British Journal of Anaesthesia 1996; **76**: 726–730

REVIEW ARTICLE

Prehospital monitoring of trauma patients: experience of a helicopter emergency medical service

A. P. MORLEY

The Helicopter Emergency Medical Service (HEMS) began operating from the Royal London Hospital in 1989. It remains the only medically staffed helicopter for the retrieval of major trauma victims in the UK. Its aim is to optimize early management and ensure rapid transport to appropriate specialist centres. When necessary, patients are anaesthetized, the trachea intubated and the lungs ventilated manually on scene. Trauma, and ensuing therapy, may be accompanied by significant physiological change. The aims of monitoring are to improve patient safety, increase the likelihood of early, accurate diagnosis, and allow assessment of subsequent treatment.

Monitors for prehospital use

The recommendations of the Association of Anaesthetists for minimal standards of monitoring in anaesthesia are well known. Continuous monitoring of cardiovascular and respiratory function is essential [2]. In addition, a recent working party has produced a report on patient management during helicopter transport, including recommendations for monitoring [6]. Both refer to the uninterrupted presence of an appropriately trained doctor throughout. Table 1 illustrates monitors that HEMS apply on arrival at scene and subsequently in the helicopter, where mechanical ventilation is often commenced. Weight limitations on equipment carried by HEMS in the aircraft and thence to scene has led to the exclusion of some otherwise desirable monitors.

Equipment for use on board aircraft requires Civil Aviation Authority (CAA) approval specific to the type and model of the aircraft in which it is to be used. Each item of monitoring equipment must be tested by a CAA approved organization [11] to exclude any potential hazards, for example fire, smoke, explosion or interference with aircraft communication and navigation systems. While the helicopter is thus unaffected by the monitor, the reverse is not necessarily the case. General monitoring problems encountered in flight, and before this in the field, are summarized in table 2.

Some qualities are desirable in monitors for use in the prehospital environment and in patient transfer (table 3). Portable multimodal monitors are available from several manufacturers, including Siemens, Datascope, Datex and PaceTech. HEMS uses the Propaq 106EL (Protocol Systems, Inc., Beaverton, OR, USA). It measures 16.3 cm by 20.5 cm by 16.8 cm and weighs 3.8 kg. Its minimum battery life is 4 h and it has electrocardiogram (ECG), non-invasive arterial pressure (NIAP), oxygen saturation (Sp_{O_2}), end-tidal carbon dioxide (PE'_{CO_2}) and temperature measurement facilities.

ELECTROCARDIOGRAPHY

ECG monitoring is a fundamental part of most resuscitation procedures. It assists the on scene diagnosis of electromechanical dissociation (EMD), arrhythmias, and myocardial injury and ischaemia. EMD may occur in trauma patients with tension pneumothoraces and hypovolaemia. Myocardial injury from blunt chest trauma may cause arrhythmias or more subtle ST segment deviations, the interpretation of which requires caution. Normal individuals can exhibit ST segment deviation on standard prehospital cardiac monitoring equipment during routine transport [22]. ECG monitoring is prone to mechanical and electrical interference, both on scene and in transit. In addition, adhesive electrodes often become detached in the rain or if blood runs onto the chest.

NON-INVASIVE ARTERIAL PRESSURE

On scene, frequent, automated NIAP monitoring helps in the early detection of hypotension, although this is a late sign of shock in the young. NIAP monitoring enables detection of hypertension accompanying increased intracranial pressure in head injured patients. The efficacy of attempts to obtund the hypertensive response to on scene laryngoscopy and intubation may also be assessed. There are several practical problems with NIAP cuff application in the field. These include lack of access where patients are trapped. Clothing usually needs to be cut and underlying limbs may be injured. When the cuff has been applied, patient movement or vibration from extrication tools may prevent accurate readings.

In helicopter transit, oscillometric readings in critically ill patients are not as reliable as direct invasive monitoring and are, in some instances,

(*Br. J. Anaesth.* 1996; **76**: 726–730)

Key words

Anaesthesia, audit. Anaesthesia, emergency service. Complications, trauma. Equipment, monitors.

A. P. MORLEY, BA, MB, BS, FRCA, Helicopter Emergency Medical Service, Royal London Hospital, Whitechapel, London E1 1BB. Present address for correspondence: Department of Anaesthesia and Intensive Care, Prince of Wales Hospital, Sha Tin, New Territories, Hong Kong.

Table 1 Recommended monitors for prehospital management and air transfer of trauma patients

On scene	In aircraft
Pulse oximeter	Continued use of on scene monitors
Electrocardiogram	
Automated NIAP	
In-line capnograph	Airway pressure monitor
Aural temperature probe	

Table 2 General monitoring problems in the prehospital management and air transfer of trauma victims

On scene	In aircraft
Environmental	
Rain	Noise
Cold	Vibration
Sunshine	Access
Noise	Electrical interference
Vibration	
Access to patient	
Distraction by events at scene	
Patient-related factors	
Injury preventing monitor application	
Displacement of sensors	
Unco-operative, confused patients	

Table 3 Desirable features in a prehospital monitor

Accuracy
Multimodality
Long battery life with recharging facility
Durability
Ease of carriage
Lightweight
Reliability in adverse environmental conditions
Ease of operation by attendant paramedical staff
Compability with equipment at receiving hospitals
Printer/downloading facility
Ease of service or part replacement
Low cost

unobtainable [35]. This may also be because of vibration. In a study by Campbell and colleagues [7] comparing methods of neonatal transport, helicopters in flight were found to produce overall vibration levels of 5.6 m sq s^{-1} in the vertical axis, with least vibration occurring in cruising fixed-wing aircraft (0.04 m sq s^{-1}). During HEMS helicopter transfers, NIAP monitoring is prone to intermittent malfunction. While invasive arterial pressure monitoring may be more accurate and reliable, the aim is to treat and transport casualties as quickly as possible from the scene to the appropriate hospital. Extra time taken attempting roadside arterial cannulation may not be in the patient's best interests.

TEMPERATURE

HEMS uses an aural probe, compatible with the Propaq 106EL, to measure core temperature. This is reasonably well tolerated by conscious patients. It indicates the presence of initial hypothermia and monitors the response to corrective manoeuvres. In trauma patients, core and mean body temperatures are inversely related to severity of injury [34]. For a given level of injury, mortality is increased in trauma patients who develop hypothermia. This is the case whether hypothermia is defined as a core temperature below 34 °C, 33 °C or 32 °C [27]. Patients often sustain injuries outdoors and may suffer prolonged exposure to cold as a result of entrapment in vehicles. Clothing may be cut or removed in order to assess the nature and extent of the injury. Attempts to reduce heat loss at scene include the use of warmed i.v. fluids and reflective insulation blankets. In the helicopter, the cabin is heated by bleeding hot air from the engine compression system. This affects engine performance slightly so heating is not possible during take off or landing.

OXYGEN SATURATION

Pulse oximetry has numerous applications in hospital monitoring and an established place in anaesthesia. Several articles have indicated its usefulness in the prehospital environment, both on scene [36, 50] and in helicopter transfers [49, 54]. Its principal application for the field anaesthetist is detection of hypoxia, which may prompt a decision to induce anaesthesia and intubate the trachea. More controversially, some authors have suggested it has a role in monitoring circulation and assessment of systolic arterial pressure.

Independently, but especially in conjunction with hypotension, hypoxia is recognized as a major extracranial variable influencing outcome in severely head injured patients [10]. Early tracheal intubation of these patients should reduce the likelihood of hypoxia and hypercapnia and may prevent secondary brain injury. In one emergency department study, a group of patients monitored with continuous pulse oximetry while undergoing emergency intubation had a lower likelihood of hypoxic episodes and a shorter duration of severe hypoxia than an unmonitored group [38]. Pulse oximetry has also proved useful in the early detection and management of tension pneumothorax [30], and in other conditions encountered regularly by HEMS, such as severe lung contusions and haemothorax.

Some authors believe that the pulse oximeter is valuable for distal circulatory monitoring in injured limbs. The use of oximetry in the hospital treatment of supracondylar humeral fractures has been reported [5, 40]. However, a prospective study of oximetric monitoring of distal circulation in fractured limbs before and after manipulation showed it had no clear role [15]. In the diagnosis of failing perfusion caused by increased intracompartmental pressure, oximetry is unreliable [37]. This is not surprising. Pulse oximeter signals can be obtained from fingers where Doppler studies indicate only 4 % flow [32], suggesting that a plethysmographic trace is no guarantee of effective blood flow to the tissues. This may explain why, while the benefits of oximetry in the management of primary respiratory arrest seem clear, its value in monitoring resuscitation from cardiac arrest is doubtful [51], despite anecdotal reports [39].

As discussed above, there are some circumstances where oscillometric arterial pressure measurement is difficult. The reappearance of a plethysmographic waveform from a distal pulse oximeter probe on deflation of an arterial pressure cuff has been used to measure systolic arterial pressure in hospitalized neonates [31] and it compared favourably with oscillometric measurements. A similar method has also been used with some success in adults [9] and in patients transferred by helicopter [53]. Unfortunately, the accuracy and reliability of the technique used in the last study were not compared with those of the oscillometric method.

Environmental factors affecting pulse oximeter function

Several environmental factors limit the usefulness of pulse oximetry in the prehospital management of trauma patients. While ambient artificial light can cause inaccurate readings [16], the effect of direct sunlight is unknown, although it certainly reduces the visibility of LED display panels. Probe displacement is common. Where this is incomplete, spuriously low Sp_{O_2} readings may occur in normoxic subjects even when heart rate is displayed correctly [29]. In hypoxic subjects, various inaccuracies may result. Importantly, some oximeters display falsely high Sp_{O_2} values at low saturations [3]. Noise on scene may drown the pulse signal. Even in experimental conditions, the change in pitch accompanying desaturation in most oximeters is detected better by some subjects than others [45].

Oximeter readings fail frequently during helicopter transit. A recent study of pulse oximetry in a German air rescue service found that more than 25 % of measurement time was subject to interference [23]. Some oximeters incorporate weighted averaging systems to filter out suspect values while enabling a rapid response to changing Sp_{O_2} [56]. By using ECG synchronization, which is a feature of the Propaq 106EL, Helm and colleagues [24] achieved more than an eight-fold reduction in passive motion artefacts in oximetric monitoring during emergency helicopter patient transfer.

Patient factors affecting pulse oximeter function

Trauma victims out of hospital are not prepared in the same way as patients before operation. Although pulse oximeter readings are unchanged by dried blood [42] and most shades of nail polish [14], oximeter failure has occurred in some HEMS patients with fingers covered in oil or bitumen.

Clinical circumstances influence interpretation of oximeter readings. Burns accounted for about 5% of the HEMS workload in 1994 and, at present, there are no facilities for measuring carboxyhaemoglobin (HbCO) on the aircraft. In the presence of HbCO, the fractional oxygen saturation is overestimated by pulse oximetry [41]. Despite absorption spectra differences between oxyhaemoglobin and HbCO, the degree of overestimation is close to the percentage of HbCO in most cases. This has been shown *in vitro* [41], in animal studies [4] and clinically for HbCO values of 1–30 % [55].

Blood loss is common in trauma victims. In the presence of normoxia, acute severe anaemia, with haemoglobin concentrations as low as 2.3 g dl^{-1}, does not significantly affect the accuracy of pulse oximetry [26]. However, at an oxygen saturation of less than 80 %, anaemia approximately doubles the error of pulse oximeters [46]. HEMS does not carry blood, and patients are resuscitated, where appropriate, with warmed crystalloid or colloid solutions. The resulting haemodilution may exacerbate any decrease in haemoglobin concentration.

Where blood loss and hypothermia coexist, the resulting peripheral vasoconstriction increases the hypotensive failure threshold of pulse oximeters [48]. Under conditions of poor perfusion, a comparison of 20 pulse oximeters showed variable performance, with all but two models failing on occasion. Where readings were obtained, mean differences from corresponding co-oximeter readings were less than 5 % [12]. The same group compared the performance of finger, nose, ear and forehead probes, under similar conditions, all of which are carried by HEMS. Their conclusion was that the overall performance of probes in sites other than the finger was worse [13]. Interestingly, there is some evidence that under conditions of profound hypoxia, another clinical state encountered frequently by HEMS, ear probes respond more rapidly and more accurately than finger probes [47].

The accuracy of pulse oximetry may be affected adversely by both patient and environmental factors. The clinical relevance of this may not be immediately apparent, given that 100 % oxygen is administered to most trauma victims as soon as ambulance crews or HEMS arrive. However, the first oximetric readings may influence the decision to intubate the trachea or insert chest drains. At present, initial ventilatory frequency, systolic arterial pressure and Glasgow coma scale are used to compile the revised trauma score. This enables the physiological state of trauma victims to be compared and has some predictive value [8]. In future, it is possible that initial oxygen saturation may also be used in this way and accurate measurement will assume even greater importance.

END-TIDAL CARBON DIOXIDE

Portable methods of $P\text{E}'_{CO_2}$ measurement are limited to disposable colorimetric devices or in-line analysers, which may be incorporated into multimodal monitors such as the Propaq.

An example of the former is the Easy Cap (Nellcor Incorporated, Hayward, CA, USA). This incorporates metocresol purple as an indicator that changes colour from purple to yellow in the presence of carbon dioxide. A colour scale allows distinction between the following ranges of $P\text{E}'_{CO_2}$; “A” purple, 0.03 to <0.05 %; “B” tan, 0.5–2 %; “C” yellow, 2–5%. In patients whose tracheas are intubated correctly, the indicator colour cycles from purple (inspiration) to yellow (expiration). The detector has an internal volume of 38 ml, a flow resistance of 3 $\pm$ 1 cm H_2O at 60 litre min^{-1} and weighs less than 30 g. It ceases to function if the indicator strip becomes moist. This is a significant limitation in traumatized patients, where the airway may be soiled with blood, sputum, gastric contents, pulmonary oedema or tracheally administered drugs.

On scene capnometry assists confirmation of tracheal intubation, assessment of cardiopulmonary resuscitation, monitoring of deliberate hyperventilation and diagnosis of circuit disconnection.

Reliable confirmation of tracheal intubation is essential in unfavourable prehospital intubating conditions. Before medical staff arrive, the trachea is sometimes intubated by paramedics who may not recognize oesophageal placement [52]. Chest auscultation is often unsatisfactory because of noise, for example extrication equipment, and $P\text{E}'_{CO_2}$ measurement, as in the operating theatre, is the best method. In one hospital study, a disposable device allowed more rapid confirmation of tracheal intubation than capnography. Speed of detection of oesophageal intubation was not significantly different for the two methods, and there were no false positive or false negative results with the colorimetric method [21]. Cautious interpretation is advisable in the field, whichever method is used. Recent ingestion of beer leads to high oesophageal $P\text{CO}_2$ in dogs [19]. In addition, manual bag and mask ventilation by paramedics is common. This produces initial, high "expired" $P\text{CO}_2$ readings where the oesophagus is subsequently intubated [33].

During cardiopulmonary resuscitation, the increase in $P\text{E}'_{CO_2}$ that accompanies the return of spontaneous circulation is detectable with a disposable capnometer [25] and is often the first clinical indicator of the event [20]. The capnograph may herald the onset of circulatory arrest [17] and even indicate the efficacy of external cardiac massage [28]. $P\text{E}'_{CO_2}$ depends on alveolar ventilation and pulmonary circulation. Where the former varies, as might be expected in roadside patients whose lungs are ventilated manually, assessment of pulmonary circulation by $P\text{E}'_{CO_2}$ measurement should not logically be reliable. However, in one hospital study where arrested patients underwent manual ventilation, minimum $P\text{E}'_{CO_2}$ values during CPR were predictive of resuscitation outcome and survival [44].

Capnography may be used to monitor the deliberate hyperventilation of head injured patients, when the trachea has been intubated on scene. Although the accuracy of most capnometers deteriorates even with a relatively modest increase in ventilatory frequency, in-line analysers of the type supplied for the Propaq 106EL are less prone to this than the sampling types [18]. During deliberate hyperventilation, interpretation of $P\text{E}'_{CO_2}$ readings usually relies on the assumption that they accurately reflect arterial partial pressures of carbon dioxide (Pa_{CO_2}). This assumption may be rendered invalid by the physiological state of trauma victims. Askrog and colleagues, for example, demonstrated the increase in $Pa_{CO_2} - P\text{E}'_{CO_2}$ gradient in anaesthetized patients deliberately rendered hypotensive [1]. More significant, perhaps, is a recent study of normovolaemic patients with multiple trauma undergoing mechanical ventilation [43] where the authors established a consistent Pa_{CO_2} to $P\text{E}'_{CO_2}$ correlation across the study population. However, there was no correlation in 22 % of individual patients, the frequency of a linear correlation was only 41 %, and the ability of $P\text{E}'_{CO_2}$ changes to predict the direction of change of Pa_{CO_2} was in error in 27 % of comparisons.

The risk of circuit disconnection in patients undergoing ventilation is greater in the relatively uncontrolled prehospital environment where patients are transferred repeatedly from one site, or mode of transport, to another. Chest wall movements may be obscured, and changes in ventilator tone rendered inaudible by environmental noise. The capnograph is a more reliable indicator of the integrity of a circuit.

Conclusion

Monitors are important in the prehospital management of trauma victims. They may provide information that determines treatment at scene or in transit. Where patients are anaesthetized at scene, the standard of physiological monitoring required does not differ from that in theatre and is approached by some of the recent, portable, multimodal monitors. None of these, however, incorporates an oxygen analyser. Oxygen cylinders frequently run out unnoticed because of the absence of a suitable alarm. Monitoring of equipment used in the field is still suboptimal in this respect.

The accuracy and reliability of monitors may be affected adversely by the prehospital environment and the nature of the patients and their injuries. For the attending physician to interpret monitor readings correctly, familiarity with the equipment, its principles of operation and its limitations is essential.

The principal aim of resuscitation in trauma victims is adequate delivery of oxygenated blood to the tissues. This is difficult to assess in the intensive care unit and even more so at the roadside. Currently available monitors can, at best, provide only a guide. It is hoped that future design modifications will overcome some of the problems with the monitors discussed in this review.

References

1. Askrog VF, Pender JW, Eckenhoff JE. Changes in physiological dead space during deliberate hypotension. *Anesthesiology* 1964; **25**: 744–751.
2. Association of Anaesthetists of Great Britain and Ireland. Recommendations for minimum standards of monitoring in anaesthesia and recovery (revised). London: Association of Anaesthetists of Great Britain and Ireland, 1994.
3. Barker SJ, Hyatt J, Shah NK, Kao YJ. The effect of sensor malpositioning on sensor accuracy during hypoxemia. *Anesthesiology* 1993; **79**: 248–254.
4. Barker SJ, Tremper KK. The effect of carbon monoxide inhalation on pulse oximetry and transcutaneous $P\text{O}_2$. *Anesthesiology* 1987; **66**: 677–679.
5. Best CJ, Woods KR. An aid to the treatment of supracondylar fracture of the humerus: brief report. *Journal of Bone and Joint Surgery* 1989; **71B**: 141.
6. Bristow, A, Baskett P, Dalton M, Ediss P, Evans I, Harris R, Leighton M, Martin L, Perry I, Roberts G, Scurr J, Skinner D, Strong J, Toff N, Wilson A. Medical helicopter systems—recommended minimal standards for patient management. *Journal of the Royal Society of Medicine* 1991; **84**: 242–244.
7. Campbell AN, Lightstone AD, Smith JM, Kirpalani H, Perlman M. Mechanical vibration and sound levels experienced in neonatal transport. *American Journal of Diseases of Childhood* 1984; **138**: 967–970.
8. Champion HA, Sacco WJ, Copes WS, Gann DS, Gennarelli TA, Elanagan ME. A revision of the trauma score. *Journal of Trauma* 1989; **29**: 623–629.
9. Chawla R, Kumarvel V, Girdhar KK, Sethi AK, Indrayan A,

Bhattacharya A. Can pulse oximetry be used to measure systolic blood pressure? *Anesthesia and Analgesia* 1992; **74**: 196–200.
10. Chesnut RM, Marshall LF, Klauber MR, Blunt BA, Baldwin N, Eisenberg HM, Jane JA, Marmarou A, Foulkes MA. The role of secondary brain injury in determining outcome from severe head injury. *Journal of Trauma* 1993; **34**: 216–222.
11. Civil Aviation Publication 553 (Airworthiness procedures where the CAA has primary responsibility for type approval of the product). London: Civil Aviation Authority, 1991.
12. Clayton DG, Webb RK, Ralston AC, Duthie D, Runciman WB. A comparison of the performance of 20 pulse oximeters under conditions of poor perfusion. *Anaesthesia* 1991; **46**: 3–10.
13. Clayton DG, Webb RK, Ralston AC, Duthie D, Runciman WB. Pulse oximeter probes: a comparison between finger, nose, ear and forehead probes under conditions of poor perfusion. *Anaesthesia* 1991; **46**: 260–265.
14. Cote CJ, Goldstein EA, Fuchsman WH, Hoaglin DC. The effect of nail polish on pulse oximetry. *Anesthesia and Analgesia* 1988; **67**: 683–686.
15. David HG. Pulse oximetry in closed limb fractures. *Annals of the Royal College of Surgeons of England* 1991; **73**: 283–284.
16. Eisele JH, Downs D. Ambient light affects pulse oximeters. *Anesthesiology* 1987; **67**: 864–865.
17. Falk JL, Rackow EC, Weil MH. End-tidal carbon dioxide concentration during cardiopulmonary resuscitation. *New England Journal of Medicine* 1988; **318**: 607–611.
18. From RP, Scamman FL. Ventilatory frequency influences accuracy of end-tidal CO_2 measurements: analysis of seven capnometers. *Anesthesia and Analgesia* 1988; **67**: 884–886.
19. Garnett AR, Gervin CA, Gervin AS. Capnographic waveforms in esophageal intubation: effect of carbonated beverages. *Annals of Emergency Medicine* 1989; **18**: 387–390.
20. Garnett AR, Ornato JP, Gonzalez ER, Johnson EB. End-tidal carbon dioxide monitoring during cardiopulmonary resuscitation. *Journal of the American Medical Association* 1987; **257**: 512–515.
21. Goldberg JS, Rawle PR, Zehnder JL, Sladen RN. Colorimetric end-tidal carbon dioxide monitoring for tracheal intubation. *Anesthesia and Analgesia* 1990; **70**: 191–194.
22. Hebel GA, Hutton K, Kanowitz A, Neuman T, Martinson L, Rosen P. The accuracy of ST segment deviation in prehospital cardiac monitoring. *Journal of Emergency Medicine* 1994; **12**: 207–211.
23. Helm M, Forstner K, Lampl L, Bock KH. Pulse oximetry in the air rescue service. 1. Quantitative detection of interfering factors on the method. (German). *Anästhesiologie, Intensivmedizin, Notfallmedizin, Schmerztherapie* 1993; **28**: 86–90.
24. Helm M, Forstner K, Lampl L, Bock KH. Pulse oximetry in the air rescue service. 2. Methods of increasing the stability of pulse oximetry measurements—ECG synchronized pulse oximetry and adhesive sensors (German). *Anästhesiologie, Intensivmedizin, Notfallmedizin, Schmerztherapie* 1993; **28**: 174–178.
25. Higgins D, Hayes M, Denman W, Wilkinson DJ. Effectiveness of using end tidal carbon dioxide concentration to monitor cardiopulmonary resuscitation. *British Medical Journal* 1990; **300**: 581.
26. Jay GD, Hughes, L, Renzi FP. Pulse oximetry is accurate in acute anemia from hemorrhage. *Annals of Emergency Medicine* 1994; **24**: 32–35.
27. Jurkowich GJ, Greiser WB, Luterman A, Curreri PW. Hypothermia in trauma victims: an ominous predictor of survival. *Journal of Trauma* 1987; **27**: 1019–1024.
28. Kalenda Z. The capnogram as a guide to the efficacy of cardiac massage. *Resuscitation* 1976/1977; **6**: 259–263.
29. Kelleher JF, Ruff RH. The penumbra effect: vasomotion-dependent pulse oximeter artifact due to probe malposition. *Anesthesiology* 1989; **71**: 787–791.
30. Laishley RS, Aps C. Tension pneumothorax and pulse oximetry. *British Journal of Anaesthesia* 1991; **66**: 250–252.
31. Langbaum M, Eyal FG. A practical and reliable method of measuring blood pressure in the neonate by pulse oximetry. *Journal of Pediatrics* 1994; **125**: 591–595.
32. Lawson D, Norley I, Korbon G, Loeb R, Ellis J. Blood flow limits and pulse oximeter signal detection. *Anesthesiology* 1987; **67**: 599–603.
33. Linko K, Paloheimo M, Tammisto T. Capnography for detection of accidental oesophageal intubation. *Acta Anaesthesiologica Scandinavica* 1983; **27**: 199–202.
34. Little RA, Stoner HB. Body temperature after accidental injury. *British Journal of Surgery* 1981; **68**: 221–224.
35. Low RB, Martin D. Accuracy of blood pressure measurements made abroad helicopters. *Annals of Emergency Medicine* 1988; **17**: 604–612.
36. McGuire TJ, Pointer JE. Evaluation of a pulse oximeter in the prehospital setting. *Annals of Emergency Medicine* 1988; **17**: 1058–1062.
37. Mars M, Hadley GP. Failure of pulse oximetry in the assessment of raised limb intracompartmental pressure. *Injury* 1994; **25**: 379–381.
38. Mateer JR, Olson DW, Stueven HA, Aufderheide TP. Continuous pulse oximetry during emergency endotracheal intubation. *Annals of Emergency Medicine* 1993; **22**: 675–679.
39. Narang VPJ. Utility of the pulse oximeter during cardiopulmonary resuscitation. *Anesthesiology* 1986; **65**: 239–240.
40. Ray SA, Ivory JP, Beavis JP. Use of pulse oximetry during manipulation of supracondylar fractures of the humerus. *Injury* 1991; **21**: 103–104.
41. Reynolds KJ, Palayiwa E, Moyle JTB, Sykes K, Hahn CEW. The effect of dyshemoglobins on pulse oximetry: part I, theoretical approach and part II, experimental results using an in vitro test system. *Journal of Clinical Monitoring* 1993; **9**: 81–90.
42. Rosewarne FA, Reynolds KJ. Dried blood does not affect pulse oximetry. *Anaesthesia* 1991; **46**: 886–887.
43. Russell GB, Graybeal JM. Reliability of the arterial to end-tidal carbon dioxide gradient in mechanically ventilated patients with multi-system trauma. *Journal of Trauma* 1994; **36**: 317–322.
44. Sanders AB, Kern KB, Otto CW, Milander MM, Ewy GA. End-tidal carbon dioxide monitoring during cardiopulmonary resuscitation: a prognostic indicator for survival. *Journal of the American Medical Association* 1989; **262**: 1347–1351.
45. Schulte GT, Block FE jr. Can people hear the pitch change on a variable-pitch pulse oximeter? *Journal of Clinical Monitoring* 1992; **8**: 198–200.
46. Severinghaus JW, Koh SO. Effect of anemia on pulse oximeter accuracy at low saturation. *Journal of Clinical Monitoring* 1990; **6**: 85–88.
47. Severinghaus JW, Naifeh KH. Accuracy of response of six pulse oximeters to profound hypoxia. *Anesthesiology* 1987; **67**: 551–558.
48. Severinghaus JW, Spellman MJ. Pulse oximeter failure thresholds in hypotension and vasoconstriction. *Anesthesiology* 1990; **73**: 532–537.
49. Short L, Hecker RB, Middaugh RE, Menk EJ. A comparison of pulse oximeters during helicopter flight. *Journal of Emergency Medicine* 1989; **7**: 639–643.
50. Silverston P. Pulse oximetry at the roadside: a study of pulse oximetry in immediate care. *British Medical Journal* 1989; **298**: 711–713.
51. Spittal MJ. Evaluation of pulse oximetry during cardiopulmonary resuscitation. *Anaesthesia* 1993; **48**: 701–703.
52. Stewart RD, Paris PM, Winter PM, Pelton GH, Cannon GM. Field endotracheal intubation by paramedical personnel: success rates and complications. *Chest* 1984; **85**: 341–345.
53. Talke P. Measurement of systolic blood pressure using pulse oximetry during helicopter flight. *Critical Care Medicine* 1991; **19**: 934–937.
54. Talke P, Nichols RJ, Traber DL. Monitoring patients during helicopter flight. *Journal of Clinical Monitoring* 1990; **6**: 139–140.
55. Vegfors M, Lennmarken C. Carboxyhaemoglobinaemia and pulse oximetry. *British Journal of Anaesthesia* 1991; **66**: 625–626.
56. Wukitsch MW, Petterson MT, Tobler DR, Pologe JA. Pulse oximetry: analysis of theory, technology and practice. *Journal of Clinical Monitoring* 1988; **4**: 290–301.