THE CRUSHED CHEST
Management of the Flail Anterior Segment

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The congestion of our roads and the higher speeds of motor vehicles have caused a progressive rise in the incidence of severe chest injuries and in consequence there is today a better appreciation of their lethal nature. The most outstanding landmark in a decade of progress has been the establishment by Carter and Giuseffi (1951) of the value of tracheostomy. By eliminating the dead space, facilitating the aspiration of secretions and reducing the resistance to airflow it enabled severely injured patients to survive. It led Blades (1955) to say that the need for traction was thereby eliminated except in the most severe cases. This may have retarded the search for a good method of internal fixation of the damaged thoracic cage, a tendency encouraged by the interest in the use of positive pressure respirators.

Although tracheostomy is undoubtedly the greatest single contribution to the problem it will not of itself ensure the survival of a patient with a large flapping anterior segment; and an efficient patient-triggered respirator, sensitive enough to eliminate flail movement, is still tantalisingly in the future. In our experience neither the Pask machine (Boyle, Gallie and Murray 1957) nor the Pneumotron (British Oxygen Company) nor the Blease "PulmoFlator" has been entirely successful in controlling flail movement. The method of inducing apnoea by hyperventilation with a simple positive pressure respirator advocated by Avery, Mörch, Head and Benson (1955) may solve the problem, but it has not yet been tried widely in this country.

In the meantime efforts to re-establish normal respiratory physiology by restoring the architecture of the thoracic cage are perhaps being abandoned too easily. This is especially true in anterior segment injuries. The poor condition of the patient, the desire to avoid any long operation and the technical difficulties of effective internal fixation of multiple rib and sternal fractures, have led surgeons to rely instead on procedures of proven value such as tracheostomy and simple traction and perhaps on positive pressure respiration. The penalties for failing to repair the anterior cage are, nevertheless, high, and when its repair is possible the benefits are immediate. It is the purpose here to illustrate the lethal nature of the anterior segment injury, to consider why this should be so and to show that there is a common type of anterior injury in which repair is easy and well worth while.

THE LETHAL NATURE OF THE ANTERIOR INJURY

The anterior injury is more severe because it reduces ventilation more seriously. It may be that it is also more likely to cause damage to the mediastinal viscera, and this may in some patients be the cause of death, but its ability to reduce vital capacity is much greater than that of the lateral injury, and this distinction is fundamental. If vital capacity is reduced below the critical level survival is impossible, and all too often this is the principal if not the sole cause of death.

In the four years 1955-58 records of twenty-three patients with flail thoracic segments admitted to Glasgow hospitals were traced and to these have since been added records of a further twelve patients. Of these thirty-five patients fifteen had injuries that were confined to the lateral part of the chest, eight had injuries involving only the anterior part of the chest, in four both aspects were clearly involved and in eight it was not possible to determine from the records the exact disposition of the flail portion (Table 1). There were seven survivors
with purely lateral segment injuries and only one with a purely anterior segment injury. None of these patients was treated by rigid internal fixation of the sternum. The group excludes six patients to be described below who were treated by rigid internal fixation of the sternum.

### TABLE 1

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Number of patients</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure lateral segments</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Pure anterior segments</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Mixed type</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Details insufficient</td>
<td>8</td>
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</table>

### THE SHAPE OF THE ANTERIOR SEGMENT

In spite of the variability in the area, speed and direction of the damaging blow, and in the shape and elasticity of the chest before injury, there is a tendency for a common pattern to emerge, and it is possible to type the fracture as regards its effects and management in terms of one essential feature. In six patients seen at the Southern General Hospital a common pattern presented in five of them, and Figures 1, 2 and 3 are based on exact post-mortem studies in three of these. The essential common feature is the level of the sternal fracture, which has been at the second or third costal cartilage. Thus while the body of the sternum is in the flail segment, the manubrium is still part of the stable undamaged cage. The distribution of the rib fractures is less important, but the segment is always broader below than above. In most reports where details are given it is remarkable how frequently the same features are described and how often the upper limit of the flail segment has been the manubrio-sternal junction (Ghent 1959; Crastnopol, Stuckey and Kletschka 1957; Henry 1957; Daumet and Michel 1958).

### ROLE OF THE STERNUM

In normal respiration four elements are described (Keith 1909, Campbell 1958). 1) The lid of the thorax, consisting of the first ribs and the manubrium, scarcely moves. In the classical anterior segment injury this part of the structure remains stable. 2) The ribs 2 to 5 swing outwards like bucket handles and upwards like pump handles to increase the capacity of the upper thorax. This function is affected to the extent to which these ribs are fractured and their anterior attachments are unstable. 3) The diaphragm and the ribs 6 to 10 to which it is attached. It is here that the disastrous effect of a flail sternum is apparent. Normally the diaphragm descends until it is stopped by the abdominal muscles acting through the viscera. It continues to contract and from this fulcrum the costal fibres now pull upwards on the lower ribs, which, being shaped like bucket handles, swing outwards. The normal action of the diaphragm is, therefore, firstly to descend, and secondly to swing the lower ribs upwards and outwards. By its descent the diaphragm is responsible for 60 per cent of the air exchanged. By descending one centimetre it pulls 270 millilitres of air into the normal chest. In anterior segment injuries the xiphisternum and most of the rib margin to which the diaphragm is attached are part of the flail segment, and in consequence the diaphragm cannot descend in a normal manner but glides ineffectually over the underlying viscera, pulling its anchorage backwards (Figs. 4 and 5). It also fails to increase the diameter of the lower thorax by swinging the lower ribs outwards because this action is dependent on an intact rib margin. 4) The floating ribs 11 and 12 and the abdominal muscles—These structures act together. They oppose the action of the diaphragm and limit its descent. This function is not affected by a simple anterior segment injury.
To this dire reduction of vital capacity must be added the paradoxical movement of the mobile segment which the anterior injury shares with the lateral injury. When all these factors are added together it is not surprising that, in spite of the enormous reserve, the tidal volume can often fall below the minimum essential for survival. The sternum is the key to it all, both directly and indirectly through its control of the movement of the rib margin.

METHODS USED TO STABILISE THE FLAIL SEGMENT

Methods of controlling the segment can in general be divided into traction methods and internal fixation.

Traction methods—These include towel clips, wire loops, wire loops covered with polythene (d'Abreu 1958), cup hooks in the sternum (Rook 1951) and a Crutchfield skull caliper applied
to the sternum (Robin 1960). In general, traction has been by weights and pulleys. At the Birmingham Accident Hospital a bed frame with adjustable springs was used (Proctor and London 1955). To overcome the obvious difficulty inherent in the traction method of allowing for good coughing and postural drainage, a number of devices have been tried here, of which possibly the back brace and loop is the most feasible. But apart from the difficulties of the patient’s posture the traction method has inherent faults; by its nature it must be either too strong or not strong enough. If it controls the worst of the paradoxical movement it simultaneously prevents good expiration. Good internal fixation, when it is possible, is better than traction if it restores normal respiratory mechanics.

**Internal fixation**—Methods described include wiring rib ends together (Coleman and Coleman 1950, Bickford and Grant 1956), wiring fractures of the sternum, lashing adjacent ribs together, or Rush nails for medullary fixation of the fractured ribs at the apex of the mobile area (Crutcher and Nolen 1956), and the use of a plate bent to pass under the mobile ribs and support them (Jacques and Munro 1958).

Only one reference in the literature to a plate being applied to the sternum has been found. Henry (1957) described a classical anterior segment injury. He applied a six-hole plate to the sternum; the paradoxical movement of the damaged segment ceased and the patient survived.

**RIGID INTERNAL FIXATION OF THE STERNUM**

**CASE REPORTS**

**Case 1**—In September 1958 a man aged sixty-five was admitted to the Royal Infirmary, Edinburgh, after a road accident. He had a flail anterior thoracic segment. He was treated...
by tracheostomy and intermittent positive pressure respiration. After eight days a Steinmann pin was passed upwards through the medulla of the mobile sternum into the stable manubrium; this controlled the paradoxical movement. The patient survived.

Case 2—In August 1959 a man aged fifty-eight was admitted to the Western Infirmary, Glasgow, after a lift shaft accident, with paradoxical movement of an anterior thoracic segment. The sternum was fractured at the level of the third rib. A plate was applied to the front of the sternum to control the paradoxical movement. Weight and pulley traction was also used, but this was later considered to be unnecessary. The patient survived.

Case 3—A man aged fifty was admitted to the Southern General Hospital in May 1958 with a flail thoracic segment involving the whole of the front and left side of the chest. He was treated by tracheostomy, but two days later he was still cyanosed and paradoxical movement persisted. A six-hole plate was applied to the sternum; paradoxical movement of the front and left side of the chest ceased at once and he was doing well until the eleventh day when he died suddenly from a coronary thrombosis.

Case 4—A man aged forty-eight was admitted to the Southern General Hospital in February 1960 with a compound fracture of the tibia and fibula and a flail anterior thoracic segment. Theibia was plated and a special sternal plate was used to immobilise the flail thoracic segment (Fig. 6). Tracheostomy was not performed. Recovery was uneventful.

Case 5—In May 1960 a man aged forty-two was admitted to the Western Infirmary with a head and chest injury which conformed to the classical anterior segment pattern. The special sternal plate was applied and tracheostomy was performed. Paradoxical movement was controlled and the patient's respirations were no longer distressed. He died on the second day. At necropsy death was shown to be due to cerebral damage. The lungs were clear. The chest wall was stable till the plate was removed from the sternum, when the flail movement of the damaged segment was again demonstrated.

If Henry's (1957) case is included we thus record six cases with the classical anterior segment injury, all showing paradoxical movement which was controlled by rigid fixation of the sternum. Two died, one from coronary thrombosis and one from cerebral damage.

THE STEGNAL PLATE

Surgeons have, no doubt, been discouraged from plating the sternum because of its thinness and its awkward and variable shape (Fig. 7). A plate of 18-gauge stainless steel has been designed to fit its contours and to spread the load widely (Fig. 6). It can be adjusted by plate benders and there are eleven screw holes. The screws require to be half an inch, five-eighths of an inch or three-quarters of an inch long to engage both cortices (Fig. 8). Wood screws are preferable and the first bite of the thread should be accepted. A cuff may be fixed to the drill to prevent it penetrating too deeply. The internal mammary vessels are not in danger (Fig. 9).

If additional fixation of the mobile segment is desired a simple and effective method is by the insertion of Kirschner wires in the axis of the rib, traversing the fracture (Fig. 10). This procedure is not difficult provided there is no comminution, and it restores the continuity and rigidity of the rib without distortion. It can be used when the fracture is through the costal cartilage. The application of the sternal plate, with the addition of two or four lateral ties of Kirschner wire if required, is a simple surgical procedure (Fig. 11).

MANAGEMENT

In the present state of our knowledge any method of dealing with the problems of a crushed chest which has been described as useful should be considered. If the surgeon has a variety of procedures in mind, one or other of them may offer the best solution in a given case.
Good methods of internal fixation, versatility in the application of traction, tracheostomy and intermittent positive pressure respiration must all be available and the choice made when all the factors are known.

Figure 6—The plate applied to the sternum in Case 4. Figure 7—The sternum is variable in size and shape. The cortical bone is thin and soft.

Figure 8—Screw lengths are one-half, five-eighths or three-quarters inch. Both cortices should be engaged and the first catch of the tightening thread should be accepted.

Figure 9—The internal mammary vessels are not in danger.

A patient with a crushed chest is often desperately ill on admission and his survival depends on good emergency treatment. It may be necessary to take him at once to the theatre ante-room and anaesthetise him in order to provide ventilation by positive pressure before
there has been time to assess the skeletal damage. With positive pressure respiration the paradoxical movement disappears, and it may then be difficult to determine the nature of the skeletal defect and to choose the best method of dealing with it. After the patient's condition has improved, if a short acting muscle relaxant has been used the shape of the defect may still be determined by allowing spontaneous respiration to return and then temporarily obstructing the airway. In the less urgent cases it will be possible to admit the patient to the ward and time will be available for fuller assessment. Pethilorphan 25–50 milligrams intravenously is of great value, and when this has taken effect it is time to examine the extent and nature of the damage of the chest wall. This is not easy. A large anterior segment can escape notice by its very size and because of the initial splinting of the chest wall by muscle spasm; and paradoxical movement is less obvious here than in the more localised lateral defects. Further, the nature of the movement of the chest wall can change radically with variations in the patency of the airway and the passing of the painful muscle spasm, so that repeated examination is necessary. Radiographs are essential for the recognition of pneumothorax and haemothorax and yield useful information about the damage to the skeleton, but they can be quite misleading about the extent of the injury. The correct choice of method will depend on correct appreciation of the skeletal damage. If the defect is an anterior one and the manubrium is still firm, the application of a sternal plate is indicated. Some lateral defects may lend themselves to fixation by the Kirschner wire method, and combinations of anterior and lateral damage may call for both. In some the damage is so extensive that the respiratory pattern defies description, and it is in these that tracheostomy and positive pressure respiration may offer the only hope. Here again, however, if a part of the picture is a recognisable flail segment its local fixation may make the difference between adequate and inadequate tidal exchange. Traction may still be an indispensable addition. Pleural drainage may be required. The advice and services of a thoracic surgeon may now be available, particularly for expert bronchoscopy, because tears of the main bronchi are easily missed. The decision to perform a tracheostomy will depend on the condition of the lungs, on the presence of a concomitant head injury and on whether tidal volume, when the patient is allowed to breathe spontaneously, is now adequate. In Case 4 tracheostomy was not necessary after a sternal plate had been applied.

Tracheostomy should not be withheld if there is any doubt about the tidal volume. The patient's age and his cardiac and respiratory status before injury may influence the decision.
SUMMARY

1. Anterior segment injuries are shown to be more dangerous than lateral segment injuries, and an explanation for this is offered.
2. A common pattern in anterior segment injuries is described.
3. When this pattern is present the application of a plate to the sternum is a useful procedure.
4. Six cases are quoted in which the application of a plate to the sternum was effective.
5. A plate has been designed for the purpose.

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REFERENCES


