TRAUMATIC SPONDYLOLISTHESIS OF THE AXIS

WILLIAM R. FRANCIS, J. WILLIAM FIELDING, RICHARD J. HAWKINS, JOHN PEPIN, ROBERT HENSINGER

From Baylor College of Medicine, Houston, Texas,
St Luke's Hospital, New York,
the University of Michigan Hospital Center, Ann Arbor, Michigan,
and the University of Western Ontario, London, Ontario

A series of 123 patients suffering traumatic spondylolisthesis of the axis is reported. This lesion is associated with extension and axial loading injury, and there is a high incidence of injuries of the face or scalp and of associated fractures of the upper cervical spine. There is a low incidence of neurological injury, which seems paradoxical in the presence of what appears to be gross instability, but protection from extremes of flexion and extension may be adequate treatment. Union is usual regardless of displacement. Traction is a safe means of treatment, but early walking in a halo support reduces time in hospital without jeopardising the result. Operation is needed only for chronic instability with or without pain, and anterior interbody fusion of C2–3 is then preferred in order to preserve rotation at the atlanto-axial joints.

Traumatic spondylolisthesis of the axis involves bilateral fractures of the pedicles and may be caused by vehicular and diving accidents, or other deceleration injuries. The lesion, which has been called "hangman's fracture", is characteristically produced by hyperextension and axial loading, but has also been described as resulting from flexion and axial loading (Grogono 1954; Norton 1962; Garber 1964; Schneider *et al.* 1965; Cornish 1968; Termansen 1974; Williams 1975; Rothman 1978).

Hanging was used as a method of execution in the Roman Empire and in the British Isles in the early fifth century by the Jutes, Angles and Saxons. Execution by this method was a public spectacle, and because the words of the law, "hanged by the neck until dead", gave no specific means of death, many offenders suffered slow strangulation (Haughton 1866; *Lancet* 1913; Marshall 1913). In the late eighteenth century efforts were made to make hanging a more certain means of execution. The length of the drop was increased, but decapitation sometimes occurred as a result of excessive drop (Schneider *et al.* 1965; Rothman 1978). A scientific approach to length of drop and placement of the knot was attempted, and Paterson (1890) published tables correlating drop distance and body weight. Marshall (1888, 1913) devised a hanging piece to ensure submental knot placement and consistent results.

In 1913 Wood-Jones first described the bony anatomy of the lesion in the dried remains of five individuals hanged with the knot in a submental position. All specimens showed bilateral axis pedicle fractures and Wood-Jones postulated that complete disruption of the ligaments and disc between the second and third cervical vertebrae has resulted in transection of the cord and instantaneous death. The mechanism of injury was hyperextension combined with sudden, violent distraction (Wood-Jones 1908). These findings were confirmed by Vermooten in 1921. In 1965 Schneider *et al.* described a similar bony lesion seen in patients after vehicular accidents and other sudden deceleration injuries, and drew attention to the common association with injuries to the face or head. Schneider *et al.* use the term "hangman's fracture", but the mechanics of the two lesions are different. Hyperextension is common to both lesions, but the distraction produced by judicial hangings is absent in the other injuries and is replaced by axial loading. This probably accounts for the very different incidence of neural damage, and "traumatic spondylolisthesis of the axis" (Garber 1964) is a more appropriate term for the lesion.

Many authors have reported on aspects of this fracture which was at first thought to be a flexion injury because of the forward movement of the body of the axis (DeLorme 1967). Other authors consider the injury to

W. R. Francis, Jr, MD, Assistant Professor, Department of Orthopedic Surgery, Baylor College of Medicine, 6535 Fannin, Houston, Texas 77030, USA.
J. W. Fielding, MD, Professor and Director of Orthopedic Surgery, St Luke's Hospital Center, New York, New York 10025, USA.
R. J. Hawkins, MD, Assistant Professor of Orthopedic Surgery, University of Western Ontario, London, Ontario, Canada.
J. Pepin, MD, Resident in Orthopedic Surgery, University of Western Ontario, London, Ontario, Canada.
R. Hensinger, MD, Associate Professor of Orthopedic Surgery, University of Michigan Medical Center, Ann Arbor Michigan, USA.
Requests for reprints should be sent to Dr J. W. Fielding.

be due to hyperextension. Opinion on initial treatment has varied with the view on inherent stability. Cornish (1968) regarded the injury as grossly unstable and recommended surgical stabilisation, but other authors did not consider primary surgical treatment to be necessary. Many different treatment regimes have been described and the question of inherent stability of the fracture is not yet resolved.

This paper reports a large series of patients suffering traumatic spondylolisthesis of the axis, with special attention to initial assessment, associated injuries, and methods of treatment related to results. Treatment has also been related to the stability of the injury and to the incidence of non-union, with comment on indications for and techniques of operation.

MATERIAL AND METHODS

This series includes 123 patients, of whom 86 were male. The age of the patients was from 9 to 78 years (mean 32.7 years) and follow-up ranged from 12 to 62 months (mean 31.3 months). Patients were seen from 1962 to 1978 in one of four centres: Baylor College of Medicine, Houston, Texas; St Luke's Hospital, New York; the University of Michigan Hospital Center, Ann Arbor, Michigan; and the University of Western Ontario, London, Ontario, Canada. All patients were assessed personally by at least one of the authors.

Patients were assessed clinically for the type and probable mechanism of the main injury and for other injuries, associated injuries of the spine, neurological deficit and regimes of treatment. Various methods of treatment were compared on the basis of results, and especially on the maintenance of reduction and the union of the fractures. Radiographs of the cervical spine were available for all patients. Oblique views were taken only if the lesion was not readily identifiable on lateral views. Tomography was used on 30 consecutive patients early in the study to confirm the diagnosis.

Classification of the fracture was made from the lateral radiographs, taken with the patient supine, before treatment. Fractures were classified according to displacement, angulation, and ligamentous instability in relation to neurological injury and to non-union, in an attempt to correlate the severity of injury and the mode of treatment with end-results. Displacement was defined as the anterior or posterior movement of the body of the axis on that of the third cervical vertebra at the posterior edges of the bodies of the vertebrae. Angulation of the axis was measured using lines drawn on the posterior aspect of the body of the axis and of the third cervical vertebra (Fig. 1). The segment was considered to be unstable when displacement was greater than 3.5 millimetres or angulation was greater than 11 degrees (White and Panjabi 1978). The segment was considered to be disrupted if displacement was more than half the sagittal width of the body of the third cervical vertebra or if angulation had produced widening at either the anterior or posterior borders of the damaged disc space greater than the height of the centre of the normal disc below (Fig. 2). An intermediate degree of ligamentous damage was recorded if displacement was greater than 3.5 millimetres, but less than half the vertebral body, if the angulation was less than the height of the adjacent disc, or if there was a compression fracture of the body of the third cervical vertebra. Table I shows the five grades of instability recorded by these methods.

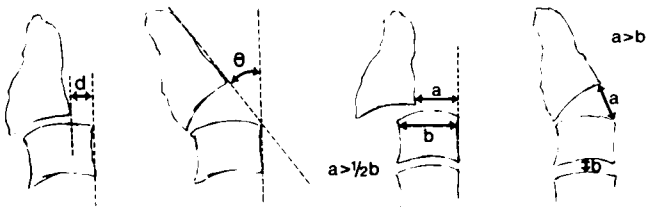

Fig. 1 Fig. 2

Figure 1—The method of measurement of displacement and angulation. Figure 2—The displacement and angulation seen in severe ligamentous instability.

Table I. Classification of injury into five grades

Grade	Displacement	Angulation *(degrees)*
I	<3.5 millimetres	<11
II	<3.5 millimetres	>11
III	>3.5 millimetres <0.5 vertebral width	<11
IV	>3.5 millimetres <0.5 vertebral width	>11
V	Disc disruption	

Vertebral width refers to the sagittal measurement of the body of the third cervical vertebra.

All patients were treated initially by either cervical or cervicothoracic braces, or by traction. Patients treated by traction were grouped into those in traction for an average of six weeks and those in traction for less than three weeks and then allowed up in a halo-pelvic brace (Fig. 3). This latter group of patients were studied prospectively to determine the results of early walking in a relatively rigid cervical orthosis. Other patients used various cervical supports, without halo devices, when they were allowed up. Healing was recorded when there was trabeculation across the fracture or spontaneous interbody fusion (Fig. 4). Operation was never performed as primary treatment, but only for established non-union, or if segmental instability caused pain despite union of the pedicle. Non-union was diagnosed if there was movement of the fracture on flexion and extension radiographs or on tomographic evidence. Union after operation was then determined by

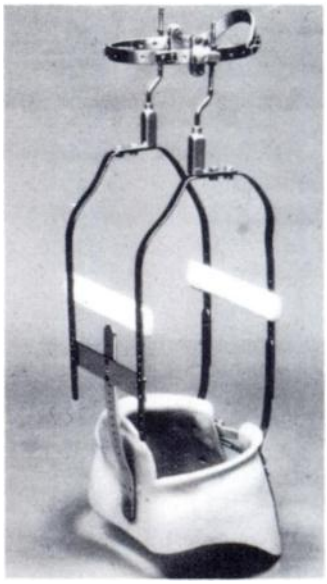

Fig. 3

A halo-pelvic brace of the type employed in 45 patients to allow early walking.

the lack of movement between the bodies of the axis and the third cervical vertebra and the absence of clinical symptoms.

RESULTS

The commonest cause of this injury was a motor vehicle accident (78 per cent). Falls with the face forward and diving accidents accounted for 21 per cent. All conscious patients suffered pain, usually localised to the upper part of the back of the neck, but neuralgia in the distribution of the greater occipital nerve was recorded in only seven patients. Seventy-nine per cent of patients sustained wounds of the face or scalp, and 94 per cent of these wounds were frontal or apicofrontal, thus supporting the concept that the mechanism of injury is hyperextension and axial loading. Five patients had wounds of the posterior vertex or occiput suggestive of flexion loading of the neck, and had sustained compression fractures of the third cervical vertebra (Fig. 5). Six patients had

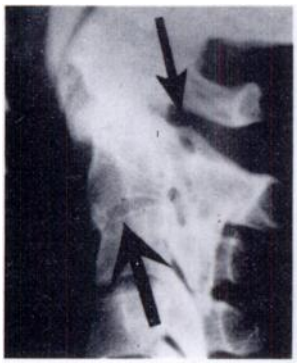

Fig. 4

Fig. 5

Figure 4—Radiograph to show union of the pedicles and spontaneous fusion of the bodies of the vertebrae. Figure 5—Radiograph showing anterior displacement of the body of the axis combined with a compression fracture of C3. This patient had been struck on the occiput, which further substantiates flexion as the mechanism of injury.

asymmetrical injuries of the pedicles suggesting rotational or lateral flexion forces at the time of injury (Fig. 6). In 26 patients, no point of impact could be established.

Thirty-nine patients had other injuries of the cervical spine with 94 per cent of these occurring in the upper three cervical vertebrae. Nine patients had additional fractures of the spine below the neck (Table II) and 46 per cent of patients had other major injuries. Significant neurological deficits occurred in only eight patients, 6.5 per cent of the series. All but two of these

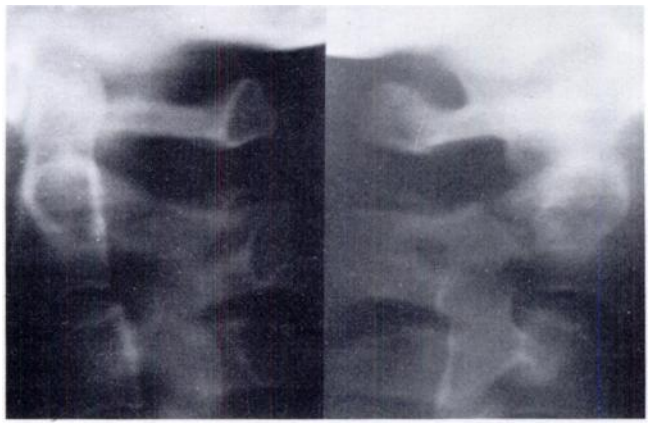

Fig. 6

Tomographs of the right and left pedicles showing asymmetrical fractures.

Table II. Distribution of other spinal injuries associated with traumatic spondylolisthesis of the axis

Multiple levels	3
Odontoid	4
C1 arch	10
C1 lateral mass	3
C1 Jefferson	2
C2 lateral mass	3
C3 compression	5
C3 arch	6
C3–6	6
Thoracic and lumbar compression	6
T12–L1 fracture-dislocation (paraplegia)	1
L5–S1 fracture	2

Table III. Details of the eight patients with neurological deficit

Patient	Deficit	Results
1	Paraesthesia of right side Monoplegia of right arm	Recovery in 5 days
2	Paraesthesia of right leg	Recovery in 22 days
3	Paraesthesia of left leg	Recovery in 1 day
4	Paralysis of both arms and one leg	Residual weakness of right shoulder after 2½ years
5	Weakness of left arm	Recovery in 15 days
6	Paraesthesia of left hand and forearm	Recovery in 2 days
7	Paresis of both arms	Recovery in 20 days
8	Brown-Séquard lesion	Residual slight spasticity in one leg after 3 months

patients gained complete neurological recovery within 22 days (Table III). One patient developed paralysis of the left arm five weeks after injury, three weeks after the application of the halo support. Traction neurapraxia was diagnosed and the brace removed. The fracture healed and there was complete neurological recovery. One patient suffered paraplegia as a result of fracture dislocation at T12 and was not included in this analysis.

The radiographs of all but 15 patients revealed typical bilateral fractures of the pedicles of the axis with fracture lines traversing either the pars interarticularis

or the foramina transversaria (Fig. 7). All patients with displacement of the fractures also had anterior displacement of the body of the axis. Only 13 patients had undisplaced fractures. Nine patients had fractures involving the body of the axis (Fig. 8). This group of

Fig. 7

Fig. 8

Figure 7—Radiograph of a typical bilateral fracture of the pedicles of the axis. Figure 8—Radiograph of a fracture involving the body of the axis, showing the narrowed space between the posterior arch of C1 and the posterior aspect of the body of the axis.

fractures differ mechanically from the typical injury in that the posterior fragment of the body of the axis may compress the cord against the posterior elements of the atlas as in an atlanto-axial dislocation. No patient sustained a single unilateral fracture.

In 117 of the 123 patients the injury could be diagnosed on lateral radiographs, and oblique views were needed in only four patients. Tomography was useful in only two cases in lieu of oblique views. Tomography was used to confirm the diagnosis of 30 consecutive cases early in the study but was discontinued because of the reliability of diagnosis from lateral radiographs.

Thirty-five patients were managed primarily in cervical or cervicothoracic supports and allowed to walk. Eighty-eight patients were treated by traction, and 43 of these were in traction for an average period of six weeks, ranging from 4 to 12 weeks. These patients were then allowed up in various cervical orthoses including halo-truncal supports, Minerva casts, and cervicothoracic braces. The other 45 patients were treated in traction for an average of 8.1 days, ranging from 3 to 13 days. These patients were then allowed up, wearing a halo-pelvic brace for from four to seven weeks, with a cervicothoracic brace for a further four weeks (Table IV). The period of bed rest and the type and rigidity of bracing support could not be correlated with the speed or incidence of union, though accuracy of reduction was not as well maintained in less rigid devices.

Healing occurred in 116 patients (94.5 per cent) in under 16 weeks, regardless of the regime of treatment, and occurred as early as eight weeks after injury in six patients. The average time for healing was 11.5 weeks. Seven patients were operated on; of six patients with non-union, four had anterior fusion of the bodies of C2–3, and two had posterior fusion of C1–3. One patient had a posterior fusion at C2–4 performed after union of the pedicles because of persistent pain and a flexion injury at C3–4 level which created an unstable kyphosis. Patients were kept in traction during operation and for 7 to 10 days afterwards. They were then allowed up in a Minerva cast or halo-vest for 8 to 12 weeks. Union occurred in all seven patients in 9 to 15 weeks with complete relief of symptoms.

Fig. 9

Radiograph of a patient with severe ligamentous injury and distraction of the C2–3 interspace.

Displacement did not appear to influence healing, being present in only two of the patients who required operation. When flexion was the mechanism, injury was of Grade II or Grade IV (Fig. 5). Five of the patients with disruption of the C2–3 interspace showed this only after traction had been applied (Fig. 9). They were placed in this group and not in that indicated by the initial lateral radiograph. It is possible that more patients would have been classified as having Grade V injury if they had been subjected to distraction. Because of the

Table IV. Incidence of non-union related to method and period of treatment

	Traction 4 to 12 weeks (mean 6 weeks)	**Traction 3 days to 3 weeks** (mean 8.1 days)	**Other treatment**
Union	39	44	33
Non-union treated surgically	4	1	2
Total	43	45	35

Table V. Incidence of non-union related to the grade of injury

Grade	**Number of patients**	**Number with non-union**
I	19	0
II	9	3
III	46	0
IV	42	1
V	7	2

risk involved, it is not recommended that traction should be used to establish the degree of ligamentous injury. The distribution of patients in the various grades in relation to those failing to unite, is given in Table V. Six of the seven patients requiring operation showed angulation on initial radiographs.

DISCUSSION

The result of bilateral fractures of the pedicle of the axis due to motor vehicle accidents and other deceleration injuries differs dramatically in its neurological component from that of the similar fracture produced by hanging with a submental knot. This difference can be explained by the anatomy and the probable mechanism of injury. The axis vertebra is transitional between the atlas and the more uniform lower cervical spine, with rotation and lateral gliding as its main functions. The upper and lower articular surfaces of the axis do not lie in the same vertical plane. This alignment creates the elongated bony bridge of the pars interarticularis, and during hyperextension and axial loading angular and shear stresses are probably maximal in this region.

The sequence of events during fracture may then be that a blow on the face causes extension of the cervical spine, stretching the anterior ligamentous structures and compressing the posterior bony facets until the pars interarticularis is fractured (Fig. 10, A and B). If extension continues the anterior longitudinal ligament and disc fail in tension with or without an avulsion of bone from the body of C2 or C3 (Fig. 10C.) Continued force will separate the disc from the body of the third, or less commonly the second, cervical vertebra with rupture of the posterior longitudinal ligament and marked separation of the bones. It is at this stage that any neurological injury probably occurs (Fig. 10, D and E). Immediately after injury the body of the axis moves forward on the third cervical vertebra, by a distance dependent on the extent of disruption of ligaments and disc (Fig. 10F). This forward movement is allowed by the loss of restraint due to fracture of the posterior element. Anterior displacement of the body of the axis enlarges the spinal canal and the invertebral foramina, and this decompression is believed to be the reason for the low incidence of neurological injury in the absence of any distraction. This forward movement led some early authors to believe the primary injury to be in flexion.

Three important features of traumatic spondylolisthesis of the axis are the high incidence (79 per cent) of associated injury of the head and of the cervical spine at other levels, the low incidence (6.5 per cent) of neurological damage and the low incidence of non-union (5.5 per cent). The presence of head injury, and especially of facial injury, has proved to be a reliable indicator of a lesion of the upper cervical spine, with the predominance of wounds in the apical and frontal regions of the skull confirming hyperextension and axial loading as the mechanism of injury.

Fractures of other parts of the cervical spine occurred in more than a third of the patients. Most of these were upper cervical lesions such as arch fractures of C1 or C3 and avulsion fractures of C2 or C3, providing further evidence for hyperextension as the mechanism of injury. Multiple fractures of the cervical spine were seen in nine patients, most being of compression type, but there were four fractures of the odontoid, an association which is uncommon. Six of the

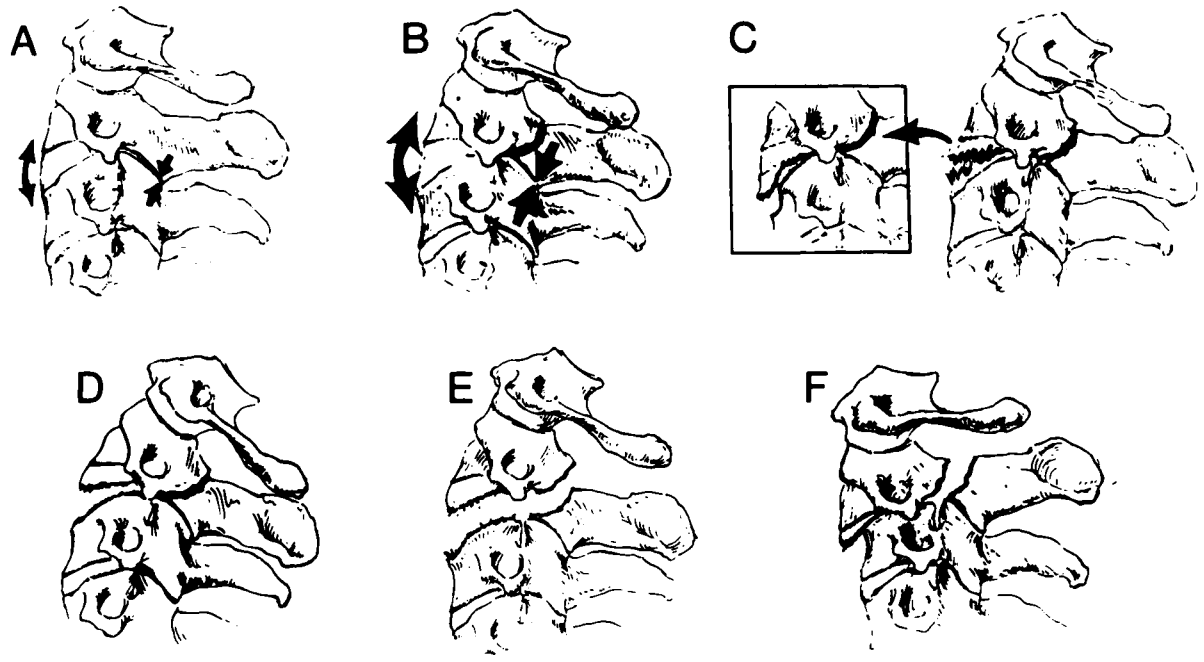

Fig. 10

Diagrams to show the theoretical sequence of injury in traumatic spondylolisthesis of the axis (see text).

nine fractures of the spine below the neck were of compression type, again suggestive of injury from axial loading.

The low incidence of neurological damage in this injury is due to the lack of distraction force during hyperextension and the enlargement of the spinal canal and nerve root foramina. It is gratifying that of the eight patients presenting with neurological deficits, six recovered completely. A nine-year-old boy who was left with residual shoulder weakness had sustained a flexion injury and, in addition to fractures of the axis, had compression injuries of the third and fourth cervical vertebrae with rupture of the interspinous ligament. His neurological deficit may well have been due to this second injury. Another boy with a Brown-Séquard lesion had a residual spastic gait. Paralysis due to traumatic spondylolisthesis of the axis has been reported, but tetraplegia or even tetraparesis must be exceedingly uncommon (Edgar *et al.* 1972).

Spontaneous union of this fracture is usual, occurring in 94.5 per cent of the series, and showing no correlation with the initial displacement or angulation. The majority of fractures healed with some displacement and it seemed that anatomical reduction was not advantageous or even necessary to secure union of the fractures. Reduction was, however, attempted in most patients. Only a few anatomical reductions were achieved and in a large percentage there was no change in position between injury and union. Gross displacement responded to mild traction in extension, but this treatment should be used with great caution under close observation to avoid "iatrogenic hangings" (Fig. 11). The degree of ligamentous instability is difficult to determine, and excessive traction could reproduce the mechanism of judicial hanging. Conservative treatment yields a high incidence of union with no difference between the result in patients walking early in a halo appliance and those treated in traction for six weeks. The duration of traction and bed rest did not influence fracture healing, and only one failure of union occurred in the 47 per cent of patients who were allowed up in less than two weeks. With the use of a halo cast, or the newer halo vest, or halo-pelvic brace, even patients with unstable fractures were managed successfully as outpatients.

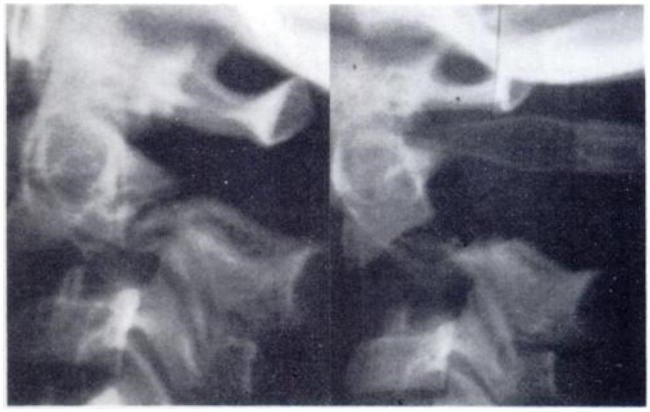

Fig. 11

Radiographs before and during the injudicious use of traction in treatment.

The fracture classification was based on angulation and displacement as features of instability likely to lead to non-union, but no correlation could be obtained other than that angulation greater than 11 degrees was seen in six of seven patients (85 per cent) with non-union. Angulation is not necessarily a determinant of non-union, but is commonly present in fractures that fail to unite. Primary treatment by operation is not indicated. An anterior fusion of C2–3 is preferred for established non-union or for segmental instability. This approach, as against a posterior fusion, avoids incorporation of the atlas and thus preserves some rotation movement by sparing the atlanto–axial articulation.

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