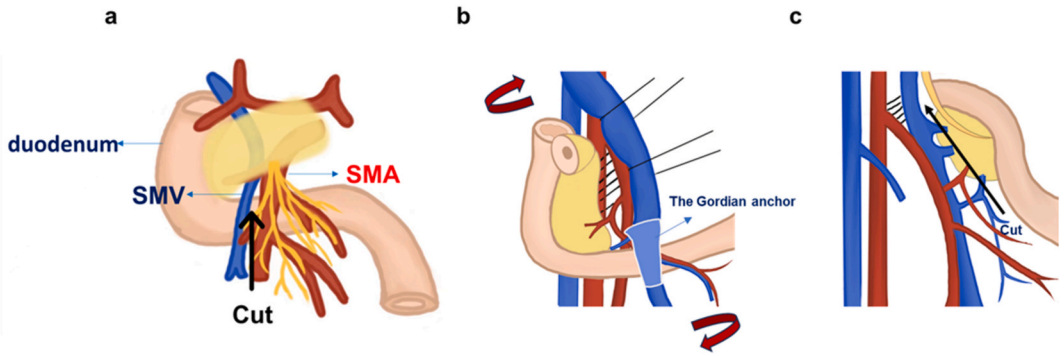

Fig. 4. a, Anterior approach; b, c, Semi-derotation technique. SMA, superior mesenteric artery; SMV, superior mesenteric vein.

2. Results

2.1. Eligible studies

After searching the PubMed database, 303 studies were identified and reviewed, of which 25 described the SMA-first approach for LPD, including 1 review, 8 comparative studies, 8 case series, and 8 case reports.

2.2. SMA-first approaches

As the previous studies reported, there are six approaches to the SMA during PD: superior, anterior, posterior, left posterior, right/medial uncinate, and mesenteric [4]. In LPD, four of these approaches are commonly used: anterior (4 articles), posterior (6 articles), right (13 articles), and left (6 articles) (Fig. 3) [10–12].

2.3. Anterior approach

Five studies discussed the surgical strategy to dissect the SMA from the anterior side (Fig. 4a–c). In their study comparing several arterial approaches, Morales et al. [9] stated that they believed that the anterior approach was advantageous for cases of tumor invasion of the venous axis and the mesopancreas could be completely mobilized from the SMA before venous resection and reconstruction to achieve a higher R0 resection rate. During the anterior approach, the first step is to locate the superior mesenteric vessels at the root of the mesentery at the lower edge of the pancreatic neck. The superior mesenteric, portal, and splenic veins (and eventually their branches) are encircled by elastic tape. The SMA's left anterior margin can be recognized behind and to the left of the venous axis, which can be easily dissected longitudinally and upward toward the origin of the SMA. The IPDA can be recognized after circular dissection of the SMA. Finally, the specimen is attached only by the venous axis, which allows easier tumor detachment after vein resection and reconstruction of the veins [9]. Further, Cai et al. [13] described a major venous resection for patients who successfully underwent LPD using the anterior approach. Kiguchi et al. [14] introduced a brand new semi-derotation technique for the arterial approach and provided a new concept, the 'Gordian anchor', in which the dorsal region of the SMA and SMV contacts the uncinate

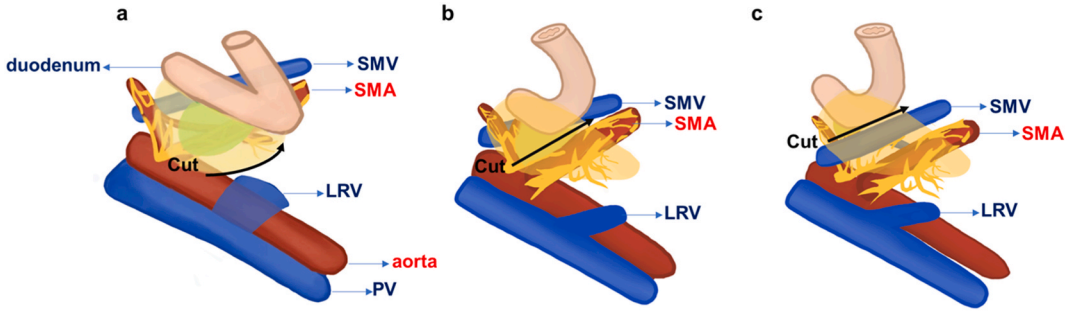

Fig. 5. a, Posterior approach; b, The mesopancreas is dissected in the posterior side; c, Exposure of the SMV/PV in the post side; LRV, left renal vein; SMA, superior mesenteric artery; SMV, superior mesenteric vein; PV, portal vein.

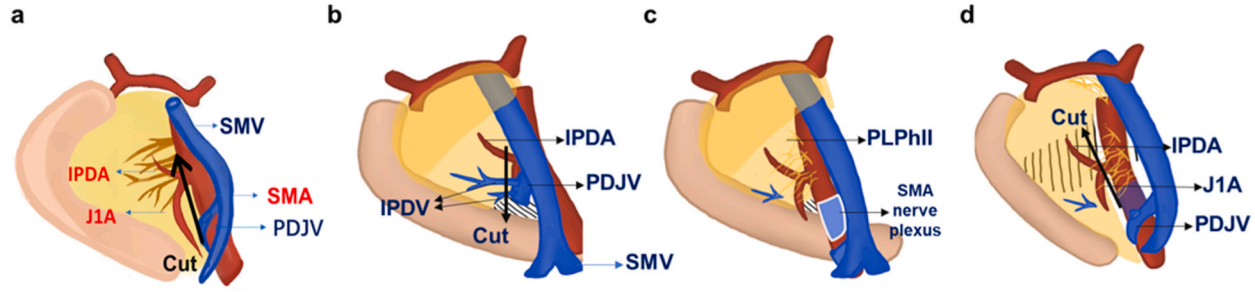

Fig. 6. a, Right medial uncinate approach; b, The IPDA and IPDV are identified; c, The nerve plexus of SMA is exposedand the pancreas mensentry and J1A are identified and the vasotomy of IPDA and mesentery dissection are performed. IPDA, inferior pancreaticoduodenal artery; IPDV, inferior pancreaticoduodenal vein; SMA, superior mesenteric artery; J1A, first jejunal artery; SMV, superior mesenteric vein.

process. In this approach, after the Kocher maneuver (a surgical maneuver to expose retroperitoneal structures behind the duodenum and pancreas) was performed, the 'Gordian anchor' is divided and cut, allowing for the easy release of the mesenteric rotational fixation. The proximal jejunum is then pulled to the SMA's right side, the severed jejunum is pulled ventrally along with the duodenum, and all superior mesenteric vessels' branches are limited to the sagittal direction. They suggested that this technique was safe and facilitated implementing an artery-first approach. Navarro et al. [15] revealed that the usage of collaborative strategies such as indocyanine green visualization may considerably help overcome the learning curve of this complex procedure.

2.4. Posterior approach

Six articles examined the posterior approach to LPD (Fig. 5a–c) [8,16–20]. During this procedure, after raising the transverse colon, the horizontal part of the duodenum is distinct at the root of the mesocolon, and the connective tissue behind the transverse mesocolon and the descending duodenum is cut to completely reveal the left renal vein and inferior vena cava; the SMA is located at the angle between the two veins. Honda et al. [18] demonstrated that the posterior approach for LPD outcomes were comparable to those of open PD, showing it to be safer with a shorter operating time. Wang et al. [16] reported a comparative study with the posterior approach (16 cases) versus the anterior approach (20 cases). Their results showed that the posterior approach could significantly reduce the operative time. In addition, the IPDA could be ligated in the early stage, which was beneficial in reducing bleeding, despite showing no statistical difference. Moreover, RRHA and RCHA, both from the SMA, were the most typical vascular abnormalities in patients, occurring in 8.6–21% and 0.4–4.5% of cases, respectively [21,22], which could be extremely easily damaged during the LPD if the surgeons could not identify them. Ogiso et al. [17] reported that the posterior approach can help reduce the risk of incidental RRHA or RCHA injuries in LPD.

2.5. The right medial uncinate approach

Due to the characteristic of the uncinate process in the right medial of the SMA, we called the approach as "the right medial uncinate approach". Thirteen articles examined the right medial uncinate SMA-first approach in LPD (Fig. 6a–d) [8,9,23–33], making it the most frequently reported approach in the literature, of which four studies described this as the uncinate-first approach. Pędziwiatr et al. [24] reported that the uncinate-first approach was viable for treating pancreatic head neoplasms, the quality of the specimens was comparable to that of the traditional laparoscopic approach and the intra- and postoperative courses were superior. During this procedure, the IPDA's branches are disconnected along the uncinate process; however, the IPDA roots are not thoroughly exposed. Therefore, completely removing the mesopancreas, no. 14 lymph node, and pancreatic head plexus II is difficult [25]. Hence,

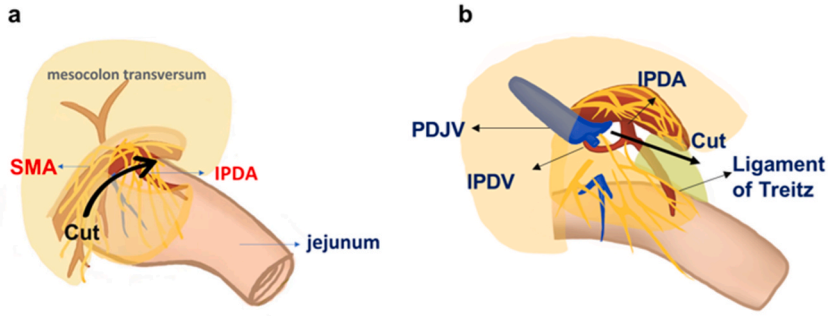

Fig. 7. Left approach. a, Exposure of the left side of the SMA; b, The vasotomy of the IPDA and J1A is performed. IPDA, inferior pancreaticoduodenal artery; J1A, first jejunal artery; SMA, superior mesenteric artery; SMV, superior mesenteric vein.

this method is more suitable for benign or borderline malignant tumors in an uncinate process.

Another right medial uncinate approach involving the preisolation of the proximal-dorsal jejunal vein (PDJV), as described by Nagakawa et al. [26], could prevent damage to the PDJV during IPDA dissection. During the procedure, the PDJV is isolated at the beginning, and the inferior pancreaticoduodenal veins (IPDVs) are divided along the PDJV on the SMA's right side. The IPDA is then divided at the root without first separating the pancreatic head from the PV and the SMV. They suggested that this technique could facilitate the right SMA approach by reducing the operative time. Asbun et al. [29] introduced their own center experiences in using the right SMA approach in LPD, including every step and tip. Mendoza et al. [31] used this approach for LPD as a minimally invasive surgical technique for periampullary tumors and confirmed its safety and feasibility.

2.6. Left approach

Six articles examined the left SMA-first approach in LPD (Fig. 7a,b) [8,9,34–37]. Shen et al. [35] demonstrated the reformation and improvement of a modified no-touch isolation technique emphasizing exploration of the distal section of the SMV and the SMA's left side prior to determining resectability. This reduces the likelihood of tumor cell metastasis by ensuring that all procedures adhere to oncologic no-touch rules. Khiem et al. [36] revealed a successful LPD via the left posterior approach involving SMA plexus preservation, while Cho et al. [34] reported on this approach in detail. Liao et al. [37] described a detailed surgical strategy to determine resectability by first preferentially exposing the SMA's left side, which also ensures the surgical effect and shortens the operative time, particularly for the resected segment.

3. Discussion

Gagner and Pomp [38] reported the first LPD in 1994, marking the beginning of an era of minimally invasive pancreaticoduodenectomy. With technological progress, laparoscopy has revolutionized many surgical procedures and is now commonly used in almost all abdominal operations [39,40]. LPD is a highly complex surgical procedure, typically performed by skilled surgeons in high-volume medical centers. In the early stages following its introduction, LPD was performed using the anterior approach, focusing on the mobilization of the region surrounding SMV and PV, whereas SMA isolation was considered the last step of the operation. This method has been successfully implemented for many years but the R0 resection could not be completely guaranteed under some conditions, such as presence of tumor invasions of the SMV/PV. Therefore, for a higher resection rate, the SMA-first approach, first reported by Pessaux et al. [41], became increasingly more popular. Although several studies have examined this approach in PD, the viewing field of LPD differs from that of open surgery, and the optimal strategy has not yet been fully clarified. This review summarizes the recent updates of various SMA approaches.

3.1. Advantages of the SMA-first approach

Early exploration of the SMA and celiac trunk can be performed to assess resectability [4,42]. In addition, invasion of the SMV can be evaluated. In cases where the region from the SMV to the PV is invaded, resection and reconstruction can be easily performed.

Hiatt et al. [43] examined the extrahepatic arterial anatomy of 1000 donor livers and found that 12.9% had aberrant right hepatic arteries. The main origins of aberrant right hepatic arteries were the SMA, celiac artery, and aorta, with frequencies of 74.1–80.7%, 18.0–19.2%, and 7.9%, respectively [44,45]. In the SMA first approach, the SMA is first isolated to facilitate the identification of any aberrant hepatic arteries, avoiding unnecessary iatrogenic hepatic artery injury, preserving liver blood supply, and reducing the occurrence of postoperative complications.

The SMA-first approach can allow for easier and complete removal of the connective tissue and lymph nodes on the SMA's right side, thereby improving the R0 resection rate [46].

Moreover, this technique maximizes compliance with the no-touch oncologic principles [35], reducing the risk of tumor cell metastasis.

The removal of the uncinate process is the procedure most prone to intraoperative bleeding and is also a technical challenge. The SMA-first approach can reduce intraoperative bleeding [47], maintain a clear surgical field, shorten the operative time, and improve the prognosis [48] because IPDA is prematurely cut.

3.2. Indications for the SMA-first approach

The indications, advantages, and disadvantages of each SMA-first approach are summarized in Table 2.

3.3. Indications for the anterior approach

The anterior approach's main advantage is that it enables early assessment of celiac trunk invasion or compression. Exposing the SMA root and dividing its branches in advance is beneficial for reducing intraoperative bleeding [9,13,47] and achieving high R0 resection rates [9]. However, the anterior approach has limited use for patients with extensive inflammatory adhesions in the pancreatic head, low SMA positions, or obesity. Moreover, surgeons would dissect the pancreas neck even the stomach in the early stage of surgery.

3.4. Indications for the posterior approach

The posterior approach takes an advantage of the dorsal view of laparoscopy, which can be fully used to operate on the posterior portion of the pancreas. Initially, the SMA root can be easily exposed from behind to evaluate its resectability, and the resection time can be significantly shorter than that of the anterior approach [16]. This approach is more suitable for tumors on the ventral side of the pancreatic head.

3.5. Indications for the right medial uncinate approach

The right medial uncinate approach has obvious advantages and is the most frequently cited approach, with 13 articles published. This method can identify early-stage SMA invasion, detect aberrant hepatic arteries to avoid injuries, and avert irreversible actions during the examination of patients with unresectable tumors [49]. In addition, the right medial uncinate approach can preserve the nerve plexus, avoiding severe postoperative diarrhea compared to the left approach. Nagakawa et al. [26] reported that preisolation of the PDJV in the right SMA-first approach helps to avoid PDJV damage during IPDA dissection. Metastasis of the para-aortic lymph nodes is considered distal metastasis, and long-term survival cannot be achieved, even with lymph node dissection [50,51]. An early lymph node biopsy in the region can be used to evaluate the optimal surgical strategy. As the uncinate process is located on the right side of the SMA, the uncinate-first approach is also considered a type of the right medial uncinate approach. Pędziwiatr et al. [24] reported that the uncinate-first approach is an effective technique for treating pancreatic head tumors. The quality of the resulting specimens was comparable to that of the conventional laparoscopic approach, whereas the intra- and postoperative courses were superior. This approach is more suitable for tumors growing from the head to the dorsal side of the pancreas, located at the lower edge of the head of the pancreas, uncinate process, posterior, or root of the SMA.

3.6. Indications for the left approach

The primary benefit of the left approach is that the SMA's root can be revealed early on to assess resectability [37]. Shen et al. [35] shown an innovation of the modified left approach to ensure that all steps conform to the oncologic no-touch principles, decreasing the risk of tumor cell metastasis. Furthermore, this method can interrupt IPDA earlier to better control the blood supply to the pancreatic head and shorten operative time. Therefore, this approach is more suitable for tumors of the uncinate process, although unsuitable for cases with severe pancreatic inflammation or adhesions or severe tumor compression.

When considering the most feasible surgical strategy, optimal dissection of the tissue around the SMA is key. In approximately 70% of cases, the IPDA and first jejunal artery (J1A) were present as co-trunks [7]. The root of the IPDA/J1A is a vital milestone for guaranteeing the safety and curability of PD [47]. The pre-isolation PDJV, a right SMA approach, was described by Nagakawa et al. [26] and can be used to avoid PDJV damage during IPDA dissection. During the procedure, the PDJV is first isolated, and the IPDVs are divided along the PDJV on the SMA's right side. Thus, the identification of these anatomical landmarks may be an appropriate surgical approach.

In summary, the SMA-first approach has been applied to an increasing number of cases, achieving a higher resectability and R0 resection. In this literature review, four LPD approaches were examined: anterior (5 articles), posterior (6 articles), right (13 articles), and left (6 articles). Each approach has its advantages and disadvantages for different patients. Of note, the successful implementation of the SMA approach could require various factors. Specifically in individual clinical cases, preoperative evaluation of the resectability and intraoperative approach selection should be performed carefully based on imageology examination, particularly the three-dimensional reconstruction techniques. In some complex cases, the combined application of multiple approaches is also recommended, such as a malignant tumor exhibiting serious invasion, the surgeons cannot smoothly perform a single SMA approach in a standard way. Regarding this condition, the surgeons can apply the left approach at the beginning to cut the IPDA's root and then dissect the pancreas neck to isolate the common hepatic artery and cut the gastroduodenal artery using the anterior approach. Thereafter, the blood supply to the pancreatic head is well controlled. Consequently, tumors can be removed using the right medial

Table 1
Summary of articles describing the approach used for laparoscopic pancreaticoduodenectomy.

Study	Year	Surgical approach	SMA Exposure	Article type
Kiguchi et al. [14]	2020	Anterior	Yes	Case report
Cai et al. [13]	2018	Anterior	Yes	Case series
Navarro et al. [15]	2019	Anterior	No	Case series
Nagakawa et al. [8]	2021	Anterior, Posterior,Right, Left	Yes	Review
Morales et al. [9]	2019	Anterior, Right, Left	Yes	Case series
Cho et al. [34]	2014	Left	Yes	Case report
Shen et al. [35]	2022	Left	Yes	Case report
Khiem et al. [36]	2022	Left	Yes	Case report
Liao et al. [37]	2017	Left	Yes	Case series
Jiang et al. [20]	2019	Posterior	Yes	Comparative study
Wang et al. [16]	2016	Posterior	Yes	Comparative study
Ogiso et al. [17]	2013	Posterior	Yes	Case series
Pittau et al. [19]	2015	Posterior	Yes	Case report
Honda et al. [18]	2013	Posterior	Yes	Case report
Zimmitti et al. [23]	2016	Right	Yes	Case report
Nagakawa et al. [26]	2018	Right	Yes	Comparative study
Kendrick et al. [27]	2010	Right	Yes	Case series
Palanivelu et al. [28]	2009	Right	Yes	Case series
Asbun et al. [29]	2016	Right	Yes	Case report
Lai et al. [30]	2012	Right	Yes	Comparative study
Mendoza et al. [31]	2015	Right	Yes	Comparative study
Pędziwiatr et al. [24]	2017	Right (uncinate-first)	Yes	Comparative study
Nagakawa et al. [25]	2015	Right (uncinate-first)	No	Comparative study
Zhang et al. [32]	2017	Right (uncinate-first)	No	Case series
Chen et al. [33]	2018	Right (uncinate-first)	No	Comparative study

SMA, superior mesenteric artery.

Table 2
Characteristics of the SMA first approaches.

Approach	Indications (Tumor locations)	Advantages	Disadvantages
Anterior	The superior border of the pancreas	Early assessment of the celiac trunk, CHC, and SMA invasion	Difficult exposure of the low SMA and early dissection of the pancreas
Posterior	The ventral side of the pancreatic head.	Early assessment of the PV-SMV, SMA invasion; identification of the aberrant Hepatic Artery	Difficulty in patients with extensive inflammatory adhesions peripancreatic head
Right medial	The lower edge of the pancreas head, uncinate process, or root of the SMA.	Early assessment of the SMA invasion; avoiding PDJV damage	Difficulty in identification of the IPDA's root
Left	Tumors along the uncinate and ventral pancreas	Early exposure of the IPDA/J1A's root, conforming to no-touch principle	Inadequate working space

uncinate and posterior approaches. Therefore, resection and reconstruction of the SMV/PV would be easily performed, if necessary. Extensive pancreatic inflammation, severe arterial invasion, and obesity are the most common contraindications to the SMA-first approach.

This study has some limitations. First, the optimal approach for selecting an individualized surgical approach or adjusting a surgical strategy promptly according to intraoperative findings remains unclear, as the analysis was primarily based on single-center retrospective studies, case reports, and case series. Additionally, there were no long-term follow-up statistics due to the relatively recent introduction of these approaches. Hence, multicenter, large-scale, randomized clinical studies should be performed.

4. Conclusions

In summary, we performed a recent update review to summarize the literature describing the SMA-first approach for LPD. LPD is a surgical technique with great technical difficulty and high risk. Herein, we summarized the advantages and indications of each SMA-first approach. To achieve optimal R0 resection rates, surgeons should be flexible in their choice, which should be based on the suitability of the approach rather than a personal preference. Nevertheless, studies focused on determining the optimal scheme among various arterial approaches are rare. Therefore, further comparative and multicenter randomized studies are required.

5. Methods

5.1. Study design

The MEDLINE, Embase, and PubMed databases were searched electronically for the following terms: "pancreatic cancer",

"laparoscopic pancreatoduodenectomy," "superior mesenteric artery", "'artery first approach," and "minimally invasive pancreatectomy", using truncated word searches and medical subject headings (MeSH) to identify all pertinent published studies. All included studies' references were examined in search of eligible studies, with the final search conducted on August 31, 2022. All databases were searched using both MeSH terms and the "Title/Abstract" field to identify relevant studies (Table 1).

5.2. Eligibility criteria

The following were the inclusion criteria for this systematic review: (1) articles written in English; (2) articles describing the characteristics or differences of vascular anatomy in LPD; and (3) articles discussing the approach or landmarks of LPD. Furthermore, reviews of randomized controlled trials, comparison studies case studies, and expert opinions that met inclusion requirements were included [8]. Animal studies, editorials, letters to the editor, reports overlapping or duplicate reports, and studies written in a language other than English were excluded [52].

Funding

There was no specific funding from public, commercial, or non-profit sector funding agencies for this study.

Data availability statement

Data availability is inapplicable, due to the nature of the review.

CRediT authorship contribution statement

Jianji Ke: Writing – review & editing, Writing – original draft. **Feiqi Liu:** Methodology. **Jianjia Ke:** Writing – review & editing. **Hongqiao Cai:** Conceptualization. **Yahui Liu:** Methodology. **Bai Ji:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank Editage for English language editing.

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