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Fractures of the Neural Arch and Odontoid Process of the Axis: A Study of Their Causation

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Summary. The anatomical findings in 43 cases with fractures of the neural arch or odontoid process of the axis have been correlated to the reconstructions of the course of events in the accidents. Bilateral fractures of the neural arch anterior to the inferior apophyseal joints were the result of a violent anteroflexion of the head. Simultaneous traction or compression of the cervical spine were possibly of contributing importance. Considerable non symmetrical fractures of the neural arch were due to oblique anteroflexion of the head combined with traction of the cervical spine. Trauma against the posterior part of the neck resulted in fractures of the neural arch posterior to the inferior apophyseal joints. The fractures of the odontoid process were the result of a violent anteroflexion or retroflexion of the head. Simultaneous compression of the cervical spine and rotation of the head were possibly of contributing importance in some cases.

Key words: Axis fractures – Hangman's fractures – Fractures of the odontoid process of the axis.

Zusammenfassung. Die anatomischen Befunde bei 43 Fällen mit Bogen- oder Densfrakturen des Epistropheus wurden mit den Untersuchungsergebnissen bei der Rekonstruktion der Unfälle korreliert. Bilaterale Bogenfrakturen vor den unteren apophysären Gelenken waren das Resultat einer gewaltsamen Anteroflexion des Kopfes. Gleichzeitige Traktion oder Kompression der Halswirbelsäule trugen möglicherweise zum Entstehen der Fraktur bei. Wenn derartige Frakturen nicht symmetrisch auf beiden Seiten des Bogens verliefen, lag eine schräge Anteroflexion des Kopfes zusammen mit einer Traktion der Halswirbelsäule vor. Ein Trauma gegen die Rückseite des Halses kann zu Bogenfrakturen hinter den unteren apophysären Gelenken führen. Densfrakturen können infolge gewaltsamer Antero- oder Retroflexion des Kopfes auftreten. In einigen Fällen war vermutlich eine gleichzeitige Kompression der Halswirbelsäule und eine Rotation des Kopfes von beitragender Bedeutung.

Schlüsselwörter: Bogenfrakturen, Ursachen – Dens-Epistropheus-Frakturen, Ursachen – Unfall, Bogen- und Dens-Epistropheusfrakturen.

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Despite many articles about fractures of the odontoid process and neural arch of the axis, knowledge of the cause of these fractures still can be considered incomplete. This is true principally because there has been a lack of exact analysis of the deformation of the cervical spine which leads to the fractures. In the present study a thorough post mortem investigation of the cervical spine has been performed in a series of accident victims. By correlating the anatomical findings with the result of the reconstruction of the course of events of the accident, the deformation of the cervical spine which caused the fracture of the axis usually could be determined.

Material and Method

Approximately 250 fatalities due to accidental blunt trauma have been investigated. After the thoroughly performed autopsies the posterior part of the base of the skull together with the cervical spine and the surrounding soft tissues (muscles etc.) were removed in one piece. Most of the preparation were sawn in the medial sagittal plane (after freezing at -20°C). After thawing, tests for abnormal mobility in any part of the cervical spine were performed, the soft tissues were investigated carefully and finally the specimens were macerated in warm tap water (60°C) allowing the soft tissues easily to be removed. This procedure resulted in identification of 20 cases of fractures of the neural arch and 23 cases of fractures of the odontoid process which form the the basis for this paper.

In all cases a reconstruction of the course of events in the accidents was performed. In most of the cases in which the fractures of the axis had occurred in automobile occupants a dummy was placed in the automobiles to study the deformation of the victim's body in the so-called second collision (impact of car occupant against the interior of the car).

Results

1. Bilateral Fractures of the Neural Arch Anterior to the Inferior Apophyseal Joints

These cases were divided into 4 groups according to the localization of the traumatized area on the body.

1.1. Trauma to the Inferior Part of the Face (12 Cases). In all cases the victims where automobile occupants who sustained straight or oblique head-on collisions and – according to the external injuries and the result of the reconstruction of the events in the accidents – were hit at the inferior part of the face from anteriorly-inferiorly by parts of the car interior displaced in posterior-superior direction (steering assembly, instrument panel, upward bent motor hood etc). In all cases the victim's body had been lifted superiorly by the facial impact or his trunk had been thrown inferiorly.

The fractures of the neural arch usually ran through the posterior part of the superior joint surfaces and the foramen transversarium. The fracture surfaces usually fitted well together in their superior parts but less well in their inferior parts, where small bone fragments often were present.

In 8 cases there were hemorrhages in the dorsal neck muscles at the level of the atlas and axis; tearings of the ligamentum flavum between the axis and C 3 and lacerations or hemorrhages in the intervertebral disc between the axis and C 3 always including, and sometimes restricted to, the dorsal part (Fig. 1). Due to the shape of the fractures and the soft tissue lacerations, the odontoid process and the corpus of the axis easily could be bent forward (anteroflexed) indicating that the fractures of the neural arch resulted from an anteroflexion of the head (Fig. 2).

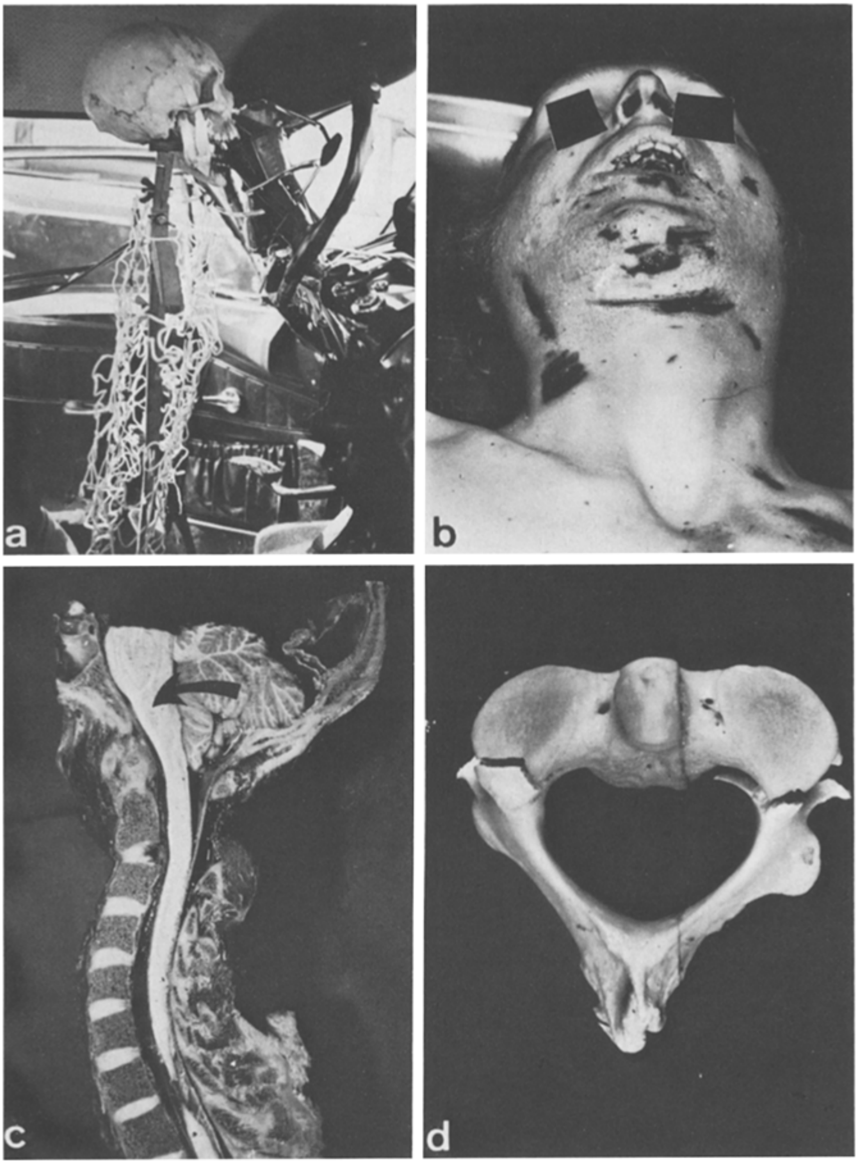

Fig. 1 a–d. Hangman's fracture due to anteroflexion of the head and longitudinal traction of the cervical spine in a driver of a head-on colliding car. **a** Reconstruction of the second collision. **b** Facial injuries. **c** Injuries to the cervical spine. **d** Fractures of the axis

In the remaining 4 cases the soft tissue connections between the body of the axis and C 3 and around the fractures were lacerated extensively but considering the external injuries, the reconstructions of the events in the accidents and the appearance of the fracture surfaces, it appears that the fractures were caused by the same mechanism, as the above-mentioned 8 fractures.

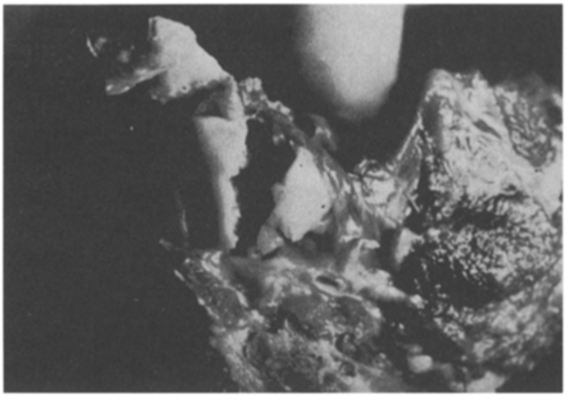

Fig. 2. Hangman's fracture due to anteroflexion of the head. Note the fracture gaping superiorly

Thus, the findings in all 12 cases indicate that the fractures of the neural arch resulted from an anteroflexion of the head. This movement was caused by the inertia of the head and/or by anteriorly directed throwing of the trunk and neck in relation to the impacting lower part of the face. Furthermore, in all cases a stretching of the cervical spine took place.

1.2. Trauma to the Anterior Side of the Neck (1 Case). In a head-on collision a front seat passenger wearing a shoulder belt had been thrown downwards and forwards under the belt (submarining) and his neck had been caught by the belt. There was a transection of the base of the epiglottis 1 cm superior to the vocal cords with extensive hemorrhage in the surrounding tissues.

In addition to the fractures of the neural arch, lacerations in the ventral and dorsal parts of the intervertebral disc between the axis and C 3 were found. The anterior and posterior longitudinal ligaments were disrupted. There were hemorrhages in the dorsal neck muscles at the level of the atlas and axis and the ligamentum flavum was torn between the axis and C 3 and between C 3 and C 4. The odontoid process and the body of the axis could be anteroflexed due to the soft tissue lacerations around the fractures. Obviously, the fractures of the neural arch resulted from an anteroflexion of the head but a stretching of the cervical spine also took place.

1.3. Trauma Against the Posterior of the Head (3 Cases). A driver of a car which sustained a rear-end collision was thrown backwards and the posterior of her head impacted upon the lower frame of the rear window due to which her chin impressed the superior part of the sternum.

The posterior neck muscles between the base of the skull and the axis showed extensive hemorrhages and there was a small laceration of the dura mater spinalis dorsally at the level of the atlas.

The impact to the posterior of her head obviously resulted in a violent anteroflexion of the head, causing the fractures of the neural arch, while the trunk – because of its inertia – was thrown in a cranial direction, causing compression of the cervical spine.

A pedestrian and a bicyclist struck from behind by cars suffered extensive injuries to the soft tissue in the superior part of the neck. Therefore, the post mortem movement tests were not conclusive regarding the deformation of the cervical spine causing the fractures of the neural arch of the axis. Taking into consideration the external injuries and the probable course of events in the accidents, the fractures of the neural arch in these two cases seem to have been caused in the same way as in the case of the driver.

1.4. Trauma Against the Feet-buttocks (1 Case). This victim jumped from a height (about 60 feet) landing on his feet and bottocks. He has no lacerations or hematomas of the head.

In addition to the fractures of the neural arch, the inferior part of the body of the axis was crushed. The posterior longitudinal ligament was ruptured at the posterior surface of the body of the axis slightly below the base of the odontoid process but the anterior longitudinal ligament was intact. The posterior neck muscles showed extensive hemorrhages. The odontoid process together with the remaining part of the body of the axis could be anteroflexed. The findings indicate an anteroflexion of the head and a compression of the cervical spine on the anterior side.

2. Bilateral Fractures of the Neural Arch Posterior to the Inferior Apophyseal Joints (1 Case)

The victim had jumped from a height (about 30 feet) hitting the ground with the posterior part of the vertex of her head somewhat to the right of the midline, causing skull fractures and cerebral contusions. However, there was also trauma against the posterior part of the neck somewhat to the right of the midline, causing fractures of C 4 due to pressure against the posterior part of the arch in anterior direction.

The bilateral fractures of the neural arch were incomplete, gaping in the superior part and situated immediately posterior to the inferior apophyseal joints. There were extensive hemorrhages in the posterior neck muscles between the posterior arch of the atlas and the neural arch of the axis. The posterior part of the arch of the axis could be bent inferiorly.

The findings indicate that an anteroflexion of the head had occurred but there were also signs of considerable trauma against the posterior side of the neck.

3. Considerable Non Symmetrical Fractures of the Neural Arch (2 Cases)

The driver of one car and the front seat passenger of another car colliding head-on were hit at the lower part of their faces from anteriorly-inferiorly by the upwards displaced steering wheel and the upwards and backwards bent motor hood respectively.

On the left half of the neural arch the fracture in both cases ran transversely through the posterior part of the upper joint surface and the foramen transversarium. On the right half of the neural arch the fracture in one case ran from the interior joint surface postero-superiorly, in the other case from a point immediately anterior to the inferior joint surface postero-superiorly. In one case there was also a small incomplete fracture running from the above-mentioned fracture on the right half of the neural arch posteriorly on the inner surface.

The soft tissue connections in the upper part of the neck were lacerated extensively, making conclusions concerning the genesis of the fractures based on study of the soft tissue damages impossible. However, in analogy with the cases showing fractures of the neural arch anterior to the inferior apophyseal joints it is reasonable to suppose that anteroflexion of the head caused the injuries to the axis, and that traction of the neck also took place. Moreover, the findings of the facial injuries located towards the left side in one case and of the incomplete fracture of the neural arch in the other case indicate that the anteroflexion of the head did not take place in the sagittal plane but obliquely.

4. Fractures of the Odontoid Process

These cases were divided into 3 groups depending on the localization of the traumatized area on the head.

4.1. Trauma to the Inferior Part of the Face (12 Cases). In all 12 cases the victims were automobile occupants who sustained straigth or oblique head-on collisions. The inferior parts of their faces had impacted against the interior of the car (9 cases), against part of another vehicle which intruded into the compartment of the car (1 case) or against that part of the bodywork situated in front of the windshield of the car (2 cases). According to the results of the reconstruction of the second collision the victims in this group had not been elevated nor was the trunk thrown downwards to any great extent after the face hit the interior of the car.

In 11 cases, the fracture fragment of the axis included the odontoid process and the superior part of its body along with medial parts of the superior joint sockets while in one case the fracture fragment was restricted to the odontoid process. The fractures ran in an approximately horizontal plane in 3 cases and in 9 cases obliquely anteriorly and inferiorly. The fracture surfaces usually fitted well together in the posterior part and less well in the anterior part where small bone fragments often were present.

In all 12 cases there were hemorrhages (and in 4 cases also lacerations) in the dorsal neck muscles at the level of the atlas and the axis, and in most cases the soft tissues on the anterior side of the axis were slightly detached inferior to the fracture. In 9 cases the posterior longitudinal ligament was lacerated at the level of the fracture and in 2 of these cases there also was a laceration of the anterior longitudinal ligament at the level of the fracture, probably caused by incision by fracture fragments. Because of the injuries to the ligaments in these 2 cases the odontoid process could be moved both anteriorly and posteriorly, while in the remaining 10 cases it could be tilted and somewhat dislocated only in the anterior direction (Fig. 3). In only one case were small hemorrhages seen in the dorsal neck muscles at the level of the axis and C 3. In no case was the disc between axis and C 3 injured or the ligamentum flavum disrupted at the level of the axis and C 3.

Thus, the findings indicate that the fractures in this group were caused by an anteroflexion of the head and that no considerable traction of the cervical spine took place.

4.2. Trauma to the Posterior Part of the Head (5 Cases). Four cases were occupants in cars struck from the right side by other cars, sustaining oblique head-on collision or overturning. All four victims were hit at the posterior part of the vertex of the head somewhat to the right side. In the fifth case a front seat passenger wearing combined

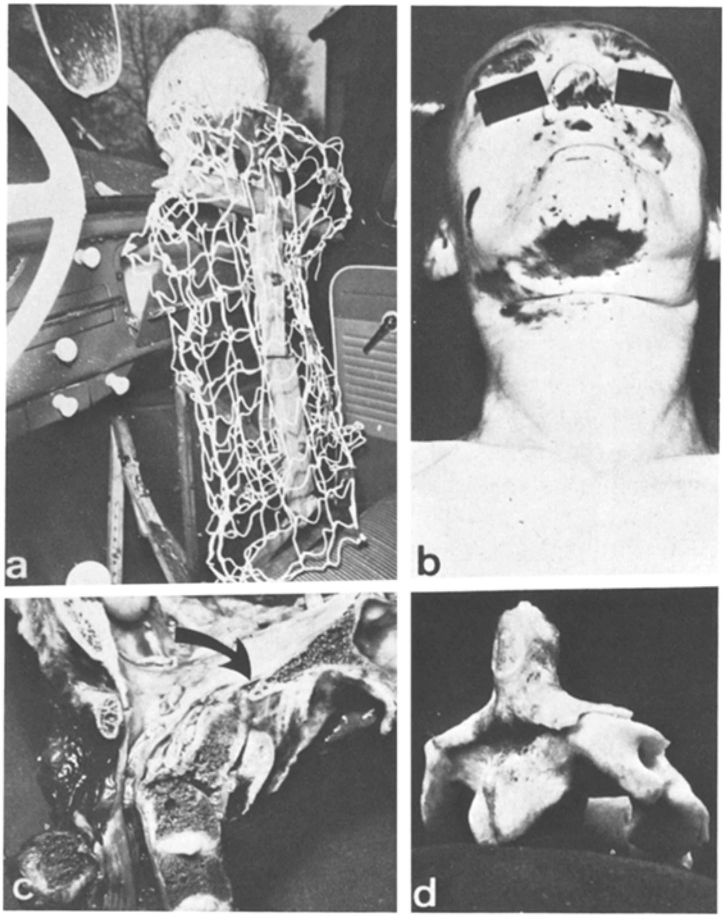

Fig. 3 a–d. Fractures of the odontoid process due to anteroflexion of the head in a front seat passenger of a head-on colliding car. **a** Reconstruction of the second collision. **b** Facial injuries. **c** Injuries to the cervical spine. Small fracture fragment anteriorly. **d** Fracture of the odontoid process. The small fragment at the anterior part of the fracture has been removed

lap-shoulder belts in a head-on collision was hit from behind by a non-belted rear seat passenger. She sustained fractures of the larynx, probably caused by impact of the anterior side of the neck against the superior border of the instrument panel.

In all cases the odontoid process together with a superior part of the body of the axis were broken off and in one case the fracture extended deeply into the central part of the body of the axis. The fracture surfaces usually fitted well together in the posterior part and less well in the anterior part, where small bone fragments were present. In the 4 cases mentioned first the fractures ran in an anterior-inferior direction extending more inferiorly on the left than on the right side and in one case there was also an oblique incomplete fracture on the anterior side of the odontoid process running in a right-inferior direction. Another case had an incomplete fracture on the inferior side of the neural arch of the axis near the midline.

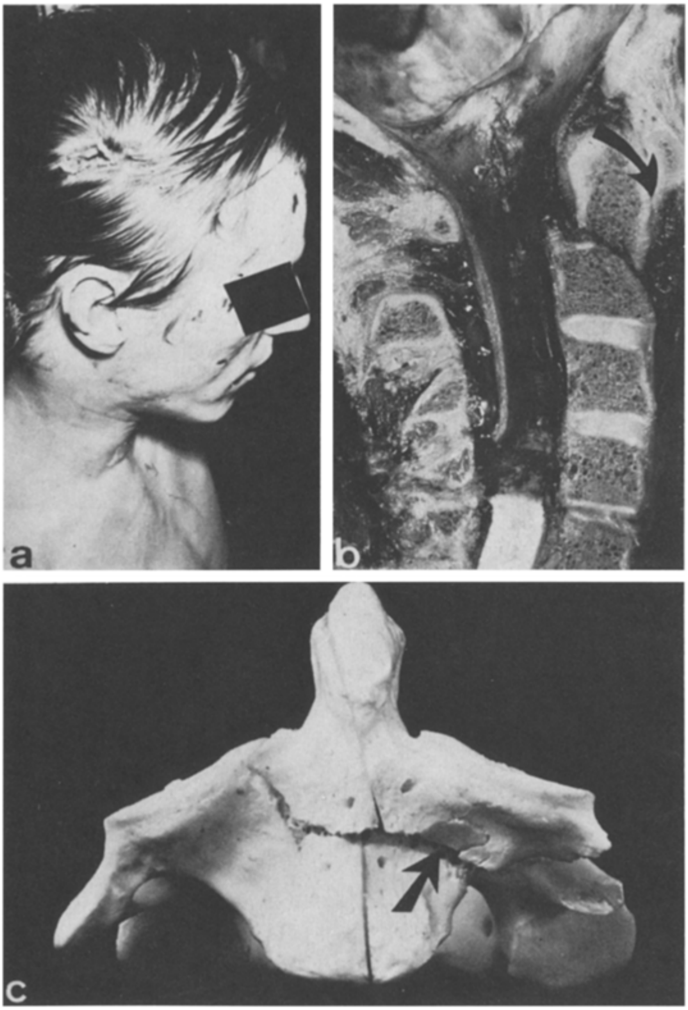

Fig. 4 a–c. Fracture of the odontoid process due to laterally directed anteroflexion and compression of the cervical spine in the driver of an overturning car. **a** Skin laceration at the right side of the vertex indicating the localization of the impact. **b** Injuries to the cervical spine. **c** The fracture of the odontoid process. Note the course of the fracture and the tilted bone fragment (arrow) indicating compression on the left side of the anterior part of the axis

In 4 cases lacerations of the posterior longitudinal ligament at the level of the fractures were present and in one of the cases the anterior longitudinal ligament was ruptured at the level of the fracture. In all 5 cases there were hemorrhages in the dorsal neck muscles at the level of the atlas and the axis. The odontoid process could be bent anteriorly in all cases and in the 4 cases mentioned first also somewhat to the left (Fig. 4). In one case the right inferior joint surface of the atlas showed an anteriorly situated impression fracture obviously due to an impression by the right superior joint surface of the axis.

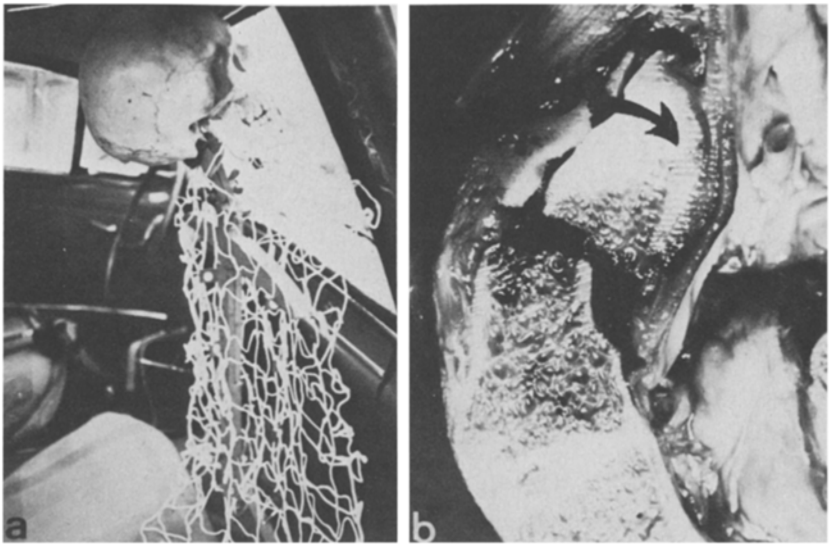

Fig. 5 a–b. Fracture of the odontoid process due to retroflexion and compression of the cervical spine in a front-seat passenger of a head-on colliding car. **a** Reconstruction of the second collision. **b** Fracture of the axis. Note avulsion of the soft tissues from the posterior surface of the body of the axis inferior to the fracture

Thus, the findings indicate that the fractures of the odontoid process of the axis were a consequence of an anteroflexion of the head, in 4 cases also somewhat to the left. These last-mentioned 4 cases had also suffered, according to the reconstruction of the events in the accident, a compression of the cervical spine.

4.3. Trauma to the Forehead (6 Cases). In 4 cases the forehead of drivers or front seat passengers in cars sustaining head-on collisions had impacted against the upper frame of the windshield (3 cases) or windshield (1 case). In 2 cases the victims fell (from height, downstairs), landing on their foreheads. No case showed skull fractures.

The fractures of the odontoid processes ran posteriorly-inferiorly in 4 cases, approximately in the horizontal plane in 2 cases. The level of the fractures varied; in one case it was superior to the base of the odontoid process and in the remaining 5 cases the fractures continued into the body of the axis. The fracture surfaces usually fitted well together in the anterior part and less well in the posterior part where small bone fragments sometimes were present.

In all 6 cases the anterior longitudinal ligament was intact and the posterior longitudinal ligament was detached from the dorsal side of the body of the axis inferior to the fracture but was not disrupted. The odontoid process could be tilted in a posterior direction (Fig. 5).

In 3 of the cases there were bilateral transversely running fractures of the posterior arch of the atlas. In one of these cases there was also avulsion of a bone fragment from the anterior margin of the foramen magnum and in another case also a fracture of the anterior arch and an impression in the posterior arch of the atlas obviously due to contact with the superior surface of the posterior part of the axis. In one case there was an impression of the right upper joint surface of the axis.

The findings thus indicate that the fractures of the odontoid process were the result of a retroflexion of the head (hyperextension) but that a compression of the cervical spine also had occured.

Discussion

Most earlier studies on the genesis of fractures of the odontoid process and neural arch of the axis have been based on investigations of surviving victims. The appearance of the fractures as observed by X-ray have been correlated with the external injuries and sometimes with available information concerning the course of events in the accident. One objection to this approach is that the dislocations of bone fragments shown by X-ray may differ from that which occurred when the fracture arose. Also, injuries to the soft tissues surrounding the fracture are shown incompletely by X-ray. In addition, it may be difficult to decide which of several external injuries was the essential one in the genesis of the fracture of the axis.

The method used here to study the genesis of fractures of the axis is a correlation of: (1) the injuries to the soft tissues – especially when not too severe – near the fracture, (2) the shape of the fracture surfaces after the bones have been cleaned by maceration, (3) the results of reconstruction of the course of the events in the accident. No study of this kind which has paid special attention to fractures of the axis has been found in the literature available.

1. Bilateral Fractures of the Neural Arch Anterior to the Inferior Apophyseal Joints

Fractures of the neural arch of the axis anterior to the inferior apophyseal joints ("hangman's fracture") are known to have been sustained in execution by hanging if the victim fell some distance before the rope tightened around the neck (the long drop) and if the knot of the noose was placed under the chin (submental knot). (For survey see Schneider et al., 1965). However, this type of fracture is also well known to occur in accident victims (Brashear et al., 1975; Böhler, 1967, 1971; Cornish, 1968; Daum and Archer, 1977; DeLorme, 1967; Elliott et al., 1972; Marar, 1975; Maurice-Williams, 1973; Portnoy et al., 1971; Rogers, 1974; Schneider et al., 1965; Seljeskog and Chou, 1976; Shapiro et al., 1973; Sherk, 1975; Taylor et al., 1976; Termansen, 1974; Williams; 1975).

Hangman's fracture is usually considered to be a consequence of violent retroflexion of the head (Brashear et al., 1975; Böhler, 1967; 1971; Cornish, 1968; Daum and Archer, 1977; DeLorme, 1967; Elliott et al., 1972; Marar, 1975; Portnoy et al., 1971; Rogers, 1974; Ruge, 1969; Schneider et al., 1965; Seljeskog and Chou, 1976; Sherk, 1975; Termansen, 1974; Williams, 1975). However, it has been claimed that the fracture also may be due to anteroflexion of the head (Balau and Hupfauer, 1974; DeLorme, 1967; Maurice-Williams, 1973, Taylor et al., 1976; Termansen, 1974).

When summing up the cases with fractures of the neural arch of the axis in this material it is evident that, (1) in those cases in which the soft tissues near the fractures were not completely lacerated, the soft tissue injuries allowed only anterior bending of the part of the axis situated anterior to the fracture. (2) The fracture surfaces usually fitted together well in the superior part indicating traction and less well in the inferior part where small bone fragments often were present, indicating compression in anterior-posterior direction. (3) In almost all cases there were lacerations of the intervertebral disc between C 2 and C 3 always including the dorsal part, and lacerations of the ligamentum flavum between axis and C 3, indicating longitudinal traction of the soft tissues in the posterior part of the neck at this level. (4) The reconstruction of the events in the accidents showed that in all cases an anteroflexion of the head could occur. Thus, the results indicate that the fracture in all cases reported here were due to a violent anteroflexion of the head. Because of the following reasons it can be supposed that anteroflexion of the head can cause bending stresses in the anterior part of the neural arch of the axis. According to Werne (1957) the range of anteroflexion in the occipito-atlantoid joint is small and limited by skeletal contact between the lower margin of the corpus of the occiput on one side and the tip of the odontoid process on the other side. Furthermore, the ligaments within the cervico-cranium (base of the skull, atlas and odontoid process – body of the axis) are very strong. In none of the cases in this material showing hangman's fracture have lacerations of these ligaments been found. The soft tissue connections between the posterior arch of the atlas and the axis have a greater physiological ability to stretch than has the soft tissue connections between the posterior parts of the axis and C 3. The apophyseal joints between the neural arch of the axis and the arch of C 3 are situated posterior to the isthmus of the neural arch of the axis, while the corresponding connection between atlas and axis is localized anteriorly to the isthmus. The inclination of the surfaces of the apophyseal joints between axis and C 3 inhibits an anterior dislocation of axis on C 3. Thus – provided that the odontoid process of the axis does not break – in violent anteroflexion in the superior part of the cervical spine the head carries the atlas and the anterior (but not the posterior) part of the axis with it, causing strains and stresses anterior to the inferior apophyseal joints. The genesis of hangman's fracture occuring in combination with fracture of the odontoid process mentioned by von Torklus (1970) and described by Daum and Archer (1977) but not seen in the present material has not been explained.

1.1. Anteroflexion in Combination with Longitudinal Cervical Traction. The reconstructions of the events in the accidents in our cases have revealed that a considerable simultaneous longitudinal strain (traction) probably occurred in the cervical spine in most of the cases with fractures anterior to the inferior apophyseal joints. This traction reasonably is responsible for extensive soft tissue lacerations around the fractures of the neural arch and between C 2 and C 3 as seen in several of our cases. DeLorme (1967), Marar (1975), Portnoy et al. (1971) and Williams (1975) mentioned traction of the cervical spine (in combination with hyperextension of the head) in the genesis of hangman's fracture. However, the ultimate importance of the traction in the genesis of these fractures has not been settled. It seems possible that the stretching of the neck inhibits the participation of the entire cervical spine in the anteroflexion of the head. This may increase the bending stresses in the upper part of the neck.

1.2. Anteroflexion in Combination with Longitudinal Cervical Compression. In some of the cases in this material with fractures anterior to the inferior apophyseal joints not only an anteroflexion of the head had taken place but also a compression of the cervical spine. It has been maintained that fractures of the neural arch of the axis arising in civilian accidents usually are due to hyperextension in combination with compression of the cervical spine (Brashear et al., 1975; Cornish, 1968; Termansen, 1974; Williams, 1975). This compression – because of the fact that the superior articular facets of the axis are localized anterior to the inferior ones – is considered to result in a shearing force on the neural arch (Brashear et al., 1975). Since in our cases the compression evidently was combined not with extension but anteroflexion of the head this explanation probably is not valid. Instead it seems possible that compression as well as traction, inhibits the participation of the middle and lower cervical spine in the anteroflexion movement of the head, increasing the strains and stresses in its upper part.

One case in the present material showed also a compression fracture of the inferior part of the body of the axis. Fielding has mentioned that neural-arch fractures of the axis may occur in flexion associated with a compression fracture of the body of the third vertebra. He suggested that when a longitudinal force is applied to a partially flexed cervical spine, collapse of the third cervical body effectively unload the anterior structures, shifting the force posteriorly to the facets. In our case the body of the second cervical vertebra collapsed in stead of that of the third, but the mechanism of the fractures of the neural arch of the axis reasonably is the same.

It is worth emphasizing that in the present material no case of hangman's fracture has been observed in which the injuries to the surrounding soft tissue and shape of the fracture fragments indicated that the fracture was due to a retroflexion of the head.

2. Bilateral Fractures of the Neural Arch Posterior to the Inferior Apophyseal Joints

Bilateral fractures of the neural arch posterior to the inferior apophyseal joints were seen only in one case in the present material. It is difficult to draw conclusions concerning the genesis of this type of injury on the basis of a single case. It seems reasonable to ascribe the fractures to the trauma against the posterior side of the neck, but an important role for anteroflexion of the head cannot be excluded.

3. Considerable Non Symmetrical Fractures of the Neural Arch

Recently a case has been observed of considerable non symmetrical fractures of the neural arch of the axis in hanging evidently caused by stretching of the neck and oblique anteroflexion of the head, that is, the stretching of the neck being most pronounced on one side (Sköld, 1978). The two cases of considerable non symmetrical fractures of the neural arch in this material probably had the same genesis. These non symmetrical fractures appear reasonably identical with the "horizontal fractures of the neural arch of the axis" mentioned by von Torklus (1970), who, however, did not discuss their genesis.

4. Fractures of the Odontoid Process

4.1. Anteroflexion of the Head. It is well known that anteroflexion of the head can cause fracture and anterior dislocation and/or tilting of the odontoid process of the axis (Blockey and Purser, 1956; Böhler, 1971; Hipp and Keyl, 1963; Ruge, 1969; Shapiro et al., 1973).

The results of the present investigation indicate that in several cases fracture of the odontoid process was due to anteroflexion of the head. This can be stated because (1) in all cases the injuries to the soft tissues near the fracture allowed anterior bending and in most cases did not allow posterior bending of the odontoid process. (2) The fracture surfaces usually fitted well together in the posterior part (indicating vertical traction) and less well in the anterior part where small bone fragments often were present (indicating vertical compression). (3) The reconstructions of the events in the accidents showed that in all cases a considerable anteroflexion of the head could have occurred.

4.1.1 Trauma Against the Posterior Part of the Head. In some of our cases the anteroflexion of the head causing fractures of the odontoid process was due to a trauma against the posterior part of the vertex of the head laterally to the midline. The fractures extended more inferiorly on the contralateral side in relation to the localization of the impact. Furthermore, in one case there was an oblique incomplete fracture on the anterior side of the odontoid process. These findings indicate that the trauma to the head had an anterior lateral direction causing not only an anteroflexion but probably also a rotation of the head around a vertical axis. Furthermore, the results of the reconstruction of the course of the events in the accidents indicate that a compression of the cervical spine also occurred, which may have been of importance in the genesis of the fractures, possibly by inhibiting anteroflexion of the middle and lower cervical spine.

In one of the cases observed here the posterior part of the head was hit straight from behind and thus no compression of the cervical spine took place. However, in this case the anterior part of the neck impacted against the instrument panel and it seems reasonable that the deceleration of the neck was of importance in the genesis of the fracture of the odontoid process. Taylor et al (1976) published a case of a car occupant who sustained a fracture through the upper part of the body of the axis with marked rotatory displacement and in which the shoulder belt impinged against the neck, which was considered a significant contributory factor.

The results of the present investigation show that trauma against the posterior part of the head from a superior-posterior direction resulting in a violent anteroflexion of the head, probably combined with a longitudinal compression of the cervical spine can cause fractures either of the odontoid process or of the neural arch of the axis. The exact details of the mechanisms resulting in different fracture types are not yet known. However, the findings may indicate that a laterally directed anteroflexion of the head promotes fractures of the odontoid process. Blockey and Purser (1956) and Hipp and Keyl (1963) mentioned rotation of the head in the genesis of the fractures of the odontoid process of the axis.

4.1.2 Trauma Against the Inferior Part of the Face. That anteroflexion of the head causing fracture of the odontoid process of the axis can be due also to trauma against the inferior part of the face has been pointed out by Blockey and Purser (1956) and Portnoy et al (1971).

In most cases in the present material with fractures of the odontoid process due to anteroflexion of the head, the anteroflexion was caused by the inertia of the head after impact of the inferior part of the face against parts of the car and the fractures probably arose in the way described by Portnoy et al (1971) ("the atlas and dens move with the flexing head while the body of the axis extends with the remainder of the cervical vertebrae"). In two of our cases the victims' faces had impacted against the part of the bodywork situated just in front of the windshield after the chest had been decelerated by the panel. This means that a considerable anteroflexion of the head had occurred before the facial impact. It is probable that this trauma to the face was of essential importance of the genesis of the fractures in the way described by Portnoy et al (1971). This opinion is supported by an investigation concerning injuries of the cervical spine in belted car occupants (Sköld and Voigt, 1977).

The reconstructions of the events in the accidents showed that considerable traction of the cervical spine probably did not occur in these cases. Therefore, as to the localization of a possible fracture to the odontoid process or neural arch of the axis due to trauma to the lower part of the face, the degree of simultaneous traction of the cervical spine seems important. Thus, the angle of impact against the face may be essential for the type of axis fracture arising during violent anteroflexion of the head.

4.2 Retroflexion of the Head. It has been pointed out that retroflexion of the head can cause fractures and posterior dislocation and/or tilting of the odontoid process (Blockey and Purser, 1956; Böhler, 1967, 1971; Hipp and Keyl, 1963; Shapiro et al., 1973).

In some of the cases in this material the fractures of the odontoid process could be ascribed to a violent retroflexion of the head. This can be stated because (1) in all cases the injuries to the soft tissues near the fractures allowed the odontoid process to be bent in a posterior direction, (2) the fracture surfaces usually fitted well in the anterior part and less well in the posterior part where small bone fragments sometimes were present, and (3) the reconstructions of the events in the accidents showed that the trauma was directed from anterio-superiorly against the forehead.

Portnoy et al (1971) and Ruge (1969) maintained that a trauma against the face may fracture the odontoid process through the anterior arch of the atlas due to shearing effect. However, the bending fractures of the atlas observed in several of these cases in our material indicate that retroflexion of the head and not shearing effect was of greatest importance for the genesis of the fractures of the odontoid process.

In all our cases with fractures of the odontoid process due to trauma against the forehead or against the posterior of the head (except the case in which the anterior part of the neck impacted against the car interior) the findings indicated that a simultaneous longitudinal compression of the cervical spine had occurred. This compression may have been of importance in the genesis of the fractures in the way suggested above. The probable importance of compression of the cervical spine in the genesis of fractures of the odontoid process due to trauma to the upper part of the head has not been emphasized earlier in the literature available.

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