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Narrative review

Perioperative peripheral parenteral nutrition to support major gastrointestinal surgery: Expert opinion on treating the right patients at the right time

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SUMMARY

Background & aims: Patients undergoing major gastrointestinal surgery may be in particular need of nutritional therapy due to potential pre-existing disease-related malnutrition and the impact of surgical procedures. Peripheral parenteral nutrition (PPN), delivered via a peripheral catheter, is aligned with the Enhanced Recovery After Surgery (ERAS) concept of minimally invasive interventions where possible. However, uncertainties regarding perioperative PPN for patients undergoing major gastrointestinal surgery arise, in part, due to lack of clinical guidelines. This paper aims to provide practical guidance on perioperative PPN, within the framework of ERAS.

Methods: A panel of surgeons and nurses convened to identify knowledge gaps and share their best practice experience regarding PPN provision for patients undergoing major gastrointestinal surgery. Clinical needs were identified and addressed based on the panel's experience and a narrative review.

Results: Key topics addressed include how PPN can support ERAS nutritional recommendations, identifying gastrointestinal surgery patient subgroups who are likely to benefit from PPN, perioperative timepoints when PPN may be required, and optimizing the delivery of PPN. An algorithm to support the identification and management of patients' perioperative nutritional needs was developed.

Conclusions: This paper aims to assist healthcare providers by addressing best practice questions related to the use of PPN during the critical perioperative period within the ERAS concept. This may facilitate timely nutritional intervention to help improve postoperative clinical outcomes and quality of life for patients undergoing major gastrointestinal surgery.

1. Introduction and aim

As recommended in the European Society of Clinical Nutrition and Metabolism (ESPEN) guidelines, perioperative nutritional therapy is indicated to address malnutrition and catabolic consequences of surgery, thereby helping to improve or maintain nutritional status and avoid postoperative complications [dataset [1]]. However, identification of surgical

Abbreviations: BMI, body mass index; CVC, central venous catheter; EORTC, European Organisation for Research and Treatment of Cancer; ERAS, Enhanced Recovery After Surgery; ESPEN, European Society of Clinical Nutrition and Metabolism; HCP, healthcare provider; i.v., intravenous; PPN, peripheral parenteral nutrition; PVC, peripheral venous catheter; TPN, total parenteral nutrition.

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patients who will benefit from nutritional intervention is often suboptimal [dataset [2,3]].

Perioperative parenteral nutrition, i.e., delivery of balanced quantities of amino acids, glucose, lipids, and micronutrients intravenously (i.v), may be required when a patient's nutritional needs cannot be met by oral or enteral routes [dataset [4]]. However, the topic of parenteral nutrition can present uncertainties as physicians often lack expertise in this field [dataset [5–7]]. Total parenteral nutrition (TPN) is administered via a central line to patients requiring complete nutritional therapy when oral or enteral support is not feasible or is contraindicated. Peripheral parenteral nutrition (PPN) is administered via a peripheral venous catheter (PVC) as a low osmolarity solution (usually ≤850–900 mOsm/L) [dataset [8,9]]. Patients may receive PPN for up to 14 days, either as a bridge to oral or enteral nutrition in order to close nutritional gaps or to provide immediate nutritional support when a central venous catheter is not available [dataset [1,9–11]].

Enhanced Recovery After Surgery (ERAS) pathways are increasingly adopted to optimize the care of patients undergoing major surgery. These pathways are available across a range of surgical settings including gastrointestinal procedures such as colonic surgery, gastrectomy, oesophagectomy, pancreaticoduodenectomy, bariatric surgery and liver surgery [dataset [12–17]]. ERAS recommendations reflect a broad continuum of care including, but not limited to, preoperative counselling and prehabilitation of patients, anaesthetic protocols, surgical procedures, analgesia, wound care, antimicrobial and antithrombotic prophylaxis and patient mobilization [dataset [12–17]]. While minimizing adverse metabolic and catabolic consequences of surgery is a key focus of ERAS recommendations, guidance on parenteral nutrition use to address this aim is limited, and specific guidance on PPN in the perioperative setting is lacking (Table 1).

This paper aims to provide concise, practical guidance on PPN during the critical perioperative period within the framework of ERAS. The group shared their best practices regarding the use of PPN before and after surgery, including how PPN can support ERAS nutritional recommendations, identifying surgical patients who may benefit from PPN, and approaches to optimize PPN delivery. This guidance is focused on patients undergoing major gastrointestinal surgery, since malnutrition associated with the underlying disease such as gastrointestinal cancer along with the short-term impact of surgery on patients' ability to eat and gastrointestinal function may necessitate perioperative nutritional support.

2. Methods

A multidisciplinary panel comprising tandems of surgeon and nurse specialists from four hospitals (located in Germany [2 sites], Italy and Spain) convened to discuss best practices regarding the provision of PPN at their institutions, focusing on patients undergoing major gastrointestinal surgery. Together, the panel had extensive clinical experience in clinical nutrition, gastrointestinal surgery and nursing, and included (but not limited to) steering committee members of the German Society for Nutritional Medicine (DGEM) and authors of the DGEM clinical nutrition in surgery guidelines [dataset [18]], director of the foregut research centre and institutional multidisciplinary surgical oncology board, institution department head of general and gastrointestinal surgery, and head of scientific activities and secretary of the Italian Association of Cancer Nurses.

Clinical questions about perioperative PPN are addressed in this narrative review based on European clinical guidelines, clinical experience of the panel members, and published clinical studies which were identified by a non-systematic search of MEDLINE for relevant English-language publications (clinical studies of PPN in gastrointestinal surgery patients). Key topics include how PPN can support ERAS nutritional recommendations, identifying subgroups of gastrointestinal surgery patients who are likely to benefit from PPN, perioperative timepoints when PPN may be required, and approaches to optimize the delivery of PPN. Opportunities and challenges which may be encountered with PPN were also discussed.

ERAS guidelines for major gastrointestinal surgical procedures were identified from the ERAS Society website (http://erassociety.org/guidelines/list-of-guidelines/). Each guideline was reviewed for relevant recommendations regarding PN, which are summarized in Table 1.

3. The surgically induced stress response

Major surgery represents a significant trauma to patients, eliciting the release of stress hormones and inflammatory mediators which result in the catabolism of glycogen, protein and lipid to facilitate healing [dataset [1,19,20]]. As has been widely reviewed, the metabolic changes associated with this surgical stress response can be detrimental, leading to the development of acute insulin resistance [dataset [19–22]]. In brief, hyperglycaemia arises from increased hepatic glucose production and decreased peripheral uptake, while breakdown of muscle protein is mediated by the reduced effect of intracellular insulin. These metabolic alterations can negatively impact patient recovery. For example, hyperglycaemia is associated with postoperative complications while loss of muscle mass and strength delay functional recovery [dataset [1,23,24]]. Reducing metabolic stress and insulin resistance facilitates anabolic processing of energy and protein intake, thereby preventing hyperglycaemia and loss of lean body mass, and

Table 1
Limited recommendations on parenteral nutrition and lack of specific guidance on peripheral parenteral nutrition in current ERAS society guidelines for patients undergoing major gastrointestinal surgical procedures.

ERAS recommendations	
Colonic surgery [17]	• "*For malnourished patients, oral nutritional supplementation (or additional PN when indicated) has the best effect if started 7–10 days preoperatively*"
Pancreaticoduodenectomy [15]	• "*EN or PN will often be necessary if major complications develop*" • "*PN should not be used routinely*" • "*PN is indicated only in patients who cannot eat and drink normally, or tolerate EN*" • "*PN should be reduced as tolerance of EN increases*"
Gastrectomy [14]	• "*PN is indicated only when the gut is not working or is inaccessible*"
Liver surgery [13]	• "*Postoperative EN or PN should be reserved for malnourished patients or those with prolonged fasting due to complications e.g., ileus >5 days, delayed gastric emptying*"
Oesophagectomy [12]	• "*Feeding after oesophagectomy may be either enteral or parenteral, with much data favouring an enteral route*"
Bariatric surgery [16]	• No guidance on PN

EN, enteral nutrition; ERAS, Enhanced Recovery After surgery; PN parenteral nutrition.

supporting patient mobilization [dataset [24]]. Surgical trauma also induces an immuno-inflammatory response involving interactions between pro-inflammatory cytokines (e.g., tumour necrosis factor-alpha [TNF-α], interleukin-1 [IL-1], IL-6, IL-8, and IL-10), hormones (e.g., catecholamines, adrenocorticotropic hormone, cortisol, and glucagon), chemokines and other cellular mediators [dataset [25]]. Increased production of proinflammatory cytokines is regularly observed following major surgery and can induce systemic inflammatory responses and/or immunosuppression, resulting in hemodynamic instability, metabolic derangements and muscle wasting [dataset [26]].

Within the ERAS multimodal strategies to reduce morbidity and enhance the recovery of patients undergoing major gastrointestinal surgery, several recommendations are directed to modulate perioperative insulin sensitivity and the associated metabolic and catabolic consequences of the surgical stress response. For example, carbohydrate loading is recommended prior to gastrectomy, pancreaticoduodenectomy, oesophagectomy and liver surgery as this has been shown to increase insulin sensitivity and reduce insulin resistance in the postoperative period [dataset [12–15,27,28]]. ERAS pathways also recommend that gastrointestinal surgical patients should be maintained in fluid balance over the perioperative period, as both fluid deficit and overload can increase postoperative complications and prolong hospital stay [dataset [17,29]]. While some ERAS recommendations directly facilitate maintenance of fluid and electrolyte balance, this can also be achieved indirectly by modulating the surgical stress response since catabolic hormones and inflammatory mediators facilitate salt and water retention [dataset [27]].

Preoperative and postoperative nutritional support which can be delivered via oral, enteral and/or parenteral routes – if indicated - can help to maintain and/or optimize nutritional status in preparation for the demands of surgery [dataset [30]]. Consequently, nutrition therapy is an important component of patient management to reduce the catabolic impact of the surgical stress response, reduce complications associated with a poor nutritional status and promote postoperative recovery [dataset [1,31]].

4. How can PPN support ERAS nutritional recommendations aimed at reducing the metabolic/catabolic stress response associated with surgery?

Given that patients require adequate preoperative physiological reserves in order to meet the demands of the surgical stress response, it is unsurprising that ESPEN guidelines on clinical nutrition in surgery and cancer recommend that all patients are screened for nutritional risk before and after major surgical procedures [dataset [1,32,33]]. The importance of preoperative nutrition screening and correction of undernutrition prior to surgery is also emphasized in many ERAS pathways including those for pancreaticoduodenectomy, oesophagectomy, liver surgery and colonic surgery [dataset [12,13,15,17,27]]. The benefits of implementing perioperative nutritional care in accordance with ERAS was demonstrated in a recent study by Martin et al. in patients undergoing colorectal surgery [dataset [34]]. Introduction of ERAS nutritional care recommendations, which included nutritional risk screening and nutritional interventions significantly reduced the length of hospital stay and improved targets for mobilization and activities of daily living [dataset [34]]. However, poor compliance with ERAS nutritional recommendations was associated with a higher proportion of patients at nutritional risk, and these individuals had slower recovery, longer hospital stay, and increased risk of post-operative complications and 30-day mortality [dataset [34]].

While oral and enteral intake is preferred, PPN can facilitate the timely delivery of perioperative nutritional support if the patient's nutritional needs cannot be met by these routes. Indeed, preoperative i.v. infusion of glucose and amino acids was shown to decrease protein catabolism induced by colorectal surgery as well as decrease muscle proteolytic gene expression and increase hepatic albumin synthesis [dataset [35]]. However, clear guidance on PPN is currently lacking in ERAS guidelines on the care of patients undergoing major gastrointestinal surgery, with the limited recommendations on parenteral nutrition not specifying peripheral or central delivery (Table 1)[dataset [12–17]] Nevertheless, the multidisciplinary expert panel agreed that PPN can enable adherence to ERAS pathways in several ways. Importantly, ERAS guidelines advocate minimally invasive procedures, for example supporting laparoscopic surgery where possible and minimizing use of abdominal/chest drainage [dataset [12–17]]. Therefore, PPN, which does not require a central line, is aligned with the ERAS strategy of minimizing invasive procedures and can benefit selected patients who are in a catabolic state or at nutritional/metabolic risk. Consequently, patients who experience postoperative complications and who cannot be nourished adequately via oral or enteral routes could benefit from additional nutrition via PPN to bridge the nutritional gap. Furthermore, PPN also contributes to fluid replacement in patients who require nutritional support.

5. Who should be considered for PPN?

Several factors influence each patient's metabolic/catabolic risk during the perioperative period. Some patients can be at particularly high risk due to their underlying disease. For example, patients with pancreatic cancer frequently experience altered glucose homeostasis, as well as abdominal pain and vomiting which impact oral intake [dataset [36,37]]. Tumour-related bowel obstruction, malabsorption due to gastrointestinal inflammation, and side effects of radiotherapy such as nausea and intestinal damage can also impact physiological reserves [dataset [30]]. Some surgical procedures can also impair a patient's ability to receive oral nutrition during the early postoperative period, thereby contributing to metabolic risk. For example, patients undergoing oesophageal resection, gastrectomy or pancreaticoduodenectomy and can experience swelling, impaired gastric emptying or paralytic ileus, the latter being associated with an increased risk of aspiration pneumonia [dataset [4,38]]. The risk of metabolic/catabolic complications of surgery may also be heightened in frail patients. Sarcopenia, characterized by loss of muscle mass and muscle strength, was found to be predictive of severe postoperative complications (Clavien-Dindo Grade III or above) in gastric cancer patients undergoing radical gastrectomy[dataset [39–41]]. Sarcopenia is also associated with shorter recurrence-free survival and overall survival in patients undergoing gastrointestinal cancer surgery as well as higher healthcare costs in this setting[dataset [39,42–45]]. Furthermore, elderly patients may have age-comorbidities and/or age-related physiological changes that reduce their capacity to withstand the stress of surgery [dataset [27,30]].

For patients requiring major gastrointestinal surgery who are unable to receive sufficient nutrition orally and/or enterally during the perioperative period, PPN is feasible as complimentary nutrition to meet caloric and nutritional goals and limit the surgical stress response. This notion is supported by study of 53 patients with moderate or severe nutritional shortfalls who received PPN, most frequently following (40%) or prior to (15%) resection of gastrointestinal cancer, or due to small bowel fistulas (15%) [dataset [11]]. PPN enabled nutritional requirements to be achieved in over two-thirds of patients (68%) within 3 days [dataset [11]].

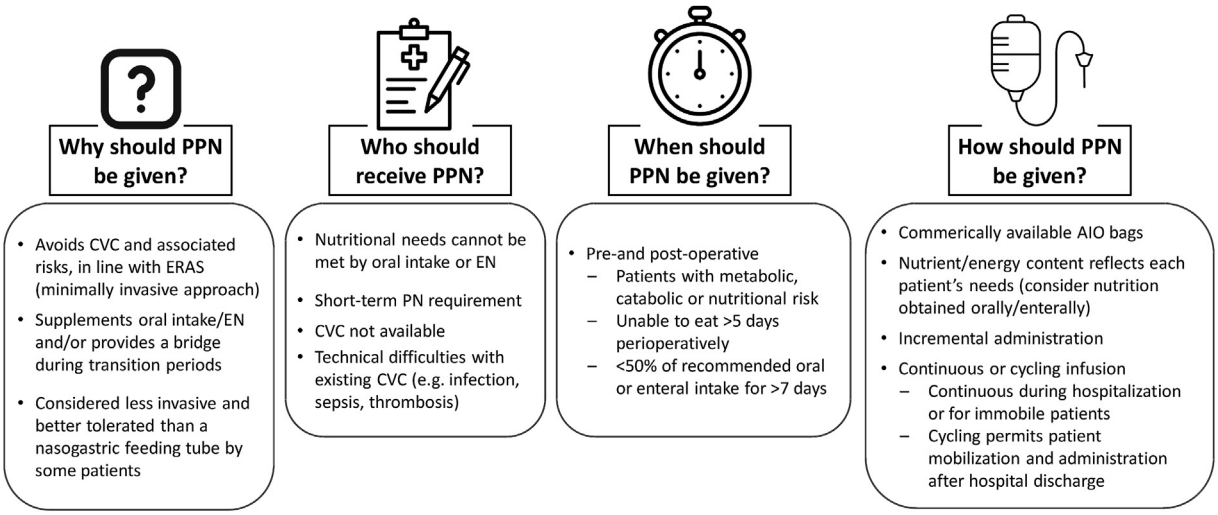

Fig. 1. Expert considerations for PPN use. AIO, all-in-one, CVC, central venous catheter; EN, enteral nutrition; ERAS, Enhanced Recovery After Surgery; PN, parenteral nutrition; PPN, peripheral parenteral nutrition.

Based on the expert group's experience, rationale for delivering nutrition via a PVC, considerations regarding patient selection, the timeframe for initiating PPN and how to administer PPN are summarized in Fig. 1. PPN may be administered to supplement limited oral and/or enteral intake at any time during the perioperative period, including postoperative day 1 and prior to surgery for patients at high risk of surgical stress response. As well as avoiding an invasive procedure and time delay establishing a CVC, PPN is also appropriate for patients with CVC complications such as infection or thrombosis. Also, while many cancer patients undergoing surgery have a central venous port or PICC line, oncologists may wish to reserve the central line to administer chemotherapy rather than it being used for parenteral nutrition. Furthermore, compared with a nasogastric tube, PPN is considered less invasive and is better tolerated by some patients [dataset [46]]. While the availability of prepared all-in-one admixtures has simplified parenteral nutrition interventions in clinical practice, it is important that perioperative nutritional support is tailored to consider each patient's underlying disease, their nutritional risk and the impact of the surgical procedure, taking into account comorbidities such as cholestasis and impaired renal and/or hepatic function. Based on the expert group's clinical experience, example scenarios for which PPN may be well positioned to provide nutritional support during the perioperative period are summarized in Table 2.

6. How can the delivery of PPN be optimized?

6.1. Catheter care

Thrombophlebitis is the most frequent complication of PVC, although the reported prevalence varies considerably across studies (2–80%), due in part to differences in survey selection, follow-up times and definitions of thrombophlebitis [dataset [10,47–50]]. As well as causing discomfort, thrombophlebitis necessitates rotation of venous access sites which can be painful and clinically challenging in some patients [dataset [10]]. However, several factors can reduce the risk of thrombophlebitis, including the composition of the infused solution. For example, the glucose content of high osmolarity solutions can be reduced by including lipids in the PPN composition as an alternate energy source,

Table 2
Examples of gastrointestinal surgical patients who may benefit from perioperative PPN.[a].

Patient characteristics[a]	PPN timeframe
Early postsurgical/rehabilitation phase	
• Oncology patient[b] undergoing esophagectomy, pancreatic or gastric resection	• Consider PPN for ~7 days post surgery
• Bariatric patient with anastomotic leakage or staple-line failure requiring remedial surgery including endoscopic repair	
• Patient[b] with postoperative complications following gastric resection e.g. septic pneumonia, paralytic ileus or anastomotic complications including postoperative fistula e.g. duodenal stump leakage ('rescue PPN' to avoid a jejunostomy tube)	• Consider PPN for a bridging period
Late postsurgical/rehabilitation phase[a]	
• Patient adjusting to feeding tube following oesophagectomy	• Consider supplemental PPN to prevent malnutrition in the first month after surgery
• Patient intolerant to tube feeding (e.g. severe diarrhea)	
Presurgical/prehabilitation phase[a]	
• Patient[b] with pancreatic cancer experiencing anorexia/cachexia/sarcopenia and significant weight loss	• Consider PPN up to 10 days before surgery
• Patient[b] with esophageal stenosis and dysphagia refusing a nasogastric feeding tube during neoadjuvant treatment	• Consider inpatient and/or outpatient PPN delivery
• Patient with large, symptomatic hiatus hernia impacting oral/enteral intake	
• Patient[b] with severe edema following neoadjuvant radio/chemotherapy for esophageal cancer	

EN, enteral nutrition; GI, gastrointestinal; ICU, intensive care unit; ONS, oral nutritional supplements; PPN, peripheral parenteral nutrition.
The clinical scenario captured in this table are examples and do not represent an exhaustive list.
[a] Oral or enteral intake do not meet caloric/nutrient requirements (PPN administered in conjunction with ONS and/or EN to reach nutritional requirements. If the nutritional goals cannot be achieved, consider administering complete parenteral nutrition via a central venous catheter).
[b] Administration of parenteral nutrition via central venous line is not feasible/appropriate.

thereby lessening the risk of thrombophlebitis as well as a supplying essential fatty acids and omega-3 fatty acids (if fish oil is included in the lipid emulsion)[dataset [9–11,50,51]]. In addition, lipids can exert a protective effect on the vascular epithelium [dataset [11,50]][dataset [10,11]][dataset [10,11]].catheter material and catheter placement. Catheters should be flexible and inert (to avoid mechanical trauma and venous irritation), with polyurethane and silicone catheters having lower thrombogenic potential than polyvinyl catheters [dataset [10,11]]. Locating catheters in large vessels away from flexures may also reduce the incidence of thrombophlebitis [dataset [10]], and use of a small diameter cannula may result in a high velocity of flow and fast dilution of the infusion solution.

Based on the authors' clinical experience, thrombophlebitis and catheter-related infections can be minimized by implementing protocols addressing catheter care. Key aspects of the catheter care protocols used at the authors' institutions are summarized in Table 3. This includes close monitoring of patients, with daily inspection of the infusion site and clinically driven catheter replacement. A recent Cochrane review also supports this approach, with removing and re-siting of catheters only if signs of inflammation, infiltration or blockage are present [dataset [52]]. Indeed, clinically driven catheter replacement can avoid pain associated with routine catheter re-siting and reduce time pressures on healthcare providers (HCPs) [dataset [52]]. Infection prevention is also critical, including hand hygiene, preparation of the insertion site with chlorhexidine solution, needle-free connectors and other sterile catheter management approaches (Table 3). Insertion, inspection, care and replacement of PVCs should also be undertaken by an experienced i.v. therapy team who are trained on catheter care and PPN delivery. It is noteworthy that studies across a range of inpatient settings support the use of multimodal peripheral catheter care protocols to reduce the prevalence of PVC-associated complications, including infection and thrombophlebitis[dataset [47,53]].

6.2. Avoidance of overfeeding

Rapid reintroduction of nutrition to severely malnourished patients under metabolic/catabolic stress can result in adverse metabolic changes, termed refeeding syndrome, which result from a rapid decline in gluconeogenesis and anaerobic metabolism, mediated by rising serum insulin levels [dataset [54]]. This can elicit a range of symptoms from nausea, vomiting and lethargy to respiratory insufficiency, cardiac failure, hypotension and delirium, and clinical deterioration can be rapid [dataset [54]]. Consequently, awareness of refeeding syndrome is important among HCPs caring for vulnerable patients who require nutritional support. Overfeeding patients during the perioperative period should therefore be avoided. Indeed, ESPEN guidelines on clinical nutrition in surgery recommend parenteral nutrition to be increased step-wise in severely malnourished patients alongside laboratory and cardiac monitoring to avoid refeeding syndrome [dataset [1]]. The expert panel recommend that for severely malnourished patients the caloric load delivered by PPN should be gradually increased over a period of approximately 3 days according to the individual's needs. When providing PPN to these vulnerable patients, HCPs should consider any additional nutrition they may be receiving orally or enterally as well as non-nutritive sources including lipids such as propofol.

6.3. Multidisciplinary care

Although not widespread practice in many countries, a multidisciplinary HCP team caring for patients' during the perioperative period (e.g., surgeon, radiologist, clinician, nurse specialist, pharmacist and dietician) is best placed to optimize the provision of nutritional therapy [dataset [55]]. Overall responsibility for coordinating this care is often provided by the lead physician or surgeon, with nurses playing a pivotal role in the placement and care of PVCs, inspection of the infusion site and PPN administration. The expert group supports the practice of the lead physician/surgeon and nurse specialist working as a pair to facilitate close collaboration among the nutritional support team members. The practice of lead physician/surgeon–nurse specialist tandem can help to ensure each patient's nutritional needs are quickly identified and addressed both before and after surgery using the most appropriate intervention.

7. What evidence from clinical trials and observational studies supports perioperative use of PPN?

There are limited studies directly investigating the impact of PPN in gastrointestinal surgical settings. However, available data

Table 3
Suggestions for catheter care based on experts' clinical practice.

PVC siting and selection [8,50]	• Forearm peripheral vein preferred – Replacement PVC inserted into contralateral forearm – Avoid using lower extremity peripheral veins, femoral vein and jugular vein (associated with increased risk of catheter contamination) • Appropriate catheter selection – 20–22 gauge polyurethane may facilitate flow and lower the risk of clotting
Clinically driven catheter replacement [52]	• Daily inspection of the infusion site – Catheter replaced if infection, blockage or infiltration is suspected • Maximum time PVC catheter *in situ*: 2–7 days
Reducing the risk of infection	• Hand hygiene and sterile gloves • Sterile catheter management including 2% chlorhexidine skin preparation – Wait 60 s before dressing • Catheter flushed with saline before and after each use – Disused catheters are flushed every 24 h or locked • Regular change of administration sets, disinfection of hubs, stopcocks and needle-free connectors before access • Use of cannular valves
Management of complications	• Clinical case discussions • Refer to local hygiene and infection protocols

PVC, peripheral venous catheter.

Table 4
Clinical trials and observational studies supporting perioperative PPN for major gastrointestinal surgery.[a].

Study design	Patients	Key outcomes
Studies of preoperative PPN		
Haffejee et al., 1985 [dataset [56]] • Single-arm, observational study • PPN (amino acids, glucose, lipid, vitamins and trace elements [~1800 kcal of non-protein energy]) administered for 14 days prior to oesophagogastrostomy or gastric bypass surgery	• Oesophageal squamous carcinoma (N = 15) • Serum albumin <3.5 g/dL • Weight loss >9 kg • Decreased food intake >2 weeks	• PPN prevented further weight loss and depletion of lean body mass • Lower than anticipated incidence of postoperative complications, including no major infections or anastomotic leakage despite patients considered at high risk of complications
Liu et al., 2013 [dataset [57]] • Retrospective cross sectional data-base study • Hypocaloric PPN (amino acids, lipids, glucose [non-diabetic patients], multivitamins and trace elements) administered (average duration of 5.6 days) in combination with EN to bridge nutritional gaps	• Rectal cancer (N = 40) ◦ Received PPN: n = 25 ◦ No PPN: n = 10 • Malnutrition Screening Tool Score ≥2	• PPN vs no PPN patients experienced: – higher postoperative albumin levels (2.5 vs 1.9 g/dL, p < 0.01) – earlier ambulation (3.0 vs 4.9 days, p < 0.05) – shorter postsurgical hospital stay (18.2 vs 33.7 days, p < 0.05) • No patients who received PPN experienced sepsis vs >25% in no PPN group
Kruger et al., 2016 [dataset [58]] • Prospective randomized, single-centre study • PPN (1000 mL/24 h, 700 kcal) or IES (1000 mL) administered as supplementary nutrition during 3 in-hospital fasting days prior to endoscopic biopsy	• Biliopancreatic lesions (N = 82) ◦ PPN: n = 42 ◦ IES: n = 40 • Median self-reported weight loss of 4 kg in prior 3 months	• Despite comparable oral intakes on non-fasted hospital days, body weight increased in PPN group only (mean [95% CI] gain:1.7 kg [0.204, 3.210] vs IES, p = 0.027) • Impact of PPN on body weight was particularly marked in cancer patients (mean [95% CI] gain: 2.7 kg [0.71, 4.76] vs IES, p < 0.01) • One case of thrombophlebitis was observed with PPN
Studies of postoperative PPN		
Hsieh et al., 2015 [dataset [26]] • Retrospective single-centre study • PPN (1500 mL solution: 0.61 kcal/mL, 20% glucose, 5.5% amino acid, 10% lipid emulsion and electrolytes) administered during post-operative fasting • Oral intake permitted when normal bowel sounds and flatus observed (~3–5 days)	• Right lobe liver donors (N = 84) ◦ PPN: n = 44 ◦ No PPN: n = 40 • Residual liver volume <50%	• PPN vs no PPN patients experienced: – more rapid recovery from hyperbilirubinemia (p < 0.001) – lower incidence of pleural effusion (4.5% vs 25%, p = 0.011) – lower incidence of atelectasis (27.5% vs 2.3%, p = 0.001) – shorter hospital stay (18.2 vs 33.7 days, p < 0.05)
Jin et al., 2018 [dataset [59]] • Randomized single-centre study • PPN (1000 mL/day: 700 kcal, 25 g protein, 30 g lipids, 75 g glucose, vitamins and trace elements) or IES (1000 mL/day) administered on day 1 post gastrectomy for 4–8 days	• Gastric cancer (N = 80) o PPN: n = 44 o No PPN: n = 40	• PPN vs no PPN patients experienced: – higher levels of albumin, prealbumin and haemoglobin (each, p < 0.05) – higher quality of life scores (EORTC QLQ-C30, p < 0.05) – higher psychological wellbeing scores (HADS-Anxiety, p < 0.05; HADS-Depression, p < 0.01; PHQ-9, p < 0.01) – improved immune function (CD3+, CD4+ and CD4+/CD8+ peripheral blood mononuclear cell counts, all p < 0.05)
Gys et al., 1990 [dataset [60]] • Randomized single-centre study • PPN (2000 mL/day: protein, lipids, glucose and trace elements) or IV fluids (1000 mL dextrose 5% with electrolytes and 1000 mL Hartmann's solution) administered on day 1 post surgery for a mean of 6 days (nil per os for a mean of 4.5 days)	• Colorectal surgery (N = 20)[b] ◦ PPN: n = 10 ◦ IV fluids: n = 10	• PPN vs IV fluid patients experienced improved nitrogen balance over days 1–5 (p < 0.001), indicating a positive impact on protein loss • Greater incidence of phlebitis leading to catheter change with PPN vs IV fluid (day 3: 100% vs 50%)
Cooper et al., 2006 [dataset [61]] • Randomized single-centre study • PPN (2000 mL/day: 1500 kcal, protein, lipid, vitamins and trace elements) administered on the day prior to surgery and for 6 days post esophagectomy, or normal diet prior to surgery and IV fluids only until day 4 post surgery (oral fluids Day 4, soft diet from Day 6)	• Esophago-gastric cancer (N = 27) •PPN: n = 16 •IV fluids: n = 11	• PPN vs IV fluids patients experienced – lower 30-day (0% vs 18%) and 90-day (0% vs 36%; p < 0.05) mortality – comparable duration of hospital stay (median 10 days) • Two cases of thrombophlebitis were observed in PPN patients

CI, confidence interval; EORTC QLQ-C30, European Organization for Research and Treatment of Cancer Quality of Life Questionnaire; HADS, Hospital Anxiety and Depression Scale; IES, isotonic electrolyte solution; IV, intravenous; PHQ, Patient Health Questionnaire; PPN, peripheral parenteral nutrition.
[a] Studies captured in this table are based on a non-systematic literature search.
[b] 16 of 20 patients underwent surgery due to colorectal cancer.

indicate PPN is a viable approach for providing supplementary nutritional support to selected patients in preoperative and postoperative settings (Table 4). Findings from these studies suggest that PPN can prevent weight loss, reduce the incidence of complications, improve quality of life measures, and shorten the duration of postoperative hospital stay (Table 4)[dataset [26,56–61]] However, limited data are available and studies tend to involve small numbers of patients and be observational or retrospective analyses. Multicentre, randomized controlled trials of perioperative PPN using endpoints capturing clinical outcomes and patient experience are required.

8. Algorithm to deliver PPN in the context of ERAS

Based on European clinical guidelines and experience of the expert panel, an algorithm was developed to assist HCPs to deliver nutritional support to selected patients undergoing gastrointestinal surgery, within the context of the ERAS pathway (Fig. 2). Firstly, in accordance with ERAS pathways and ESPEN guidance on clinical nutrition in surgery, all patients should be screened for metabolic/catabolic stress and nutritional risk prior to surgery [dataset [1,12,13,17]]. The impact of both the underlying disease and surgical procedure on nutritional requirements should be considered. Screening should be conducted

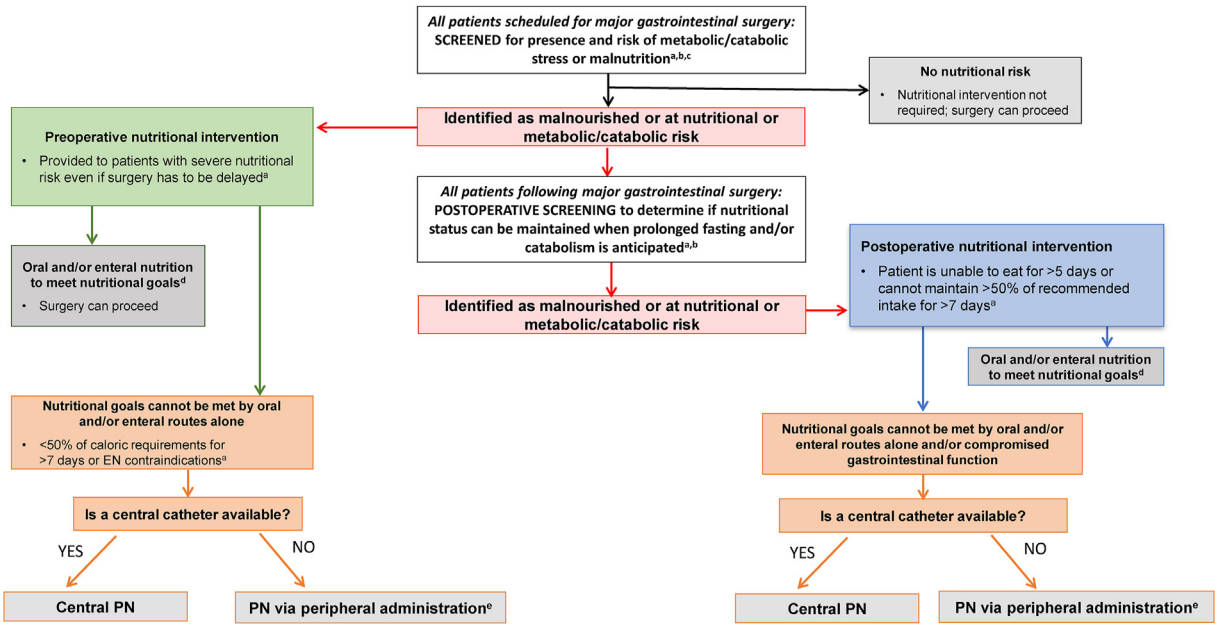

Fig. 2. Proposed algorithm for delivering PPN in the context of ERAS. EN, enteral nutrition; PN, parenteral nutrition, [a]Recommended in ESPEN Guideline: Clinical Nutrition in Surgery [dataset [1]] [b]Assessment using appropriate tools such as GLIM or ESPEN criteria [dataset [62,63]] [c]Recommended in ERAS guidelines [dataset [12,13,17]] [d]Energy and protein requirements of surgical patients may be estimated as 25–30 kcal/kg and 1.5 g/kg ideal body weight [dataset [1]] [e]If total parenteral nutrition is indicated, consider central parenteral nutrition; peripheral parenteral nutrition may be used if the patient is waiting for central access.

using an appropriate tool such as Global Leadership Initiative on Malnutrition (GLIM) criteria which require one or more phenotypic criterion (involuntary weight loss, low body mass index [BMI], or reduced muscle mass) and at least one aetiologic criterion (reduced food intake/assimilation, or inflammation or disease burden)[dataset [62]]. Alternatively, ESPEN recommend two diagnostic criteria: low BMI, or unintentional weight loss combined with either reduced BMI or low fat free mass index [dataset [63]]. Nutritional support should be provided promptly to all patients identified at nutritional risk to prevent or correct undernutrition, even if this necessitates delaying surgery for a short period [dataset [1,13]]. Screening for nutritional risk should be repeated in all patients after surgery to ensure that the nutritional status can be maintained when prolonged fasting and/or catabolism is anticipated [dataset [1]]. ESPEN guidelines recommend nutritional therapy for all patients anticipated to be unable to eat for >5 days or who cannot maintain >50% of recommended intake for >7 days during the perioperative period [dataset [1]]. Nutritional support should be managed by a specialist team with regular follow-up. In line with the ERAS approach of minimally invasive treatment where possible, perioperative parenteral nutrition should be provided if the patient's nutritional goals cannot be met by oral and/or enteral routes alone, and administered peripherally if a CVC is not available (Fig. 2). ESPEN guidelines recommend PPN for surgical patients requiring short-term (4–7 days) parenteral nutritional and delivery via a CVC if parenteral support is anticipated for more than 7–10 days [dataset [1]].

9. Summary and outlook: Improving nutritional support for patients undergoing major gastrointestinal surgery

Improved awareness of the adverse impact of poor nutritional status as well as metabolic stress on patients undergoing major gastrointestinal surgery and the benefits of timely and appropriate nutrition support, which include shorter hospital stay, fewer complications and improved patient wellbeing, is warranted [dataset [57,59]]. Implementation of ERAS recommendations for perioperative nutritional support can help to optimize patient outcomes [dataset [34]]. However, in line with ESPEN guidelines in clinical nutrition in surgery, ERAS evidence-based nutrition recommendations for gastrointestinal surgery are focused on oral and enteral intake[dataset [1,12–14,16,17]]. Indeed, ERAS evidence-based guidance on nutritional support for patients whose needs cannot be met by oral or enteral routes is limited, likely due to limited clinical studies on PPN in this setting. For patients undergoing major gastrointestinal surgery, PPN can facilitate the provision of timely nutritional support during the perioperative period by avoiding the need for invasive CVC insertion, in line with ERAS concept of minimizing invasive procedures where possible.

PPN is generally well tolerated, and side effects such as thrombophlebitis can be largely avoided when venous access and care are carried out in accordance with catheter care protocols by appropriately trained HCPs. With this in mind, the expert panel developed an algorithm to support the identification and management of patients' perioperative nutritional needs (Fig. 2). Use of perioperative PPN in selected patients can help to maintain the nutritional status and reduce the surgically induced stress response, thereby preventing adverse metabolic consequences following the demands of major gastrointestinal surgery. The practical guidance summarized by this expert panel may facilitate HCPs to provide timely nutritional interventions to gastrointestinal surgery patients, thereby helping to improve postoperative clinical outcomes and patients' quality of life.

Statement of authorship

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