Metabolism in the Trauma Patient

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The Metabolic Response to Trauma

Ebb and Flow

Severe injury and illness results in a complex cascade of metabolic responses that attempt to restore physiologic homeostasis in the injured organism. Sir David Cuthbertson is credited with the original recognition of the stress response in patients that suffered limb injuries. In 1942, he identified that there are two temporal physiologic categories and termed them the "ebb" and "flow" phases. The ebb phase is initiated immediately after the traumatic insult and persists for less than 24 h. This phase is characterized by decreased body temperature, decreased oxygen consumption (VO_2), as well as decreased basal metabolic rate and glucose tolerance [1]. The intended physiologic responses are aimed at reducing posttraumatic energy depletion but this initial response is short lived.

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Thereafter, the "flow" phase ensues. This phase is characterized by a hypercatabolic condition as evidenced by increased consumption of energy and oxygen. This results in elevations of cardiac output, body temperature, glucose production, and increased total body catabolism. Furthermore, mobilization and use of substrates such as glucose, fatty acids, and amino acids increase [2]. This process peaks several days after injury and may return to baseline in a few weeks. However, if homeostasis is not achieved, multiple organ failure develops. This is perhaps a simplified version of the cellular sequence of events that ultimately leads to a cascade of complex reactions, each inciting further autocrine and paracrine reactions.

A more contemporary perspective was recently suggested by Aller and colleagues. They proposed three classifications of phenotypes related to the injury response: the ischemia/reperfusion phenotype, the leukocytic phenotype, and the angiogenic phenotype [3]. The first phenotype represents the nervous system-related alteration in response to injury. Afferent nerve signals from the site of injury result in humoral and neuronal responses and edema. This phase regulates the metabolic supply to cells by diffusion. The leukocytic phenotype is characterized as an intermediate phase of the response to trauma. In this phenotype, leukocytes and bacteria infiltrate edematous, injured tissues. The anaerobic environment results in shock and hypercatabolism and hypermetabolism which leads to the hyperdynamic response including hyperthermia, increased oxygen consumption, glycogenolysis, lipolysis,

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proteolysis, and futile substrate cycling. The third angiogenic phenotype is the late phase and is characterized by a return of oxidative metabolism with resultant angiogenesis, tissue repair and regeneration. Though, this staging system is likely a superficial representation of these innumerable complex biochemical interactions [4].

Catabolic Response to Trauma

Traumatic injury induces inflammatory and hormonal responses that change metabolic processes and alter nutrition requirements. The stress response evolves temporally as the patient moves through the ebb and flow phases and into the rehabilitative period. Although initially beneficial, the exaggerated and prolonged inflammatory, metabolic and catabolic responses induce clinical complications, delay recovery, and increase morbidity. Nevertheless, these are part of a systemic reaction that encompasses a wide range of endocrine, immunologic, and hematologic effects. Surgery initiates changes in metabolism that can affect virtually all organs and tissues. The metabolic response results in hormone-mediated mobilization of endogenous substrates that leads to stress catabolism. Hypercatabolism has been associated with severe complications related to hyperglycemia, hypoproteinemia, and immunosuppression. Proper metabolic support is essential to restore homeostasis and ensure survival [5].

During this initial catabolic stage, metabolic changes are best understood as redistribution of macronutrients from labile reserves to more active tissues for host defense, visceral protein synthesis, and heat production. Hyperglycemia is due to increased hepatic glucose production and peripheral insulin resistance in skeletal muscle. Lipid metabolism increases and results in fatty acid recycling, hypertriglyceridemia, increased lipolysis, and hepatic steatosis. Skeletal and muscle catabolism results in depletion of lean body mass, as glutamine becomes the preferred energy substrate for enterocytes. Hepatic protein synthesis shifts to production of acute phase reactants [6].

Significant basal metabolic rate elevations occur in patients with over 30 % or more of total body surface area involved. Inflammatory, hormonal, and stress signaling mechanisms drive this hypermetabolic response including elevations of circulating catecholamines, glucocorticoids, and glucagon. This subsequently results in gluconeogenesis, glycogenolysis, and protein catabolism. Insulin resistance and peripheral lipolysis increase as well [6]. Patients with major injuries that do not receive adequate nutrition can develop cumulative caloric and protein deficits leading to increased incidence of infection and organ failure. Early enteral nutrition is recommended as prospective randomized controlled trials have clearly demonstrated the positive effect of early enteral nutrition regarding infection rates, duration of hospital stay, and improved overall outcome [7].

The net effect of these pathways is the liberation of peripherally stored substrates to meet the increased energy requirements due to the stress response. The fatty acids liberated provide an energy source for cardiac and skeletal muscle as well as the liver and additional tissues. The majority of amino acids are shuttled to synthesize acute phase proteins and act as substrates for thermogenesis and tissue repair. Once the cellular homeostasis is achieved, anabolism becomes the dominant phenomenon [8]. Hypercatabolism occurring after a burn, trauma, or septic events culminates in acute protein malnutrition, ultimately resulting in multiple organ failure. Nutritional support may prevent this cascade of events from leading to MOF and death.

Neuroendocrine Response to Trauma

Part of the initial response to injury is the stimulation of the hypothalamic–pituitary–adrenal axis. Immediately following injury, a cacophony of afferent neural signals are sent to the hypothalamus and the hypothalamus subsequently signals the pituitary to release hormones. Stimulation of the adenohypophysis results in increases of adrenocorticotropic hormone (ACTH) and growth hormone (GH). The ACTH released

circulates and stimulates the adrenal glands to release cortisol. Cortisol is a catabolic hormone that mobilizes energy stores to prepare the body for the "fight-or-flight" response. The normal feedback inhibitory mechanisms fail due to stress and an unregulated, hyper-response occurs. The release of cortisol results in hyperglycemia by stimulating the liver to increase gluconeogenesis. This leads to increased blood glucose levels. Hyperglycemia is detrimental and reduces the rate of wound healing, increases the incidence of infections and may contribute to sepsis, ischemia, and death. Additionally, the rate of protein breakdown exceeds that of protein synthesis and results in the net catabolism of muscle proteins to provide substrates for gluconeogenesis. Moreover, lipolysis provides further substrates for gluconeogenesis with the breakdown of triglycerides into fatty acids and glycerol [6].

The release of growth hormone from the pituitary results in propagation of the insulin-like growth factors. Signaling via these effectors regulates catabolism by increasing protein synthesis, reducing protein catabolism, and promoting lipolysis. Similar to cortisol, GH increases blood glucose levels by stimulating glycogenolysis. The anti-insulin effects of GH amplify the hyperglycemic effects [9].

Moreover, stimulation of the neurohypophysis results in the release of vasopressin. Its antidiuretic effects are due to stimulation of the aquaporin channels into the renal tubule. These channels result in the reabsorption of water from the renal tubule back in the systemic circulation and acts to conserve hydration and blood pressure in the setting of hypotension. Additionally, pain alone can stimulate the release and effects of vasopressin [10].

Trauma patients have an impaired capacity to oxidize glucose, and glucose infusion is less effective as a means of suppressing endogenous glucose production. Moreover, trauma patients have a high rate of consumption of host tissue for gluconeogenesis and the capacity to directly oxidize glucose increases. Injured patients are heavily reliant on fat as an energy substrate with an increased rate of fatty acid oxidation. Additionally, there is a net protein loss. Furthermore, the hormonal response to trauma results in increased plasma insulin and cortisol levels. The metabolic and hormonal response collectively results in trauma patients developing hyperglycemia. Although the direct oxidation of plasma glucose to CO_2 is lower in trauma patients, Cori cycling is enhanced and the net result is an inefficient use of carbohydrate. The liver has a limited ability to suppress glucose production which can result in hyperglycemia and glycosuria. Moreover, trauma patients are additionally relatively resistant to the action of insulin [11]. These combined occurrences contribute to hyperglycemia in the injured patient.

While hyperglycemia has been associated with poor outcomes in patients with critical illness, the ideal goal glucose level is hotly debated in the critical care literature. Hyperglycemia could reflect an adaptive, beneficial response to critical illness proportionately to the severity of illness, or alternatively, it could induce complications, as in diabetes mellitus, and therefore contribute to adverse outcomes. In 2001, Van Den Berghe et al. found that maintaining a blood glucose level at or below 110 mg/dl reduces mortality amount of critically ill patients in the surgical intensive care unit [12]. Subsequent studies revealed that this strict glucose control was associated with episodic hypoglycemia, which similarly negatively affected patient outcomes [13]. The NICE-SUGAR trial found that intensive glucose control increased mortality among adults in the intensive care unit (ICU). Furthermore, this study revealed that a blood glucose target of 180 mg or less per deciliter resulted in lower mortality than did a target of 81–108 mg/dl [14]. Further randomized controlled trials to assess the impact of preventing and/or treating hyperglycemia as compared with tolerating hyperglycemia in severely injured patients are necessary.

In traumatic brain-injured patients, hyperglycemia is indicative of the severity of injury. In this subset of trauma patients, the mechanism for poor outcomes is associated with the conversion to anaerobic metabolism after acute injury. This results in a buildup of brain tissue lactic acid

which leads to secondary brain injury. Findings from a retrospective study by Liu-DeRyke et al. suggested that a glucose level ≥160 mg/dl within the first 24 h of admission following traumatic brain injury is associated with poor outcomes irrespective of severity of injury [14].

Additionally, numerous other studies have corroborated that hyperglycemia is associated with poor outcomes and that tighter glucose control may improve outcomes [15–19]. Prospective trials are necessary to determine the optimal level for glucose control in traumatic brain-injured patients.

The Cytokine Response to Trauma

Multiple organ failure is the leading cause of morbidity in the ICU following trauma. Injury and stress result in a constellation of signs and symptoms known as the systemic inflammatory response syndrome (SIRS). The term "SIRS" was established to differentiate sepsis from a noninfectious, inflammatory cause [20]. SIRS was defined as two or more of the following conditions: temperature >38 °C or <36 °C, heart rate greater than 90 beats/min, respiratory rate greater than 20 breaths per minute or $paCO_2$ lesser than 32 mm Hg, or white blood cell count > 12,000 or < 4,000, or > 10 % bands. SIRS could represent the symptoms from an infectious or noninfectious source. The pattern of changes seen in plasma proinflammatory and anti-inflammatory cytokine concentrations is similar for sepsis and trauma. The remarkably similar metabolic sequelae seen in critically ill patients following the onset of severe sepsis or major trauma may constitute a universal response to the induction of the systemic inflammatory response syndrome [21]. Multiple Organ Failure (MOF) is defined as the presence of altered organ function in an acutely ill patient such that homeostasis cannot be maintained without intervention and is the culmination of septic shock and multiple end-organ failure. Effectively, MOF is the end of a continuum that ranges from SIRS to severe organ dysfunction.

The subsequent balance between the proinflammatory (SIRS) and anti-inflammatory response has been referred to as the mixed antagonistic response syndrome or MARS [22]. If the balance of these two systems is disturbed, the inflammatory response becomes systemic and deregulated. The result is whole-body activation of the inflammatory response, with resultant disruption of normal cellular metabolism and microcirculatory perfusion. Both of these responses, if unchecked, can result in complications, the former leading to MOF and the later secondary infections. At the site of injury, endothelial cells and leukocytes coordinate the local release of mediators of the inflammatory response, including cytokines interleukins, interferons, leukotrienes, prostaglandins, nitric oxide, reactive oxygen species, and products of the classic inflammation pathway. It is this functional biologic response that becomes unregulated and leads to MOF [23, 24].

Genetic factors also play a role in determining the severity and progression of organ failure. Genetic variants, particularly single-nucleotide polymorphisms (SNPs), are critical determinants for individual differences in both inflammatory responses as well as clinical outcomes in trauma patients. Individuals who possess specific genetic polymorphisms in genes controlling the synthesis of cytokines or toll-like receptors (TLR) may be predisposed to excessive inflammatory response to sepsis which increases their risk for the development of MODS. For example, toll-like receptor 9 (TLR9) signaling plays an important role in the innate immune response. Trauma patients with SNPs of TLR9 have been found to have a greater responsiveness of their peripheral blood leukocytes as well as a higher risk of sepsis and multiple organ dysfunction. These functional polymorphisms involved in innate immunity predispose patients to severe infections and death [25].

Moore and colleagues demonstrated that MOF follows a bimodal distribution [26]. It may be initiated by trauma, burns, infection, or inflammation. Early MOF was defined as organ failure that developed within 72 h of the initial diagnosis of sepsis and late MOF as organ failure that developed after 72 h. Multiple theories exist regarding the cause for MOF and it is likely that these pathways overlap to cause initially organ insufficiency which, unless reverses, ultimately leads

to failure. Although there are multiple hypotheses to explain the cause of MOF, the cytokine hypothesis and the gut hypothesis are most relevant to trauma patients [27]. The "true" physiologic process is likely a combination of multiple hypotheses.

The Cytokine Hypothesis of MOF

In the cytokine hypothesis, the immune response to infection or inflammation results in excessive or prolonged activation or stimulation of mediators. These include interactions between polymorphonuclear neutrophils (PMNs), endothelial cells, and macrophages. PMN stimulation results in "priming" of the neutrophil and can lead to overzealous production, surface expression, and liberation of cytokines [28]. These mediators often have an exaggerated response and the products of these cascades exert damaging local and systemic effects. Cytokines predictive of MOF in trauma patients include inducible protein (IP)-10, macrophage inflammatory protein (MIP)-1B, interleukin (IL) IL-10, IL-6, IL-1Ra, and eotaxin [29]. Several lines of evidence support the central role of inflammatory cells in the pathogenesis of lung and systemic organ injury. Tumor necrosis factor (TNF) has been considered one of the most potent proinflammatory cytokines identified in SIRS and sepsis. Administration of TNF to experimental animals creates the hemodynamic and metabolic observations consistent with SIRS. Analysis of cytokine serum biomarkers has shown that patients with MOF show a biphasic elevation of IL-6 and significantly higher soluble TNF receptor (sTNF-R) concentrations [30]. Activation of leucocytes and their subsequent inappropriate sequestration in organs appears to additionally be one of the key events in the development of early MOF. Once activated, leukocytes have the capacity to release their cytotoxic factors including nitric oxide and lysosomal granules, which aid in polymicrobial killing. These factors can cause necrosis and inflammation of organs, such as the lung, despite a lack of an infectious stimulus. Additionally, PMN stimulation provokes endothelial and epithelial injury through up-regulation of adhesion molecules on these cells. This prompts changes in the cell wall leading to increased permeability and cell swelling that culminates in cellular dysfunction.

Gut Hypothesis of MOF

The gut is considered an immunologically active organ and a main barrier in the burden of infection-induced systemic inflammation. Gut barrier dysfunction can occur for a variety of reasons including trauma, shock, infection, and malnutrition. It is proposed that, as a result of the loss of the gut barrier function, intestinal bacteria and endotoxin cross the mucosal barrier and lead to exposure of the intestinal immune cells. The production of gut-derived toxins and inflammatory products reach the systemic circulation through the intestinal lymphatics, leading to SIRS and MOF [28]. These translocating bacteria are phagocytosed by intestinal immune cells and contribute to the intestinal inflammatory response. Some of these translocating bacteria or their toxic products are trapped in the intestinal lymph nodes, causing inflammatory reaction. This hypothesis is supported by the demonstration of circulating levels of endotoxin in the peripheral blood of critically ill patients with sepsis and SIRS. Reports of endotoxemia in these critically ill patients, even without clinical or microbiologic evidence of infection with Gram-negative organisms supports the potential role of translocation in the production of MOF [31]. The phenomenon of bacterial translocation however, is not sufficient to explain the development of MOF. The development of MOF in these high-risk patients is likely due to intestinal dysfunction and the resultant inflammatory cascade that reaches the systemic circulation via the intestinal lymphatics. The use of early enteral nutrition is known to reduce infectious complications after trauma and it thought to work by maintaining the gut barrier.

Nutrition in the Trauma Patient

Once an association between MOF and persistent hypermetabolism was realized, it was proposed that early administration of exogenous substrates to meet the increased metabolic demands would slow the development of acute protein malnutrition and improve patient outcomes. In the early 1970s, total enteral nutrition (TEN) was initially favored as it was inexpensive and readily available. However in the early 1980s, enteral nutrition was delayed until the gastrointestinal tract was clearly functioning and simultaneously, total parenteral nutrition (TPN) became more available and became the preferred route of nutrition administration in critically ill patients. In the late 1980s, it became clear that enterally delivered nutrition was better utilized and did not result in the hyperglycemia associated with TPN. Over the 1990s more data emerged supporting the relationship between nutritional support, gut function and MOF [32]. In addition to preventing acute protein malnutrition, TEN promotes normal gut function, and enhances systemic immune responsiveness, thereby preventing nosocomial infections [33]. A number of studies in the severely injured patient have substantiated the positive effect with regards to decreased infections, shorter hospital stays, and improved overall outcomes [34–36].

Estimating Nutritional Needs

The catabolic response to injury increases caloric requirements in the trauma patient due to increased metabolism and elevated nitrogen losses. These needs are increased over baseline by approximately 25 % in skeletal trauma, 50 % in sepsis, and 75–100 % in severe burns. Estimated needs range between 25 and 30 kcal/kg adjusted body weight and approximately 1.5 g protein/kg. However, predictive equations are less accurate in determining resting energy expenditure, especially in obese patients [37]. Indirect calorimetry remains the most accurate means for determining caloric requirements, though specific studies in trauma patients are lacking. Efforts should be made to provide approximately 85 % of goal calories by the enteral route over the first week of hospitalization.

Nutritional Assessment

Nutritional assessment in the ICU population should begin with a thorough history and physical exam focused on identifying clinical signs of malnutrition. A pre-injury history of recent weight loss or poor oral intake signals the need for early aggressive nutritional support. While provision of enteral nutrition is the preferred method of delivery, the overall hemodynamic status of the patient must be taken into consideration. The development of ischemic bowel is a rare but potentially fatal complication of enteral nutrition, occurring in <1 % of all patients [38]. Therefore intravascular volume depletion should be reversed prior to the initiation of enteral nutrition. This is especially true in patients that are receiving vasopressors [37].

Monitoring the Response to Nutritional Supplementation

Once nutritional support has been initiated, it is important to perform routine monitoring to assess the adequacy of the nutritional support that is being delivered and make modifications when necessary. Numerous diagnostic tests exist that can be utilized to assess nutritional adequacy. These include body measurement testing (weight change, anthropometric measures), body composition testing (determination of percent body fat, lean body mass, etc.), and laboratory testing (urine analysis, pre-albumin, etc.). In the setting of critical illness there can be short-term alterations in patient's fluid status, rendering the body composition testing inaccurate. Serum proteins are often measured to help assess for nutritional adequacy. Pre-albumin is commonly used due to its short half-life of 2–4 days. In the critically ill patient, it is important to note that the serum prealbumin level may be increased in patients with

renal failure or in patients receiving corticosteroids. On the other hand, with ongoing stress pre-albumin may be artificially low. The body reprioritizes hepatic protein synthesis away constitutive proteins such as pre-albumin to acute-phase reactants such as C-reactive protein (CRP). CRP is a sensitive acute phase reactant that increases from a normal level to 20–30 within 48 h of injury. Its elevation can be used as an indicator of the severity of injury or inflammation. When the levels begin to decline, the liver can again begin to synthesize constitutive proteins such as albumin, pre-albumin, and transferrin. Therefore, the use of serum pre-albumin to assess nutritional adequacy is of limited use until there is resolution of the acute phase response as documented by a drop in CRP. Lastly, pre-albumin levels may be decreased in patients with liver disease, those patients receiving hemodialysis, and patients with severe hyperglycemia.

Potential Modulators of Metabolism

Glutamine

Glutamine is a conditionally essential nutrient in states of serious illness or injury. It is the preferred fuel source for the enterocyte and the small intestine is the principal site for glutamine absorption. In addition to glutamine's gut protective effects, glutamine is also important in nucleotide synthesis; it is anti-catabolic, has antioxidant properties via metabolism to glutathione, and may enhance immune responsiveness [39].

There have been extensive studies on the effect of supplemental glutamine added to enteral formulas or as an isolated pharmaconutrient, though few specifically in trauma patients [40]. An updated meta-analysis examining the results of enteral glutamine supplementation in critically ill patients noted a modest treatment effect but with wide confidence intervals and the presence of heterogeneity across the studies [41, 42]. The largest effect on mortality was attributable to one study in burn patients [43], while the decrease in infectious complications was attributed to the study by Zhou et al. in burn patients and by Houdijk et al. in trauma patients [44, 45]. Recently, Heyland et al. in a blinded 2×2 factorial trial involving 40 international ICUs, randomized 1,223 critically ill, mechanically ventilated, adult patients with multiorgan failure to glutamine supplementation or no glutamine and antioxidants or no antioxidants [46]. There was increased harm associated with glutamine supplementation. The authors attribute this to two observations. First critical illness is not necessarily associated with a low plasma glutamine level as was believed. They actually reported supra-normal levels of plasma glutamine in 15 % of patients prior to any treatment. Secondly, previous studies reporting beneficial effects of glutamine were performed in less ill patients. Based on these results it is recommended that any patient in multiorgan failure in the ICU should not receive glutamine. For trauma and burn patients not in multiorgan failure, consideration can be given to providing enteral glutamine enterally [47].

Arginine

Arginine is a semi-essential amino acid obtained both from dietary sources and endogenous synthesis. Under nonstressed conditions, arginine contributes to adequate wound healing, an enhanced immune response, and stimulation of various anabolic hormones. L-arginine is also a unique substrate for the production of nitric oxide (NO). Sustained production of nitric oxide is thought to be a major contributor to the deleterious effects of post-injury inflammation and the reason for caution when utilizing arginine in patients with sepsis [39].

The metabolic fate of arginine is determined by nitric oxide synthase or arginase, depending on the immune state of the host and associated cytokine expression. In T-helper-1 immune states, such as sepsis, iNOS expression is preferentially expressed. In trauma, a T-helper 2 immune state predominates which increases arginase I expression. Ochoa et al. demonstrated that peripheral mononuclear cells of trauma patients have increased arginase-1 expression, corresponding to increased immune cell arginase

activity and decreased plasma arginine and citrulline levels [48]. Supplemental arginine may therefore be beneficial in trauma patients by altering metabolic pathways in immune cells that leads to reduced nitric oxide production in the post-injury period.

However, a recent update in criticalcarenutrition.org concluded that there was a lack of a treatment effect with respect to mortality and infections [41], similar to those in a recent meta-analysis of immunonutrition in ICU, trauma, and burn patients [49]. Therefore, given the possible harm in septic patients the use of arginine was not recommended in critically ill patients.

Nutritional Challenges in the Trauma Patient

There are a number of nutritional challenges posed by the trauma patient. These can include the institution of enteral feeds as well as the advancement and continuation of feeds. The institution of feeds may be delayed in patients undergoing prolonged resuscitation or damage control laparotomy. This is particularly true after a bowel resection with the bowel ends left in discontinuity. In general, these patients should return to the operating room in 24 h for reestablishment of gastrointestinal continuity and placement of a feeding tube. Feeds can then be instituted in the immediate postoperative period.

There have now been several studies examining the potential benefits of feeding patients with an open abdomen after a damage control laparotomy, though results are not consistent. Both fascial closure rates and ventilator-associated pneumonia rates have yielded conflicting results [50–52]. A recent study by Burlew et al. examined feeding practices in 597 patients who required an open abdomen after trauma, the vast majority of which were following a damage control operation [53]. Less than half the patients received EN initiated before abdominal closure, suggesting an opportunity for improvement. When comparing patients that received EN to those that were nil per os (NPO), logistic regression demonstrated no association between EN and complication rates but there was an association between EN and decreased mortality. In patients without a bowel injury, EN was associated with a higher fascial closure rate, decreased complication rates, and decreased mortality. EN for patients with bowel injuries did not affect outcomes in this retrospective study however this high risk subgroup of patients is now being studied prospectively by the same group.

For patients with a recent bowel anastomosis, evidence not only demonstrates safety of this practice but potential benefit as well, though there are no studies specific to trauma. A recent meta-analysis performed by Osland et al. reviewed 15 studies involving over 1,200 patients comparing surgical outcomes following the administration of nutrition proximal to a gastrointestinal anastomosis within 24 h of gastrointestinal surgery [54]. There was a significant reduction in total postoperative complications with no negative outcome on mortality, anastomotic dehiscence, or return of bowel function. It is our practice to initiate/resume enteral feeds in the immediate postoperative period following a gastrointestinal anastomosis.

Lastly, many trauma patients require frequent trips to the operating room for abdominal washouts and closure attempts, washout and debridement of open fractures and wounds, and post-injury complications. With few exceptions, feeding tubes should be considered at the time of take back in patients requiring damage control laparotomy. The use of guided placement of gastric or small bowel feeding tubes can provide prolonged access for even the most critically injured patient. The traditional use of NPO after midnight [55] in these patients poses a real risk of feeding inadequacy and malnutrition. Fear of aspiration or reflux in critically injured trauma patients has perpetuated this practice. Additionally, procedures are frequently delayed or postponed, leaving the patient without nutrition for extended periods of time. There are several potential ways to improve nutritional delivery in these patients. First, most anesthesia policies permit the use of enteral feeds until the time of operation if a post-pyloric feeding tube is in place. Second, recent data suggest that enteral feeds can similarly be

safely administered until the time of surgery in trauma patients receiving gastric feeds. Pousman et al. found a trend towards improved nutrition delivery with no increase in adverse outcomes including aspiration [56]. Enteral feeds have also been safely administered to burn patients during operative procedures without a significant increase in infective complications [57]. Even in the noncritically injured patient, the use of supplemental EN should be considered if frequent operating room trips are anticipated.

In summary, it is appropriate to attempt to provide judicious EN in patients with recent bowel anastomosis, open abdomens, and even through periods of ileus [50, 52, 58, 59]. Attention to early placement of feeding tubes and institution of enteral nutrition should be strongly considered in critically injured patients.

Nutritional Adequacy in the Critically Injured Trauma Patient

Despite the known benefits of early enteral nutrition in the critically ill, evidence clearly shows that ICU patients are significantly under fed [60]. For the trauma patient, this practice translates into reduced muscle mass and strength, reduced function, and prolonged recovery. Heyland et al. demonstrated in their large international nutrition survey involving 167 intensive care units (ICUs) in 2,772 mechanically ventilated patients that patients received an average of only 1,034 kcal/day and 47 g protein/day. Importantly, an increase of 1,000 cal/day was associated with reduced mortality and an increased number of ventilator-free days [61]. The effect of increased calories and protein was associated with lower mortality in patients with a body mass index of <25 and surprisingly ≥35. These findings formed the basis for the TOP UP (A Randomized Trial of Supplemental Parenteral Nutrition in Under and Over Weight Critically Ill Patients) study, which is an on-going prospective randomized study examining the use of supplemental parenteral nutrition in critically ill mechanically ventilated patients receiving enteral nutrition. Trauma patients with their risk factors for gut dysfunction and thus underfeeding are ideal for the study.

We recently examined feeding practices in critically injured trauma patients from an international database involving 355 ICUs and 8,838 critically ill adult patients mechanically ventilated within 48 h that remained in ICU for more than 72 h [62]. Patients admitted with a trauma diagnosis (10 % of the total population) were identified and nutritional practices and clinical outcomes were compared between trauma and nontrauma patients. More trauma patients received enteral feeding than non-trauma patients. The majority of patients were fed by the enteral route, 81 % in patients with traumatic injuries and 78 % in the non-trauma patients. Trauma patients were prescribed more calories and protein compared to non-trauma patients. However, nutritional adequacy, calculated daily as the percent of received/prescribed calories or protein, and was low in both trauma and non-trauma patients. Trauma patients had a cumulative deficit of 43.0 % in calories and 47.4 % in protein. Our highest risk trauma patients are receiving less than half of their estimated needs, suggesting that the benefits of early EN are being mitigated by our feeding practices.

The existence of malnutrition preoperatively or the deterioration of nutrition status through the perioperative period is a well-recognized factor increasing postoperative complications and hospital length of stay [63]. But unlike guidelines to optimize intraoperative conditions and reduced complications, little attention has been paid to standardizing nutrition management [64, 65]. In the elective surgical patients, there is a recent new appreciation of the role of perioperative nutrition therapy with an emphasis away from the prevention of malnutrition to attenuating oxidative stress, reducing inflammation, and modulating the metabolic response to planned surgical stress [66]. When feasible, it is recommended that malnourished patients forego elective surgical procedures and undergo a period of preoperative nutritional repletion. Unfortunately, in trauma, we do not have the ability to provide preoperative nutrition or base surgical procedures on nutritional risk. Therefore, we need to focus our attention and efforts to optimizing postoperative nutrition.

Critically Injured Elderly

Critically injured elderly patients and their metabolic requirements represent a unique set of problems. Malnutrition is more common among the elderly compared to younger patients and is associated with poor outcome. The reported incidence of malnutrition in the elderly ranges from 1 to 5 % in the community setting but up to 20 % in the hospitalized elderly [67–69]. Many elderly are presenting malnourished at the time of injury and are thus at higher risk than younger patients. Additionally, the elderly have lower muscle mass and are at risk for further loss after injury. Maintaining muscle mass is important for sustaining key metabolic processes such as glucose homeostasis and immune function. When differences between elderly and non-elderly trauma patients were examined using our international database [70], the elderly were found to have similar BMIs compared to younger patients. Interestingly, only 2 % of the elderly were underweight, similar to younger patients, while 54.4 % were overweight or obese. Despite similar BMIs, elderly trauma patients were prescribed fewer calories and protein than younger patients. Both groups had low nutritional adequacy.

Sarcopenia, or low muscle mass, is also associated with worse outcomes in critically ill surgical patients [71–73]. Importantly, sarcopenia increases with advanced age, as does the incidence of postoperative complications. A recent report by Sheetz et al. demonstrated that sarcopenia was associated with high payer costs and negative margins after major surgery [74]. A number of modalities have been used to calculate muscle mass, including X-ray absorptiometry (DXA), computed tomography (CT), and magnetic resonance imaging (MRI). Although DXA may be ideal for whole-body composition analysis, the use of CT scanning is more applicable for the trauma patient as CT scans are frequently performed at the time of injury [75, 76]. Single slice CT images in the 3rd lumbar region can predict whole body muscle and adipose tissue volume in healthy [77] and disease [78] populations.

We conducted a study of severely injured elderly patients admitted to the ICU and found at the time of admission, 71 % were sarcopenic based on admission CT scans [79]. Importantly, patients identified as sarcopenic had significantly increased mortality and decreased ventilator-free and ICU-free days. Interestingly, despite the frequency of sarcopenia in our injured elderly population, 7 % of the patients were underweight, while 37 % were normal weight and 57 % were overweight/obese by body mass index. Neither BMI nor serum albumin on admission were predictive of survival, ventilator-free days, or ICU-free days. This study suggests that at risk patients may be overlooked using traditional indicators of nutritional status such as weight and body mass index. Muscularity therefore represents a potential new marker for risk of mortality and increased length of stay but more importantly may allow the early identification of patients who may benefit from aggressive nutritional and rehabilitative interventions.

Given the impact of ICU-acquired muscle weakness on clinical outcomes, recent research has focused on noninvasive methods to measuring muscle thickness. Although CT scanning is accurate and scans are typically available for trauma patients, calculation of muscle mass using CT scans is time consuming and not universally available. Additionally, a noninvasive tool to be able to follow critically injured and ill patients over time in the ICU could prove valuable. The use of ultrasound to measure the rectus femoris muscle thickness has been proposed [80, 81]. We recently examined the use of US in normal healthy volunteers and found excellent intra- and inter-reliability in the US measurements [82]. Further evaluation of this technique is required to evaluate the validity and clinical utility in critically ill patient and such studies are underway.

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