FLEXION-COMPRESSION INJURY OF THE STERNUM

A. W. Fowler, Bridgend, Wales

Injuries of the sternum are commonly due to either direct violence to the front of the chest or indirect violence from flexion-compression of the spine. Injuries from hyperextension are exceedingly rare and will not be considered further. Nowadays many injuries of the sternum result from road accidents. Crushing injuries are frequently due to the impact of the steering column, and flexion-compression injuries may occur if the vehicle turns over or if passengers are flung out. In order to emphasise the distinctive features of the flexion-compression injury a short description of both kinds of sternal injury will be given.

Direct injuries—Direct violence may cause two different types of sternal injury. The first and by far the commoner is due to crushing of the lower part of the front of the chest. The lower mobile part of the sternum receives the impact, but the sternum yields at a variable level above the site of impact. The sternum usually gives way near the junction of the mobile body with the relatively fixed manubrium in the same way that a branch of a tree breaks off near the trunk (Figs. 1 to 3). The second type of direct sternal injury occurs when the blow on the chest is localised and at a higher level (Figs. 4 and 5). The sternum is injured at the site of impact, and one fragment of the sternum may be displaced behind

![Diagram of the human chest with labeled figures](image-url)
Case 1—Tomograph showing fracture of upper part of body of sternum with backward angulation and compression fracture of T.4.

Case 2. Figure 13—Posterior dislocation of manubrium. Figure 14—Compression fracture of T.9. Figure 15—Sternum after open reduction and wiring.
the other. The commonest variety of this injury is a posterior dislocation of the body of the sternum on the manubrium.

Direct sternal injuries are often accompanied by rib fractures (Fig. 1), and in severe cases there is paradoxical movement in the anterior chest wall. The skin is bruised and the underlying viscera may be damaged. Local symptoms therefore are marked and the pain, which is aggravated by breathing, causes considerable distress.

**Flexion-compression injuries**—In contrast to the two types of direct injury, flexion-compression violence produces one distinctive type of sternal injury. This injury has two characteristic features: 1) it is always in the first two segments of the sternum—usually at or near the manubrio-sternal joint; 2) the upper or manubrial fragment is depressed in relation to the lower fragment. The commonest injury is a dislocation or fracture-dislocation of the manubrio-sternal joint with backward and downward displacement of the manubrium on the body of the sternum (Figs. 6 and 7). In other cases flexion-compression causes a fracture of either the manubrium or the upper part of the body, with a similar displacement of the upper on the lower fragment (Figs. 8 and 9). Rarely the injury takes the form of a fracture of the manubrium or upper part of the body with backward angulation (Figs. 10 and 11).

Flexion-compression injuries are frequently associated with head injuries and fracture of the spine (Figs. 24 and 25). Pain in the chest is relatively mild, and the clinical picture is often dominated by the more serious injuries to the head and spine. The clinical differences may be summarised by saying that flexion-compression injury of the sternum may be present but not suspected, whereas direct injury may be suspected even when it is not present. Six cases of flexion-compression injury of the sternum will be described.

**CASE REPORTS**

**Case 1**—A woman aged twenty-nine was the front seat passenger in a car which rolled down a hillside. She complained of severe pain in the chest and back, but radiographs of the ribs showed no bone injury. Treatment was given for a dislocation of the left elbow and a cut over the left temple. Two months later the pain in the back persisted and a swelling over the sternal angle was noted. Radiographs of the sternum were then taken, and showed a fracture just below the manubrio-sternal joint and a compression fracture of T.4 vertebral body (Fig. 12). Treatment consisted of breathing and postural exercises. The pain in the sternum gradually subsided but she was left with some permanent tendency to backache.

**Case 2**—A man aged twenty was flung from the pillion seat of a motor cycle which ran into a ditch. He felt an immediate constriction in the chest and was unable to speak for a few minutes. When seen later he was not distressed but complained of pain in the front and back of the chest. There was a step deformity at the sternal angle but no bruising or evidence of a blow on the sternum. Radiographs showed a posterior dislocation of the manubrium and small compression fractures of T.8 and 9 vertebral bodies (Figs. 13 and 14). The dislocation was not reduced by extension of the spine and on the third day open reduction was undertaken. The manubrio-sternal joint was exposed through a transverse incision over the sternal angle. The second ribs were found to be attached to the manubrium. After soft tissues had been cleared from between the fragments the manubrium was pulled forward by means of a curved spike inserted into a drill hole. The reduction was unstable, and suture of the soft tissues was inadequate to hold it securely. A Kirschner wire was drilled obliquely into the body of the sternum and up into the manubrium. The distal end of the wire was allowed to protrude an inch, and it lay almost parallel with the skin (Fig. 15). The patient reported immediate relief from discomfort in the chest. He was discharged on the sixth day and after three weeks the wire became loose and came out. He was forbidden to return to heavy work for a further month. After a further month he was able to resume his occupation as a coal miner. When seen three months after the injury he had no symptoms and a radiograph showed a normal manubrio-sternal joint.

**Case 3**—A farmer aged fifty-nine rolled off a hay wagon and landed on the back of his neck. He complained of pain at the base of the neck and tingling in both arms. He had abrasions over the occiput and left scapula. There was a depression of the upper part of the sternum which disappeared when he lay down but recurred on sitting up. There was no bruising or abrasion on the front of the chest and he did not complain of pain in the sternum. Radiographs showed an oblique fracture of the second sternal segment with depression of the manubrium and a fracture-dislocation of the
fifth cervical vertebra (Figs. 16 and 17). The patient was laid flat on an operating table and a Kirschner wire was inserted through a skin puncture and drilled across the sternal fracture under radiographic control (Fig. 18). A plaster jacket was applied, with a headpiece holding the neck extended. After three weeks the wire was withdrawn and after three months the plaster was removed. Both the sternum and the cervical spine healed without deformity.

Case 4—A man aged thirty-five fell fifty feet on to his head. He sustained severe concussion, an extensive laceration of the scalp, a fracture of the left clavicle, and an oblique fracture of the manubrium. There was no evidence of a blow on the sternum. Figure 8 is drawn from a poor quality radiograph taken on admission, when there was a marked depression of the manubrium. This deformity disappeared with a click when the spine was extended over a pillow placed behind the scapulae (Fig. 19). Radiographs of the spine showed wedging of the upper thoracic vertebrae but no definite evidence of a recent fracture. The patient was kept in bed for three weeks because of his head injury. The sternal deformity did not recur and required no further treatment.

Case 5—A man aged sixty-two was descending a ladder while facing away from it. The lower end of the ladder slipped, and he dropped eight feet and landed on his buttocks. He complained of pain in the back and over the upper part of the sternum. On examination there was tenderness over the whole spine, and especially in the cervico-thoracic and thoraco-lumbar regions. There was a slight swelling at the sternal angle, and when he coughed the manubrium appeared to move backwards. Radiographs showed a fracture of the manubrium with slight backward displacement of the upper fragment (Fig. 20), and a small compression fracture of the first lumbar vertebra (Fig. 21). After a short period of recumbency he was allowed up. His only complaint from the sternum was a pain on coughing.
Case 6—A miner aged forty-five was in a sitting position when a heavy stone fell two feet on to the back of his head. He was not concussed and had a clear recollection of the accident. His head was forced down but his chin did not strike forcibly against his chest. There was a small cut over the occiput and a fracture through the second piece of the sternum with slight backward displacement of the upper fragment; there was no gross injury to the cervical spine.

TREATMENT

Reduction of the displacement in manubrio-sternal flexion-compression injuries is usually simple: laying the patient flat and extending the thoracic spine over a pillow or the end of a table is usually effective. When the sternal injury is stable after reduction and the spinal injury is insignificant no further treatment is necessary (Cases 4 and 5). But if the sternal deformity recurs when the patient sits up it is necessary to maintain extension either by recumbency or by splintage. The usual treatment is by a frame or a plaster jacket; an alternative is to use some form of internal splint. The experience with Case 2 shows that a Kirschner wire gives adequate fixation and allows the patient complete freedom of movement. The wire was redundant in Case 3 but it demonstrated how easily a wire can be inserted under radiographic control, using a local anaesthetic if necessary.

If there is an important spinal fracture, as in Case 3, that should take precedence in treatment. Reduction of the spinal displacement will usually correct the sternal deformity and the same fixation will maintain the reduction of both injuries.

Occasionally manipulation fails to reduce a posterior dislocation of the manubrium and operation is necessary to secure reduction (Case 2). Two similar cases have been described before. Hartzell (1935) after elevating the manubrium held it in place with periosteal sutures. The subsequent development of dense callus and a sequestrum at the site of operation suggests
that this fixation was inadequate. McKim (1943) fixed the fragments with two Kirschner wires, one driven into the manubrium and the other into the right second rib. The subcutaneous situation of the sternum makes open reduction and wire fixation such a simple procedure that it is recommended in all irreducible dislocations of the sternum.

**DISCUSSION**

This study of flexion-compression injuries of the sternum is based on six personal cases and fifteen cases described during the last fifty years (Table I). Table I includes only those injuries in which flexion-compression can be inferred with certainty either from the history of the accident or from associated injuries.

**THE JOURNAL OF BONE AND JOINT SURGERY**

### Table I

**Fifteen Flexion-Compression Injuries of the Sternum Described During the Last Fifty Years**

<table>
<thead>
<tr>
<th>Author and date</th>
<th>Sex</th>
<th>Age</th>
<th>Nature of accident</th>
<th>Nature of sternum injury</th>
<th>Associated injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alexander 1906</td>
<td>M</td>
<td>60</td>
<td>Fell 8 feet on to head</td>
<td>Fracture of sternum just above level of third ribs; lower fragment slipped forwards and upwards on upper fragment</td>
<td>Bruise and cut on back of head above the occiput</td>
</tr>
<tr>
<td>Brunn 1913</td>
<td>M</td>
<td>49</td>
<td>Hit on neck by 1 cwt. sack of hides</td>
<td>Fracture of manubrio-sternal junction with transverse ridge palpable</td>
<td>Painful mid-thoracic kyphosis</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>53</td>
<td>Hit on neck by 3 cwt. object</td>
<td>Manubrium displaced posteriorly with step deformity</td>
<td>Painful mid-thoracic kyphosis</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>45</td>
<td>Hit on neck by 80 lb. sack of tobacco leaves</td>
<td>Manubrium completely dislocated posteriorly and overlapping body by 1 centimetre</td>
<td>Painful mid-thoracic kyphosis. Fracture of fibula</td>
</tr>
<tr>
<td>Pazzi 1926</td>
<td></td>
<td></td>
<td>Thrown from car, striking occipital region</td>
<td>Anterior dislocation of body on manubrium</td>
<td>—</td>
</tr>
<tr>
<td>Holderman 1928</td>
<td>M</td>
<td>20</td>
<td>Squeezed between trams in a colliery</td>
<td>Anterior dislocation of upper end of body at the joint</td>
<td>Compression fracture of L.2</td>
</tr>
<tr>
<td>Pendergrass 1929</td>
<td>F</td>
<td>55</td>
<td>Motor accident</td>
<td>Posterior depression of manubrium on body; fracture of manubrium and upper end of body</td>
<td>Compression fracture of T.4</td>
</tr>
<tr>
<td>Rothbart 1929</td>
<td>F</td>
<td>42</td>
<td>Fell from window on to head</td>
<td>Fracture of manubrium with dorsal displacement</td>
<td>Contusion of occipital region</td>
</tr>
<tr>
<td>Brown 1931</td>
<td></td>
<td></td>
<td>&quot;Jacknifed&quot; under car with head forced between knees</td>
<td>Complete posterior dislocation of manubrium and fracture of upper end of body</td>
<td>—</td>
</tr>
<tr>
<td>Stuck 1933</td>
<td>M</td>
<td>44</td>
<td>Crumpled forward by cave-in of ditch</td>
<td>Fracture of manubrium</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>75</td>
<td>Motor accident</td>
<td>Fracture of manubrium</td>
<td>Compression fractures of T.4 and 5</td>
</tr>
<tr>
<td>Ellis 1935</td>
<td></td>
<td></td>
<td>Powerful forward flexion from fall on buttocks</td>
<td>Irregular oblique fracture of upper end of body running into joint, with slight forward displacement of lower fragment</td>
<td>—</td>
</tr>
<tr>
<td>Hartzell 1935</td>
<td>M</td>
<td>32</td>
<td>Thrown through top of car</td>
<td>Posterior dislocation of manubrium</td>
<td>Contusions of occipital region</td>
</tr>
<tr>
<td>Kirkham 1941</td>
<td>F</td>
<td>67</td>
<td>Fell downstairs with head flexed forwards as in gambolling</td>
<td>Fracture of sternum at junction between manubrium and body. Manubrium displaced behind body</td>
<td>Compression fracture of T.5</td>
</tr>
<tr>
<td>Robertson 1955</td>
<td>M</td>
<td>13</td>
<td>Severe tetanus</td>
<td>Depressed fracture of manubrium</td>
<td>Compression fractures of T.4 to 8</td>
</tr>
</tbody>
</table>
Etiology—This is analysed in Table II and compared with seventeen cases from the previous half-century collected by Tarnowsky (1905). About a third of the injuries are due to road accidents. Changes in methods of transport are reflected in the fact that in all the road accident cases in Tarnowsky's series the patients had fallen off their vehicles, whereas to-day the injury occurs in those who have been flung out of vehicles or rolled about inside them. A detailed history of the accident is often lacking because the frequent association of concussion makes an accurate reconstruction of the accident impossible. I have been careful to exclude from this study any sternal injuries in which there is evidence that direct violence was applied to the chest. The sternal injury due to tetanus (Robertson 1955) is included in this series because it was clearly caused by flexion-compression of the thoracic spine which in turn was caused by powerful muscular contractions.

The sternal injury—A comparison of Figures 6 to 11 will show that all the flexion-compression injuries of the sternum are basically similar. The sternum gives way at or near the manubrio-sternal joint. The anatomy of the joint determines whether the injury takes the form of a dislocation, fracture-dislocation or fracture. Dislocations are likely to occur only when the manubrio-sternal joint is synovial. Rivington (1874) examined 100 manubrio-sternal joints and found the following types: cartilaginous fifty-one, synovial thirty-two, intermediate eleven, and ossified six. He found the synovial type of joint more frequently in adults than in children and postulated that it was formed by absorption of cartilage during growth. A recent study by Ashley (1954) has shown that synostosis of the manubrio-sternal joint is not a senile change but is found in about 10 per cent of all subjects after the age of thirty. These anatomical studies explain why dislocation of the manubrio-sternal joint usually occurs in adults and may occur in the elderly.

In dislocation of the manubrio-sternal joint the second rib always remains attached to the manubrium. This is due to the fact that when the manubrio-sternal joint is synovial the cartilage of the second rib is much more firmly attached to the manubrium than to the body of the sternum (Maisonneuve 1842). Lane (1884) explained that the movements of the body of the sternum upon the relatively fixed manubrium caused absorption of cartilage and the formation of synovial joints between the body on the one hand and the manubrium and second rib on the other.

There is no general agreement about the exact nature of the displacement in this injury. Eight authors described the injury as a posterior displacement of the manubrium and four described it as an anterior displacement of the body of the sternum (Table I). I believe that in most cases the manubrium is displaced backwards. The radiological appearances in Case 1, the operation findings in Case 2 and the clinical features in Case 3 indicate that the manubrium was depressed in these patients. The nature of the displacement will depend on the mechanism of the injury, and in the discussion on mechanisms I shall give reasons for believing that the upper fragment is depressed in at least two-thirds of these injuries.
The spinal injury—Nine out of twenty-one flexion-compression injuries in this series were accompanied by proven fractures of the spine, comprising six fractures of the thoracic spine, one fracture of the cervical spine and two fractures of the lumbar spine. The fracture of the spine in Case 2 was only detected by careful radiography; it is therefore possible that some patients in Table I had undetected fractures of the thoracic spine. In four road accident cases the spinal fractures provided the only clue to the mechanism of the spinal injury.

The spinal injuries are usually simple wedge fractures. This indicates a large vertical component in the force applied to the spine (Fig. 22). Comminuted fractures and fracture-dislocations of the spine are caused by acute angulating forces (Fig. 23) and are not accompanied by fractures of the sternum. It is for this reason that fractures of the sternum do not complicate the thoraco-lumbar fractures and fracture-dislocations in miners, which are due to a fall of roof on a bent back. The sternal injury from tetanus provides us with a "slow motion" study of the accompanying spinal injury. Robertson (1955) stated that the spasms caused vertical compression of the spine, the head being drawn down vertically towards the thoracic inlet.

Mechanisms of the sternal injury—There are three possible routes by which the forces might be transmitted to the sternum: 1) along the clavicles, 2) by the descending chin, and 3) along the ribs. Maisonneuve (1842) and Lane (1884) attached importance to the part played by the clavicles. This is difficult to understand in view of the mobility of the clavicles and the fact that they lie mainly in the coronal plane. Martin (1901) recorded a fracture of the manubrium caused by a lateral impact on the clavicle; this caused a vertical fracture of the left edge of the manubrium with forward displacement. Lane (1884) produced an oblique fracture between the second costal cartilages without displacement by dropping a weight vertically on the outer end of the clavicle in a cadaver. Neither of these injuries corresponds to the typical flexion-compression injury of the sternum; both were caused by blows over the outer end of the clavicle, whereas flexion-compression injuries are caused by forces acting along the spine. The only circumstances in which the clavicles might be brought into line with such forces are in falls on the fully extended and outstretched arms. Tuttle (1885) reported a manubrio-sternal dislocation in a man who dived into shallow water. He postulated that the force was transmitted to the manubrium along the outstretched arms and through the clavicles. His argument is weakened by the fact that his patient said that he fell on his head. Moreover no other flexion-compression injury of the sternum has been recorded in which the victim landed on his outstretched arms.
With regard to the descending chin, I agree with the conclusion of Rivington (1874) that it plays a part mostly, if not entirely, in cases of injury to the cervical spine (Fig. 25). It is easy to demonstrate this in the cadaver; even when the manubrio-sternal ligaments have been divided the chin will cause dislocation of the manubrium only after the cervical spine has been fractured. If the chin were responsible for displacing the manubrium one would expect to find bruising beneath the jaw; no evidence of this is found in any of the recorded cases.

It is probable that the ribs play the most important part in the transmission of forces to the sternum. Convincing evidence of this can be obtained in the cadaver. The sternum is removed by dividing the costal cartilages close to the bone, and movements of the rib ends are observed while the spine in manipulated. Flexion of the neck and thoracic spine imparts a downward and backward movement to the upper ribs—particularly the upper two ribs. Flexion of the lumbar and thoraco-lumbar spine has no effect on the ribs until the posterior abdominal wall abuts against the thoracic cage—the lower ribs are then pushed upwards and forwards. Therefore in a uniform flexion of the spine the sternum is subject to two opposing forces: the manubrium is forced downwards and backwards by the upper two ribs and the body of the sternum is forced upwards and forwards by the lower ribs. The sternum yields at its weakest point between these two forces.

I believe that in the majority of flexion-compression injuries the upper ribs dominate in the production of the sternal deformity, the manubrial fragment being twisted off the rest of the sternum. In eleven out of twenty-one cases the injury was known to be caused by a blow or fall on the head or neck, and six out of nine proven fractures of the spine were above the mid-thoracic level. In both of these groups, which together comprise two-thirds of the cases, we can infer that the upper part of the spine was flexed on the lower and that the manubrial fragment was displaced by the upper ribs (Fig. 24). There is a group of five cases due to crushing injuries and falls on the buttocks in which it may be assumed that the lower part of the spine was flexed and that the sternal deformity may have been partly or wholly due to the upthrust of the lower ribs.

FIG. 24
Mechanisms of flexion-compression injury. Figure 24—Fall or blow on upper part of spine. Flexion-compression fracture of thoracic spine. Manubrium twisted off body by upper ribs. Figure 25—Blow or fall on back of head and neck causing fracture of cervical spine. Descending chin may assist in depressing manubrium.

FIG. 25
Mechanisms of flexion-compression injury. Figure 24—Fall or blow on upper part of spine. Flexion-compression fracture of thoracic spine. Manubrium twisted off body by upper ribs. Figure 25—Blow or fall on back of head and neck causing fracture of cervical spine. Descending chin may assist in depressing manubrium.
There are anatomical reasons for believing that the upper two ribs must take an active part in displacing the manubrium. The manubrium is firmly attached to the spine by short and relatively rigid ribs which effectively transmit a twisting force from the spine to the manubrium. The body of the sternum, however, is joined by longer and more flexible ribs which will only transmit a flexion force from the spine indirectly. Several authors (Servier 1889, Tarnowsky 1905, Stuck 1933) argued that the manubrium, being solidly fixed to the spine, retains its position, whereas the body of the sternum, articulating with longer and more mobile ribs, is displaced. This would be true if flexion-compression were confined to the lower part of the spine. But when the upper spine is flexed the manubrium being firmly attached to the spine will be moved out of position.

The first costal cartilages are massive and hold the upper two-thirds of the manubrium in a vice-like grip. It seems likely therefore that the first rib is chiefly responsible for the control of the manubrium. When the manubrium itself is fractured the line of fracture is at the junction of the upper two-thirds with the lowest third (Figs. 8 and 10); the level of this fracture is further evidence of the importance of the first rib in the mechanism of the injury.

**SUMMARY**

1. Injuries of the sternum from flexion-compression violence are described and contrasted with injuries from direct violence. The characteristic feature of flexion-compression injuries is a dislocation or fracture at or near the manubrio-sternal joint with backward displacement of the manubrium.

2. Treatment is outlined, with special reference to the indications for open reduction and wire fixation.

3. The mechanism of flexion-compression injuries of the sternum is discussed. The opinion is expressed that most of the force is transmitted to the sternum by the ribs—especially the upper ribs.

I wish to thank Mr G. Hyman, Mr J. G. H. James, Mr H. J. Richards, Mr G. Rowley and Mr J. N. Wilson for allowing me to treat their cases. I am grateful to Mr J. G. H. James and Mr H. J. Richards for helpful criticism.

**REFERENCES**

Tuttle, J. P. (1885): Coincident Fracture and Dislocation of the Sternum by Indirect Force. Medical Record, 28, 681.