David S. Warner, M.D., Editor

Promoting Perioperative Metabolic and Nutritional Care

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ABSTRACT

Surgery represents a major stressor that disrupts homeostasis and can lead to loss of body cell mass. Integrated, multidisciplinary medical strategies, including enhanced recovery programs and perioperative nutrition support, can mitigate the surgically induced metabolic response, promoting optimal patient recovery following major surgery. Clinical therapies should identify those who are poorly nourished before surgery and aim to attenuate catabolism while preserving the processes that promote recovery and immunoprotection after surgery. This review will address the impact of surgery on intermediary metabolism and describe the clinical consequences that ensue. It will also focus on the role of perioperative nutrition, including preoperative nutrition risk, carbohydrate loading, and early initiation of oral feeding (centered on macronutrients) in modulating surgical stress, as well as highlight the contribution of the anesthesiologist to nutritional care. Emerging therapeutic concepts such as preoperative glycemic control and prehabilitation will be discussed. **(ANESTHESIOLOGY 2015; 123:1455-72)**

ALTHOUGH efforts have been made to enhance the pharmacological and physiological management of the surgical patient, insufficient attention has been paid to nutrition and metabolic preparation. Yet, an accumulation of data lends support to the positive impact that nutrition has on surgical outcome.[1–6] Enhanced recovery programs (ERPs) have introduced a collaborative care approach among the perioperative team, including anesthesiologists, surgeons, nurses, dietitians, and physical therapists, with the aim to ensure continuity of care and improved patient outcomes.[7,8] In particular, the anesthesiologist, by introducing specific perioperative metabolic strategies, may promote early recovery through attenuation of catabolism and utilization of oral nutrients.[9] The goal of the current article is to draw the clinician's, and particularly the anesthesiologist's, attention to: (1) how nutritional strategies (focused mainly on macronutrients) modulate the metabolic stress response; (2) identify risk factors associated with perioperative undernutrition and surgical risk; and (3) introduce collaborative nutritional and metabolic strategies to conserve lean body mass and improve surgical outcome. The aim of this review is to present the evidence for nutrition in modulating surgical stress in order to raise awareness and overcome underutilized nutritional strategies in perioperative care.

Surgery and Its Impact on Intermediary Metabolism

Surgical trauma induces a state of stress that threatens metabolic and physiologic homeostasis.[10] This state is acknowledged by inducing a "stress response," which is characterized by hormonal, hematological, metabolic, and immunologic changes in order to reestablish cellular equilibrium[10,11] (fig. 1). Activation of the *immune-hypothalamic–pituitary–adrenal axis* and sympathetic nervous system, mediated by afferent nerves and cytokines generated from the site of injury, marks the onset of the stress response.[11,12] The extent in which the stress response is evoked parallels the degree of tissue injury.[11] The functional purpose of the elicited response is believed to be an innate survival mechanism that maintains plasma volume (salt and water retention), increases cardiac output and oxygen consumption, as well as modulates metabolic processes in order to mobilize energy reserves (glycogen, adipose, skeletal tissue) to provide substrates for metabolic fuel processes, tissue repair, and synthesis of proteins involved in the immune response.[13,14] An *ongoing* or *exaggerated* stress response, however, has adverse clinical consequences including hyperglycemia, catabolism, hypertension, tachycardia, and immunosuppression. Clinical therapies should thus aim to attenuate catabolism while preserving the processes of the surgical stress response that promote recovery and immunoprotection.[13,14]

Hyperglycemia

Increased Hepatic Glucose Production and Insulin Resistance. As a result of the stress response to surgery, glucagon concentration is often elevated and roughly correlated with the extent of injury.[11] A rise in glucagon, among other factors including catecholamines, promotes an increase in

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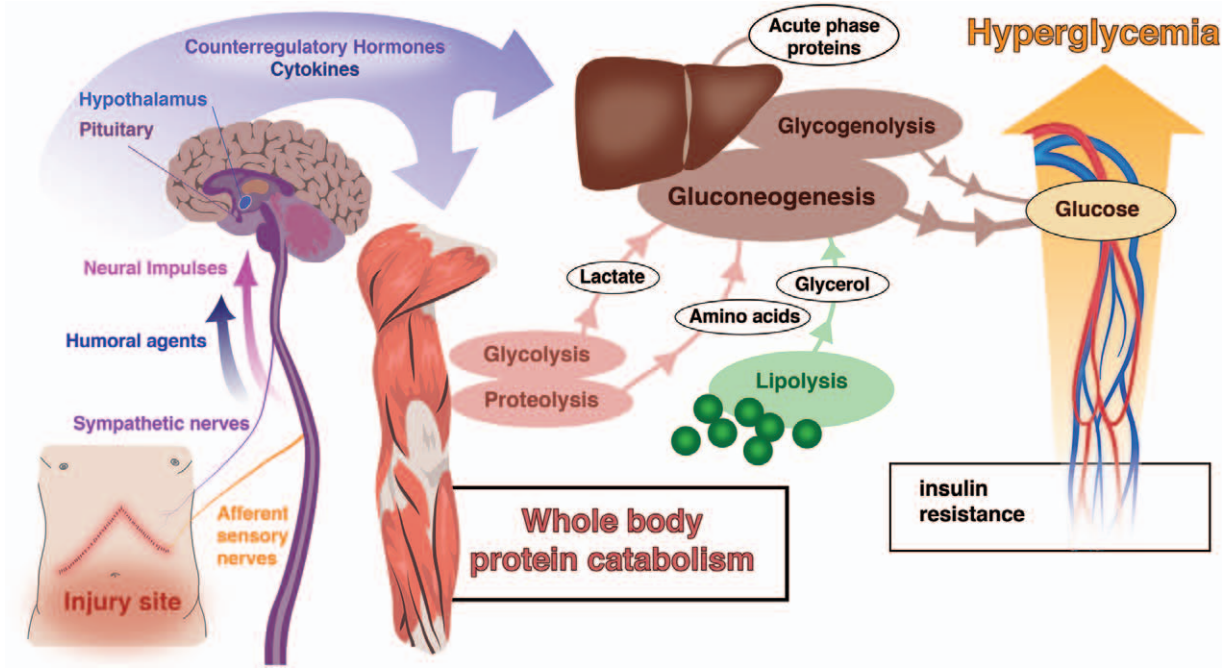

Fig. 1. A rise in circulating glucocorticoids, catecholamines, and glucagon (*i.e.*, counterregulatory hormones) is elicited by activation of the hypothalamic–pituitary–adrenal axis and sympathetic nervous system. The response is mediated by afferent nerves and humoral factors including cytokines generated from the site of injury. Mobilization of energy reserves promotes hyperglycemia and catabolism. Hyperglycemia develops as a consequence of insulin resistance coupled with an inappropriately high hepatic glucose production. Proteolysis and lipolysis accelerate to provide precursors for gluconeogenesis. The resultant amino acid efflux also supports the synthesis of proteins involved in the acute phase response.

cyclic adenosine monophosphate.[15] Consequently, glycogen phosphorylase is activated while glycogen synthase is inactivated, promoting the depletion of glycogen stores (liver glycogen depletes more rapidly than skeletal reserves[11]) and halting glycogen synthesis.[15] The reduction in glycogen synthase activity has been reported to last for at least a month.[16] The rising glucagon concentration also activates the synthesis of phosphoenolpyruvate carboxykinase, the rate limiting enzyme in the synthesis of gluconeogenesis, and enhances hepatic glucose production (HGP).[15,17] HGP is fueled by a number of nonglucose substrates including lactate, glycerol, and gluconeogenic amino acids released into systemic circulation and taken up by hepatocytes.[11] After surgery, HGP has been found to be somewhat refractory to the effects of exogenous glucose.[18]

Impairment of both peripheral and central insulin sensitivity is the primary cause of perioperative hyperglycemia.[15,19] Peripheral insulin resistance is mostly the result of impaired insulin-mediated glucose uptake in skeletal tissue, whereas central insulin resistance refers to the inability of insulin to suppress HGP.[15] In the healthy postprandial state, insulin concentration rises six to eight times greater than basal in response to a meal.[19] As a result, HGP is abolished, and peripheral glucose uptake is enhanced. Insulin-stimulated glucose uptake in skeletal tissue is accomplished through the translocation of glucose transporter type 4 to the plasma membrane.[15] After surgery, however, a state of insulin resistance develops in otherwise healthy individuals and appears to persist for 2 to 3 weeks even after uncomplicated, moderate, elective surgery.[19] Hormonal and inflammatory mediators generated by the stress response are believed to be involved in the reduction of insulin-mediated glucose uptake in skeletal and adipose tissue by way of: (1) a defect in insulin signaling pathways, particularly phosphoinositide-3-kinase–protein kinase (P13K), resulting in reduced signaling or (2) a defect in the translocation of glucose transporter type 4 to plasma membrane (fig. 2).[19] Furthermore, the degree of insulin resistance observed after surgery is believed to parallel the degree of surgical trauma. In fact, cholecystectomy performed laparoscopically reduces insulin resistance by more than half of open cholecystectomy.[19] Overall, surgical stress elicits a rise in blood glucose as a consequence of insulin resistance coupled with an inappropriately high HGP.[20]

Potential Clinical Consequences of Hyperglycemia. It has been suggested that at the core of poor patient outcomes lies the perturbations found in peripheral glucose uptake after elective surgery.[19] Indeed, when insulin is infused to maintain euglycemia after major elective surgery, the main components of metabolism are normalized so that infused nutrients can be utilized appropriately—glucose is oxidized, lipolysis depressed, and neutral protein balance achieved.[21] In fact, results of the Surgical Care and Outcomes Assessment Program in Washington State of 11,633 patients at 47 different hospitals undergoing elective colorectal and

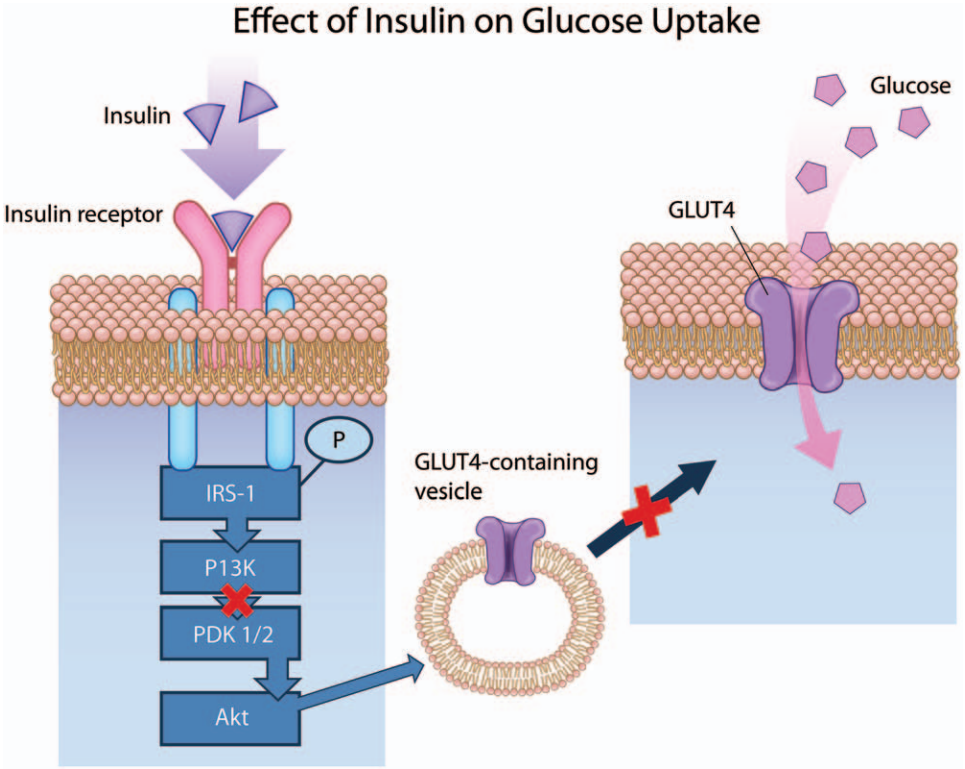

Fig. 2. In the healthy postprandial state, glucose concentration rises, and the subsequent increase in circulating insulin activates intracellular signaling cascades that ultimately result in the translocation of glucose transporter type 4 (GLUT-4) to the plasma membrane. Following elective surgery, hormonal and inflammatory mediators generated by the surgical stress response produce a state of insulin resistance. A reduction in peripheral insulin–mediated glucose uptake is observed and believed to be the cause of: (1) a defect in insulin signaling pathways, particularly phosphoinositide-3-kinase–protein kinase (P13K) or (2) a defect in the translocation of GLUT-4 to plasma membrane. Akt = serine/threonine protein kinase; IRS-1 = insulin receptor substrate 1; P = phosphorylation; PDK1/2 = 3-phosphoinositide-dependent protein kinase 1.

bariatric surgery found that perioperative and postoperative hyperglycemia (>10 mM or 180 mg/dl), regardless of diabetic status, was associated with higher risk of infection, in-hospital mortality, and surgical complications.[22] Likewise, a retrospective chart review of Veterans Affairs Surgical Quality Improvement Program database found that in 7,576 procedures, moderate hyperglycemia (8.9 to 11.1 mM or 161 to 200 mg/dl) at the time of surgery was associated with surgical site infections, and of the 5,773 procedures examined on the first postoperative day, even mild hyperglycemia (6.7 to 8.9 mM or 121 to 160 mg/dl) or hypoglycemia was associated with increased myocardial infarction.[23] For these reasons, improvement in postoperative insulin resistance has been the target of much research and many postoperative therapies. Yet, optimal glucose concentrations for improving clinical outcome have yet to be established and the benefits observed with intensive insulin therapy[24] have not been reproduced. A 2012 Cochrane review identified that intensive glycemic control protocols for patients with diabetes mellitus undergoing surgical procedures were not supported by adequate scientific evidence,[25] and a separate Cochrane review found insufficient data to support the routine adoption of strict perioperative blood glucose control to prevent surgical site infections.[26] Indeed, some evidence suggests that moderate *acute* hyperglycemia (7.8 to 12.2 mM or 140 to 220 mg/dl), as would be observed with most elective surgical patients, might be protective.[27] Acute hyperglycemia has recently been suggested to promote blood glucose availability for nonoxidative uses,[28] establish a concentration gradient that permits enhanced cellular uptake during periods of reduced blood flow in critical illness, and protect against cell death following ischemia.[27,28] It is unclear, however, whether these results can be extended to elective noncardiac surgical patients. It therefore appears as though an association between severity and duration of hyperglycemia and poor clinical outcome exists; however, the relationship and consequences are poorly understood.

Protein Catabolism

Mobilization of Amino Acids. The surgically stressed state is characterized by an elevation in protein turnover, release of amino acids into circulation, urinary nitrogen losses, and impaired uptake of amino acids in skeletal tissue (fig. 3).[11,14] Whole body protein breakdown accelerates, while protein synthesis is unable to match the degree of catabolism, leading to a negative whole body protein balance.[29] Alterations

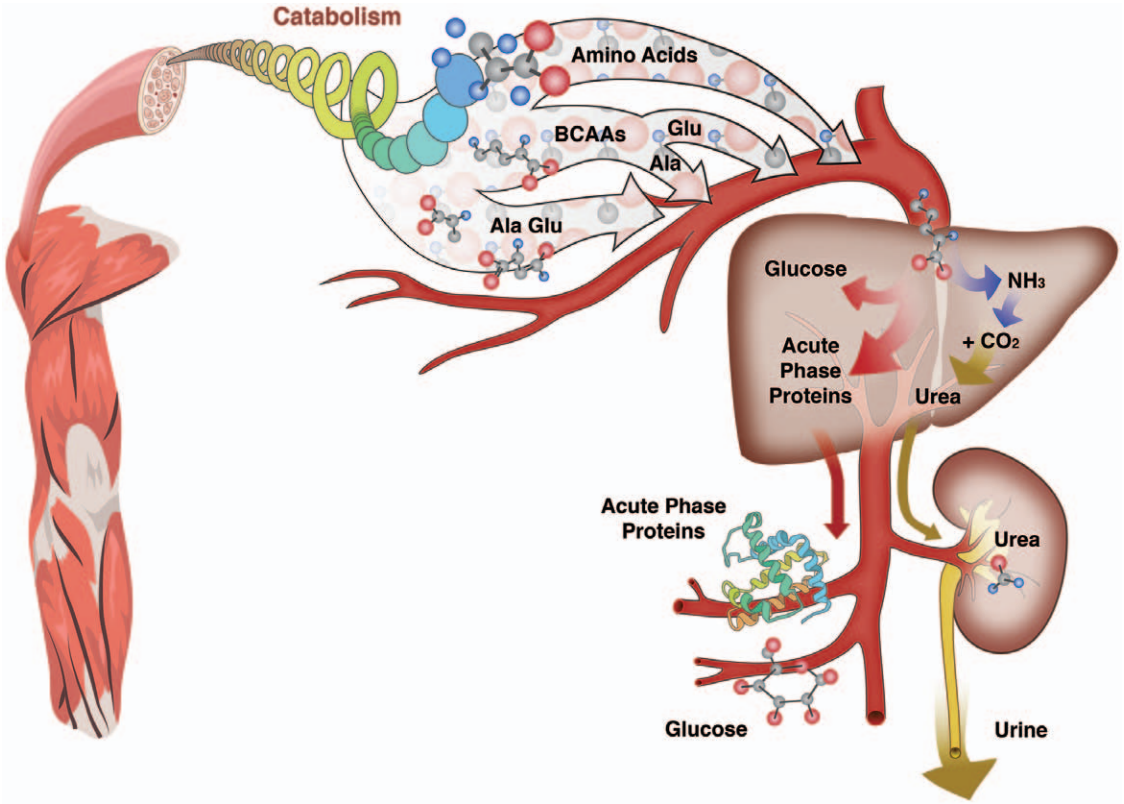

Fig. 3. The surgically stressed state is characterized by an elevation in protein turnover (*i.e.*, protein synthesis and degradation), release of amino acids into circulation, urinary nitrogen losses, and impaired uptake of amino acids in skeletal tissue. Lean tissue is catabolized, releasing amino acids into circulation (including glutamine, alanine, and the branched chain amino acids [BCAAs]), while hepatic amino acid uptake is enhanced. This allows for reprioritization of protein synthesis to acute phase reactants and the production of glucose *via* gluconeogenesis. Glutamine (Glu) and alanine (Ala) account for the majority of the amino acid efflux from peripheral tissues and are readily extracted from circulation by the liver. The excess nitrogen is converted in the liver to urea by combining ammonia (NH_3) with CO_2 (carbon dioxide). Urea is then released into circulation, traveling to the kidneys, where it can be filtered into urine. The BCAAs undergo irreversible degradation in skeletal tissue, in part for synthesis of glutamine and alanine, which reduces availability of these indispensable amino acids for reutilization in protein synthesis. Collectively, these metabolic changes promote whole body protein catabolism.

in whole body protein balance typically involve skeletal muscle wasting, which is the largest "reservoir" of amino acids, although other lean tissues are also affected including respiratory and gut tissues.[30]

While skeletal tissue is mobilized, hepatic amino acid uptake is enhanced, allowing for reprioritization of protein synthesis to acute phase reactants and the production of glucose *via* gluconeogenesis.[11] Remarkably, the amino acid composition of these acute phase proteins is quite different from that of skeletal tissue and thus poses a catabolic dilemma.[31] For instance, dietary intake must compensate for the new demand of aromatic amino acids required to synthesize the positive acute phase reactant fibrinogen otherwise muscle catabolism might be exaggerated. In point, a stable isotope investigation estimated that in fasted patients with pancreatic cancer experiencing an ongoing inflammatory response, 2.6 g of muscle protein would need to be catabolized to synthesize 1 g of fibrinogen.[32]

Derangements in intra- and extracellular amino acid concentrations are commonly described after surgery.[33] The amino acid efflux supports tissue synthesis and the inflammatory response at the site of injury.[17] Glutamine and alanine account for approximately 70% of the amino acid efflux from peripheral tissues and are readily extracted from circulation by the liver for production of glucose (*i.e.*, gluconeogenesis) and acute phase protein synthesis.[17] The branched chain amino acid pools may also be depleted after surgery owing to irreversible degradation in muscle, in part for *de novo* synthesis of glutamine and alanine, reducing availability for reutilization in protein synthesis. If indispensable amino acids are not replenished, tissue catabolism may be exacerbated.[34]

Potential Clinical Consequences. An elevated protein turnover, elicited by surgical stress, increases dietary protein requirements, persisting well into the postoperative period. Four months into convalescence whole body protein breakdown has been found to remain elevated above healthy controls.[35] Inherently, enhanced catabolism serves a beneficial purpose: the amino acid efflux provides substrates to repair tissues and synthesize proteins involved in immune

responses. As a result, a well-nourished young patient, with an uncomplicated recovery, will usually not suffer any major clinical consequences from the temporary negative protein balance that arises postsurgery.[14] It is generally accepted, however, that in any catabolic patient, a certain degree of functional decline will ensue if an intervention is not implemented as soon as possible to conserve functional capacity.[36] Furthermore, the ability to withstand a catabolic insult is compromised in older and malnourished patients bearing poor functional reserve before surgery. In fact, older patients tend to experience a decline in strength that does not recover to preoperative stamina as quickly as younger adults.[37]

An older study by Hill *et al.*[38] found that 2 weeks following major surgery, breakdown of protein accounted for 20% of the observed weight loss. Participants lost 3 kg of weight: 1,400 g composed of fat, while 600 g (6% of body protein) and 1,000 g were composed of protein and water, respectively. Similarly, in a newer investigation using dual-energy x-ray absorptiometry, approximately 2 kg total lean mass was lost 6 weeks post–uncomplicated hemicolectomy.[39] Loss of lean body mass is accompanied by loss of function. Unsurprisingly, the trajectory of functional recovery for a patient undergoing an elective major abdominal operation involves a rapid deterioration in functional capacity in the first few postoperative weeks and a gradual improvement back to baseline function thereafter.[40] This reduction in functional capacity is experienced as reduced walking capacity (as measured using the six-minute walk test [6MWT]),[41] lower self-perceived levels of physical activity,[41] and prolonged return to activities of daily living.[42] The resolution of functional capacity may not return for several weeks postoperatively. Post–colorectal surgery, for instance, only 40% of patients receiving standard of care, which included ERP care, had returned to their preoperative functional walking status by the eighth postoperative week.[43]

Acute Phase Response. "Acute phase reactants" is the term used to describe several plasma proteins with an altered concentration (at least 25%) following an inflammatory response in both acute and chronic states of inflammation.[44] More specifically, a rise in the plasma concentration of the positive acute phase reactants (*e.g.*, fibrinogen and C- reactive protein) is observed while a reduction in the concentration of the negative acute phase reactants (*e.g.*, transferrin and albumin) takes place. The main proinflammatory cytokines released in the early stages of stress are thought to be interleukin (IL)-1 and tumor necrosis factor-α. IL-1 and tumor necrosis factor-α trigger the second cytokine release, which includes IL-6.[11] IL-6 is believed to regulate the acute phase response and its concentration in blood is thought to be representative of the degree of systemic inflammation elicited.[13] Considering that whole body protein synthesis is not consistently elevated after surgery, it was classically assumed that protein synthesis shifted in favor of the positive acute phase reactants. Therefore, the synthesis of proteins involved in nutrient transport (*e.g.*, albumin) would be reduced, whereas the synthesis of proteins involved in host defense would increase (*e.g.*, fibrinogen).[45] Several more current studies, however, note a postoperative depression in muscle protein synthesis, and subsequent rise in hepatic protein synthesis, which suggests that whole body protein synthesis shifts toward the synthesis of acute phase reactants in its entirety.[46,47] To quantify this concept, a stable isotope study in which synthesis of muscle and hepatic secretory plasma proteins was measured 4 h after coronary artery bypass graft surgery indicated that fractional synthesis rate (FSR) of muscle protein was inhibited by 36% while fibrinogen synthesis was elevated by 186% and albumin elevated by 41%.[48]

Plasma albumin concentration is dictated by net hepatic synthesis, degradation, and distribution into extravascular compartments as a result of transcapillary escape.[45] Surgery-induced hypoalbuminemia was historically believed to be mediated by a reduction in FSR of albumin, which was supported by animal and *in vitro* studies.[49,50] In rats, for instance, inflammation causes a reduction in mRNA encoding albumin synthesis.[49] The FSR of albumin in humans, however, is elevated despite the presence of hypoalbuminemia after surgery in head-injured patients,[46] conditions with an inflammatory or ongoing acute phase response,[51] and within hours of endotoxin administration to healthy volunteers.[52]

It is likely that the hypoalbuminemia observed postoperatively is facilitated by transcapillary escape. Sixty min after induction of anesthesia, albumin concentration dropped by 15%,[53] whereas transcapillary escape increased 100% post–cardiac surgery.[45] It has been proposed that the synthetic rate of albumin varies with degree of insult: the greater the inflammatory response elicited, the greater the elevation observed.[46] In point, the FSR of albumin was found to be higher during acute cholecystitis than immediately post–elective cholecystectomy without an inflammatory response.[54] Furthermore, 8.5 h after coronary artery bypass graft, which would elicit a significant stress response, albumin synthesis was significantly elevated.[48] The evidence suggests that albumin synthesis decreases during surgery and then rises with the onset of an inflammatory response and that the magnitude of the response elicited drives albumin synthesis.[48] It should therefore go without saying that the concentration of plasma albumin observed after surgery is not indicative of its synthetic rate and is not a measure of nutritional status.[55] Indeed, postoperatively, the use and interpretation of plasma albumin is confounded by its relatively long half-life (approximately 14 to 20 days), patient's fluid status, and redistribution as a result of capillary permeability, inflammation, or infection.[55]

Lipid Oxidation

Elective surgery elicits insulin resistance associated with reduced glucose uptake, reduced glucose oxidation, and a decrease in glycogen synthesis.[11] In order to conserve glucose and meet elevated energy demands, fat oxidation accelerates and becomes the major source of fuel postoperatively.

Adipocyte lipolysis is enhanced through activation of adipocyte hormone–sensitive lipase and releases free fatty acids and glycerol from stored triglycerides into circulation.[11] Glycerol contributes up to 20% of glucose production *via* hepatic gluconeogenesis, while free fatty acids are oxidized in liver or muscle, converted to ketone bodies, or reesterified back to triglycerides.[11,15] Significantly higher levels of nonesterified fatty acids have been documented in the immediate postoperative period, and it has been suggested that the rise in nonesterified fatty acid concentration augments insulin resistance.[56]

Nutrition-focused Clinical Strategies That Attenuate Metabolic Stress

Activation of the hypothalamic–pituitary–adrenal axis and sympathetic nervous systems marks the onset of the surgical stress response. Clinical therapies (table 1) that modify these events alter the stress response and can enhance recovery.[8] Neural blockade, for instance, abates the neuroendocrine response by diverting afferent stimuli from injury.[9] ERPs, such as Enhanced Recovery After Surgery (ERAS), are a bundle of evidenced-based multimodal clinical strategies designed to modulate the stress response in the care of patients undergoing elective surgery.[7] Several studies and at least two meta-analyses of randomized controlled trials (RCTs) have demonstrated that when compared with traditional perioperative treatment, ERP care, particularly in the context of abdominal surgery, reduces rates of morbidity and prompts earlier hospital discharge.[7,57,58] Furthermore, ERP patients require less parenteral nutrition (PN) support, tolerate oral nutrients earlier, pass stool sooner, and have been found to preserve lean body mass and muscle strength during the hospitalization period.[59] It should be noted, however, that institutional ERP implementation requires appropriate training and collaboration and thus should not be carried out independently. The main nutrition-related ERP guidelines include nutritional risk screening before surgery and perioperative oral nutrition supplementation (ONS) if risk of undernutrition is present; avoidance of long periods of fasting with the use of preoperative carbohydrate loading; establishment of early and sustained oral feeding; fluid management; and ONS with meals after surgery.[7] These nutritional guidelines are integral elements of ERP care. For instance, of the 19 ERP elements implemented at one institution, advancement of oral intake was identified as an independent determinant of earlier hospital discharge and morbidity post–colorectal resection.[60] That being said, it is believed that it is the combination of each of the different elements, rather than a single element of an ERP, that produces the greatest effect.[36] In fact, an RCT employing a combination of early enteral nutrition (EN), preoperative oral carbohydrate loading, and epidural anesthesia found that the metabolic response to surgery was modulated such that protein balance and normoglycemia (average blood glucose of 5.8 mM or 104.4 mg/dl) were achieved.[36,61]

Table 1. Clinical Strategies Thought to Directly or Indirectly Modulate the Surgical Stress Response and Nutritional Outcome

	Hormonal	Metabolic	Inflammatory
Minimally invasive surgery	✓	✓	✓
Neural blockade	✓	✓	✓
Opioid-sparing pain control	✓		
Prevention of hypothermia	✓	✓	
Perioperative fluid management	✓		
Anabolic agents (*e.g.*, growth hormone)	✓	✓	
Glucocorticoids	✓	✓	✓
β-blockade	✓	✓	
α2-agonists	✓		✓
Exercise	✓	✓	✓
Carbohydrate loading	✓	✓	✓
Immunonutrition		✓	✓
Early oral nutrition	✓	✓	✓
Adequate dietary protein		✓	
Insulin (glycemic control)	✓	✓	✓

Preoperative Nutritional Assessments to Recognize Undernutrition

Undernutrition is a product of inadequate intake and/or metabolic and inflammatory alterations that produce wasting, suppress fundamental immune functions, and ultimately lead to diminished physical function.[5,62] Optimal convalescence requires sufficient preoperative physiologic reserve to support the stress-induced mobilization of energy reserves.[62,63] Sorely, the prevalence of nutritional risk before abdominal surgery has been identified, through various nutritional risk screening tools, to be as high as 47%.[4] Convalescence also requires perioperative nutritional care to support synthesis of acute phase proteins, immune cells, and wound healing,[63] while simultaneously mitigating the depletion of energy stores so that physiologic integrity and strength are not compromised. Furthermore, undernutrition suppresses the distribution of T cells and the time for lymphocyte activation to occur.[64–66]

Undernourished hospitalized patients experience more complications that can ultimately lead to poorer outcomes, longer hospital stays, and generate significant costs compared with well-nourished counterparts.[63,67] Simply, a decline in nutritional status during a 7-day hospital stay or longer, regardless of nutritional status at admission, has been associated with increased costs and odds of complications.[68] In fact, European Society for Clinical Nutrition and Metabolism (ESPEN)[63] cites undernutrition an independent risk factor for the incidence of infectious complications, mortality, length of hospital stay, and costs for hospitalized and surgical patients. RCTs and meta-analyses have suggested that when compared with traditional care treatment of hospitalized patients (particularly abdominal surgery and disease-related malnutrition patients), perioperative oral nutrition

supplements or EN reduces rates of mortality and morbidity including wound infections.[3,67–69] Additionally, the results of a recent prospective observational study suggested that patients who are undernourished or at risk of undernutrition are twice as likely to be readmitted within 30 days following elective colorectal surgery.[70] In corroboration, the three most common reasons for 30-day hospital readmission following general surgery were recently reported to be gastrointestinal complications, surgical infections, and malnutrition.[71]

Severely malnourished patients clearly benefit from preoperative nutrition support. Schricker *et al.*[72] demonstrated, using stable isotope technology, that a significant correlation (r^2 = 0.85) exists between the degree of catabolism found before surgery and the anabolic effect achieved with perioperative nutrition support. Indeed, ESPEN guidelines[63] suggest that severely malnourished patients be supplemented before elective surgery. Seven to 14 days of preoperative nutritional support is indicated (PN support guidelines suggest 7 to 10 days,[63] whereas EN support guidelines recommend 10 to 14 days[62]) even if surgery has to be delayed. Low-level ERAS recommendations for severely malnourished patients are to provide 7 to 10 days of preoperative supplementation with oral nutrition supplements.[7] While a prospective observational study by Jie *et al.*[4] found that malnourished patients experienced a 50% reduction in postoperative morbidity with only 5 to 7 days of sufficient preoperative nutrition therapy. It is clear that preoperative nutrition support is recommended for severely malnourished patients; the duration of nutrition support, or an outcome measure to suggest nutrition support goals have been reached, needs to be further defined. Concern for progression of an underlying condition necessitates punctually scheduled surgeries, however, the Canadian Oncological Society states that in the case of nonemergent colon cancer, it is unlikely that delays longer than 6 weeks from first diagnostic test negatively impacts surgical mortality or overall survival.[73]

Severe malnutrition, according to the ESPEN working group, can be identified when at least one of the following criteria is present: weight loss more than 10 to 15% within 6 months; body mass index less than 18 kg/m^2; subjective global assessment of grade C; or serum albumin less than 30 g/L (with no evidence of hepatic or renal dysfunction).[62,63] Hypoalbuminemia is considered an indicator of inflammation, not nutritional status that predicts risk of morbidity. A number of nutrition screening tools are available, and a comprehensive review of all nutrition screening tools is beyond the scope of this review. That being said, the nutrition risk screening tool–2002 and subjective global assessment have been used and validated in surgical populations more often than other tools.[74] The nutrition risk screening tool–2002 is presently regarded as the best predictor of postsurgical complications, with evidence suggesting that preoperative nutritional repletion at a score greater than 5 improves patient outcome.[4] Interestingly, recent consensus recommendations from the North American Surgical Nutrition Summit suggest that preventative preoperative nutrition therapy should be a central focus that involves "metabolic preparation" in *all* patients at risk of undernutrition, rather than simply correcting deficiencies in severely undernourished patients.[75] This recommendation is based on the concept that preoperative nutritional care should be introduced for non–malnourished patients to maintain proper nutritional status throughout the perioperative period.[75] Although a comprehensive definition of "preoperative nutrition" therapy has yet to be described (*i.e.*, it may include immunonutrition, screening tools, and preoperative diet counseling), evidence does suggest that preoperative nutritional optimization contributes positively to patient outcome.

Avoid Preoperative Fasting: Feed Patients with Oral Carbohydrates

Perioperative fasting can exacerbate the surgical stress response,[11] aggravate insulin resistance,[16] exaggerate protein losses,[76] and impair gastrointestinal function.[77] A stable isotope trial, in which patients were randomized to receive hypocaloric PN 20 h preoperatively to avoid fasting or remain fasted until surgical incision, demonstrated that the nutritional support regimen initiated before surgery blunted postoperative proteolysis achieving neutral protein balance on the second postoperative day. The fasted group, in contrast, remained catabolic despite receiving an identical nutrition regimen at the time of surgical incision.[78] Additionally, preoperative fasting is associated with a number of patient-centered consequences including thirst, hunger, headaches, and anxiety.[16] It is now known that preoperative overnight fasting is unnecessary in most cases; clear fluids taken up until 2 h before induction does not increase gastric volumes, therefore poses no risk for aspiration, and in fact has been found to stimulate gastric emptying.[79]

Delivery of sufficient exogenous carbohydrate is considered the best method to induce a metabolically fed state before elective surgery by eliciting an insulin response similar to that observed after ingestion of a meal from approximately 72 pmol/l (12 μU/ml) to approximately 360 to 420 pmol/l (60 to 70 μU/ml).[19,80] The functional purpose of the carbohydrate load is meant to be two-fold: (1) fasting depletes energy reserves before surgical stress onset, whereas carbohydrate loading allows maximal glycogen storage and a metabolically fed state at the start of surgery; and (2) insulin resistance is attenuated, and thus insulin's anabolic actions preserved.[80–83] The mechanism behind this observation has not been fully delineated, although it has been found that the P13K signaling pathway, which interacts with insulin receptor substrate in order to regulate glucose uptake (fig. 2), remains activated and glucose oxidation maintained with this carbohydrate treatment.[19] A recent Cochrane review identified that preoperative carbohydrate treatment for elective surgical patients was associated with a small reduction in length of hospital stay compared with placebo or fasting, but did not affect rates of morbidity.[82] Preparing the patient for

surgery by maximizing energy (glycogen) stores and preserving insulin sensitivity (including insulin's anabolic and anti-inflammatory effect), however, is likely to create a setting in which the patient is better able to withstand the impending surgical insult and better able to utilize the nutrients provided postoperatively.[81]

Carbohydrate loading is typically accomplished with the consumption of 50 g of carbohydrates in the form of a clear liquid 2 h before induction and 100 g the evening before.[7,80] However, the evening dose has recently been questioned[84] as most national anesthesia societies recommend that patients are allowed to eat solids up to 6 h before surgery.[85] For best results, the morning dose should be consumed rather quickly. Indeed, when healthy volunteers consumed 50 g of glucose over 5 min *versus* sipping over 3 h, major differences were found in insulin response. The insulin area under the curve was reduced by 54%,[86] suggesting that sipping at a reduced rate over a longer period of time reduced the need for insulin production, which is not desirable for the preoperative patient. The carbohydrate product most often cited in the literature contains maltodextrin as the main source of carbohydrate. When compared with other carbohydrate polymers or pure glucose, maltodextrin has been found to produce faster gastric emptying, which is thought to be related to its lower osmolality, although this is not entirely accepted in the literature.[87,88]

Future carbohydrate loading guidelines may also incorporate an easily digested protein or insulinotropic amino acids.[89] The combined oral intake of protein and carbohydrate appears to have a synergistic effect that augments insulin concentrations.[89,90] A mixture containing both carbohydrates and amino acids could therefore be used to elevate insulin concentrations before surgery to achieve a metabolically fed state, with the added benefit of supplying amino acids, which have a greater anabolic effect than carbohydrate regimens alone.[91]

Provide Optimal Postoperative Nutritional Care: Achieve Anabolism with Early Oral Feeding and Sufficient Amino Acids

Early Oral Feeding. Anabolism, a positive whole body protein balance, is required for optimal patient recovery after surgery.[62,63] Patients undergoing major elective surgery present with a negative whole body protein balance, generated from an increase in proteolysis, as early as the first postoperative day.[92] The primary goal of perioperative nutritional care is thus the provision of protein to attenuate catabolism as well as maintenance of normoglycemia, adequate hydration, and avoidance of fasting.[62,83] Although perioperative nutritional support is useful in modulating the stress response, the extent to which this is accomplished depends not only on the medical care provided, including ERP, but also the timing, route of delivery, and composition of the nutritional support regimens provided.

Early resumption of oral feeding is now realized to be safe[93] and is associated with a decrease in postoperative complications, length of stay, and costs.[94,95] In fact, several meta-analyses conducted in this area report that feeding within 24 h post–gastrointestinal surgery decreases mortality as well as major morbidity.[96,97] Furthermore, early feeding, compared with standard measures of withholding feeding until return of bowel function, was not found to contribute to anastomotic breakdown or significantly invoke nausea. Although some reports of increased risk of vomiting have been documented with early feeding, these reports are generally made in the absence of multimodal anti-ileus and prophylactic anti–postoperative nausea and vomiting (PONV) therapies of ERP.[7] Currently, ERAS protocols for colorectal surgery recommend oral intake of regular solid food within 24 h of the operation.[7]

Early enteral delivery of nutrients, in particular, is well tolerated, preserves the structural integrity of gut mucosa, reduces bacterial translocation and overgrowth through stimulation of immunoglobulin A secretion and promotion of intestinal contractility, maintains the immunological functions of the gut, and is cost-effective.[77,98] Intestinal epithelial cells are replaced every 4 to 5 days, and luminal exposure to nutrients is required to maintain its structural and functional integrity.[17] Indeed, nutrient delivery that bypasses the gut promotes atrophy of gut-associated lymphoid tissue, which, consequently, generates both systemic and local immune suppression.[77,99] Finally, enteral delivery promotes the use of commensal bacteria, which ferment fiber and other prebiotics producing short-chain fatty acids such as butyrate.[100]

Perioperative enteral delivery promotes glucose utilization, partly through the conservation of insulin sensitivity.[101] Indeed, following abdominal surgery, the use of EN compared with PN requires less insulin to achieve euglycemia and reduces the incidence of hyperglycemia.[102] Although the exact mechanism by which delivery of nutrients by the gut improves glycemia has not been elucidated, it is believed to be in part related to the physiological effect of utilizing the entero-pancreatic-hepatic axis (bypassed during parenteral feeding).[103] The route of delivery appears to be essential in maintaining glucose control. An RCT conducted with esophageal cancer patients who were provided 70% of their requirements peripherally and 30% enterally exhibited improved glycemic control, as a result of enhanced insulin secretion and improved insulin resistance, compared with the patients who received 100% requirements through PN.[104] Moreover, enteral feeding elicited a greater release of gut peptides, including the incretin hormone, glucose-dependent insulinotropic polypeptide. These gut peptides stimulate insulin release and inhibit glucagon secretion.[105]

Amino Acids. Although adequate energy intake has been linked to protein utilization,[106] a number of RCTs have shown that after surgery, anabolism can *only* be achieved with amino acids. Amino acids administered parenterally or orally attenuate postoperative proteolysis[29,91,107] and produce a stimulatory effect on insulin secretion.[108] Indeed, provision of an intravenous glucose infusion has consistently

been ineffective in generating anabolism and in some cases aggravate insulin resistance.[91,109] Hypocaloric nasojejunostomy glucose feedings[61] and oral glucose drinks[109] in the immediate postoperative period have been equally ineffective. Anabolism cannot be achieved in the postoperative period when glucose is administered alone.[91,110,111] Unfortunately, provision of energy alone continues to be at the forefront of surgical nutrition messages. ERP guidelines, for instance, recommend the use of ONS with meals,[7] yet do not specify that protein supplements are ideally suited. Inadequate protein intake is associated with loss of lean mass, which can impair physiologic function, while provision of protein, regardless of whether or not energy requirements are met, can maintain lean mass and reduce the risk of incident frailty in older adults.[112–114] Achievement of anabolism is influenced by the magnitude of the inflammatory response elicited by surgery, insulin sensitivity, nitrogen quantity, quality and digestibility, as well as meal composition and timing, and engagement of physical activity.[34,48,115–118] A detailed review is beyond the scope of this article; however, protein quantity will be discussed.

An injured patient requires more nitrogen than a noninjured patient in order to: (1) heal wounds; (2) support stress-induced acute-phase protein production; and (3) account for the oxidative and catabolic losses produced from amino acid mobilization for HGP.[63] In fact, protein oxidative losses are believed to account for approximately 20% of resting energy expenditure after colorectal surgery.[72,119] Although optimal protein requirements have not been established for surgical patients, several investigators recommend 1.2 to 2.0 g/kg,[120] whereas others recommend 1.5 to 2.0 g/kg per day.[63,74] Unfortunately, in the absence of dietitian support, many patients do not meet protein needs with oral nutrition alone in the immediate postoperative period.[5,62] An institution employing ERP care and a room service cafeteria system found that in the first 3 days post–elective colorectal surgery, patients were able to meet more than 60% of energy requirements when ONS was provided with meals, yet dietary protein intake did not meet this minimally acceptable requirement.[70] Although oral intake after surgery is affected by a loss of appetite, feelings of worry, and other factors,[70] it has been observed that those patients who receive nutrition counseling on the second day post–gastrointestinal surgery, compared with those who do not receive counseling, improve their dietary intake.[5] In fact, these counseled patients consumed 20% more protein to reach a minimally acceptable intake.

Anesthetic Strategies to Facilitate Nutritional Gains and Optimize Metabolic Functions

In addition to optimizing the patient's medical conditions and supporting preoperative feeding strategies (as discussed previously), the anesthesiologist can be involved in nutrition-related perioperative strategies that attenuate metabolic stress and facilitate the restoration of gut function (table 2).

Epidural Blockade Enhances Nutrient Utilization

Epidural blockade is the most widely studied anesthetic technique on surgical metabolism. In the absence of surgery, epidural blockade with bupivacaine does not have an effect on fasting protein, glucose, or lipid metabolism[121]; yet, perioperatively epidural blockade with bupivacaine enhances exogenous nutrient modulation of surgical stress.[122] An effective epidural, established before and continued after abdominal surgery (maintained for 48 h[123]), with the administration of intravenous glucose suppresses endogenous glucose production,[124] improves glucose uptake, and spares protein breakdown,[122] though hyperglycemia persists.[122] The effect appears to be more pronounced with the use of epidural compared with opioid patient-controlled analgesia.[124] The addition of amino acids to the glucose infusion produces an anabolic effect by virtue of blunting postoperative proteolysis.[125] In fact, the provision of exogenous intravenous amino acids alone (*i.e.,* without glucose) is sufficient to elicit a positive whole body protein balance and maintained an average blood glucose of 6.1 mM (110 mg/dl),[91] which is especially useful for the diabetic population.[126] This favorable metabolic outcome might be partially explained by the inhibitory effect of the neural blockade on insulin resistance, thereby conversing insulin's anabolic action and promoting glucose, rather than protein, oxidation.[127] However, amino acid provision in itself appears to favor a positive whole body protein balance regardless of the type of anesthesia used.[128]

Optimize Fluid Dynamics

Judicious perioperative fluid management contributes to a reduction in postoperative ileus and delayed gastric emptying, which permits adequate food intake and rapid recovery.[129,130] Indeed, fluid management aimed to maintain preoperative body weight by replacing actual losses has been found to improve postoperative bowel function and reduce postoperative morbidity.[7] Intraoperatively, circulatory volume and organ perfusion are maintained while avoiding fluid accumulation in respiratory and gastrointestinal tissues (contributing to the development hypoxia and ileus) by sustaining near-zero fluid balance.[131] Evidence suggests that in moderate to high risk patients, monitoring of fluid replacement with individualized goal-directed fluid therapy is appropriate.[132,133] Postoperatively, in the absence of surgical losses, patients are encouraged to drink approximately 25 to 35 ml/kg of water per day beginning 2 h postsurgery.[134]

Multimodal Analgesia and Control of Nausea and Vomiting

Although the use of opioids to relieve postoperative pain is inevitable, several adjuvants are available to spare the use of opioid medication and thus reduce the negative impact on the gastrointestinal system.[7,135] Nevertheless, strategies to avoid PONV, which are often associated with the use of opioids,

Table 2. Contribution of the Anesthesiologist to Nutritional Care

	Implementation	Purpose	Nutritional Status
Avoid preoperative fasting by feeding patients orally with carbohydrates	Typically accomplished with the consumption of 50 g of carbohydrates in the form of a clear liquid 2 h before induction and 100 g the evening before (although it should be noted that the necessity of the evening dose has been questioned)	Carbohydrate loading allows maximal glycogen storage and a metabolically fed state at the start of surgery. Insulin resistance is attenuated and thus insulin's anabolic actions preserved	Promotes glucose, rather than protein, oxidation. This action can spare protein and allow amino acids to be directed toward anabolic, rather than energy, pathways
Enhance nutrient utilization with epidural blockade	Sensory block maintained for 48 h, plus exogenous amino acids and glucose	Interrupts the afferent nervous pathway, thus attenuating the provocation of the hypothalamic–pituitary–adrenal axis and the release of catabolic hormones	Enhances exogenous nutrient modulation of surgical stress by suppressing endogenous glucose production, improving whole body glucose uptake, and attenuating catabolism for an overall anabolic effect
Optimize fluid dynamics	Preoperatively, maintain hydration with clear fluids up to 2 h before induction and avoid routine mechanical bowel preparation. Intraoperatively, sustain near-zero fluid balance. Postoperatively, patients commence oral fluid intake within 2 h postsurgery in order to maintain fluid balance themselves	Circulatory volume and organ perfusion are maintained while avoiding fluid accumulation in respiratory and gastrointestinal tissues (contributing to the development hypoxia and ileus)	Reduced rates of ileus and gastric emptying permit oral food intake
Control nausea and vomiting with multimodal analgesia	Mitigate the opioid effect on gastrointestinal function with aggressive use of antiemetic prophylaxis at the beginning of surgery and continue into the immediate postoperative period	Several adjuvants are available to spare the use of opioid medication and thus reduce the negative impact on the gastrointestinal system	Reduced rates of nausea and vomiting permit oral food intake
Facilitate mobilization	Adequate analgesia to facilitate ease of mobilization	Long-term bed rest produces marked changes in protein metabolism including reduced whole body muscle protein synthesis and resistance of muscle to anabolic stimuli	Mobilization is associated with improved gastrointestinal function, body composition, and oral food intake

need to be implemented. PONV is the most common postoperative complaint (as high as 80% in high-risk patients in the absence of prophylaxis treatment)[136] and results in delayed recovery as well as extended hospital discharge.[137] Evaluation of patient risk factors and aggressive use of antiemetic prophylaxis initiated at the beginning of surgery and continued in the immediate postoperative period has been found to mitigate the opioid effect and accelerate oral intake, which ultimately abates catabolism.[7,135,136] A comprehensive review on this topic can be found elsewhere.[136]

Mobilization

Long-term bed rest, common after surgery, produces marked changes in protein metabolism.[138–141] Indeed, 2 weeks of limb immobilization in healthy men reduced quadriceps lean mass by almost 5%, as determined by dual-energy x-ray absorptiometry analysis, and reduced isometric strength by nearly 30%.[142] Remarkably, 6 weeks of rehabilitation training was required to regain the muscle lost in the 2 weeks of immobilization. Healthy older adults confined to bed rest are particularly vulnerable as just 10 days of bed rest resulted in 0.95 kg loss of lean leg mass, substantial loss of lower extremity strength, power, and aerobic capacity.[138] For an older adult, a period of muscle disuse, as simple as a reduction in daily step count, can accelerate muscle losses.[143] The consequences of skeletal muscle atrophy include prolonged hospitalization and delayed recovery of function as well as poor response to chemotherapy for cancer patients.[141,144]

Early initiation of physical activity, such as walking and light weight-bearing, as part of enhanced recovery or rehabilitation care, is also associated with better gastrointestinal function, improved body composition, oral intake, and successful outcome of ERAS.[7,145,146] Mobilization should therefore be considered an important factor in achieving anabolism, and this can be facilitated with adequate analgesia. Every effort must be made to avoid motor block of the lower limbs if epidural analgesia is used, and thoracic, but not lumbar, epidural is indicated for gastrointestinal surgery.[7] Hypotension can be a limiting factor to early mobilization, particularly during the first postoperative day; however, strategies to minimize hypotension such as optimal

perioperative fluid management, decreasing the amount of epidural administered, and introducing multimodal analgesia can be implemented.[7,147]

Emerging Concepts: Optimizing the Preoperative Period

Glycemic Control

Preoperative glycated hemoglobin (HbA1c) has recently been proposed as a prognostic biomarker in surgical patients.[148] The HbA1c test measures the percentage of hemoglobin that is coated with glucose (*i.e.*, glycated). The average lifespan of human erythrocytes is approximately 100 to 120 days, thus the HbA1c level is representative of the average blood glucose state of the previous 3 to 4 months.[148]

Several retrospective reports reveal that preoperative HbA1c concentration correlates well with postoperative glucose values and that an elevated HbA1c concentration significantly increases the risk of perioperative complications. A prospective observational study of noncardiac surgical diabetic patients found that patients with a preoperative HbA1c more than 7.0% had a greater mean (1.86 mM; 33.5 mg/dl) postoperative glucose concentration than those with HbA1c less than 7.0%.[149] Comparably, the results of a retrospective review of 468 patients who underwent gastric bypass demonstrated that poor preoperative glycemic control was associated with poor postoperative glycemic control. Moreover, a raised mean postoperative glucose concentration was independently associated with morbidity.[150] Gustafsson *et al.*[151] found that colorectal patients with a preoperative HbA1c more than 6.0% had higher mean postoperative glucose and C-reactive protein levels than patients with an HbA1c less than 6.0%. Postoperative complications were also greater in patients with an elevated HbA1c. Finally, an evaluation of a large sample (n = 141,680) of elderly patients hospitalized with acute myocardial infarction identified a dose–response association between elevated admission glucose levels and greater risk of 30-day mortality in patients without known diabetes.[152] Although admission hyperglycemia is believed to be associated with risk, a follow-up study in 16,871 acute myocardial infarction patients identified that mean hospitalization glucose, or persistent hyperglycemia, appears to be a better predictor of mortality risk.[153]

Importantly, presurgical nondiabetic patients represent a population that commonly experiences perturbation in glucose metabolism before surgical insult. A large retrospective study of 39,434 noncardiac patients showed 10% of patients had undiagnosed diabetes mellitus and 11% impaired fasting glucose before surgery.[154] Furthermore, approximately 26% of nondiabetic patients undergoing colorectal surgery were reported to have HbA1c more than 6.0%.[151] Future studies should thus confirm that poor preoperative glycemic control adversely affects outcomes of surgical patients. It would also be necessary to determine in specific surgical populations whether improved glycemic control reduces complications so that cutoff values for specific target populations, cost-effectiveness, and appropriate interventions can be established.

Prehabilitation: Using Nutrition, Exercise, and Stress-reduction Strategies to Enhance Functional Capacity before Surgery

The American College of Surgeons identified functional health status as one of the 15 preoperative variables predicting higher risk in colorectal surgery.[155] Indeed, a number of retrospective and prospective observational studies using cardiopulmonary exercise testing have found that exercise capacity predicts complications after abdominal surgery.[156,157] The requirement for oxygen increases after surgery, and this oxygen demand must be met with an adequate physiologic reserve (ability of organs to function before exhaustion[158]) to increase cardiac output and oxygen delivery.[159] Patients with reduced functional capacity are unable to sustain oxygen delivery at the required level, creating an oxygen debt and putting them at increased risk for complications after surgery. For instance, elderly patients who scored below 11 ml/kg/min on an anaerobic threshold test before surgery were found to have a mortality rate of 18%, whereas those who scored above 11 ml/kg/min were reported to have a mortality rate of 0.8%.[160] Comparably, slower walking capacity before surgery, as measured by the 6MWT, is associated with increased postoperative complications after elective colorectal resection.[161]

Likewise, identification of frailty before an operation might facilitate better care. Quantifying frailty can be done with a variety of measures, and no single measure has been identified as ideal.[162] The most well-known and used measure is the frailty score developed by Fried, which identifies frailty as the presence of three or more out of five criteria—weight loss, exhaustion, weak grip strength, slow walking speed, and low physical activity. The Canadian Study of Health and Aging Frailty Index with the National Surgical Quality Improvement Program data set have identified 11 preoperative variables that have been used to create a modified Frailty Index.[163,164] Items present in the patient's preoperative history are divided by the total 11 items used in the assessment to provide a sense of accumulated deficits from 0 (no items present) through 1.0 (all 11 items present). The risk of both mortality and morbidity has been found to increase for each unit increase in Frailty Index.[164] Further research is required to refine and validate frailty scores for surgical risk as well as establish interventions to improve patient outcome. One such intervention might be *prehabilitation*.[165]

In theory, developing a functional reserve to withstand the stress of surgery, similar to training for a marathon, promotes an earlier functional recovery. In point, observational evidence suggests that patients with higher preoperative lean body mass (reserve) are better able to cope with surgical stress, reporting reduced complications and earlier discharge.[166–168]

The effectiveness of a preoperative program, known as prehabilitation, is currently being evaluated. Prehabilitation[165] employs a multidisciplinary approach to modify behaviors that have an impact on postoperative recovery including smoking, mental wellness, obesity, poor glycemic control, reduced functional capacity, and malnutrition. Indeed, surgical complications are 12 times more likely to occur in obese patients, and preoperative smoking cessation decreases perioperative risk of both pulmonary complications and surgical site infections.[83] The prehabilitation package is delivered at least 4 weeks before surgery as a multimodal intervention involving aerobic and resistance exercise and psychological, medical, and nutritional care with whey protein supplementation.[43,169] Two recent RCTs suggest that prehabilitated colorectal surgical patients experience an earlier recovery of their functional walking capacity, as assessed with 6MWT, compared to standard[43] and rehabilitation treatment.[169] In fact, 84% of patients who received prehabilitation had recovered baseline function by the eighth postoperative week,[169] while 62% of rehabilitated patients had recovered,[169] and only 40% of those patients following standard care had returned to baseline function.[43] Moreover, evidence suggests that patients who improve functional walking capacity over the preoperative waiting period have a better postoperative recovery, regardless of the type of intervention.[170] By contrast, the patients who deteriorate by more than 20 m preoperatively experience a greater rate of complications.[170] Patients must attain a 1.2 m per second gait to be functionally ambulatory in most urban communities,[170,171] which works out to be approximately 60%[170] of each patient's predicted 6MWT value based on age and sex.[172] It is for this reason that this value has begun to be used as an indicator of poor postoperative functional recovery in the colorectal population.[169] Although there is available evidence for the use of 6MWT as a measure of surgical recovery,[41] further study on its preoperative predictive value (and cutoff points) must be conducted.

Although ERP recommendations have been found to greatly benefit rates of morbidity and length of hospital stay, there is very little available evidence indicating that improved functional recovery can be achieved. Patients receiving standard care with or without ERP have been found to recover functional waking capacity at a similar rate. In fact, 41% of non-ERP patients recovered functional walking capacity, measured with the 6MWT, 3 weeks after colorectal surgery,[173] while a separate study indicated that 40% of ERP patients had recovered by 8 weeks after colorectal surgery.[43] Although larger, multicentered trials are required to verify the effects of prehabilitation, a prehabilitation component may be a positive addition to current ERP protocols in the future.

Conclusions

Mobilization of energy reserves following surgery promotes hyperglycemia, which develops as a consequence of insulin resistance coupled with an inappropriately high HGP. Proteolysis and lipolysis accelerate to provide precursors for gluconeogenesis. The resultant amino acid efflux also supports the synthesis of proteins involved in the immune response. Ultimately, an exacerbated response to surgical stress can lead to poor wound healing, infection, a compromised immune status, pulmonary complications, as well as breakdown of lean body tissue that contributes to the development of poor strength, reduced functionality, fatigue, and longer hospital stay. There is a strong realization that many of the consequences associated with surgical stress can be attenuated, thus facilitating the recovery process. Identification of areas of improvement and implementing adequate interventions that abates the response to surgical stress and promotes convalescence requires multimodal, multidisciplinary, collaborative strategies.

The anesthesiologist should encourage the use of carbohydrate loading, as appropriate. Avoiding preoperative and prolonged fasting is an integral component in the achievement of postoperative anabolism due to preservation of energy reserves, promotion of insulin sensitivity, and maintenance of the structure and function of the gut. Future studies should examine the use of insulinotropic amino acids in combination with oral carbohydrates on both gastric emptying rates and insulin resistance. Amino acids are the major determinant of whole body protein balance.

Early initiation of oral intake and optimal postoperative nutritional regimens are essential for early convalescence, but the effectiveness is certainly lost without the ability to tolerate and use the nutrients provided. The anesthesiologist can enhance nutritional outcome and promote early functional recovery by facilitating the tolerance to and utilization of oral nutrients. This is done by minimizing the use of opioids for pain relief and avoiding overhydration fluid strategies, which contribute to postoperative ileus. Moreover, epidural blockade with local anesthetics has been found to augment nutrient modulation of catabolism and encourage normoglycemia.

Table 3. Four Potentially Modifiable Factors to Be Included in Preoperative Risk Assessments

Undernutrition: Nutritional repletion required
NRS-2002[4]: >5*
SGA[63]: C
Weight loss[63]: >10–15% within 6 months
BMI[63]: <18 kg/m^2
Poor functional capacity: Consider prehabilitation
Six-minute walking test[161,169]: <60% of predicted*
Frailty: Consider prehabilitation
Frailty index[164]: Increase in risk for each unit increase in this 11-point frailty index
Fried[162]: Frailty is identified by the presence of three or more components
Poor glycemic control: Appropriate intervention before surgery
HbA1c[157]: >6%*

Predicted six-minute walk test is a calculation based on gender and age.[169,172]

* Based on little available evidence to identify preoperative cutoff value for surgical patients.

BMI = body mass index; HbA1c = glycated hemoglobin; NRS-2002 = nutritional risk screening tool-2002; SGA = subjective global assessment.

Future trials might investigate other modes of regional analgesia (*e.g.*, field block, infiltration, lidocaine infusion), under ERP care, to determine how nutrient metabolism and recovery of both traditional (*e.g.*, length of hospital stay) and patient-centered outcomes (*e.g.*, functional capacity) are affected.

Integrated, multidisciplinary medical strategies, including perioperative nutritional support, attenuate the metabolic response to surgical stress and promote earlier patient recovery of major surgery. It is becoming increasingly evident that these interventions should begin *preoperatively*. The use of appropriate assessments, for instance, that include evaluations of nutritional, functional, and glycemic status before surgery permits patient-specific treatments that can improve metabolic status before surgical insult (table 3). Appropriate postoperative interventions can then maintain the effects gained from the preoperative interventions. It is therefore necessary that the anesthesiologist, as a perioperative physician, becomes actively involved in facilitating these strategies.

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Competing Interests

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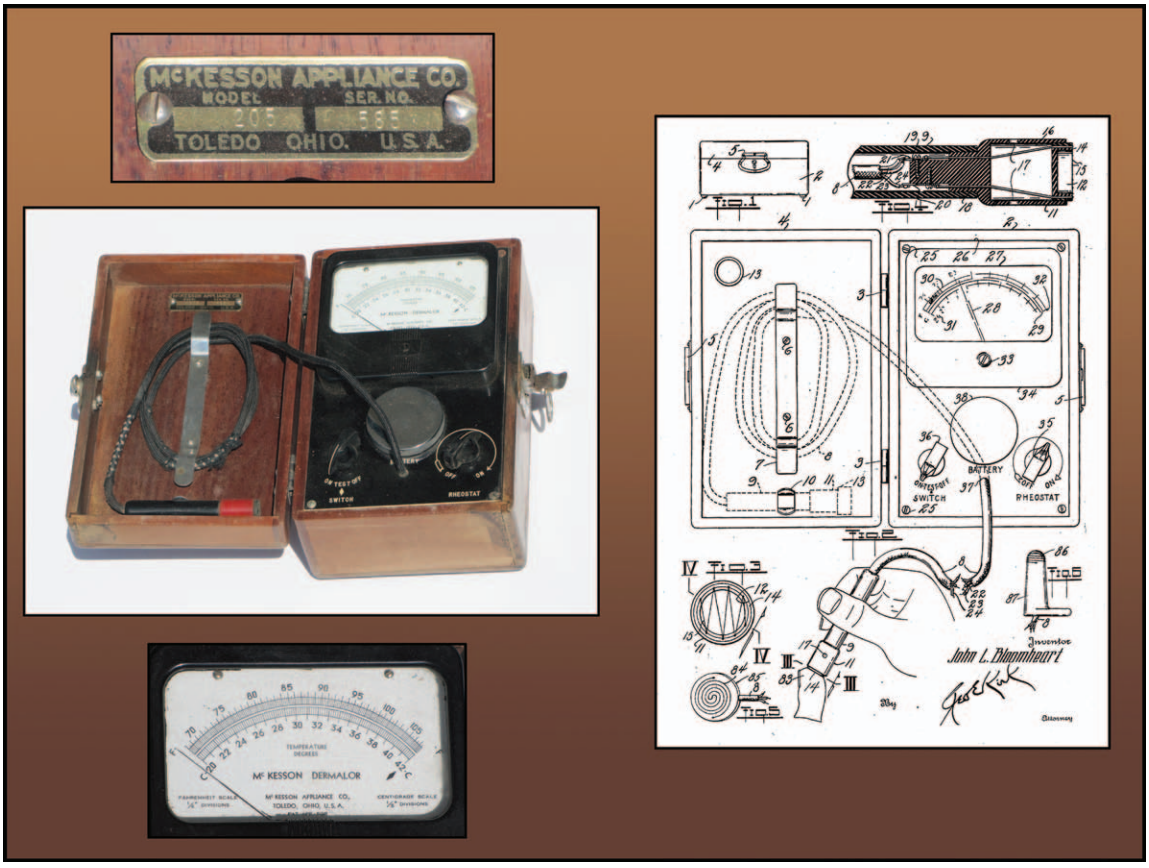
Bloomheart's "Contact Thermometer" Patent: The McKesson Dermalor



From Toledo, Ohio, in April of 1938, inventor John L. Bloomheart filed for a U.S. patent on his "Contact Thermometer." On March 26, 1940, he was granted U.S. Patent No. 2,195,019 (*right*), which noted that he had assigned his rights to Toledo's Martha F. McKesson. She was the widow of Elmer I. McKesson, M.D., who had built much of his reputation on perioperative monitoring of patients' vital signs. Using Bloomheart's patent, the McKesson Appliance Company (plaque, *top left*) produced the wood-boxed "McKesson Dermalor" (*middle left*) for measuring skin or other contact temperature. Using "a Wheatstone bridge including an applicator tool having a high temperature-coefficient of resistance as a first leg thereof," the Dermalor's indicator needle swung through a "CENTIGRADE SCALE" (enlarged, *bottom left*) with 0.2 °C divisions of temperatures ranging from 20 to 42 °C or through the corresponding Fahrenheit range by divisions of 0.25 °F. Besides monitoring the temperature of human patients or veterinary subjects, the battery-operated Dermalor could be used for contact thermometry in the laboratory. (Copyright © the American Society of Anesthesiologists, Inc.)

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