working experience had been gained by the team; the brakes, door locks, jacks and floor covering were then reported faulty and duly rectified.

As no form of warning device had been installed in the trailer to enable a passenger on finding some fault developing—such as loose equipment—to warn the driver, a push button and warning horn were installed.

From reports received, the vehicle has functioned well and in accordance with expectations. Perhaps the best index of its worth is the number of cases handled: in its first five full working months up to the end of December, 1956, it has handled an average of 3,238 cases per month, a most satisfactory figure considering the long distances involved. Interpretation of these films is carried out by the radiologist at the B.M.H., Kinrara.

It is hoped that construction of a second M.M.R. vehicle of similar design, for which the X-ray set is already available, will start soon.

Much credit is due to Captain J. Hardie, R.E.M.E., who was in general charge of construction of the trailer; to Staff-Sergeant J. Greaves, R.E.M.E., who with his Chinese technicians actually built it; and to Lieut.-Colonel G. A. Marsh, R.E.M.E., who as officer in charge of Workshops was largely responsible for the technical design and who first suggested the type of chassis to be used.

TREATMENT OF CRUSH INJURY OF THE CHEST
BY
INTERMITTENT POSITIVE PRESSURE RESPIRATION
AND CONTINUOUS CURARISATION

BY

J. A. THORNTON, M.B., F.F.A.R.C.S., D.A.
Senior Registrar, Department of Anaesthetics, Guy’s Hospital
Formerly Junior Specialist in Anaesthetics, Royal Army Medical Corps

The method of treatment of crush injury of the chest is dependent to a large degree on the type and severity of the injury. Treatment may range from strapping, rest and analgesics in the milder cases to skeletal traction and plaster in the more severe. Hagen (1945) and Brooks (1942) have used mechanical respirators with considerable success. Gray (1942) and Watson-Jones (1955) also advise their use. Recently, Hulman (1957) summarised the rationale of tracheotomy described by various authors in the past: Carter & Giuseffi (1951, 1953, 1954), Von Leden (1953), Gray (1954), Williams (1951, 1955), Baronofsky, Dickman & Vanderhoof (1950), Avery et al. (1955, 1956) have described treatment with continuous hyperventilation and intermittent positive pressure.

This paper is the record of a failure, but the patient, moribund on admission with a “stove-in” chest, was kept alive for six days, so it is felt that a description of the methods used, mistakes made, and lessons learnt is worth reporting.
The patient, a well-built young soldier of 22 years, was admitted to the British Military Hospital, Nicosia, having sustained a severe crush injury to his chest following a road accident in February, 1956. He was seen on admission (half an hour after the accident).

**Condition on admission.** The patient was severely shocked with an unrecordable blood-pressure. Examination of the chest revealed a severe "stove-in" injury and a fractured right clavicle with considerable hæmatoma formation around the right shoulder. Clinically there was evidence of a right hæmopneumothorax of considerable size. Respiration was paradoxical, every inspiratory movement causing insucking of the chest and considerable respiratory embarrassment. There was marked pallor, followed by cyanosis as the blood pressure became elevated. There was no clinical evidence of head, central nervous system or abdominal injury. Bowel sounds were present and remained so until he died. The skin surface was intact.

**TREATMENT**

The patient's blood was immediately grouped and a dextran drip set up. Oxygen was administered by an oro-nasal B.L.B. mask with no relief of cyanosis or respiratory embarrassment. After consultation, it was decided that the only possible way of saving this patient was to inflate his lungs by intermittent positive pressure. Accordingly, after the administration of atropine sulphate gr. 1/100 intravenously, a small dose of thiopentone sodium (2 ml. of a 2.5 per cent solution with the addition of 2 ml. Nikethamide to 10 ml.) was given, followed by 20 mg. of "Tubarine" intravenously. The vocal cords were sprayed with 5 per cent cocaine, the patient inflated with 100 per cent oxygen and a No. 10 cuffed Magill tube passed under direct vision. Blood and mucus were present in the trachea in great quantity and this was sucked clear with a gum elastic catheter. His condition at the time did not justify the strain of bronchoscopy. 100 per cent oxygen was then administered by positive pressure on the rebreathing bag of a standard Boyle's machine. As a result of this procedure there was a marked improvement in the patient's general condition and resuscitation was continued with the administration of blood.

Radiography of the chest by portable apparatus confirmed the clinical finding of hæmopneumothorax on the right side and the presence of fractured right clavicle, fracture of the first to eighth ribs at their angles on both sides, and scattered fractures at other sites on the ribs.

An intercostal thoracotomy was therefore performed under local anaesthesia. This resulted in the immediate withdrawal of three pints of blood under pressure and considerable quantities of air. There was a further marked improvement as a result of this procedure. A needle passed into the left chest resulted in a dry tap.

In view of the improvement so far gained it was decided to continue inter-
mittent positive pressure and the endotracheal tube was connected up to a Radcliffe positive pressure machine. Further surgical treatment was postponed at this time, thoracotomy not being considered advisable.

Six hours later, his clinical improvement allowed him to be respired with air and added oxygen (70 per cent approximately). The total amount of intravenous fluids given at this stage was eight pints of blood and six pints of dextran. It was of interest to note that on admission a dextran drip had been set up in the right arm, and fluid draining from the thoracotomy was like pure dextran, which led one to suppose the right subclavian vein might have ruptured into the right pleural cavity.

The first difficulty encountered was when the effect of the curare had worn off and the patient attempted to breathe. Paradoxical respiration again developed and the patient attempted to "resist" the machine, with the result that he became distressed and much blood was poured into the tracheobronchial tree.

It was therefore decided to keep the patient curarised until such time as the chest became more stabilised (possibly 14-21 days). A rigid routine was therefore adopted. Any attempt at voluntary respiration was countered by the administration of curare. A total of 900 mg. was given in divided doses intravenously over a period of five days.

Tracheotomy was performed twenty-four hours after admission and a shortened endotracheal tube (cuffed) was passed through the opening and artificial respiration maintained by this route. Bronchoscopy was done after the first forty hours and again twenty-four hours later, and on each occasion much blood and blood-stained mucus were aspirated. The trachea was sucked out every half-hour by means of a gum elastic catheter passed down the endotracheal tube. Thirty-six hours after admission, shock had been controlled by the administration of a total of twelve pints of blood and the blood pressure stabilised at 120/80.

Urinary output had returned to a reasonable figure (there was a fear at one stage of the patient developing anuria) and the patient was fully conscious, being able to understand a cable from home. It was also found that it was possible to wean the patient of added oxygen, but at no time, except on the day of his death, was it possible to respire the patient on air alone without the onset of cyanosis.

In view of the extensive injury to the chest it was thought inadvisable to move the patient more than was necessary for the treatment of pressure areas, and therefore a procedure was adopted in which the bed was tilted in four directions by insertion of blocks under the legs. The bed was moved every hour. Intravenous drip was discontinued after thirty-six hours (a total of twelve pints blood and six pints dextran having been given) and nourishment and electrolytes were given by intragastric drip. For the first forty-eight hours the patient was catheterised every twelve hours if required and after this he was able to pass urine into a bottle. The cuff on the endotracheal tube was let down every hour. Penicillin (200,000 units six-hourly) and streptomycin (1g. twice daily) were administered. The patient's haemoglobin was maintained as high as possible by the administration of blood, and the blood chemistry was checked daily (Table 1).
Table 1. The blood chemistry

<table>
<thead>
<tr>
<th></th>
<th>Blood Urea</th>
<th>Blood Cl⁻</th>
<th>Hb%</th>
<th>CO₂</th>
<th>Urine Cl⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Day</td>
<td>116 mg.%</td>
<td>98 mEq/l</td>
<td>80</td>
<td>48</td>
<td>2 g/l</td>
</tr>
<tr>
<td>2nd Day</td>
<td>70</td>
<td>90</td>
<td>70</td>
<td>52</td>
<td>3 g/l</td>
</tr>
<tr>
<td>3rd Day</td>
<td>75</td>
<td>98</td>
<td>72</td>
<td>48</td>
<td>5 g/l</td>
</tr>
<tr>
<td>4th Day</td>
<td>70</td>
<td>88</td>
<td>90</td>
<td>82</td>
<td>3 g/l</td>
</tr>
</tbody>
</table>

As it was likely that the patient would naturally suffer much pain and discomfort from the whole proceedings, he was kept heavily morphinised for the first forty-eight hours. Thereafter he was semi-conscious and it was impossible to keep him oxygenated without adding oxygen to the inspired air, and it was felt that the coma was possibly due to carbon dioxide poisoning resulting from the persistently high percentage of oxygen. Furthermore, attacks of elevation of the blood pressure and sweating occurred from time to time. This was undoubtedly attributable to carbon dioxide retention. They were not, however, reversed by increasing the respiratory rate and tidal exchange of the machine. Of further interest was the fact that increasing dosage of curare was necessary to achieve the desired effect.

On the day of death (14-2-56) the effects of curare were reversed by administering prostigmin and an attempt made to let him breathe on his own. This led to severe respiratory embarrassment and it was therefore decided to curarise him again. The patient died quite suddenly and unexpectedly fourteen hours after this procedure, there being no obvious immediate cause of death. His colour was good and the blood pressure was 120/60 two minutes before death, the pulse suddenly rising from 90 to 130.

POST-MORTEM REPORT

Respiratory System. On the left side of the chest there were fractures of the first rib one inch from the sternum and of the second to eighth ribs at their angles. On the right side of the chest the first rib was fractured three inches from the sternum, and the second to seventh ribs were fractured at the angles. The right side of the chest contained about one pint of blood and air and the left side about two pints of blood. There was a tracheostomy sinus leading into the trachea through the fifth, sixth and seventh tracheal rings. There was oedema of the glottis, and ulceration of the larynx on either side, just under the vocal cords. There was congestion of the trachea which was full of thick tenacious blood-stained mucus. The only air-containing tissue in the lungs was that of the anterior segments of the left upper and the right middle lobes. All the other pulmonary tissue was consolidated and very edematous. There was a penetrating wound two inches deep in the posterior border of the right upper lobe overlying the fracture of the fifth rib at its angle. The whole of the upper lobe surrounding this injury was replaced by blood clot.
Alimentary System. The peritoneal cavity contained about two pints of blood. There was a tear on the superior surface of the spleen, one inch long, surmounted by blood clot.

Cause of Death: (1) Consolidation of lungs.
(2) Bilateral hæmorrhages.
(3) Fracture of ribs.
(4) Rupture of spleen.

DISCUSSION

It would be impossible to treat such a case in time of war except under special circumstances as there would be neither the facilities nor the time. In this particular case, the extent of this patient's injuries were so severe that recovery was unlikely from the outset.

It was essential to keep the patient well curarised as any effort on the part of the patient to breathe produced embarrassment of respiration and paradoxical breathing. Hyperventilation rather than curarisation has been used by Avery et al. (1955, 1956). They observed no demonstrable changes in the blood chemistry, although these are likely to occur with hyperventilation. A large percentage of oxygen was required in this case, because of the diminished area of lung tissue on account of consolidation and collapse.

In retrospect, it would appear that an opportunity to attempt mechanical fixation of the ribs was missed on the second day after admission, when the patient's condition reached its optimum. At the time he was not considered fit for surgery, and his improvement had been so dramatic that further improvement was expected. There is no doubt that considerable lung damage occurred due to constant friction of the lung tissue against fragments of rib.

An interesting point to note is that the ruptured spleen was symptomless and undiagnosed in the presence of more severe thoracic injuries. This masking of signs appears to be quite common in severe crush injury to the chest complicated by intra-abdominal injury.

Hulman (1957) has stressed the advantages of tracheotomy in these cases, which he gives as follows:

(a) Tracheo-bronchial toilet is more easily carried out.
(b) Reduction in dead space.
(c) Resistance of upper air passages is removed.
(d) Oxygen consumption is decreased on account of reduced muscular activity. Patients with severe crush injury very often use their accessory muscles of respiration. Reduction of dead space and removal of the resistance of the upper air passages will often tide them over a critical stage.
Severe crush injury to the chest carries a heavy mortality. Death appears to be due to:

(a) Severe embarrassment of respiration.
(b) Other complicating factors, e.g. ruptured spleen and fat embolism.

This patient had both—a less severe case would have perhaps stood a better chance of survival. Results from America (Avery et al., 1955, 1956) with hyperventilation are encouraging.

Tracheotomy, curarisation and intermittent positive pressure enable adequate control of tracheo-bronchial secretions, adequate oxygenation and abolition of paradoxical respiration. If the patient becomes adequately stabilised and recovers from the initial shock, respiratory control will allow other surgical procedures to be carried out, e.g., splenectomy.

SUMMARY

A case of severe crush injury to the chest treated by tracheotomy, curarisation and positive pressure respiration using an endotracheal tube inserted through the tracheostome is described.

A plea is made for its further use in a condition which carries a heavy mortality.

I am indebted to Lieut.-Colonel J. C. Watts, M.C., F.R.C.S., R.A.M.C., under whose care this case was admitted, for his help and advice, and to Captain J. L. Turk, R.A.M.C., for the autopsy report.

REFERENCES