THE MECHANISM OF CLAVICULAR FRACTURE

A CLINICAL AND BIOMECHANICAL ANALYSIS

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A consecutive series of 150 patients with clavicular fractures is presented. In 81% detailed information regarding the mechanism of the injury was available and, of these, 94% had fractured their clavicle from a direct blow on the shoulder; only 6% had fallen on the outstretched hand. This finding, at variance with commonly held views regarding the mechanism of this injury, was further investigated by biomechanical analysis of the forces involved in clavicular fractures. The biomechanical model supported the clinical findings.

It has been suggested that the clavicle is a surplus part of the skeleton (Abbott and Lucas 1954). However, it is the only bony strut maintaining the width of the shoulders. When the clavicle is fractured the shoulder slumps downward and forward due to muscle spasm and the effect of gravity. The injury has long been thought to be due to a fall on the outstretched hand, yet it is unclear from the literature how this view arose. More recently Fowler (1962) and Sankaran Kutty and Turner (1975) linked clavicular fractures with direct shoulder trauma; and Allman (1967) divided the fracture into three groups, proposing different mechanisms of injury for each. Group 1 consisted of fractures of the middle third, and for these a fall on the outstretched hand or point of the shoulder was the proposed mechanism. Group 2 were fractures distal to the coracoclavicular ligament, described as resulting from a force on the point of the shoulder driving the humerus and scapular downward. Group 3 were fractures of the proximal end of the clavicle and for these the mechanism of injury was given as direct violence applied at an angle from the lateral side. This paper reports a clinical study of the mechanism of fracture and also analyses the forces involved in such an injury by the use of a biomechanical model.

PATIENTS AND METHODS

A consecutive series of 150 patients presenting with clavicular fractures during 1986 at the Northern General Hospital and Children's Hospital in Sheffield were assessed as to the mechanism of their injury. All patients were asked to complete a pro forma in which they described and recorded from a series of pictures how they had sustained the injury (Fig. 1). This approach avoided question bias which could arise during oral descriptions of the cause of the fracture. Patients who were unsure how the injury had occurred and young children whose injury was sustained in the absence of a reliable witness were excluded from the study.

All patients were examined for clinical evidence, such as skin grazing, to corroborate the mechanism they had described. When present, this was recorded and photographed.

RESULTS

One hundred and twenty-two patients (81%) were able to provide a detailed account of how they had sustained their fracture whilst 28 patients (19%) were excluded on the basis that the mechanism of injury was unclear. Of those studied, 106 (87%) had fallen onto the shoulder; in a further nine (7%) the clavicle was fractured by a direct blow on the point of the shoulder. Only seven patients (6%) stated they had fallen onto the outstretched hand. In 10% of patients clinical evidence (skin grazing) was found over the point of the shoulder to substantiate the described mechanism of injury. No correlation was found between site of fracture and mechanism of injury (Table 1).

An analysis of clavicular impact loading

If a symmetrical specimen of bone is loaded uniaxially in tension then the initial deformations are elastic. Increased loads produce yielding, plastic flow and permanent deformation (Currey 1970). In contrast, when strongly compressed longitudinally, bone demonstrates buckling (Chamay and Tschantz 1972). Shear failure, along lines which lie at an angle to the line of application of the force, occurs on the tensile side. Fractures occur when the stress rises sufficiently for minute imperfec-
tions in the material to increase in size by using the elastic strain energy induced by the deformation (Griffith 1921; Andrews 1968).

There are three basic mechanisms, apart from uniaxial tension, which can elevate local stress levels in slender bones sufficiently to initiate crack propagation and subsequent fracture. These are bending, torsion and compressive buckling with resultant bowing. The freedom afforded the clavicle by the sternoclavicular joint makes pure bending an unlikely candidate for fracture during clavicular impact loading. Similarly the available rotation about the longitudinal axis of the clavicle (approximately 50°) virtually eliminates torsion as the mechanism of clavicular fracture. The most likely cause of fracture is compressive loading of the clavicle by a force transmitted through the abutment with the acromion process of the scapula. For a bone articulated like the clavicle the critical buckling force \( F_c \) is given by \( F_c = \pi^2 EA/(L/r)^2 \), where \( E \) is the Young’s modulus of the bone, \( A \) is the cross-sectional area of the strut, \( L \) is its length and \( r \) is the least radius of gyration of the cross-section.

Figure 2 shows the variation of the critical buckling force \( F_c \) given in terms of body weight, with the slenderness ratio \( L/r \). It can be seen that elastic buckling occurs when the compressive force is approximately that of the body weight. In reality, the S-shaped curvature and the geometrical changes (tubular to flat) along the axial length of the clavicle are likely to accentuate this effect and reduce the critical buckling load.

With impact loading, the force transmitted to the clavicle will only act over the time interval associated with the application of the force. Hence, for clavicular fracture, the critical force will depend on the speed at which the body contacts the ground or other solid object and the time taken for the collision, as well as the weight of the person. Fracture is more likely with a direct blow when the impact energy is absorbed quickly than with a glancing blow in which the impact energy is dissipated more slowly.

The direction of the applied force is also important. Figure 3 shows the transmitted force when a subject falls on the outstretched arm. It is directed through the head of the humerus to the scapula alone. There is no direct contact with the clavicle. The applied force to the clavicle is through contact with the acromion process. The only component of force which will produce clavicular compression is \( F_y \), directed axially along the clavicle. The two components \( F_y \) and \( F_z \) will tend to move the scapula upwards and backwards, away from the clavicle, with a predisposition to dislocation rather than clavicular fracture (Falstie-Jensen and Mikkelsen 1982). Only in those cases when the outstretched arm is in the coronal plane relative to the body, is it likely that the force component \( F_z \) will be sufficient to produce compressive buckling and fracture. With an upwards and backwards movement of the scapula it is unlikely

### MECHANISM OF INJURY

<table>
<thead>
<tr>
<th>Site of fracture</th>
<th>Direct injury to shoulder</th>
<th>Fall onto arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal third</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Junction of proximal and middle thirds</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Middle third</td>
<td>65</td>
<td>4</td>
</tr>
<tr>
<td>Junction of middle and distal thirds</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Distal third</td>
<td>34</td>
<td>2</td>
</tr>
</tbody>
</table>

Pro forma given to patients for self assessment of the mechanism of clavicular injury.
that the force transmitted from the attached ligaments and muscle heads is sufficient to produce clavicular bending and fracture.

In contrast, Figure 3 shows that with a direct blow to the shoulder it is possible for the entire impact force to be transmitted along the clavicular axis, via the acromion process, so that the force components $F_y$ and $F_z$ are zero. In this case the critical buckling force is reached at values close to body weight (Fig. 2). If the direct blow is of a more glancing nature, the component $F_x$ along the clavicular axis will be reduced and the components $F_y$ and $F_z$ increased. This presents conditions more favourable to dislocation than fracture (Jain 1984).

**DISCUSSION**

The mechanism of clavicular fracture is generally assumed to be a fall on the outstretched hand (Sharrard 1979; Kessel 1982; Apley and Solomon 1982). This view, however, is not supported by the clinical or biomechanical results that we have presented.

In this study 94% of patients had sustained their fracture as a result of a direct injury to the shoulder, with 10%, having skin grazing over the point of the shoulder to substantiate the proposed mechanism of injury. This finding is consistent with that of Sankaran Kutty and Turner (1975) but unlike these authors we would suggest that a direct blow on the shoulder may also be the mechanism of injury in those who describe a fall on the outstretched hand. In this situation, as the hand makes contact with the ground, the patient's body weight and falling velocity are such that movement is not arrested at this point, but the fall continues with the shoulder becoming the upper limb's next contact point with the ground. Biomechanical analysis of the forces involved indicate that with a direct injury the critical buckling load will be exceeded at a compressive force equivalent to body weight, resulting in clavicular fracture. When the force is applied along the axis of the arm, however, the forces are such that dislocation of the shoulder is the more likely outcome.

![Graph showing critical buckling force](image)

**Fig. 2**

The variation of buckling force (in terms of body weight, $W$) with the slenderness ratio of the clavicle.

![Diagram of force vectors](image)

**Fig. 3**

(a) The impact force vector $F$ is directed along the humerus when falling on the outstretched arm. This force has been resolved into three perpendicular components $F_x$, $F_y$, and $F_z$ along and perpendicular to the axis of the clavicle.

(b) The impact force vector $F$ associated with a direct blow on the shoulder also has three components along and perpendicular to the axis of the clavicle. If $F_x$ and $F_z$ are both zero, then the blow will be directed purely along the clavicular axis ($F_y$).
It is interesting to note that the clavicle is not always fractured when the elastic limit of the bone is exceeded. In children, plastic deformation has been shown to occur which absorbs the impact energy without observable fracture but leaves the clavicle permanently bowed (Young 1976). Similar permanent deformations caused by trauma have been observed in the femur (Cail, Keats and Sussman 1978), humerus (Rogers et al. 1978) and fibula (Cook and Bjelland 1979; Martin and Riddervold 1979).

No evidence was found from the clinical analysis to support Allman's (1967) proposal that fractures at the proximal, middle and distal thirds of the clavicle have different mechanisms of injury. We recorded fractures at each site after direct injury to the shoulder (Table 1).

From our clinical observations and biomechanical analyses we would suggest that clavicular fractures result most frequently from direct injury, with a fall onto the point of the shoulder being the most commonly described mechanism.

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REFERENCES


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