Review article

CURRENT CONCEPTS OF RESPIRATORY INSUFFICIENCY SYNDROMES AFTER FRACTURE

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Episodes of hypoxia and acute respiratory insufficiency often occur after orthopaedic trauma.^{1,2} Most patients who have sustained a major injury to the pelvis or a long bone are monitored using pulse oximetry, and the onset of respiratory symptoms is usually presaged by episodes of desaturation.³ The reason for the hypoxia is often apparent after careful clinical assessment (Table I), and it is usually reversible by the administration of oxygen and treatment of the precipitating cause. In a few patients, however, the cause of the deterioration in respiratory function is not obvious or easily correctable and demands more sophisticated investigation. In these, the onset of hypoxia may be associated simultaneously with the development of dysfunction of other vital organs. The terms fat embolus syndrome (FES) and acute (or adult) respiratory distress syndrome (ARDS) have both been used to describe this pattern of unexplained refractory hypoxaemia.

The fat embolus syndrome (FES) was first described in 1862,⁴ although much of the research into this condition was carried out between 30 and 40 years ago and coincided with the recognition of ARDS as a discrete entity in the critically-ill patient.⁵ The considerable overlap, and the lack of concrete definitions, have dictated that both terms have continued to be used almost interchangeably. The expression 'fat embolism' is often loosely employed to describe both the intravasation of fat into the circulation (fat embolisation or FE) and the specific cluster of respiratory, dermatological and neurological symptoms and signs which occur in some patients after injury (FES). These should not be confused, because they do not necessarily always occur in tandem. ARDS is used to describe the respiratory failure associated with evidence of multiple-organ dysfunction, which occurs in patients after high-energy injury.

There have been much speculation and debate about the pathogenesis of these syndromes, and their inter-relationship. Both share common clinical features and may be produced by a variety of non-traumatic causes. Most of the

recent discussion has taken place in specialties such as intensive care and respiratory medicine, molecular biology and in immunology in which there have been considerable advances in our understanding of the pathological basis of ARDS. Clinicians in these fields are also involved increasingly in the medical management of patients who develop these complications and the role of the orthopaedic trauma surgeon is in danger of being marginalised to that of a technician.

Despite the increasing sophistication of medical and anaesthetic management, however, there is ample evidence to indicate that the early treatment of fractures in a multiply-injured patient has a significant effect on the risk of the subsequent development of respiratory complications. A multidisciplinary approach, with continued input from the orthopaedic trauma surgeon, is therefore vital in the early care of these patients.

Current theories of the pathophysiological mechanisms

Injury causes activation of cellular defence mechanisms and the elaboration of humoral and cell-surface mediators of inflammation and coagulation.^{1,6} These responses are protective, acting as a barrier against infection, removing damaged tissue and initiating repair. Recently, natural anti-inflammatory mediators have also been described which modulate these processes.⁷ It is hypothesised that an imbalance may lead either to a generalised proinflammatory state (systemic inflammatory response syndrome or SIRS) which produces endothelial cell damage, increased microvascular permeability and interstitial oedema, or to suppression of inflammation and anergy (compensatory anti-inflammatory response syndrome or CARS) producing susceptibility to sepsis.⁸ This imbalance may be produced either by severe injury or as an idiosyncratic response by the individual.⁹

The clinical syndrome of ARDS is considered to be a local manifestation of SIRS. The lung is prominently targeted in the early stages, but if the patient survives, features of cardiac, gastrointestinal, renal, hepatic, haematological and cerebral failure become apparent, as part of the syndrome of multiple-organ dysfunction (MODS). Evidence of MODS is almost invariably found at post-mortem in patients who die from ARDS after 72 hours.^{10,11}

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Table I. Common underlying causes for arterial hypoxaemia after trauma

Upper airway obstruction
Foreign body in upper airway or oropharynx
Malposition of endotracheal tube if the patient is intubated
Chest injury
Chest wall/diaphragm - flail chest, open pneumothorax, traumatic diaphragmatic hernia
Pulmonary - pneumothorax, haemothorax, pulmonary contusion
Mediastinal - cardiac tamponade, myocardial contusion, aortic disruption
Circulatory failure
Hypovolaemic shock
Cardiac failure - usually in an elderly patient after overzealous fluid resuscitation
Head injury
Drug toxicity
Drug ingestion/overdose by patient before injury (including alcohol)
Drugs given during resuscitation, including anaesthetic agents
Pre-existing medical comorbidity
Metabolic disorders
Chronic respiratory disease
Miscellaneous

At present, we have incomplete knowledge of the complex series of inflammatory events which leads to ARDS after trauma, although the local release of cytokines,¹² the complex interactions between platelets and circulating leucocytes with vascular endothelial cells,¹³ the extravasation and degranulation of neutrophils to produce toxic products,¹⁴ and the activation of neuroendocrine, complement, coagulative and fibrinolytic pathways,^{14,15} are certainly involved. The histological findings include microvascular occlusion from fibrin and platelet aggregates and interstitial leakage of protein- and neutrophil-rich fluid, leading to diffuse alveolar damage.¹⁶ Subsequently, proliferation of fibroblasts leads to fibrosis and the formation of a hyaline-like membrane if the patient survives. Detectable changes in the physiology of the lung include decreased functional residual capacity, decreased compliance and increased pulmonary vascular resistance. There is also evidence of pulmonary vascular shunting because of ventilation-perfusion mismatch, which is considered to be the major cause of the refractory hypoxaemia.¹⁷

Clarification of the factors which provoke the development of ARDS after trauma is of considerable interest since they could, potentially, be preventable. A severe pro-inflammatory response may be sufficient to precipitate ARDS soon after injury and sepsis is implicated after prolonged supportive care. It is also hypothesised that secondary events (or 'hits') after injury may also drive a patient with a primed inflammatory response towards ARDS.¹⁸ The clinical evidence for this is still unconvincing, but the theory is attractive, since it may help to explain why some trauma patients deteriorate after a latent period.

Significant secondary events may include episodes of hypoxia, circulatory imbalance (especially residual hypovolaemia), sepsis, blood transfusions, and other unknown factors.¹⁸ The timing and type of surgery for fractures may also constitute a modifiable secondary insult.^{19,20} From a pathophysiological viewpoint, the operation may provoke

further activation of inflammatory pathways, blood loss, or episodes of tissue hypoperfusion/hypoxia. FE, produced either at the time of injury or during an operation (particularly if an intramedullary nailing technique is used), may also be a trigger for the development of ARDS.

Fat embolisation after fracture: is it important? There is strong circumstantial evidence that post-traumatic FE has a central role in the development of respiratory compromise. Fat can be detected in the lungs soon after fracture^{21,22} and may pass into the systemic circulation through pulmonary capillaries and shunts,^{21,22} or through a patent foramen ovale,²³ to produce the characteristic features of systemic embolisation.

The biological plausibility of fat as a major cause of post-traumatic respiratory insufficiency is supported by animal experiments in which intravenous injections of fat emulsions produced pathophysiological features similar to those of FES.^{24,25} FE can also produce tissue damage by direct injury as a result of vascular occlusion, breakdown to toxic free-fatty acids, and by activation of platelets and the coagulative and fibrinolytic cascades.^{24,26,27}

The intravasation of fat was seen as the major culprit in the pathogenesis of post-traumatic respiratory compromise in the 1960s, when much of this work was performed. It is now appreciated, however, that embolism occurs in over 90% of patients after fracture²⁸ and invariably during reamed nailing of fractures.²⁹ It is uncertain whether the degree of FE correlates with the severity of injury to the lung or the risk of ARDS,^{28,30} but only 1% to 5% of patients develop FES.²¹ Further studies in animal models have shown that intravascular fat appears to produce a negligible inflammatory response.^{27,31,32} The importance of fat as a cause of ARDS in the multiply-injured patient therefore remains in doubt.³³ There is often ample evidence of other secondary triggers for ARDS after injury,^{34,35} and the role of FE is difficult to define.

The exact role of FE in the FES also deserves further scrutiny. Several of the features of the latter syndrome,

including its 'sporadic' occurrence in patients after relatively minor injury, the systemic embolic features of cutaneous and central nervous involvement, and the occurrence of a fulminant form which leads to acute right ventricular failure and cardiovascular collapse,²³ suggest that it may well be important. As with the mediators of ARDS, it is conceivable that FES may occur either from massive FE, particularly in the presence of a patent foramen ovale, or may represent an abnormal response of the individual to intravasation of fat.³⁶

More recent work has provided evidence of important interactions between FE, the coagulative effect which it produces and the inflammatory response, further confirming the complexity of the pathogenic mechanisms involved.^{15,37-39} Many of the minor features of FES are similar to those of SIRS and the pulmonary disease process is identical to ARDS. There may be a final common pathological pathway for both FES and ARDS (Fig. 1).

Epidemiology of post-traumatic respiratory compromise

The accurate estimation of the incidence of ARDS and FES

in patients with fractures is difficult. Prospective studies with less stringent diagnostic criteria have reported higher levels than retrospective studies with rigorous diagnostic measures. There is considerable overlap between the two conditions and many patients who were thought to have FES in the 'preintensive care' era would now be considered to have ARDS. It is generally accepted that the incidence of these complications has decreased due to improvements in both the resuscitation and early treatment of fractures during the last 30 years.

The incidence of ARDS after major trauma is probably between 5% and 8%,^{34,40} but is much lower after an isolated fracture. There is a 'biological gradient' of risk with increasing severity of injury.⁴¹ The incidence of FES after fracture is 0.5% to 5%,⁴²⁻⁴⁴ although it is possible that this may only be the 'tip of the iceberg' with subclinical forms being more common than has been generally appreciated.² The incidence of FES has been noticed to increase with the severity of injury in some studies,^{42,45} whereas others have suggested that the condition is sporadic.⁴⁶

Both conditions are commonest in young individuals with fractures of the pelvis or long bones in the leg, possibly because they are more commonly sustained in

Fig. 1

Flow diagram showing the possible pathological mechanisms involved in post-traumatic respiratory compromise.

Table II. Suggested framework for evaluation of patients with unexplained post-traumatic respiratory dysfunction

Diagnostic criterion	ALI/ARDS	FES
Injury severity	Severe multiple-system injury (ISS > 18) or multiple fractures (a 'biological gradient' of increased likelihood with increasing severity of injury)	Variable but often low-energy isolated injury ('sporadic occurrence')
Pulmonary involvement	Three main diagnostic criteria: 1) bilateral 'snowstorm' appearance on chest radiographs, 2) absence of signs of cardiac failure, and 3) $\text{PaO}_2/\text{FiO}_2$ ratio > 26.7 and < 40 (ALI) or $\text{PaO}_2/\text{FiO}_2$ ratio < 26.7 (ARDS)	Same diagnostic criteria as for ALI or ARDS
Systemic inflammation	Often present before signs of respiratory involvement. Diagnosis of SIRS depends on finding two or more of: 1) tachycardia > 90 beats/min, 2) temperature > 38°C or < 36°C, 3) respiratory rate > 20 breaths/minute or $\text{PaCO}_2/\text{FiO}_2$ < 4.3 kPa, and 4) white blood count > 12 000 cells/mm ³ or > 10% immature forms)	Similar diagnostic criteria should now be used as for systemic inflammation in ALI/ARDS ('classic' signs of FES include tachycardia, increased respiratory rate, pyrexia and raised ESR and may be similar in aetiology to SIRS)
Other organ involvement	Scoring of MODS: typically cardiovascular (heart rate or mean arterial blood pressure), respiratory ($\text{PaO}_2/\text{FiO}_2$ ratio), renal (urea and creatinine levels or urine output over 24-hour period), hepatic (bilirubin levels), CNS (Glasgow Coma Scale), haematological (platelet count, white blood count, prothrombin time)	Similar scoring systems to MODS scores in ALI/ARDS
Systemic embolism	Typically absent: unable to elicit CNS signs if the patient is anaesthetised and ventilated; observe for signs of a petechial rash which may suggest FE as a cause of ALI/ARDS	Petechial rash on upper torso; CNS involvement includes acute confusional state or any form of focal neurological deficit

high-energy injuries. They are uncommon in children and the elderly, although they may occur in patients with fractures of the hip.

Clinical assessment

FES and ARDS cannot in themselves be considered to be diagnoses. There is no single test or sign which is confirmatory and both describe clusters of clinical signs and abnormal investigations. Many of the 'major' and 'minor' criteria for FES, however, which were used in previous studies,⁴⁷⁻⁵⁰ now appear to be outdated or have been shown to be non-specific for the condition. An updated framework for the investigation and diagnosis of both conditions is shown in Table II and is discussed in more detail below.

Pulmonary compromise. The cardinal pulmonary signs of ARDS and FES are refractory hypoxaemia, not correctable by high-dose oxygen therapy (60% to 100%), associated with the development of a characteristic 'snowstorm' appearance in both lung fields on chest radiography (Table II). The degree of respiratory compromise cannot be estimated by assessment of the arterial oxygen concentration alone, since this is dependent on the inspired oxygen concentration, whether administered by mask or ventilator. Correction is made by dividing the arterial oxygen concentration by the fractional inspired oxygen concentration to obtain the $\text{PaO}_2/\text{FiO}_2$ ratio.⁵¹ The diagnosis is established by a process of exclusion after all other remediable contrib-

utory causes for respiratory failure have been eliminated (Table I). Diagnostic pitfalls include cardiac failure from the overzealous administration of fluid in attempts at resuscitation, which should be excluded by measuring pulmonary capillary wedge pressures, and the presence of diffuse pulmonary contusions, which are usually apparent immediately after the injury and are more pronounced in one lung field.

ARDS is best considered as a spectrum of disease and this is reflected by its subdivision into ARDS proper, and a less severe form of acute lung injury (ALI).⁵² The use of these two terms is appropriate after trauma since the degree of arterial hypoxaemia may initially be mild (Table II). Respiratory failure is also seen in 75% of patients with FES⁴⁸ and is clinically indistinguishable from ALI/ARDS.

These definitions are more difficult to apply in patients receiving mechanical ventilation. Other more complex considerations including the duration of mechanical ventilation, the extravascular water volume of the lung, static compliance of the chest wall and the requirement for positive end-expiratory pressure have been described, although none has found general acceptance.⁵² More specialised diagnostic techniques, which may have an increasing role in the future, have been used experimentally, including examination of bronchoalveolar lavage fluid for inflammatory mediators⁵³ or fat-laden macrophages,⁵⁴ and the cytology of fluid retrieved from the pulmonary microvascular circulation.⁵⁵

Other systemic features. Scoring systems for SIRS and MODS have been suggested using relatively simple diagnostic tools^{11,56,57} (Table II). As with the lung, there is a spectrum of dysfunction of other solid organs and the diagnosis of MODS rests on exclusion of other underlying causes, including organ dysfunction from direct trauma during the original injury.

The classic 'early' signs of FES⁴⁷⁻⁴⁹ including tachycardia, increased respiratory rate and pyrexia, are similar to those of SIRS, and the 'minor' clinical signs of circulatory, renal and hepatic dysfunction seen in this condition are indistinguishable from MODS. A characteristic petechial rash is found in 60% of patients with FES⁴⁸ and neurological features are encountered in over 80%,⁵⁸ including the development of an acute confusional state or a focal neurological deficit (Table II).

Much has been made of the 'latent period' before the onset of the clinical features of FES and ARDS. This cannot be seen as a specific diagnostic criterion since many patients develop signs immediately after injury. Similarly, the laboratory detection of evidence of FE in the blood, retina, urine or sputum and the development of anaemia, a raised ESR or thrombocytopenia, are non-specific features of FES. Specialist imaging techniques, including MRI and transcranial Doppler studies, have occasionally been useful, although their specificity is unknown.^{59,60}

The clinical distinction of FES from ALI/ARDS. In the presence of multiple injuries (injury severity score (ISS)⁶¹ greater than 18), the clinicopathological features of FES and ALI/ARDS overlap to such an extent that absolute distinction is usually not possible. This is particularly so if the patient is anaesthetised and receiving mechanical ventilation, when the clinical signs of cerebral dysfunction will be absent. In this situation the diagnostic criteria for ALI/ARDS should then be applied and routine screening for evidence of SIRS, MODS and signs of systemic embolism undertaken (Table II). The use of the term FES should now be restricted to situations in which definite evidence of systemic embolisation can be confirmed by the presence of two of the 'major' triad of respiratory, cutaneous and neurological signs (Table II). In the rare instances when the characteristic petechial rash on the upper torso or cerebral signs occur in isolation, the presence of features of SIRS/MODS should be seen as confirmatory evidence of FES.

Until we have further clarification of the basic pathological processes, it is suggested that future research studies should record measurements of the five groups of parameters shown in Table II.

Controversies in the treatment of fractures in patients at risk of ARDS/FES

Most of the comparative studies carried out in the last 20 years have shown a reduction in the risk of ARDS/FES after early definitive stabilisation of the fractures, both in

patients with isolated fractures^{42,62-66} and in those with injury to multiple systems (Fig. 2).^{62,63,67-74} The protective effect of early surgery has also been demonstrated in children.^{75,76} There is also evidence of a reduction in mortality, the duration of mechanical ventilation, nosocomial infections, thromboembolic disease and the cost of treatment after early stabilisation of the fracture.^{63,77} Most of these studies have examined patients with diaphyseal fractures in the leg in which the standard operative treatment has evolved from the plate fixation to reamed intramedullary nailing.

There are, however, a number of concerns regarding these previous studies, many of which have been small, retrospective or uncontrolled quasi-randomised trials, with considerable potential for confounding and bias from the variation in complexity, site and severity of injury. Recruitment into randomised controlled trials of these injuries is difficult and most studies have enrolled relatively small numbers of patients. It was recently estimated that over 2000 patients would need to be included in any study to examine definitively whether two different methods of treatment of a fracture had significant differences in their rates of pulmonary complications.⁷⁸

During the last 20 years, there have also been significant improvements in the speed of delivery of emergency services, in techniques of resuscitation and the provision of intensive care, which must also have had a significant impact in reducing pulmonary complications. The impact of modern methods of the treatment of fractures has also, perhaps, led to an overstatement of the importance of the musculoskeletal injury in determining the risk of respiratory complications in multiply-injured patients. In most studies, this risk is increased to a much greater extent by the presence of a concomitant chest or head injury, hypovolaemia or the requirement for repeated blood transfusion.^{34,79-82}

The wisdom of attempting early definitive surgery for all patients with fractures has been questioned in recent years. Most of the debate has centred on whether there are particular anatomical and physiological patterns of injury which may benefit from either a delay in a definitive operation or the use of alternative techniques to that of reamed nailing. In practice, such injuries seldom occur in isolation without a degree of injury to other body systems. In multiply-injured patients, however, considerable damage to another body system may determine the priorities in initial management and act as a 'modifier' to the ideal treatment which would be recommended for an isolated fracture. It is therefore useful to consider these various patterns of injury.

Patients with fractures and no significant injury to other body systems. The ideal treatment for patients with an isolated fracture without injury to other systems remains early definitive fixation, ideally carried out within 24 hours. Reamed intramedullary nailing is the method of choice for most isolated femoral and tibial fractures. The widespread

Fig. 2

Summary of the previous English-language studies which have compared the effects of early operative stabilisation of the fracture (usually within 24 hours) with late or non-operative treatment on the incidence of post-traumatic respiratory complications. As ARDS, FES and other more non-specific terms have been variously used to describe refractory hypoxaemia after fracture, these outcome measures are considered together. The figures to the right of the reference show the number of patients with evidence of post-traumatic respiratory complications (n) as a proportion of the total population (N). The analysis is substratified into studies which have examined multiply-injured patients (with ISS > 18) and those with isolated fractures. The overall relative risk (RR) reduction in post-traumatic respiratory insufficiency is statistically significant, suggesting a 70% reduction in the rates of pulmonary complication with the use of early fixation (RR = 0.30, 95% confidence intervals (CI) 0.22 to 0.40).

increase in its use during the last 20 years has not coincided with any substantial escalation in the incidence of FES. Some patients develop this syndrome before stabilisation of their fractures and the use of reamed nailing in this situation often causes concern because it is likely to produce further substantial FE. There is, however, evidence that the use of nailing may actually be protective against FES in this situation.^{42,83}

Patients with pathological fractures treated by nailing and patients with fractures of the hip treated by cemented hemiarthroplasty are at a higher risk of developing a fulminant form of acute FES, either as a result of florid intra-operative FE, or from a pre-existing coagulopathic state.^{30,84-86}

The severely injured patient with multiple injuries (ISS>18)

Patients with physiological instability or occult hypoxia/hypoperfusion. In approximately 5% of fractures of the long bones in the leg, the patient is 'physiologically unstable' after initial resuscitation because of coagulopathy, haemodynamic instability, raised intracranial pressure, vascular damage or injury to a solid organ.^{87,88} The treatment of these life-threatening conditions takes priority over the orthopaedic injuries in the early stages, and the use of external fixation is advocated, dictated by the requirement for rapid temporary stabilisation of the fracture. If these patients survive, they are also at a much higher risk of ARDS within the first week after injury and it is important

that early revision to definitive fixation is carried out as soon as they are stabilised.

This form of extreme physiological instability is comparatively rare after musculoskeletal trauma. A larger proportion of patients, however, may have clinically occult tissue hypoxia or hypoperfusion, despite an apparently successful initial resuscitation,^{89,90} as has been increasingly recognised with the use of more invasive forms of monitoring. Many of these patients also have evidence of SIRS and concerns have been raised about the safety of early reamed nailing because the procedure may act as a secondary 'hit', which may trigger the development of ARDS.^{9,19,20,89}

Modifications to the basic protocol of early reamed nailing have been examined including the use of temporary external fixation until the inflammatory response has settled or resuscitation is complete,^{88,91} the employment of different methods of fixation such as unreamed nails^{78,92,93} or compression plates,^{94,95} or of techniques designed to reduce fat embolisation during reamed nailing including venting,⁹⁶ lavage of the medullary canal⁸⁶ or an altered design of reamer.⁹⁷

As yet, definitive clinical evidence of a beneficial effect from the use of these measures is lacking and the results of experiments in animals are conflicting.^{31,98-101} There is some evidence to suggest that patients who have been incompletely resuscitated have a higher incidence of pulmonary complications when the operation is carried out early,^{89,102} although it is possible that such patients have a greater initial severity of injury, which is responsible for their poor prognosis.¹⁰³ If delayed fixation is used, it is still not clear how long the delay should be, since reliable laboratory markers of the inflammation or occult tissue hypoperfusion are not generally available.

It could be argued that early definitive fixation should be seen as an even higher priority in patients with evidence of SIRS or occult hypoperfusion because of their increased risk of subsequently developing ARDS. Those who develop this complication may be too medically labile to undergo further surgery for some weeks after this initial phase, and prolonged external fixation may then produce a poor functional outcome or substantially complicate later definitive surgery.¹⁰⁴

The patient with a concomitant chest injury. Attention has also focused on the subgroup of multiply-injured patients with chest injuries, typically a pneumothorax, a haemothorax or pulmonary contusion, since the FE produced by reamed nailing may further compromise their impaired pulmonary function. Similar modifications to the management of the fracture to those described above have been suggested to reduce the extent of FE. The available clinical evidence, however, suggests that it is the chest injury which primarily determines whether the patient develops ARDS and not the femoral fracture,^{67,68,74,82,93,95,105,106} since the risk of this complication in patients with an injured chest remains the same, irrespective of whether or not they have an associated femoral fracture (Figs 3a and 3b). This is substantiated by the

absence of a significant difference in the risk of ARDS when comparing patients with chest injury alone with those who also have femoral fractures (Fig. 3c).

Although some studies using animal models have suggested that reamed nailing is detrimental in the presence of lung contusion,^{107,108} this has not been supported by others.^{109,110}

The patient with a concomitant head injury. Some studies have suggested that early definitive stabilisation of the fractures in patients with a concomitant head injury is safe¹¹¹ or may actually reduce the risk of pulmonary complications,¹¹² while others have indicated that early nailing may be deleterious.¹¹³ It has also been suggested that the timing of fixation of the fracture is less important than the severity of the head injury in determining the risk of ARDS¹¹⁴ and that surgery is best carried out after the patient has been fully resuscitated.¹¹⁵ There are also theoretical concerns regarding the cerebral FE produced during nailing, which may compromise neurological recovery. Most cerebral FE, however, appears to occur at the time of fracture and is not necessarily produced during its stabilisation.⁶⁰

Other injury combinations. Patients with multiple fractures of long bones are at a greater risk of ARDS than those with single fractures, although this may be because they also tend to have more severe injuries to other body systems.¹¹⁶ Although there is little supportive clinical evidence, it is probable that patients with musculoskeletal injury and concomitant abdominal, pelvic, spinal or maxillofacial trauma and those with burns have a higher risk of developing respiratory complications.

Overview of the current treatment of fractures. In addition to the considerable variation in the severity and distribution of injury, patients respond differently to it because of the variation in their immune and physiological status. It is difficult to be prescriptive in the orthopaedic management and a flexible approach is likely to be more successful than rigid adherence to a particular technique or protocol. In general terms, however, the more severely injured patient (with ISS>18) with physiological instability, requires temporary methods of fixation until this has been corrected, when definitive fixation can be carried out. For most patients, fractures are best stabilised at an early stage after initial resuscitation. Reamed nailing is the best method of fixation for fractures of long bones in the leg, combined with other techniques to stabilise associated pelvic, spinal, metaphyseal and intra-articular fractures. As yet, there is no convincing clinical evidence to support the routine use of alternative strategies in the presence of occult hypoperfusion or SIRS, chest or head injury or multiple fractures of long bones.

Current management of established ARDS and FES

The mainstay of treatment for the patients who develop these complications remains largely supportive. Admin-

Fig. 3a

Fig. 3b

Fig. 3c

Summary of the previous English-language studies which have examined the effects of a chest injury (TI) and/or fracture of a long bone treated by nailing (LBF) on the incidence of post-traumatic respiratory complications in multiply-injured patients. The data are displayed as in Figure 2. The analysis is stratified to compare the incidence of respiratory complications in patients with chest injury alone with those with fracture of a long bone alone (a), fracture of a long bone alone with concomitant chest injury and fracture of a long bone (b), and chest injury alone with concomitant chest injury and fracture of a long bone. (c) Patients with chest injury have a significantly increased risk of pulmonary complications, irrespective of whether they have a concomitant fracture of a long bone ($RR = 0.33$, b) or not ($RR = 0.35$, a). There is no significant difference in risk between patients with chest injury alone and those with combined chest and fractures of a long bone ($RR = 0.87$, p value not significant (c)).

istration of adequate humidified oxygen is titrated against the patient's needs by monitoring arterial blood gas levels, together with fluid replacement and physiotherapy to the chest to minimise the risk of secondary infection. In the patient who is not managing to maintain adequate oxygenation or who is becoming 'tired' because of prolonged air-hunger, mechanical ventilation may be required, although a trial of application of constant positive airways

pressure (CPAP) to a tight-fitting mask may obviate this. If mechanical ventilation is used, the hypoxaemia is addressed by manipulating the concentration of inspired oxygen and using positive end-expiratory pressures. Antibiotics may be required for secondary infection and tracheostomy and nutritional support may be needed if prolonged ventilation is necessary.

Specific methods of treatment which have been subjected

to randomised trials include the administration of corticosteroids,¹¹⁷ heparin,¹¹⁸ dextran¹¹⁹ and anticytokines.⁸ Although some of the results have been encouraging, none of these interventions has been widely adopted because each has a substantial risk of harmful and occasionally catastrophic side-effects.

Prognosis

The mortality in both of these conditions remains considerable, although there is evidence that the overall survival has improved in recent years.¹²⁰ It is generally considered that the prognosis from ARDS is worse, with an expected mortality in the vicinity of 50%, although most studies have been carried out in intensive-care units on patients with severe trauma to multiple systems in whom the death rate is expected to be higher.¹⁰ The cause of death in approximately one-third of patients is due to other injuries, especially to the head. In the remainder, death is usually either as a result of overwhelming secondary sepsis or MODS. The mortality from FES is usually reported as between 5% and 15%,⁴³ but it may be as high as 36% in patients who require mechanical ventilation.¹²¹

There is little information on the residual respiratory morbidity from the sequelae of pulmonary involvement in ARDS and FES. Patients with FES may have persistent neurological deficits,^{48,58} although spontaneous recovery may occur gradually over many months. Severe hepatic and renal involvement in both ARDS and FES may result in permanent impairment in the function of these organs.

Summary

Initial diligent resuscitation of the multiply-injured patient, with early fixation of the major orthopaedic injuries, has significantly reduced the incidence of post-traumatic respiratory complications from the unacceptably high levels which were seen 20 years ago. With these improvements we may be entering an era in which the risk of these complications is independent of the orthopaedic injury and is determined largely by the severity of injury to other body systems or by the immune and physiological status of the patient. Substantive proof of any beneficial effect from modification of the timing and technique of fracture stabilisation will be difficult to achieve without large multicentre randomised trials. It is conceivable that these interventions have a negligible effect on outcome or may actually be detrimental.

Unravelling the basic molecular and cellular pathogenic processes of ARDS and FES will lead to improved therapeutic strategies for the treatment of this condition. For the present, however, the evidence suggests that expedient and appropriate early treatment of fractures in most instances protects against the development of post-traumatic respiratory insufficiency. Currently, the best and most effective therapeutic tool of the practising orthopaedic/trauma surgeon is prevention.

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