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Fractures of the Arches of the Atlas: A Study of Their Causation

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Summary. The autopsy findings in 32 accidental deaths which showed fracture(s) of the arches of the atlas have been correlated to reconstructions of the course of events in the accidents.

Flexion of the head causing fracture(s) of the neural arch or odontoid process of the axis also resulted in fracture(s) of the posterior arch due to downward traction. Extension of the head causing fracture of the odontoid process of the axis gave rise to fractures of the posterior arch due to pressure from below. Tilting of the head caused marginal fractures of the anterior arch due to oblique traction. Tilting of the head also caused fracture(s) of the anterior and/or posterior arch due to transverse extension of the atlas ring and/or superior dislocation of one lateral mass in relation to the other. Oblique flexion or extension of the head resulted in similar fractures. Flexion of the head with some rotation combined with compression of the neck can cause the anterior margin of one upper joint surface of the axis to act as a wedge separating the anterior arch of the atlas from below. Extension of the head with some rotation combined with compression of the neck can lead to a fracture running through one lateral mass due to its tilting-dislocation in posterior direction.

It is striking that there was no fracture of the atlas which could be ascribed to a simple and symmetric compression of the neck (classical Jefferson's fracture).

Key words: Atlas fractures – Fractures of the arches of the atlas

Zusammenfassung. Die Sektionsbefunde bei 32 Unfalltoten mit Atlasfrakturen wurden mit den Ergebnissen der Rekonstruktion des Unfallherganges korreliert, um eine Auffassung über den Verletzungsmechanismus am Atlas zu bekommen. Dabei zeigte sich folgendes: Anteroflexion des Kopfes, die Anlaß zu Frakturen des Neuralbogens oder des Dens axis gibt, kann auch infolge einer caudalwärts gerichteten Zerrung in Frakturen des posterioren Atlasbogens resultieren. Retroflexion des Kopfes, die zu einer Fraktur des Dens axis führt, kann infolge eines cranial gerichteten Druckes zu Frakturen des posterioren Atlasbogens führen. Gewaltsame Beugung des Kopfes nach der Seite kann marginale Frakturen des vorderen Atlasbogens infolge einer

einseitigen Zerrung erzeugen. Seitwärtsbeugung des Kopfes kann auch Frakturen des vorderen oder hinteren Bogens hervorrufen infolge einer transversalen Extension des Atlasringes und/oder einer cranialwärts gerichteten Dislokation der einen Massa lateralis. Schräge Anteroflexion oder Retroflexion des Kopfes kann in ähnlichen Frakturen resultieren. Anteroflexion des Kopfes zusammen mit Rotation und Kompression des Halses kann dazu führen, daß die vordere Kante der oberen Gelenkflächen des Axis wie ein Keil den vorderen Atlasbogen von caudal her spaltet.

Retroflexion des Kopfes zusammen mit Rotation in Kombination mit einer Kompression des Halses kann in einer Fraktur einer Massa lateralis resultieren, was durch deren Kippung und Verschiebung in dorsaler Richtung hervorgerufen wird.

Es ist auffallend, daß in dem untersuchten Material in keinem Falle eine Atlasfraktur von einer einfachen axialen Kompression des Halses (klassische Jefferson-Fraktur) erzeugt wurde.

Schlüsselwörter: Traumatologie, Atlasfraktur – Atlasfraktur, Verletzungsmechanismus

Introduction

As early as in 1920 Jefferson claimed that atlas fractures usually arise indirectly and presented theories of their genesis. In the 62 years since then only a few other mechanisms for atlas fracture have been suggested. Jefferson's conclusions rested mainly on studies of museum specimens and cases described in the literature. Subsequent publications have been based mainly on clinical observations. This report describes the results of an investigation based on close reconstruction of the course of events and careful anatomic preparation of the neck and discusses possible mechanisms for these fractures.

Material and Methods

In approximately 300 fatalities due to accidental blunt trauma, the autopsies were performed with special attention to the upper part of the neck. Injuries to the soft tissue were carefully studied, especially if these injuries permitted movements of fracture fragments of the atlas and axis in one direction only, i.e., the same direction as that taken at the moment of the accident. The appearance of fractures was also recorded in detail.

In all cases, attempts were made to reconstruct the course of events in the accident—in traffic accidents, the so called "second collision".

It is well-known that the course of events in accidents is often very complicated. Several cases had to be excluded as a satisfactory reconstruction was impossible. Cases with extreme head and neck injuries and cases with anatomic anomalies of the atlas were also excluded. With reasonable certainty we could determine the movements of the head and neck which took place at the moment of the accident and caused the fractures of the atlas in 32 cases.

These movements were determined through a synthesis of several observations: (1) The point of impact to the head as judged by the external injuries correlated to the findings at the scene of the accident, (2) the direction of the trauma based on the findings of the reconstruction of the course of events, and (3) the appearance of the fracture(s) of the atlas and axis and the manner in which injuries to the soft tissues (which are not presented in detail) around fractures permitted movements of one fracture fragment relative to another (i.e., on which side the fractures gaped).

The 32 cases which form the basis of this publication have been divided into groups according to the movements of the head and neck likely to have taken place during the accident.

Results

1. Lateral Tilting of the Head (11 Cases)

All victims had been hit on the right or left side of their heads. (Seven victims were occupants in cars that were hit from one side by another car or a train or which collided laterally with a tree; two victims were occupants in cars that rolled over; one victim was a bicyclist hit by a car; one victim was a pedestrian hit by a car.) In all cases there were injuries to the muscles and ligaments between the base of the skull and the upper part of the neck, in most cases more pronounced on one side.

Eight of these victims showed marginal avulsions (complete or incomplete fractures) from the inferior margin of the anterior arch of the atlas. In some cases the medial part(s) of the inferior joint surface(s) were included. Some of the fractures gaped on the ipsilateral, some on the contralateral side in relation to the point of impact on the head. These fractures must probably be ascribed to traction from the membrane and muscles attached to the lower margin of the anterior arch of the atlas.

In one of these eight cases there was also a fracture of the left part of the posterior arch, an incomplete fracture of the anterior side of the posterior arch near the midline and an incomplete fracture in the lateral part of the right half of the posterior arch (Fig. 1). These injuries show that the atlas ring had been extended transversly. Such an extension is probably due to lateral dislocation of the atlas in relation to the axis, a movement which would be counteracted by contact between the lateral mass of the atlas on the contralateral side and the odontoid process of the axis. The lateral dislocation of the atlas may be due to the vertebra following the head in its dislocation caused by impact against its contralateral side. Furthermore, it is possible that the lateral tilting of the head caused such a compression of the corresponding lateral mass of the atlas that the atlas moved in this direction. Because of the inclination of the joint surfaces of the atlas toward the occipital condyles (sloping medio-inferiorly) and toward the superior joints of the axis (sloping medio-superiorly), compression of one lateral mass of the atlas between the skull and the axis tends to dislocate it laterally.

Another two of these eight cases showed not only marginal fractures of the anterior arch, but also other fractures of the atlas. In one case there was one vertical fracture in the anterior arch and one fracture in the posterior arch. Both fractures gaped inferiorly. The other case showed an incomplete fracture of the inferior portion of the right half of the posterior arch running at approximately right angles to the arch. The findings in both cases indicate upward dislocation of one lateral part of the atlas in relation to the other probably caused by traction

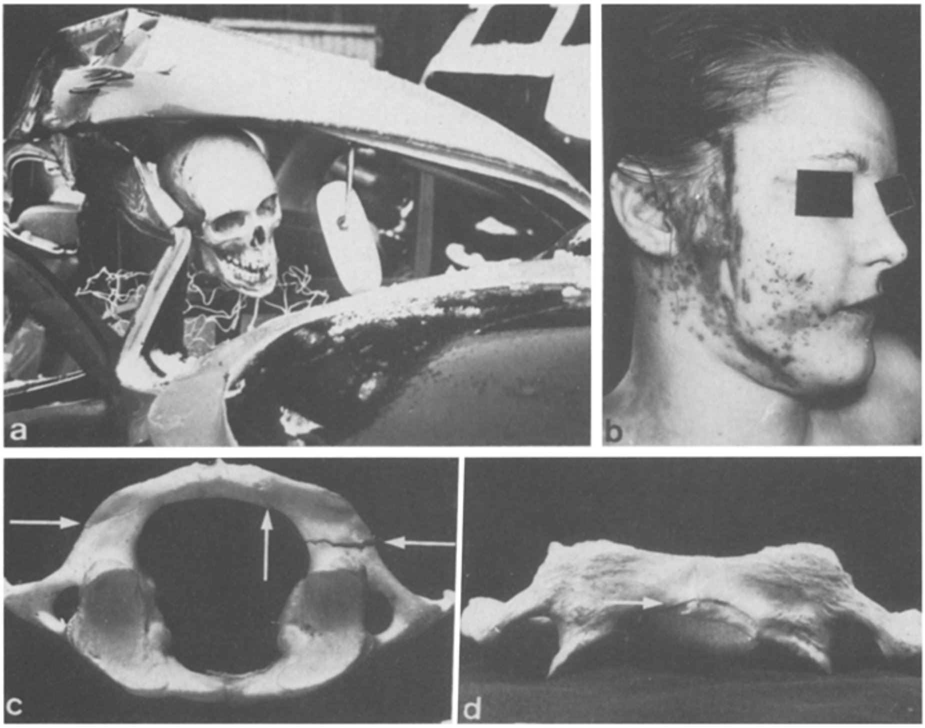

Fig. 1a–d. Trauma against the right side of the head causing lateral tilting of the head. **a** Reconstruction of the impact of the head with a simple dummy. **b** Facial injuries. **c** Fractures of the posterior arch of the atlas *(arrows)* indicating extension of the atlas ring in transversal direction. **d** Avulsion fracture of the inferior margin of the anterior arch

from the soft tissue connections between the base of the skull and the upper part of the neck.

Three cases showed no marginal fracture but a vertical one in the anterior arch and another one in the left part of the posterior arch. These were complete in one case and incomplete and situated on the inferior side in two cases. The fractures have the same appearance as those in the above-mentioned two cases, and the mechanism is probably the same (upward dislocation of one lateral part of the atlas).

2. Flexion of the Head in the Sagittal Plane Without Rotation (Two Cases)

Both victims were occupants of automobiles involved in head-on collisions, one with another car and the other one with a moose. One victim had been struck on the posterior part of the vertex of his head, while in the other case the point of impact could not be determined. Both victims showed bilateral, almost symmetric fractures of the neural arch of the axis in the isthmus region (Hangman's fracture). These fractures gaped superiorly implying that they were caused by flexion of the head.

In one of the cases the atlas showed bilateral fractures in the lateral parts of the posterior arch gaping superiorly. In the other case there was a single fracture in the left part of the posterior arch and the part of the posterior arch situated immediately to the right of the fracture was permanently dislocated downward. The fracture(s) of the atlas may be ascribed to a considerable traction inferiorly to its posterior arch, probably exerted by the soft tissue connections between the posterior arch of the atlas and the neural arch-spinal process of the axis. This traction probably arose because the atlas accompanied the odontoid process and body of the axis in their dislocation and anterior tilting which took place during the abrupt flexion of the head occurring after the moment of the axis fractures.

3.1. Flexion of the Head with Some Rotation Combined with Traction of the Neck (Three Cases)

All victims had been struck in the lower face from the front and from below. (All had been front seat occupants of passenger cars involved in slightly oblique head-on collisions.) They all showed bilateral fractures of the neural arch of the axis. These fractures gaped superiorly indicating flexion of the head. The flexion of the head around the point of impact at the lower part of the face was probably due to the inertia of the head. The point of impact to the face was in all cases lateral to the midline, and the localization of the fractures of the neural arch of the axis was notably non-symmetric. These findings indicate that the flexion of the head was oblique.

In all three cases the atlas showed bilateral fractures of the lateral parts of the posterior arch. These fractures can be ascribed to downward traction by the soft tissue connections to the neural arch-spinal process of the axis as proposed above (2.). In two of the cases there was also an approximately vertical fracture in the anterior arch. It seems probable to ascribe these fractures to the mechanism suggested above (1.), i.e., superior dislocation of one lateral part of the atlas in relation to the other. Because the flexion of the head was probably oblique there was also a lateral tilting of the head. Therefore, the traction from the soft tissue connections between the base of the skull and the upper part of the neck was probably most pronounced on one side.

3.2. Flexion of the Head with Some Rotation Combined with Compression of the Neck (Seven Cases)

Two victims showed fractures of the odontoid process of the axis, which could be tilted and dislocated antero-laterally, indicating oblique flexion of the head. (One victim jumped from a height landing on her feet, while the other was the driver of a car hit by a train who had sustained impact at the posterior-lateral part of the vertex of his head.)

In both cases the atlas showed bilateral fractures in the lateral parts of the posterior arch which can be explained by downward traction as suggested above (2.). In one of the cases there was also a vertical fracture in the anterior arch which may be ascribed to lateral dislocation of the atlas and transverse extension of the atlas ring, as suggested before (1.). This dislocation and transverse exten-

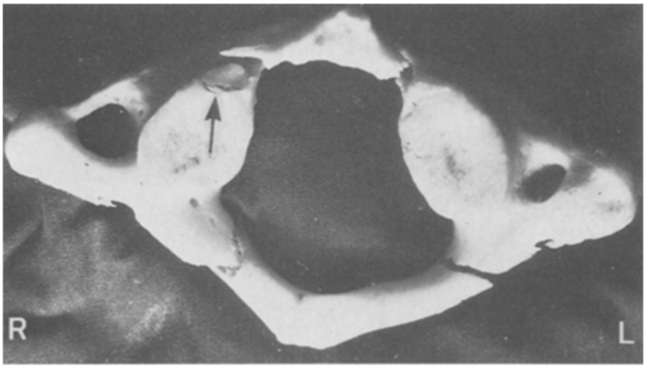

Fig. 2. Trauma against the vertex of the victim's head causing compression of the right-anterior part of the upper cervical spine causing bilateral fractures of the anterior and posterior arch of the atlas. Inferior view. Note the impression in the most anterior part of the right lower joint surface

sion is most likely due to the compression of the neck being most pronounced laterally because of the simultaneously occurring oblique flexion.

Four victims showed fractures of the atlas of quite different appearance. All victims had been subjected to trauma to the vertex of their heads lateral to the midline. (Two victims fell from heights landing on their heads; one victim was hit by a heavy falling object; one victim was the back-seat passenger of a car, the roof of which was crashed.) All the victims showed vertical, bilateral fractures of the anterior arch of the atlas at the junctions between the anterior arch and the lateral masses. In one of the victims, struck on the left side of the vertex of the head, small bone fragments were separated and dislocated anteriorly from the right inferior border of the anterior arch. Immediately posterior to them there was a small impression in the most anterior part of the right lower joint surface (Fig. 2). Furthermore, an incomplete vertical fracture was present at the posterior surface of the anterior arch. The separated anterior arch, especially its inferior part, could be dislocated anteriorly. The findings indicate that due to compression of the upper cervical spine, mainly its right anterior part, the anterior margin of the right upper joint surface of the axis acted as a wedge, separating the anterior arch of the atlas from below and also making an impression on the anterior aspect of the right lower joint surface. The type of trauma and the appearances of the fractures were essentially the same in the remaining three cases, and it seems reasonable to assume that fractures in these cases were caused by the same mechanism.

In three of the four cases showing bilateral fractures of the anterior arch there were also fracture(s) of the posterior arch (bilateral and lateral in one case and a single, vertical fracture close to the midline in two cases). These fractures may be ascribed to lateral dislocation and transverse extension of the atlas as suggested above (1.) due to the compression of the neck being most pronounced on one side.

One victim (a pedestrian hit by a car and sustaining impact to the postero-lateral part of the vertex of his head) showed a fracture of the atlas with quite another appearance, i.e., avulsion of a bone fragment from the inferior border of the anterior arch. Furthermore, the anterior longitudinal ligament was partially ruptured at the level of the fracture and there was a rupture of the transverse ligament of the atlas. The skull and the atlas could be dislocated and tilted forward in relation to the axis indicating flexion of the head. However, the anterior part of the upper joint surface of the axis situated contra-laterally to the point of impact to the head was impressed, indicating that the flexion of the head took place in an oblique direction. The avulsion of the bone fragment from the inferior border of the anterior arch was probably due to traction via the soft tissues inserting at the lower margin of the anterior arch during the anterior dislocation and oblique flexion of the head and atlas.

4.1. Extension of the Head Without Rotation Combined with Compression of the Neck (Four Cases)

The victims were hit on their foreheads from the front and from above (two victims were front-seat passengers of cars involved in head-on collisions; one fell headlong into a hollow, one fell headlong from a cart to the ground).

All the victims showed fracture of the odontoid process of the axis which could be disclosed and tilted in a posterior direction, indicating extension of the head. Furthermore, all the victims showed bilateral fractures of the lateral parts of the posterior arch of the atlas, gaping inferiorly. In one of the cases there was also a small impression on the antero-inferior surface of the posterior arch of the atlas at the midline, obviously caused by contact with the neural arch-spinal process of the axis. Thus, the findings indicate that the atlas accompanied the odontoid process in its dislocation and posterior tilting. During this movement the posterior arch of the atlas was pressed against the spinal process-neural arch of the axis and fractured.

4.2. Extension of the Head Without Rotation Combined with Traction of the Neck (One Case)

The victim, the driver of a car which collided head-on with a tree, was struck on the chin from in front and from below by the steering-wheel.

The axis was uninjured but the atlas showed bilateral fractures in the lateral parts of the posterior arch. The reconstruction of the second collision showed that flexion of the head could not have taken place because of lack of space in the deformed car interior, while extension could have occurred. The movement tests of the fracture fragments of the atlas as well as the injuries to the soft tissues in the upper part of the neck were not conclusive. Therefore, it was not possible to determine whether the fractures of the posterior arch were due to pressure from the occipital bone or against the neural arch-spinal process of the axis during the extension of the head.

5. Extension of the Head with Some Rotation Combined with Compression of the Neck (Four Cases)

All victims were struck on their foreheads or at the anterior part of the vertex of their heads from in front and from above. The point of impact was located lateral

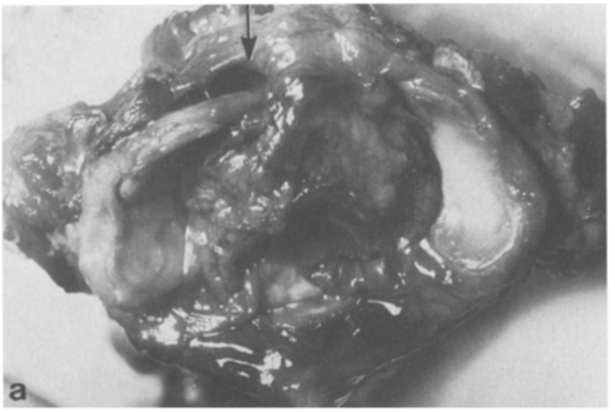

Fig. 3a, b. Trauma against the vertex of the victim's head causing extension of the head with some rotation combined with compression of the neck. **a** Avulsion of the soft tissues from the anterior side of the anterior arch of the atlas to the left of the fracture. Dislocation of the left part of the atlas in posterior direction. **b** Single fracture of the anterior arch and bilateral fractures of the posterior arch caused by dislocation and tilting of the left lateral mass in postero-inferior direction

to the midline (two victims were the drivers of cars colliding head on with another car; one victim was thrown out from an over-turning car; one victim was a pedestrian hit by a car).

All victims showed an approximately vertical fracture running through the upper joint surface and lateral mass of the atlas situated contralaterally to the point of impact to the head. In two of the cases the fracture gaped superiorly, in two cases the shape of the fracture surfaces and the injuries to the surrounding soft tissues did not allow any conclusion in this respect. In one case there was a small impression in the postero-lateral part of the upper joint surface of the axis situated contralaterally to the point of impact to the head. In one case the soft tissues were avulsed from the anterior part of the atlas laterally to the fracture (Fig. 3). The above-mentioned findings indicate that one lateral part of the atlas had been tilted and dislocated in a posterior direction. This dislocation and tilting was evidently caused by pressure from the corresponding occipital condyle.

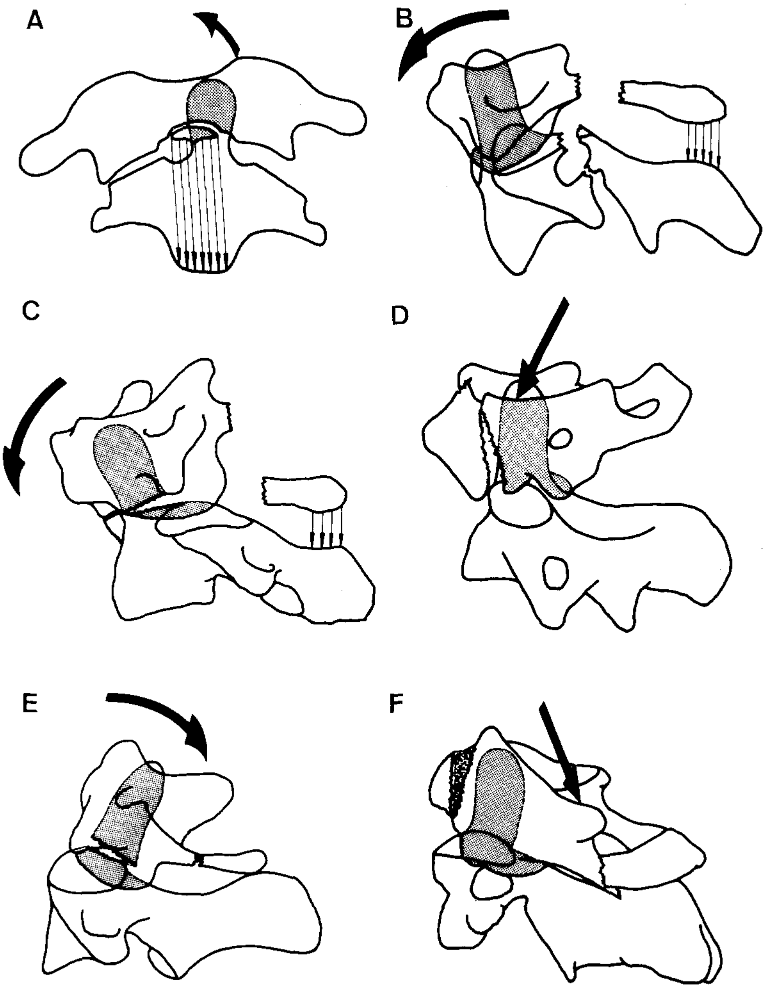

Fig. 4a–f. Movements causing fractures of the arches of the atlas. **a** Lateral tilting of the head. **b** Flexion of the head (with fractures of the neural arch of the axis). **c** Flexion of the head with some rotation combined with compression of the neck (with fracture of the odontoid process of the axis). **d** Flexion of the head with some rotation combined with compression of the neck (without fracture of the odontoid process of the axis). **e** Extension of the head combined with compression of the neck (with fracture of the odontoid process of the axis). **f** Extension of the head with some rotation combined with compression of the neck

Thus, during oblique extension of the head and compression of the neck, the occipital condyle on the side situated contralaterally to the point of impact on the head, exerts pressure against the posterior part of the corresponding joint socket of the atlas. Because the posterior part of the joint sockets slope postero-superiorly, the pressure tends to dislocate and tilt this part of the atlas posteriorly. This movement is probably counteracted by pressure on the posterior surface of the anterior arch and/or the inner surface of the lateral mass on the opposite side against the odontoid process. Thus, strains and stresses and possible fracture(s) will arise in the atlas ring between the part in contact with the odontoid process and the part being dislocated by the occipital condyle.

In one of the cases there was also a fracture in the posterior arch. This fracture can be ascribed to pressure at the posterior arch from the occipital bone or against the neural arch-spinal process of the axis.

Discussion

The classical fracture mechanism presented by Jefferson in 1920 and considered still fully valid is the suggestion that compression of the neck due to a direct and symmetric blow to the vertex can give rise to fractures of the atlas ring due to its transverse extension (so-called Jefferson's fracture). More exactly, because of the sloping of the joint surfaces of the atlas toward the occipital condyles (medio-inferiorly) and toward the upper joint surfaces of the axis (medio-superiorly) compression of the atlas between the base of the skull and the axis tends to dislocate the lateral masses laterally (wedge-effect) (Barker et al. 1976; Braakman and Penning 1971; Graubard and Ritter 1949; Hatchette 1941; Hinchey and Bickel 1945; Hipp and Keyl 1963; Jefferson 1920, 1927; Plaut 1938; Rijsbosch 1971; Rogers 1957; Ruge 1969; Shapiro et al. 1973; Sherk and Nicholson 1970; Sherk 1975, 1978; White and Panjabi 1978).

In the material presented here there are several cases in which the victim had been subjected to compression of the neck. However, in all these cases there were findings indicating that there had been not only dislocation of the head inferiorly but other movements of the head as well. Thus, there is no case in which the fractures of the atlas can be ascribed entirely to a simple and symmetric compression of the neck. It may be argued that victims contracting a classical Jefferson's fracture usually survive because bone fragments are not dislocated toward the spinal cord which therefore remains uninjured. It may be that such cases are included in reports based on clinical observations and not in studies based on autopsy cases. However, if this mechanism was the usual one, it seems likely that at least some cases of this kind would have appeared among the many cases investigated here. Therefore, the results of the present investigation indicate that in most victims sustaining atlas fracture(s) associated with compression of the neck, there are other movements of the head that are of importance in the genesis of the atlas fracture(s). This observation indicates that at the moment of impact the head and neck are usually not fixed in an upright position and/or the direction of the trauma is usually not directed through the center of gravity of the head.

It is of special interest that in several of the above-mentioned cases the findings indicate that the fractures of the atlas arose due to mechanisms not earlier suggested in the literature available:

1. When compression of the neck is combined with oblique flexion of the head the anterior arch of the atlas can be split off. This is because the anterior margin of the upper joint surface of the axis, situated contralateral to the point of impact to the victim's head, can act as a wedge, separating the anterior arch of the atlas from below.

2. When compression of the neck is combined with oblique extension of the head, fracture(s) of the atlas can arise due to pressure from the occipital condyle situated contralateral to the point of impact to the victim's head. Such pressure causes posterior dislocation and tilting of the corresponding lateral part of the atlas. However, at the same time the posterior surface of the anterior arch and/or the inner surface of the lateral mass on the opposite side is pressed against the odontoid process. Thus, strains and stresses can arise between the part of the atlas in contact with the odontoid process and the part being dislocated by the occipital condyle.

The second fracture mechanism presented by Jefferson in 1920 and considered still fully valid is that extension of the head can cause fractures of the posterior arch of the atlas, due to its compression between the occipital bone and the neural arch of the axis (Braakman and Penning 1971; Graubard and Ritter 1949; Hatchette 1941; Hipp and Keyl 1963; Jefferson 1920; Plaut 1938; Rijsbosch 1971; Shapiro et al. 1973; Sherk and Nicholson 1970; Sherk 1975, 1978; Shrago 1973; von Torklus and Gehle 1970). White and Panjabi (1978) discussed in detail which ways the bending stresses in the posterior arch of the atlas could arise during extension of the head. Fractures of the posterior arch of the atlas combined with bilateral fractures of the neural arch of the axis were considered due to hyperextension of the head by Saternus et al. (1978).

Several cases in this material showed fractures of the posterior arch following extension of the head. In most cases there were also fractures of the odontoid process of the axis. Although it may be argued that victims lacking fracture of the odontoid process are more prone to survive the accident and thus appear in studies based on clinical cases it seems most probable to suppose that tilting-dislocation of the odontoid process in a posterior direction considerably increases the risk of the posterior arch of the atlas being fractured. This is due to the fact that the anterior arch of the atlas is fixed to the odontoid process and thus the atlas accompanies the odontoid process in its posterior tilting-dislocation. As the posterior arch of the atlas is pressed against the upper surface of the neural arch-spinal process of the axis, bending stresses arise, causing fractures of the posterior arch, usually its lateral parts.

The third fracture mechanism suggested by Jefferson in 1920 and in 1927 is the suggestion that extension of the head can cause fracture(s) of the anterior arch of the atlas due to pressure against the odontoid process of the axis. No such case has been found in the present material. This finding supports the opinion that a sufficient pressure of the anterior arch of the atlas against the odontoid process usually results in fracture of the odontoid process (Hatchette 1941).

Another interesting observation that can be made from this material relates to the genesis of the avulsion fractures of the inferior margin of the anterior arch of the atlas. These fractures are probably identical with the horizontal fractures of the anterior arch described by von Torklus and Gehle (1970) and Stewart et al. (1977). These authors suggested that they arose during hyperextension of the head and were caused by the anterior border of a fractured odontoid process or the anterior longitudinal ligament and anterior atlanto-axial membrane (von Torklus and Gehle 1970), the odontoid process or the superior oblique portion of the longus colli muscles and the anterior longitudinal ligament

(Stewart et al. 1977). Our findings support the opinion that these fractures are caused by traction from the ligaments and muscles attached to the lower margin of the anterior arch but also indicate that they usually arise during oblique movements of the head, in most cases lateral tilting but sometimes oblique flexion, combined with anterior dislocation of the atlas in relation to the axis. Thus, these fractures seem usually to be due to oblique traction and not traction in a vertical plane.

Finally, the findings in this study indicate that flexion or extension of the head without rotation above all causes fractures in the lateral parts of the posterior arch of the atlas (the grooves for the vertebral arteries), while movements of the head in oblique directions usually result in fractures in other parts of the atlas ring and/or fractures of the posterior arch of different appearances. In this context it is worth mentioning that Schmitt and Gladisch (1977) have published a case with multiple fractures of the atlas considered due to a whip-lash mechanism in oblique direction.

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