Evaluation and treatment of atlas burst fractures (Jefferson fractures)

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Although several large series of atlas fractures have been reported recently, none has concentrated on the evaluation and treatment of atlas burst fractures (Jefferson fractures). The treatment of this fracture is challenging. Its diagnosis may easily be missed due to concerns about associated trauma and absence of neurological signs. In addition, the open-mouth anteroposterior x-ray study, which is usually pathognomonic for the diagnosis, is often inadequate or not obtained. In order to clarify the diagnosis and treatment of this disorder, 17 cases of Jefferson fracture treated between 1982 and 1989 at the Louisiana State University Affiliated Hospitals are presented.

The diagnosis was delayed in three patients because of a low index of suspicion and inadequate x-ray films. Four patients were noted to have unstable Jefferson fractures; all of these had an associated Type II odontoid fracture and were treated with occiput-C2 wiring and fusion. The remainder of the patients had stable Jefferson fractures and were managed with Minerva jackets or rigid collar stabilization. No significant complications related to the treatment of the Jefferson fracture occurred in this series. One patient died from associated injuries; however, the remaining patients enjoyed an excellent long-term result with the acquisition of spinal stability and the resolution of subjective complaints.

Key Words • atlas fracture • spinal trauma • spinal fusion • immobilization

Geoffrey Jefferson's paper published in 1920 presents a description of four personally observed cases and a review of 42 additional cases from the literature involving all types of atlas fractures. More importantly from a historical perspective, Jefferson hypothesized the pathophysiology of the atlas ring burst fracture that currently carries his name. Although Hadley, et al.,25,26 Dickman, et al.,14 and others9,36,37,44,56 have reported larger series of atlas fractures, none limit their discussion to the unique fracture that bears Sir Geoffrey Jefferson's name. Consequently, our experience in the treatment of the true Jefferson fracture is unusually large.

Clinical Material and Methods

Seventeen patients with the diagnosis of Jefferson fracture were treated at Louisiana State University Medical Center and its affiliated hospitals (Table 1). The patients ranged in age from 4 to 78 years (mean 39 years). There were 10 males and seven females. Patients with pathological fractures were excluded. The mechanisms of injury were motor-vehicle accident in eight patients, falls in three, and aggravated assault in two; one patient each suffered a motorcycle accident, a diving accident, a water-skiing accident, and an equestrian accident.

The most common chief complaint was pain localized to the cervical and/or occipital regions. In general, patients were uninjured neurologically; only one patient exhibited a neurological deficit: a right upper extremity paresis in association with an unstable Jefferson fracture in combination with a Type II odontoid fracture.

Routine radiological evaluation consisted of plain x-ray films (including open-mouth anteroposterior views) and computerized tomography (CT) scanning (Fig. 1). Sagittal and coronal CT reconstructions occasionally added further information, especially with regard to the evaluation of odontoid fractures and their displacement. Conventional tomography was used to confirm the plain-film and CT findings (Fig. 2). One patient was evaluated by magnetic resonance (MR) imaging.

The mode of therapy was determined by the presence or absence of C-1 stability and the presence of other fractures. Unstable Jefferson fractures were defined as
TABLE 1
Clinical summary in 17 patients with Jefferson fracture

<table>
<thead>
<tr>
<th>Case No</th>
<th>Age (yrs), Sex</th>
<th>Mechanism of Injury</th>
<th>Neurological Findings</th>
<th>Radiological Studies</th>
<th>Type of Fracture</th>
<th>Therapy</th>
<th>Associated Injuries</th>
<th>Presenting Complaint</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27, M</td>
<td>aggravated assault</td>
<td>intact</td>
<td>plain x-ray/CT</td>
<td>stable</td>
<td>rigid collar</td>
<td>none</td>
<td>dysphagia, neck pain</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>58, F</td>
<td>MVA</td>
<td>intact</td>
<td>CT/plain x-ray</td>
<td>stable</td>
<td>rigid collar</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>4, M</td>
<td>fall</td>
<td>intact</td>
<td>plain x-ray/CT</td>
<td>stable</td>
<td>Minerva jacket</td>
<td>1: occiput-C-2 fusion</td>
<td>none</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>59, M</td>
<td>fall</td>
<td>intact</td>
<td>plain x-ray/CT</td>
<td>unstable</td>
<td>Minerva jacket</td>
<td>2: Type II odontoid fracture</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>50, M</td>
<td>fall from diving</td>
<td>RUE</td>
<td>plain x-ray/tomos/CT</td>
<td>stable</td>
<td>1: occiput-C-2 fusion</td>
<td>Type II odontoid fracture</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
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<td>MVA</td>
<td>intact</td>
<td>plain x-ray/CT</td>
<td>unstable</td>
<td>2: Minerva jacket</td>
<td>type II odontoid fracture</td>
<td>head &amp; neck pain</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>19, F</td>
<td>MVA</td>
<td>water-skiing accident</td>
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<td>stable</td>
<td>rigid collar</td>
<td>none</td>
<td>neck pain</td>
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<td>8</td>
<td>22, F</td>
<td>MVA</td>
<td>transient diffuse par-</td>
<td>plain x-ray/</td>
<td>stable</td>
<td>rigid collar</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
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<tr>
<td>9</td>
<td>33, F</td>
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<td>intact</td>
<td>plain x-ray/</td>
<td>stable</td>
<td>soft cervical collar</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
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<tr>
<td>10</td>
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<td>intact</td>
<td>plain x-ray/CT</td>
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<td>Minerva jacket</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
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<td>11</td>
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<td>plain x-ray/CT</td>
<td>stable</td>
<td>SOMI</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>78, M</td>
<td>MVA</td>
<td>intact</td>
<td>plain x-ray/CT</td>
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<td>rigid collar</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>18, F</td>
<td>MVA</td>
<td>CHI</td>
<td>plain x-ray/tomos/CT</td>
<td>stable</td>
<td>1: occiput-C-2 fusion</td>
<td>CHI</td>
<td>NA†</td>
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<td>14</td>
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<td>MVA</td>
<td>T-6 paralysis</td>
<td>plain x-ray/CT</td>
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<td>none</td>
<td>thoracic burst fracture</td>
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<td>0</td>
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<td>15</td>
<td>32, F</td>
<td>MVA</td>
<td>intact</td>
<td>plain x-ray/CT/MRI</td>
<td>stable</td>
<td>halo vest</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
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<td>plain x-ray/CT</td>
<td>stable</td>
<td>rigid collar</td>
<td>none</td>
<td>neck pain</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>63, M</td>
<td>MVA</td>
<td>CHI</td>
<td>plain x-ray/CT</td>
<td>stable</td>
<td>rigid collar</td>
<td>intracranial hemorrhage</td>
<td>none</td>
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</tr>
</tbody>
</table>

*CT = computerized tomography scan; MVA = motor-vehicle accident; tomos = tomograms; CHI = closed head injury; RUE = right upper extremity; AP = anteroposterior; SOMI = skull occiput mandibular immobilization; MRI = magnetic resonance imaging.†NA = not available. This patient had a CHI diagnosed on admission radiography before she was able to verbalize.

Fig. 1. Axial computerized tomography image of an atlantal burst fracture. This is the diagnostic procedure of choice to delineate the integrity of the ring of the atlas.

Those demonstrating displacement greater than 5 mm between the dens and the posterior aspect of the anterior arch of C-1 on lateral flexion/extension radiographs and/or total lateral displacement of the lateral masses of the atlas of 7 mm or greater in an anteroposterior view (Fig. 3). Stable Jefferson fractures were treated with external immobilization. All four patients with unstable injuries were treated with early operative fixation with occiput-C-2 wiring and fusion (Fig. 4) followed by external immobilization for 10 to 12 weeks with a Minerva jacket.

Results
Three patients were lost to follow-up review after their 4-month postinjury visit. The remaining patients were followed for at least 1 year. All patients enjoyed improvement in their cervical and/or occipital discomfort, and the patient with a neurological deficit improved to normal. One patient with an unstable Jeffe-
Atlas burst fractures (Jefferson fractures)

Fig. 2. Open-mouth tomogram, anteroposterior view, demonstrating the displaced lateral masses of C-1, more prominent on the left than on the right.

Fig. 3. Open-mouth tomogram, anteroposterior view, demonstrating the markedly displaced lateral masses of C-1 (arrows). The total displacement in this image is suggestive of a tear of the transverse ligament.

Fig. 4. Upper: Artist’s depiction of the occiput-C-2 wiring and fusion technique utilized in the present series. Two braided sublaminar wires are placed at the C-1 and C-2 levels as well as through two burr holes near the foramen magnum: one on each side of the midline. Subsequently, the braided wires are sequentially twisted in order to secure the block of iliac crest. Lower: Lateral plain film demonstrating the same technique.

Son fracture and an associated Type II odontoid fracture died 11 days following an occiput-C-2 fusion. This death was secondary to pulmonary complications related to associated injuries. The three surviving patients who underwent surgery did not complain of restriction of cervical movement at their 1 year follow-up examination. There were no complications related to the method of external immobilization.

Diagnosis was delayed in three cases. These delays were generally due to the lack of a thorough radiological evaluation of the upper cervical spine in patients who had an associated head injury or who were otherwise uncooperative. Moreover, the initial treating physicians may have become preoccupied with more apparent and seemingly more significant injuries. In the present series, the most common concurrent upper cervical spine fracture was a Type II odontoid fracture which was present in all four cases of unstable Jefferson fracture. The only patient who presented with a neurological
deficit referable to the upper cervical region had such a combination fracture.

**Discussion**

The diagnosis of an atlas fracture is facilitated by ever more sophisticated and available radiological technology as well as increasing clinician awareness. Jefferson\(^50\) discussed 46 fractures of the atlas, while a 2% to 13% incidence of atlas fractures among all cervical fractures have subsequently been reported.\(^4,12,61\) Burst fractures, however, represent less than one-third of all atlas fractures.\(^36,37,56\) In order to illuminate some of the issues associated with the mechanisms of injury, diagnosis, and treatment of the Jefferson fracture, further discussion is warranted.

**Autopsy Studies**

Autopsy studies of multitrauma victims have revealed a high incidence of upper cervical spine trauma. Alker, et al.\(^7\) reported a 24.4% incidence of radiographically demonstrable cervical spine injuries among a series of 312 victims of fatal traffic accidents. The vast majority of these injuries occurred at the craniovertebral junction and/or at the upper two cervical levels. Bucholz and Burkhead\(^60\) likewise found a 23% incidence of cervical spine fractures among a similar cohort, with more than one-third of these being atlanto-occipital dislocations. As demonstrated in these studies, the discovery of upper cervical spine injuries even at autopsy requires a thorough radiographic evaluation with routine as well as dynamic views obtained by the application of axial traction or utilization of flexion/extension views.\(^2,10\)

**Pathophysiology**

There have been many reports alluding to the unique osteological and ligamentous anatomy of the occipito-atlantoaxial regions.\(^11,30,36,37,47,63,70\) however, Jefferson\(^50\) was the first to discuss the mechanisms of atlas burst fractures. He categorized them into those caused by direct and indirect violence. The atlas is well protected by surrounding soft tissue and bone, thus fractures resulting from direct violence such as penetrating injuries due to gunshot wounds are relatively uncommon.\(^53\) Consequently, atlas fractures, including Jefferson fractures, most frequently are a result of indirect violence.\(^50,55\) The most common mechanism of injury is axial loading (such as via a fall upon the vertex of the head where the transmitted force is applied to the base of the skull and to the atlas).\(^30,31,37,61\) Occasionally, a falling object may strike the head which essentially generates the same force pattern.\(^30,60,61\) Since the atlas has no bony centrum, the whole force passes through the planes of the articular facets with the anterior and posterior arches playing no part in the transmission of forces.\(^50\) Due to the planes of inclination of the articular facets, the sum of the forces exerted at impact results in a lateral spread of the masses. This essentially leads to a bilateral chisel effect with a tension fracture resulting at the weak points of the ring as lateral spread occurs (Fig. 5).\(^12,64\) The not infrequent concomitantly occurring odontoid fracture indicates that an extension or flexion force vector was also applied at the moment of impact. This may account for the more common neurological involvement in the setting of these combination fractures, as noted by us and others.\(^2,26,31\)

**Presenting Signs and Symptoms**

The classic clinical triad of an upper cervical spine injury consists of pain, cervical muscle spasm, and limitation of neck movement.\(^30,31,54,56,61\) The presenting symptoms of the group described here are consistent with this. Other reported symptoms relate to pain and difficulty with swallowing secondary to hematoa formation or muscle injury in the retropharyngeal region.\(^61\) Also, symptoms related to neuralgia or hypesthesia secondary to injury to the greater or lesser occipital nerves are commonly noted (the greater occipital nerve is particularly vulnerable as it passes posteriorly through the atlanto-axial membrane).\(^12,53,61\) Less frequently reported problems are alterations of phonation and taste secondary to damage to the glossopharyngeal, palatal, or chorda tympani nerves.\(^62,64\) The vertebral artery is rarely injured in this setting. A transient loss of consciousness, visual disturbances, or other symptoms of posterior fossa ischemia, however, may occur secondary to vertebral arterial compression, or an arteriovenous fistula may develop as a result of atlantoaxial instability or atlas fracture.\(^5,13,17,19,23,30,46,49,61,69\)

Patients suffering upper cervical spine injuries are frequently unscathed neurologically.\(^3,4,11,16,33,36,37,41,50,52,53,58,61,82\) Two important anatomical points contribute to this phenomenon. One is the large cerebrospinal fluid (CSF) space in the upper cervical canal, especially at C-1 where the spinal cord is about 10 mm in diameter and the bone canal measures an average of 30 mm transversely and 25 mm sagitally.\(^12,37,49,54,58\) Steele\(^66\) reported the "rule of thirds" at the atlantoaxial level: the intracanalicular space consisting of one-third spinal cord, one-third odontoid process, and one-third CSF space. The second factor is connected with the relative neural protective mechanism provided by the centripetal spread of fracture fragments due to axial loading.\(^31,62\) On the other hand, Jefferson fractures associated with odontoid fractures are more prone to neurological injury than are those occurring alone. This has been the experience of others and is demonstrated by the single case of upper-extremity paraesthesia observed in the present series.\(^12,26,30,33\) As suggested previously, a number of C1–2 region injuries are immediately fatal and the patients do not present for treatment.\(^2,30,37\)

**Radiographic Evaluation**

The combination of the absence of neurological deficits and relative inability to make the diagnosis of Jefferson fracture on routine anteroposterior and lat-
Atlas burst fractures (Jefferson fractures)

Fig. 5. Artist's depiction of the classic atlantal burst fracture with the ring being fractured in four separate locations accompanied by a tear of the transverse ligament.

eral radiographs may lead to delays in diagnosis.45,57 The pathognomonic radiograph associated with the diagnosis of Jefferson fracture is the open-mouth anteroposterior x-ray film of the atlantoaxial articulations.39,49,53,54,55 With this view, the appearance of a bilateral offset of the lateral masses of the atlas is indicative of a burst fracture.66 Unfortunately, the open-mouth view may be difficult to perform in an uncooperative patient.

Plain lateral radiographs are good screening studies to use in identifying posterior arch fractures, which account for over two-thirds of all atlas fractures.66 However, isolated posterior arch fractures do not affect the stability of the C1-2 junction. Identification of retropharyngeal soft-tissue swelling (the normal shadow is less than 5 mm thick) on the lateral radiograph in the acute setting provides indirect evidence of anterior upper cervical spine trauma.51 Anterior soft-tissue swelling is usually absent in isolated posterior arch fractures.57

Conventional tomography will occasionally add to the information obtained from plain films.52 Anteroposterior tomography can more clearly delineate the lateral masses of C-1 and the relationship to their articulation with C-2 and the occiput as well as the status of the odontoid process; however, patient cooperation again is necessary. Computerized tomography is the diagnostic procedure of choice for demonstrating the integrity of the ring of C-1.14,26,33,52 Although the relationship of the odontoid to the ring of the atlas may be readily displayed with this technique, a transverse odontoid fracture may be missed.31 Sagittal or coronal CT reconstruction may be helpful in this regard; however, thin-cut imaging techniques are required.57

The presence of a dislodged bone fragment from the medial aspect of the lateral mass of C-1 at the expected site of transverse ligament attachment is suggestive of the disruption of this stabilizing complex. This finding was initially described with tomography in an antero-

posterior projection, but now can be demonstrated by CT.22,29 Obviously, it is imperative to obtain follow-up flexion/extension views to demonstrate the possibility of delayed instability.

Magnetic resonance imaging is being employed more frequently for the evaluation of cervical spine trauma. Although CT and/or routine x-ray films better address the issues of bone integrity, MR imaging allows early assessment of spinal cord edema, hemorrhage, compression, or transection.68 Furthermore, damage to supporting soft-tissue structures is readily detectable by this technique.

Therapeutic Considerations and Treatment

Nearly all stable Jefferson fractures will heal with external immobilization only;26,27,36,37,52,59,67,68,71 however, the degree of required immobilization varies, hence each case must be individualized. Based on the work of Spence, et al.,69 on cadavers, one can predict the stability of Jefferson fractures by measuring the lateral displacement of the lateral masses on anteroposterior roentgenograms. If the lateral masses are displaced to the point that the transverse ligament of the atlas is disrupted, subluxation of C-1 on C-2 is likely. In their cadaver studies, the authors noted a total excursion of the lateral masses from a resting width to transverse ligament rupture ranging from 4.8 to 7.6 mm in total. They concluded that a high probability exists that the transverse ligament is intact if the spread of the lateral masses is less than 5.7 mm in total; equally, if the spread is greater than 6.9 mm, the probability that the ligament has been torn is high.70 With tearing of the transverse ligament, the stability of the atlantoaxial joint is greatly compromised.61,65 Obviously, rupture of the transverse ligament does not absolutely dictate that significant C1-C2 instability coexists, because other structures such as the alar ligaments and portions of the facet capsules may remain intact.36,37 However, the integrity of these latter structures must be questioned in the face of extensive upper cervical trauma. Knowledge of the amount of lateral mass displacement may aid in the determination of the degree of immobilization required for successful treatment, especially in the absence of demonstrable instability of flexion/extension radiographs.

Conservative Management

Historically, initial immobilization techniques consisted of prolonged bed rest with or without traction. Jefferson48 advocated nonoperative therapy unless the surgeon believed that bone fragments were pressing on the medulla, an uncommon occurrence in clinical practice. Later, Norrell’s72 and Levine and Edwards21 advised the initial use of skull traction for 6 to 8 weeks, followed by a longer period of rigid external support in a halo vest. This was based on two premises: 1) halo traction reverses the axial loading force of the injury and allows reduction; and 2) earlier mobilization into a halo vest...
was associated with the loss of reduction. Stauffer also preferred immobilization with a halo but did not discuss unstable fractures or the indications of surgery. Despite these thoughts, experience has shown that the use of either a halo vest or other less restrictive external orthoses alone can be used safely and successfully. For example, stable Jefferson fractures have been treated successfully with only rigid collars, or skull occipitomandibular immobilization (SOMI) braces for 8 to 12 weeks. Hadley, et al., and Spence, et al., have advocated more aggressive immobilization for unstable fractures. Spence, et al., recommended surgical stabilization early in this situation, while Hadley, et al., have had success with rigid external immobilization via a halo vest for a duration of 10 to 14 weeks. Following either therapy, dynamic flexion and extension cervical radiographs should be performed to rule out late instability. Furthermore, caution should be exercised when treating injuries with immobilization alone when transverse ligament disruption is suspected. The possibility that atlantoaxial instability may result in acute or chronic myelopathy or sudden death must be weighed against the risk of surgery.

Surgical Options

A variety of surgical options are available for stabilization of the upper cervical spine. Posterolateral fixation with wire and bone (as illustrated in Fig. 2) provides immediate postoperative stability. However, posterior fusions compromise motion in the upper cervical spine to a greater degree than in the remainder of the cervical spinal axis because the atlantoaxial articulation reportedly supplies approximately 50% of cervical rotation.

The operative procedure utilized in the present series was occipit-C-2 wiring and fusion with an iliac crest graft. A clinically significant loss of cervical mobility was not encountered by adding the occipit-C-1 segment to the fusion mass in this small surgically treated group, and furthermore is not supported by biomechanical studies. An additional argument against the use of occipit-C-2 fusion is the notion of an associated higher rate of non-union. This was again not encountered in the presented series and has not been adequately documented in the literature.

Although successful C1–2 fusions have been reported in the setting of a unilateral fracture of the posterior cervical ring, there is minimal difference in disability between an occipit-C-2 and a C1–2 fusion. Moreover, a posterior C1–2 fusion for treatment of a unilateral posterior arch fracture is more likely to result in a tenuous construct.

An alternative form of therapy relates to an initial period of rigid external immobilization to allow healing of the atlantal posterior arch, followed by C1–2 wiring and fusion if instability persists. After the delayed fusion, the patient would be required to undergo another period of external immobilization. This practice adds the risk associated with an increased duration of treatment in patients who have a high chance for failure of nonoperative management.

Postoperative Immobilization

Immobilization for at least 12 weeks is required following surgical stabilization. The use of a rigid collar or SOMI brace may be sufficient; however, we preferred the more rigid form of immobilization provided by the Minerva jacket. Although a halo device theoretically provides more immobilization for the upper cervical spine, the degree of immobilization provided by the Minerva jacket has been adequate. In addition, complications associated with halo immobilization make it less appealing for the treatment of this injury.

Associated Axis Fractures

Concurrent axis fractures are not uncommon in patients with Jefferson fracture. The most frequently associated axis fracture is the Type II odontoid fracture (24% in the present series). There are many treatment alternatives from which to choose in cases of axis-atlas combination fractures. It has been appropriately suggested that the initial treatment of these fractures should be directed at the anatomy of the axis fracture. For example, if the axis fracture is an odontoid Type III fracture or a hangman’s fracture, then external immobilization for 8 to 14 weeks should be the initial treatment. However, the Type II odontoid fracture heals less optimally with external immobilization. Consequently, early surgical stabilization and fusion followed by a period of external immobilization with either a halo vest or a Minerva jacket is recommended. A particularly worrisome state of instability is present when a Type II odontoid fracture occurs in a patient having a Jefferson fracture with total lateral mass displacement greater than 6.9 mm. In this instance an early occipit-C-2 fusion is probably the treatment of choice, as was the situation with our four operative cases.

Pediatric Consideration

Jefferson fractures are unusual in the pediatric population. The present series includes one patient in this age group. As with other reported cases, this patient was successfully treated with external immobilization. Similar criteria for the determination of instability and surgical treatment should be applied to children as for the older age group. Not uncommon in the pediatric group is the presence of congenital defects of the anterior and posterior arches. Although these defects are rarely of clinical importance (fusion of the posterior arch usually occurs by 3 years of age), there are reports of “fractures” occurring through these “defects,” thus predisposing to a more unstable situation.
Conclusions

Although the majority of Jefferson fractures are stable and may be treated nonoperatively, an understanding of the complex anatomy of the upper cervical region is imperative. This leads to the proper assessment and treatment in patients with the more uncommonly occurring unstable fracture.

References


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