

*Review*

## **Military nutrition: maintaining health and rebuilding injured tissue**

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Food and nutrition are fundamental to military capability. Historical examples demonstrate that a failure to supply adequate nutrition to armies inevitably leads to disaster; however, innovative measures to overcome difficulties in feeding reap benefits, and save lives. In barracks, UK Armed Forces are currently fed according to the relatively new Pay As You Dine policy, which has attracted criticism from some quarters. The recently introduced Multi-Climate Ration has been developed specifically to deal with issues arising from Iraq and the current conflict in Afghanistan. Severely wounded military personnel are likely to lose a significant amount of their muscle mass, in spite of the best medical care. Nutritional support is unable to prevent this, but can ameliorate the effects of the catabolic process. Measuring and quantifying nutritional status during critical illness is difficult. A consensus is beginning to emerge from studies investigating the effects of nutritional interventions on how, what and when to feed patients with critical illness. The Ministry of Defence is currently undertaking research to address specific concerns related to nutrition as well as seeking to promote healthy eating in military personnel.

**Keywords:** military; operational ration packs; nutrition; critical illness

### **1. INTRODUCTION**

Nutrition and the military are fundamentally entwined. Without a regular supply of food and water, no army can hope, or expect to successfully prevail in its principal role: warfighting. Appropriate food, in terms of both quality and quantity, and adequate hydration are required to ensure that the physical capacity and mental performance of military personnel remain at optimal levels. Nutrition is a major contributor to the wound healing process in those who are injured, as well as influencing their subsequent recovery and rehabilitation.

This paper will initially present a brief historical overview of the military's understanding of the importance of good nutrition, before then discussing current UK feeding policy for military training and on operations. The role of nutrition in wound healing will be considered in relation to the current paucity of data to inform clinical dietetic practices in trauma medicine. Finally, this paper will introduce contemporary work that is addressing these knowledge gaps, with the aim of providing an evidence base to inform future clinical nutrition interventions.

### **2. THE HISTORY OF MILITARY NUTRITION**

There are many examples in history that illustrate the impact of feeding provision on the success (or otherwise) of military campaigns.

Scurvy was responsible for the loss of more sailors than enemy action in the eighteenth century. During Lord Anson's circumnavigation of the world (1740–1744), 636 of 961 sailors in his fleet died [1]. While serving as ship's surgeon on board *HMS Salisbury* in 1747, James Lind, Royal Navy (RN), famously undertook the first prospective interventional trial, investigating the treatment of scurvy. 'A Treatise of the Scurvy' was published in 1753, recommending that citrus fruits were used to treat and prevent scurvy in the RN [2]. In 1776, Captain James Cook RN wrote in the *Philosophical Transactions of the Royal Society* that the addition of malt, sauerkraut and wild celery to the diet, along with strict adherence to cleanliness and a regular supply of fresh water aboard ship, meant that not one crew member succumbed to scurvy during the 3 year voyage of the *Resolution* (1772–1775) [3].

Preservation of food during long voyages remained a problem until 1800 when a French chef, Nicolas Appert, responded to Napoleon Bonaparte's offer of a 12 000 franc reward for inventing a means of preserving food for the military. Appert used airtight glass containers, laying the foundation for pre-packaged food. Appert's idea was further developed by

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Pierre Durand, a British merchant, who developed tin-covered iron canisters in 1810. Three years later, the British Army and the RN were supplied with food preserved in tin cans.

Napoleon is also credited with coining the phrase 'an army marches on its stomach'. This mantra was dramatically highlighted during his failed invasion of Russia in the summer of 1812. Napoleon's army numbered 600 000 soldiers. The 'scorched earth' policy adopted by the retreating Russians and the vast distances involved in resupplying food to the advancing front, allied to inhospitable weather conditions and dire sanitary conditions, meant that five months later the French were forced to retreat having lost 500 000 men to disease and starvation.

In the Crimean War, vast losses of life were caused by poor hygiene and inadequate nutrition. It took the intervention of two civilians to change the situation. Florence Nightingale and Alexis Soyer—also a French chef—collaborated to improve sanitation and restructure the provision of nutrition to the fighting troops and the sick [4,5].

The military and health implications of soldiers' nutritional intake on active service were well recognized [6] by the turn of the last century: 'the soldier who is well fed is not only in better bodily health and better able to resist disease, but he is more cheerful in difficulties and therefore more equal to any strain he may be called upon to endure' (p. 378). It was also understood that feeding requirements of soldiers differed whether in barracks, at war or in hospital [7].

More recently, nutrition on military operations has become a focus for research and investment. Problems with feeding soldiers in austere conditions are multifactorial [8], as seen during the Falklands War in 1982: 'During hostilities the main food supply was either the Arctic or the General Service 24 h ration pack; a significant number of troops did not eat all their rations with a consequent loss of weight and possible loss of efficiency. Reasons given for this failure ranged from 'unappetising' foods, shortage of time, nature of operations, and the lack of potable water with which to prepare the meal—particularly the Arctic ration' (p. 75). These issues remain a concern and have prompted ongoing research into military nutrition.

### 3. CONTEMPORARY MILITARY NUTRITION

Recent evidence supports the view that wider societal trends towards increased body mass and obesity are also prevalent in the armed forces, and could adversely impact upon operational capability [9–11]. The armed forces represent an occupation with a required fitness standard on entry, a structured military fitness programme during phase-1, phase-2 recruit and officer cadet training and career-long fitness monitoring as part of the conditions of service. This fitness requirement is supported in the three services through programmed exercise time as part of the working week, and access to remedial training packages for those personnel failing to achieve the required fitness standards. Nevertheless, in more sedentary occupational branches of all three services, physical activity can be relatively easily avoided if the chain of

command does not specifically monitor and sanction the required fitness levels in personnel. Concerns regarding the physical fitness, and associated exercise and nutritional habits, of recruits prior to the start of military training are presently being addressed through a research collaboration between the RN and the Royal Air Force [12].

Current Ministry of Defence (MOD) nutrition provision and dining doctrine for duty military service personnel in barracks is described in Joint Services Publication (JSP) 456, Defence Catering Manual [13]—a policy document which states that the MOD 'undertakes to provide military personnel with a basic knowledge of nutrition, with the aim of optimising physical and mental function, long term health, and morale' (p. 4A-1). To this end, it provides information on the roles and functions of dietary nutrients and refers to the Military Dietary Reference Values for guidance on appropriate macro- and micro-nutrient intakes [14].

JSP 456 forms the basis for the feeding provision that contracted caterers are required to serve within military establishments. As a catering manual, it also details advice for caterers in terms of examples of what might be provided; however, it is limited in terms of providing explicit evidence-based direction of what should be served. Indeed, JSP 456 is regarded as a *minimum* standard, rather than an *optimum* standard for feeding provision. Further documentation in the form of JSP 404 [15] and Cesarani *et al.* [16] provides detail to inform portion control. In terms of data quality and data applicability, the Military Dietary Reference Values [14] represent a mixed collection of standards drawn from varied sources (e.g. UK Department of Health recommendations, military and non-military nutrition research and US Nutritional Standards for Operational and Restricted Rations; [17,18]). Importantly, UK civilian population dietary guidelines [17] are based on sedentary individuals with the aim of promoting and maintaining good health through nutrition, while preventing ill health—standards are based on avoiding insufficiency rather than optimizing sufficiency. Such guidelines may be applicable to some military personnel who do not undertake regular arduous physical activity and are engaged in a less active role, but would not be appropriate for personnel operating at high levels of physical activity for sustained periods of time (either during operations or training) and under challenging environmental conditions.

JSP 456 encapsulates the MOD's nutrition policy, direction and guidance but has yet to be evaluated in terms of providing appropriate nutrition; this is particularly pertinent with reference to the Pay as You Dine (PAYD) menu policy. Originally proposed in 1975, PAYD was introduced in May 2005 as a means of helping to ensure financial equality and reducing food waste. PAYD has been criticized in the national press for abolishing the previous system where all soldiers received three meals per day from the cookhouse, in return for a flat daily messing rate charge [19,20]. Catering for military recruits and officer cadets during initial training, and for all operational units, does not come under the PAYD system.

Inadequate nutrition can result in poor physical and cognitive performance (e.g. inability to carry out physical tasks, poor concentration and decreased vigilance) [21,22]. The long-term effects of both macro- and micro-nutrient imbalances include increased risk of vitamin and mineral deficiencies (potentially predisposing some individuals to an increased risk of stress fractures and rickets), obesity, hypertension, coronary heart disease, diabetes, osteoporosis and kidney failure. The implications of having a poorly nourished force may result in an increased risk of ill health (with associated medical-care costs), reduced manning levels owing to absenteeism and ultimately a reduced state of operational readiness.

The MOD has been pro-active in supporting healthy eating among service personnel through targeted educational lectures in phase-1 training, as well as the publication of nutrition guides [23–25] and educational DVDs [26]. The efficacy of such educational support has not been specifically evaluated, and indeed anecdotal evidence would support that ‘best-practice nutrition’ is not widespread among service personnel (especially during initial training) and off-duty calorie consumption, including alcohol, is more difficult to regulate.

#### 4. NUTRITION ON OPERATIONAL DEPLOYMENT

On operations or on military exercises, if a field kitchen and fresh food are not available, UK military personnel subsist on Operational Ration Packs (ORPs) provided by their chain of command. The ORP, as stated by the UK MOD Nutrition Policy Statement [13], is ‘designed to sustain troops on operations and during field exercises, with the aim of preserving life, preserving physical and mental function, maintaining mood and motivation, preventing fatigue and speeding up recovery’ (p. 4A-1). The responsibility for the content of ORPs belongs to the Defence Food Services Team (DFST), part of Defence Equipment and Support, with scientific support from the Institute of Naval Medicine (INM), Alverstoke, UK, and the Defence Science and Technology Laboratory, Porton Down, UK. Operational nutrition has been the subject of recent media and political attention [27,28] and is of importance not only for health, but also for military efficiency and morale. Operational catering aims to ‘provide as near normal a diet as possible in all environments’ (p. 8-1) and a mainly ORP-based provision should be replaced by fresh rations after no more than 44 days (i.e. 14 days warfighting and 30 subsequent days) [13].

The basic unit of the ORPs is the recently introduced Multi-Climate Ration (MCR), which replaced the previous 24 h General Purpose (GP) ration pack. The MCR is designed to provide adequate energy and nutrients to sustain a soldier for 24 h and comes in 38 different menu options, which includes six Sikh/Hindu variants, six Halal variants and six vegetarian variants.

If all of the components of the MCR are consumed, it will provide a mean (across all variants) energy intake of 4098 kcal, which includes 651 g of carbohydrate, 130 g of protein and 92 g of fat (Lt Cdr

Table 1. Examples of meals contained within 24 h multi-climate ration pack.

meal	examples
breakfast	all day breakfast, sausage and beans, fruity muesli, strawberry porridge
main meal	chicken stew with herb dumplings, chilli con carne, lamb curry
pudding	treacle pudding, chocolate pudding in chocolate sauce, exotic fruit cocktail, rice pudding with jam sachet

Table 2. Contents of a 10-man operational ration pack (menu A).

meal	components
breakfast	bacon grill, baked beans in tomato sauce, porridge oats, strawberry jam, reconstituted egg
main meal	chicken in juice, potato flakes, rice—long grain, garden peas, whole carrots, instant custard, fruit cocktail in syrup, plain noodles
snacks	curry flavour, tuna chunks in vegetable oil, cheddar cheese, fruit and nut mix, milk chocolate bar, mixed fruit sweets
drinks	tea bags, instant coffee, semi-skimmed milk powder, drinking chocolate, vegetable stock drink, tropical drink powder, lemon drink powder, granulated sugar
sauces	balti sauce, beef and tomato soup

(RN) N. Horwood 2008, personal communication). The energy and macro-nutrient profile of the MCR has been analysed [29], and the utility of the MCR was reviewed by the INM [30] against the Military Dietary Reference Values for hot-climate ORPs [14]. The rations comprise a breakfast, a main meal and a pudding, snacks (trail mix, boiled sweets, energy bars and biscuits), soup and drinks (tea, coffee, chocolate and orange or lemon). All of the meals are packaged in aluminium foil laminate packets that can be immersed in hot water (boil-in-the-bag) to cook on hexamine stoves or can be eaten cold. Examples of the meals within the MCR ORPs are shown in table 1.

The 10-man ORP is designed to feed 10 men for a 24 h period (or five men for 2 days); it requires field catering equipment and a chef (or someone trained with basic catering skills) to prepare one of the five menu variants. The actual nutrient quality and quantity, and the day-to-day variety, of the food prepared from the 10-man ORP is very much dependent upon the skill of the military field chef, and how the basic components of the ration are made into meals to sustain military personnel. The 10-man ORP contains some commercial components that can be adapted to vary the meals, which can also be supplemented with fresh food when available. A recipe book has been developed to help the field chef achieve the most from the 10-man ORP components [31]. A full list of the components of the 10-man ORP (menu A) is presented in table 2.

There is a dearth of robust evidence supporting the nutritional adequacy of UK rations in terms of sustaining warfighting. There is no published literature investigating change in body mass or body composition in soldiers eating ORP compared with fresh rations, or whether the ORP affects combat effectiveness. Work is presently ongoing to address this issue. The limited research available involved questioning users of the old 24 h GP ORP, from which it was concluded that between 25 and 55 per cent of the 24 h GP ORP was discarded immediately on receipt and the most frequently discarded items were the snack items, which contained most (43%) of the energy [32,33]. Whether the contents of an ORP are consumed ultimately depends on the choices made by individual soldiers, but will be affected by numerous factors including palatability, weight of rations and load carriage considerations (soldiers currently patrolling in Afghanistan are, at times, carrying in excess of 50 kg), concurrent illness (especially diarrhoea and vomiting), altitude and environmental temperature, intervention of commanders and the tempo of operations.

MCR was introduced for soldiers in Afghanistan in 2009 following successful trials by the DFST involving the addition of hot-climate supplements to the GP ORP in 2007 and 2008. MCR was developed in response to problems encountered with the GP ORP (in particular menu repetition and unpopularity of certain items) with the aid of feedback from soldiers. MCR was also developed to be acceptable in a greater variety of climatic conditions. There is evidence to suggest that environmental heat increases energy requirements, but a far more pressing concern is the anorectic effect of a hot environment [34,35]. Thus, development of the MCR was, in the main, driven by the practical requirements of providing nutrition to a warfighting population with the aim being to encourage eating (energy and nutrient intake) and drinking (hydration). If a ration is not practical in terms of being readily consumed under hostile conditions or unpalatable under extreme environmental conditions, the nutritional content is largely irrelevant, as soldiers will be unable or unwilling to consume the contents, even if this is potentially detrimental to health [36,37]. From a duty of care perspective, the nutritional content of ORPs is also paramount—DFST has engaged with dietetics expertise to ensure that the energy and nutritional content is appropriate relative to current operational evidence, although the MCR is yet to be systematically evaluated within an operational theatre.

Studies from the United States of America in the 1980s reported conflicting evidence on whether US rations, called 'Meal, Ready-to-Eat' (MRE), resulted in body weight loss in an operational field setting [38]. In 1995, male soldiers who participated in a 30 day field study during which they were only provided with MRE rations lost 3.8 per cent body weight, compared with a 1.2 per cent loss in body weight in soldiers fed hot, cook-prepared meals (state of hydration was unaffected) [39]. Dual X-ray absorptiometry (DEXA) and anthropometric measurements indicated that the body weight loss was almost entirely

fat mass, which was attributable to a reduced intake of carbohydrate, resulting in a net daily energy deficit of 600 kcal. Nevertheless, it has been suggested that military performance may not necessarily be impaired in soldiers with body weight losses of 3–6% consuming operational rations for more than 10 days [39]. Recent evidence has suggested that providing food that can be readily snacked on throughout the day can improve physical activity during sustained arduous work [40]. Thus, lighter, more nutrient-dense food items would be preferable in such a situation—the DFST is currently trialling patrol rations, specifically designed to meet this purpose.

The effect of operational nutrition and/or body weight loss on physical and cognitive performance is an area of intense research interest. Partitioning out these subtle outcomes from other stressors (e.g. sleep deprivation, cold, fear) is very challenging. This lends itself to questioning which (if any) performance areas or physiological parameters, apart from maintenance of body weight, operational nutrition should aim to influence, and how these parameters can be measured. There is also a growing body of evidence suggesting that caffeine can improve performance across a wide range of physical activities, as well as reducing fatigue and improving alertness [41]. Caffeine has been shown to improve running performance and maintain vigilance during an overnight field operation for US Special Forces personnel [42,43] and improve cognitive performance in sleep-deprived US Navy SEALs [44].

Early in 2010, the INM in collaboration with the Royal Center for Defence Medicine (RCDM) commenced a study as part of Surgeon General's Armed Forces Feeding Project. This study will evaluate the inter-relationships between occupational energy expenditure, dietary intake, anthropometric measures, physical fitness, nutritional status and gut hormone concentrations in volunteer Royal Marines undertaking a six month tour of duty to Afghanistan on Operation HERRICK. Measures were taken at four time points—pre-deployment, before and after mid-tour leave and immediately post-deployment on the Marines' return to the UK. These data will be used to address important military and medical questions concerning the possible physiological significance of changes in body composition and to clarify the specific nature of any body mass loss associated with an operational deployment (i.e. relative fat and lean tissue loss) and the reasons behind any such losses. The aims of this study are to provide evidence to support nutritional policy and advice for service personnel prior to and during operational deployments.

## 5. NUTRITION IN THE WOUNDED

As a result of current military operations in Afghanistan, military personnel are regularly sustaining severe, multiple injuries caused by bullets, improvised explosive devices and mine strikes [45]. The success of military medical care has resulted in a significant number of 'unexpected survivors' from catastrophic injuries [46]. Those with multiple injuries who require intensive care treatment are likely to develop a catabolic state of

negative energy balance and resultant rapid loss of lean body mass (principally skeletal muscle) [47]. Even with the best medical care, recovery from critical illness can take months [48] and significantly prolongs return to normal function [49] and to work [50]. As yet there are no effective treatments to slow or reverse the loss of lean body mass [51,52]. The challenge, therefore, is to reduce the period of rehabilitation and the time to return to normal functional levels in soldiers with critical illness.

Military patients are, by definition, a more homogeneous group than the usually diverse population seen on a civilian intensive care unit. The majority of patients arising from current military conflicts tend to be young males, with higher aerobic fitness levels, and without additional co-morbidities. Therefore, it is possible that not all studies relating to nutrition in critical illness are applicable or relevant to this specific military population. In the absence of current, prospective studies that report specifically on nutrition in military critical care patients, the civilian medical literature must be relied upon, while recognizing the caveats listed above.

## 6. THE AIMS OF NUTRITIONAL SUPPORT IN CRITICAL ILLNESS

Malnutrition is common in hospital and intensive care units [53,54]. Although unlikely to be an issue for military personnel prior to injury, detection of established or incipient malnutrition is imperative: protein–energy malnutrition causes increased morbidity and mortality, skeletal muscle weakness, increased infective complications, impaired wound healing and increased length of stay on the intensive treatment unit (ITU) [53,55,56]. An adequate supply of nutrients prevents or limits many of these complications [57].

A new paradigm in nutritional support is emerging—nutrition should be no longer seen as simply a means to prevent malnutrition and micro-nutrient deficiencies; instead, it should be viewed as an independent treatment modality in its own right, with the potential to positively influence patients' outcomes, but also the potential to cause harm [58,59].

## 7. MEASUREMENT OF NUTRITIONAL STATUS

There is no single test that can be employed to accurately determine nutritional status of intensive care patients, be they military or civilian [60]. Rather, a combination of biochemical, anthropometric, clinical and physiological measurements over time—with a clear understanding of their limitations—and clinical experience is used [61].

Serial measurement of body mass is recommended [62] to monitor for developing or established malnutrition. The clinical risks and logistical difficulties of weighing a sedated, intubated patient on intensive care, however, often make this difficult. Significant loss of lean body mass may be masked by the development of oedema and/or receipt of large volumes of intravenous fluid (both common in critical care), resulting in no net change in body weight [47]. Unintentional weight loss of more than 10 per cent is

indicative of malnutrition and is associated with increased morbidity and mortality [61]. Calculations to assist estimating body mass are available for patients who have had amputations [63].

Oedema, burns and peripheral soft tissue injuries may also affect the accuracy of anthropometric measurements, such as the mid-upper arm circumference (MAC) or triceps skinfold thickness, which are used to estimate muscle and fat mass respectively [60]. Anthropometry is simple and safe to perform but involves considerable unavoidable intra-observer and inter-observer variance [64,65]. MAC does not correlate with energy intake or energy balance, nor with biopsied muscle fibre area in critically ill patients with multi-organ failure [66]. Measurement of skinfold thickness makes assumptions about hydration status, body density and percentage body fat, relies on comparisons with predetermined standards and is slow to reflect changes in recovery of nutritional status [67]. Furthermore, the usefulness of skinfold thickness in intensive care patients has yet to be validated [68].

Blood tests measuring plasma proteins, in particular serum albumin, pre-albumin and transferrin, are often mistakenly thought to be a useful guide of nutritional status. In fact, all three markers are decreased in acute inflammatory states seen after critical injury, but also in protein-losing states, and in liver disease. Albumin's long half-life (approx. 20 days) means that it cannot reflect changes in response to a nutritional intervention within an appropriate time scale, making it a poor tool for nutritional assessment, particularly in the critical care setting [69,70]. Transferrin and pre-albumin, with shorter half-lives than albumin, have shown some promise as markers of nutritional status but neither is used in routine clinical care and they remain invalidated in intensive care [68]. Nitrogen balance can be determined by measuring urinary concentrations of either nitrogen or urea and comparing with dietary protein intake. Laboratory measurement of urinary nitrogen is technically difficult, and the relationship between 24 h urea excretion and total nitrogen excretion varies significantly both inter- and intra-individually, such that neither method is routinely performed [68].

Functional assessment is thought to be a more sensitive means of assessing changes in nutritional status. Respiratory muscle weakness is associated with delayed extubation and prolonged ventilation [71]. Handgrip dynamometry was originally described as an indicator of pre-operative surgical risk [72], and has subsequently been suggested as a means of detecting 'intensive care unit associated-paresis', which is independently associated with hospital mortality [73]. In response to improved nutritional status, changes in grip strength are evident earlier than anthropometric measurements [60], but dynamometry requires a conscious, motivated patient who is free from the effects of sedative medication for consistent results. Its use in critical care research has been largely overtaken by techniques that evoke stimulated muscle contraction [74]. Electrical stimulation of a peripheral nerve and measurement of the strength of

contraction and rate of relaxation (typically the ulnar nerve at the wrist and the adductor pollicis muscle) have been used to analyse nutritional status [75,76]. This technique, however, is difficult to apply in intensive care [77].

Most methods of measuring body composition assume that the relationship between the lean body mass and adipose tissue is constant—this invariably is not the case in critical illness [78]. Densitometry (including underwater weighing) is considered the gold standard of body composition analysis, but remains a research tool and is not applicable to critically ill patients. Employing ultrasound to assess changes in muscle thickness during critical illness has been validated [79], but is not used widely. Other imaging modalities such as computer-aided tomography, magnetic resonance imaging and DEXA scanning have not been fully investigated in critical care nutrition.

The National Institute for Health and Clinical Excellence recommends measuring or estimating energy expenditure and then calculating energy requirements, before commencing nutritional support in critically ill patients [80], although the inherent heterogeneity of these patients makes this difficult [81]. There is a wide variation in energy expenditure during a 24 h period and from day to day [82,83]. Although considered the 'gold standard' [56], indirect calorimetry remains firmly in the realm of research and is rarely performed in routine clinical care. More than 200 predictive equations exist to assist estimation of energy expenditure. Those commonly used in intensive care [84–87] should be used with care because they have been shown to be inaccurate [88] and have a poor correlation with measurement of energy expenditure derived from continuous indirect calorimetry [89]. This makes regular monitoring and adjustment of nutrient provision by skilled dietitians essential. Whether determination of energy requirements by indirect calorimetry or predictive equations affects outcomes in enteral feeding remains unclear [56].

It is evident that many of the individual measurements of nutritional status and energy expenditure in critical care are flawed, invalidated, inapplicable or inappropriate. Caution and experience must be used with equal measure when analysing results. Rate of wound healing has been shown to be a useful guide to the effectiveness of nutrition in burns patients [90] and is a reminder that the clinical condition of the patient should be the first consideration when assessing nutritional status.

## 8. THE EFFECTS OF SERIOUS WOUNDS ON THE NUTRITIONAL STATUS OF MILITARY PERSONNEL

Hypermetabolism following trauma has long been recognized [91]. The body weight loss that is frequently observed in intensive care patients with multiple organ failure comes not from fat stores but from protein reserves broken down to their constituent amino acids to support increased protein synthesis [92]. Initially, the majority of proteins come from skeletal muscle; later visceral protein is also used [47], resulting in a

catabolic state. Regardless of nutritional supplementation, patients on intensive care units can lose up to 1 per cent of their total body protein per day [93], worsening muscle weakness and delaying weaning and rehabilitation [93,94]. Military personnel wounded during combat may have reduced fat and glycogen stores, which could contribute to accelerated catabolism and further aggravate body weight loss [95]. At the present time, there is no method of preserving nutritional status after critical illness. Trauma, especially head injuries and burns, significantly elevates resting energy expenditure for weeks after the injury, even during recovery [47,96], as does sepsis [97].

## 9. FEEDING WOUNDED SOLDIERS

There is considerable debate with regards to the timing and route of feeding and composition of feed for sedated patients on intensive care. It is now generally accepted that, where possible, early enteral nutrition is preferred to parenteral (intravenous) feeding, which has been shown to be harmful [56,98]. Early enteral feeding limits the hypermetabolic response and increases visceral protein synthesis [99] and has fewer septic complications when compared with parenteral nutrition [98,100]. If started within 24–48 h of admission to ITU [101] or 24–72 h after injury [84], depending on which guidelines are adhered to, enteral nutrition reduces infectious complications [84] and improves outcomes [101]. In other intensive care subpopulations (such as burns and head injury patients), evidence is also accumulating that enteral nutrition is beneficial [102]. While robust evidence is lacking, a jejunal (small bowel), rather than gastric (stomach) feeding tube is recommended for enteral nutrition in military and civilian patients [102,103]. Jejunal feeding may reduce the incidence of ventilator-associated pneumonia caused by micro-aspiration, a particular concern during aeromedical evacuation of casualties from theatres of operation abroad [104]. It also results in fewer interruptions of enteral nutrition during the multiple operating theatre visits frequently experienced by military personnel following transfer to role 4 (UK hospital) care.

In critical illness, it is recommended that daily energy intake is increased to match increased demands to the order of 20–30 kcal kg<sup>-1</sup> body mass [47,58,101]. Objective evidence demonstrating the benefit of matching energy demands with supply is lacking [105]; however, there are harmful consequences associated with over- and underfeeding [55,58,106]. Again, evidence to inform the rate at which enteral nutrition is started and then maintained is limited. Nevertheless, it has been suggested that in military patients, feeding should commence slowly and build up gradually over 24 h with regular assessment of gastric residual volumes [102]. Protein is usually given 1.2–2.0 g kg<sup>-1</sup> ideal body weight to compensate for large nitrogen losses seen in burns, trauma and sepsis [80,84,107]. Protein should comprise 15–20% of artificial feed [84]. It is recommended that carbohydrate (in the form of glucose) makes up 30–70% and fats the remaining 15–30% diet [84]. High-protein diets, peptide-based formulae, high-fat/

low-carbohydrate or low-fat/high-carbohydrate diets for critically ill patients all lack robust evidence of efficacy [108].

The full pathophysiological mechanisms of critical illness have yet to be fully elucidated. Oxidative stress caused by reactive oxygen species (ROS) is now considered to be a key causative factor in the multi-organ failure that frequently develops after serious injury [109,110]. These compounds have physiological roles in cell signalling but an exaggerated response, stimulated by inflammation, causes mitochondrial dysfunction and cellular damage [111]. Reduced concentrations of antioxidant cofactors (e.g. selenium, zinc, etc.), enzymes such as superoxide dismutase and glutathione peroxidase, vitamins and their precursors are seen in critical illness and may be caused by the increased activity of ROS [110]. These nutritional deficiencies are associated with depressed immune function and increase the likelihood of infection, multi-organ failure and death [109].

*Immunonutrition* or *immune-modulating diets* incorporate supplemental nutritional elements within the feed. These include selenium, glutamine, arginine, omega-3 fatty acids, branched chain amino acids, vitamins A, C, E, beta-carotene and RNA nucleotides, often in combination with one another. More than 30 randomized control trials of immunonutrition in surgical and critically ill patients have been undertaken and at least seven meta-analyses generated. Unsurprisingly, extrapolating meaningful results from a heterogeneous population fed a variable combination of micro-nutrient supplements at differing stages of their disease process has proved challenging [59,109]. Treatment recommendations can only use the available evidence; the European Society for Parenteral and Enteral Nutrition's 'Guidelines on Enteral Nutrition: Intensive care' [58] and the continually updated Canadian meta-analysis (available at [www.criticalcarenutrition.com](http://www.criticalcarenutrition.com)) provide clear guidelines that are mostly in agreement. Glutamine (a conditionally essential amino acid used as a substrate in many metabolic processes, especially in the gut) is recommended in trauma and burns patients who are both enterally and parenterally fed [58] and also in military trauma patients in a field intensive care unit (unless there is a brain injury) [102].

There is some evidence that giving intravenous trace elements to burns patients on days 1–7 after injury may be beneficial [112] and many burns units follow protocols that provide additional copper, zinc and selenium, in addition to enteral nutrition provision. The new dogma of pharmaconutrition—that the provision of nutrient supplements is dissociated from provision of energy—will be addressed by studies that seek to clarify which micro-nutrients should be administered, the dose, route and duration of treatment [109].

British military patients in Afghanistan who require enteral nutrition receive either Jevity or Osmolite with no immunomodulating supplements. Jevity (Abbott Nutrition) is a 1.0 kcal ml<sup>-1</sup> isotonic liquid enteral feed with mixed fibre and fructo-oligosaccharides. In contrast, injured American soldiers are currently receiving immune-modulating formulae containing

glutamine, arginine, omega-3 fatty acids, dietary nucleotides and up to 30 g d<sup>-1</sup> enteral glutamine [62].

## 10. CURRENT WORK

The INM and RCDM are undertaking a study, commissioned by the Surgeon General, to investigate how pre-injury nutritional status influences the course of recovery and rehabilitation following combat injury. The Surgeon General's Casualty Nutrition Study will assess changes in body composition and nutritional status in volunteer wounded military personnel returning to the UK from Afghanistan. These data will be correlated with injury severity, clinical course and routine blood test results, and compared with pre-injury measurements to: (i) identify whether pre-morbid physical and nutritional status affects the rate and nature of recovery after trauma of military personnel wounded on overseas operations; (ii) clarify the specific nature of body mass loss associated with a combat injury in terms of the relative fat and lean tissue loss; and (iii) provide preliminary data to elucidate the appropriate time points for potential intervention with nutritional therapies to improve recovery, rehabilitation and ultimately return to service.

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