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THE ARTERIAL SUPPLY OF THE ODONTOID PROCESS OF THE AXIS

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A study has been carried out of the arterial supply of the odontoid process of the axis. Among the arterial sources there are paired anterior and posterior ascending arteries arising from the vertebral artery. Arteries penetrate into the odontoid process at its base from both the anterior and posterior ascending arteries. A transverse arterial arcade is formed above its top by the anastomosing anterior and posterior ascending arteries. In this investigation it was demonstrated that a branch of the ascending pharyngeal artery (from the external carotid artery) joined this arcade after passing through the canalis hypoglossi of the occipital condyle. Moreover, there were inferior and superior horizontal arteries apparently coming from the internal carotid artery, which supplied the odontoid process. It was shown that the superior horizontal arteries penetrated the anterior atlanto-occipital membrane and ran across to the supraodontoid arterial arcade. There were also arteries which reached into the odontoid process via the accessory and apical ligaments. Vessels described—but not demonstrated—to reach the odontoid process via the alar ligaments could not be observed in this investigation. It was shown that inside the odontoid process the arteries formed a rich anastomosing network. The odontoid process of the axis is thus in the centre of a dense arterial network.

Key words: odontoid process; arterial supply; paired ascending arteries; supraodontoid arterial arcade; intraosseous anastomotic arterial network

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The odontoid process has a stabilizing effect on the function of the atlanto-axial articulation. This stability is jeopardized in fractures of the odontoid process, but a delayed or failed bony union need not necessarily give rise to any symptoms. Schatzker et al. (1971) have reported a frequency of non-union (pseudarthrosis) in 64 per cent and Blockley & Purser (1956) in 63 per cent. Lower frequencies have been reported by Amyes & Anderson (1956) who found a rate of pseudarthrosis of 5 per cent which was also found by Böhler (1965). There are also reports (Nachemson 1960, Anderson & d'Alonzo 1974) with non-union frequencies of the order of 44 per cent and 26 per cent. The difference between the reported extremes of 64 per cent and 5 per cent appears to be due to the technique of examination which in the high frequency series includes tomography and radiography of the cervical spine in flexion-extension.

The reason for non-union has been debated (Nachemson 1960, Schatzker et al. 1971). It is argued that the vascular supply becomes disturbed to an extent that revascularization does not occur

satisfactorily. An impairment in healing follows. It has been suggested that in so-called low fractures, i.e., fractures through the base of the odontoid process, no vital vessels become injured and thus healing occurs uneventfully (Schatzker et al. 1971, Bailey 1974). In high fractures, however, the large vessels reaching the odontoid process via the accessory ligaments become injured and it has been postulated that this may impair circulation to such an extent that non-union of an odontoid fracture ensues. Moreover, the opinion has been advanced that the vascular supply to the odontoid process is so poor in general that odontoid fractures consequently heal badly (Schmorl 1971, Bailey 1974). The pertinent problem, therefore, seems to be to analyse in more detail the vascular arrangement of the odontoid and furthermore relate the observations to the most common localizations of odontoid fractures.

Therefore the aim of this investigation was:

1) to make a detailed study of the arteries surrounding, penetrating into and running in the odontoid process and
2) to produce experimental fractures and correlate the anatomy of arteries to the fractures obtained. This latter part of the investigation will be reported separately.

ANATOMY

Embryonal development

Between the twentieth and twenty-fourth foetal week two laterally situated ossification centres appear (Figure 1). These unite at birth. About 2 years later an ossification centre appears on top of the fused lateral centres (Figure 1). Between the odontoid process and the remaining axis there is a cartilage plate which becomes ossified between 10 and 20 years of age. In the individual case the cartilage plate may, however, remain into adulthood.

During the second decade there is a fusion of the apical ossification centre with the two lateral.

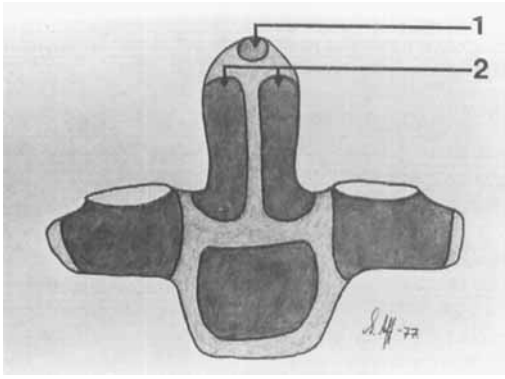

Figure 1. Embryonal development.
1. Apical ossification centre.
2. Lateral ossification centres.

Ligaments

The odontoid process is important for the stability of the atlanto-axial articulation. Its position in relation to the posterior facet of the anterior part of the atlas is secured by the strong transverse ligament running posterior to the odontoid. The accessory ligaments arise from the massa lateralis of the atlas and insert into the lateral aspect of the base of the odontoid process. The apical ligament arises from its tip and inserts into the anterior rim of the foramen magnum (Figure 2). There are two more ligaments—the alar— which arise posterolaterally from the odontoid and insert into the occipital condyles.

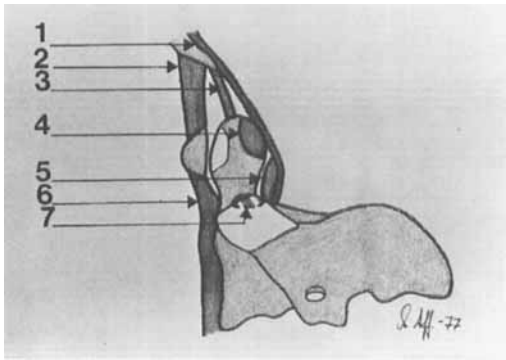

Figure 2. Ligaments around the odontoid process.
1. Tectorial membrane.
2. Anterior atlanto-occipital membrane.
3. Apical ligament.
4. Alar ligament.
5. Transverse ligament.
6. Anterior longitudinal ligament.
7. Accessory ligament.

The anterior atlanto-occipital membrane runs from the anterior lamina of the atlas to the base of the skull (Figure 2).

Main arteries in the odontoid region (Figure 3)

Adjacent to the odontoid process there are two main arteries, the internal carotid artery and the vertebral artery. The internal carotid artery runs anterolaterally in a cephalad direction and enters the skull through the canalis caroticus. The vertebral artery passes through the foramina transversaria of the cervical vertebrae and curves over the posterior lamina of the atlas. It then continues into the skull through the foramen magnum.

Close to the internal carotid artery there is the ascending pharyngeal artery, a branch of the external carotid artery.

Arteries to the odontoid process

Review of the literature. Only a few publications have been presented on the vascular supply of the odontoid process and there is a lack of uniformity in the descriptions. Schatzker et al. (1971, 1975) described two main vascular sources. One was derived from so-called central arteries which entered the odontoid at its base and then ran in a cephalad direction inside its body. The other source was described in a schematic drawing showing arteries which from the massa lateralis of the atlas reached the odontoid via the accessory ligaments. Moreover, it was suggested that vascular connections existed at the insertions of the alar and apical ligaments. In the illustrations it is not conclusively demonstrated that these arteries actually penetrate into the odontoid process. Arteries were demonstrated within the odontoid process but "it was impossible to show with certainty what areas of the dens were supplied by these vessels (through the apical and alar ligaments) or whether any anastomoses existed between the vessels which entered the dens through the apical and alar ligaments and the central and peripheral arteries" (Schatzker et al. 1971).

Schiff & Parke (1973) demonstrated a regular vascular pattern *around* the odontoid. Three main groups of vessels were described:

1) anterior ascending arteries,
2) posterior ascending arteries and
3) cleft perforators (horizontal arteries).

The latter arose from the internal carotid artery and anastomosed with the anterior ascending arteries at the odontoid base. The anterior and posterior ascending arteries which appeared in pairs arose from the vertebral artery. These arteries assembled in a vascular arcade on the top of the odontoid. The anterior ascending arteries gave branches to the anterior aspect of the vertebral body of the axis, to the base of the odontoid process and to its anterolateral surface. The posterior ascending arteries gave branches to the posterior aspect of the vertebral body of the axis. Further, Schiff & Parke (1973) described small holes on the surface of the odontoid and concluded that these were places of entrance for the arteries. No arteries were demonstrated within the odontoid process.

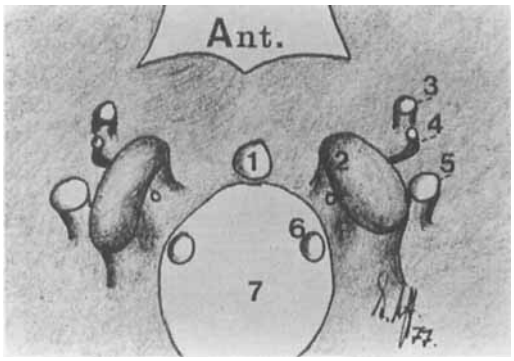

Figure 3. Main vessels just below the skull base in relation to the odontoid process and occipital condyles. Seen from below and posteriorly.

1. *Odontoid process.*
2. *Occipital condyle.*
3. *Internal carotid artery.*
4. *Ascending pharyngeal artery.*
5. *Internal jugular vein.*
6. *Vertebral artery.*
7. *Foramen magnum.*

MATERIAL AND METHODS

The material for this investigation consisted of six human cadaver cervical columns. The individuals had died from causes not related to disease in the vascular system. Their ages were 62, 65, 67, 67, 70, 76 years, respectively. There were two women and four men. All specimens were injected *in situ* with a contrast medium intra-arterially. On excision the specimen contained the cervical column with the base of the skull.

The contrast medium consisted of a mixture of two parts 10 per cent formaldehyde and one part Micropaque. The injections were given according to Mulfinger & Trueta (1970) 36–48 hours following death. Mulfinger & Trueta (1970) demonstrated that by injecting vessels 36–48 hours post-mortem—during which time the capillary bed is destroyed by autolysis—the contrast medium does not pass over to the veins.

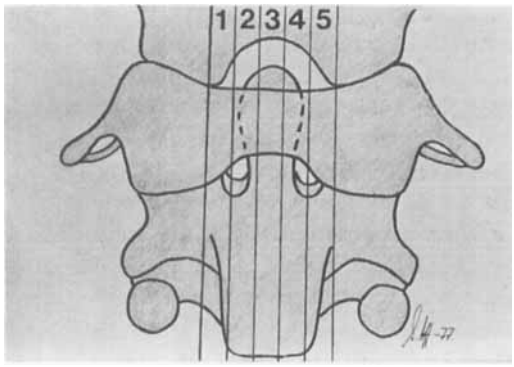

Figure 4 a. Longitudinal in sagittal plane.

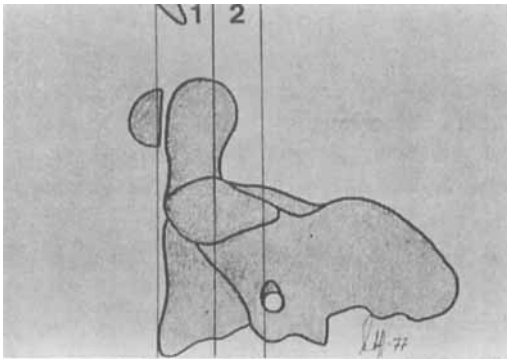

Figure 4 b. Longitudinal in frontal plane.

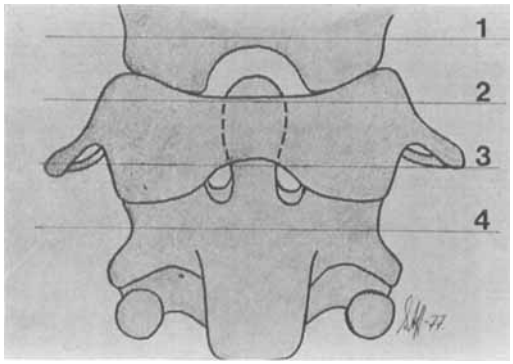

Figure 4 c. Transverse in horizontal plane.

Figure 4. Sections of axis used for preparation according to the Spalteholtz method.

The contrast medium was injected into the common carotid artery and/or the vertebral artery. Three specimens were injected in both common carotid arteries and both vertebral arteries via four parallel coupled catheters. One specimen was filled through one common carotid artery only and two through one common carotid artery and one ipsilateral vertebral artery. The injection was stopped when the white contrast medium was seen to appear either in the intercostal arteries or when the skin blanched. The filling pressure was that of manual compression of a 10 cm^3 injection syringe. The filling procedure lasted for some 30 minutes. All arteries through which contrast medium leaked were tied. Following the filling procedure the cervical column and part of the base of the skull were excised and some contrast medium was seen to disappear from the carotid and vertebral arteries before it had adhered to the vessel walls.

The specimens were frozen and once hardened by the freezing procedure they were cut in longitudinal sections in both the sagittal and frontal planes (Figure 4 a, b). Horizontal sections (Figure 4 c) were also made. Each individual section was then x-rayed. A particular soft tissue technique also used for mammography was employed (Mammodiagnost, Philips). Film-focal distance 30–35 cm: exposure 25 kV, 0.2–1 s. Kodak film (Industrex C®) was used.

Following radiography the sections were prepared according to the Spalteholtz technique (Spalteholtz 1914) by which they were made translucent. This technique permits a three-dimensional study of the course of the arteries.

Once prepared by the Spalteholz technique the specimens were x-rayed a second time. More information regarding the distribution of the arteries was thus obtained as the Spalteholtz technique involves decalcification which makes the arteries stand out more clearly.

RESULTS

In this investigation previous observations that the odontoid process receives its arterial supply via a system of longitudinal (ascending) and horizontal arteries could be confirmed. The paired anterior and posterior ascending arteries arose from the vertebral artery. The paired horizontal arteries apparently came from the internal carotid artery. In this investigation difficulties arose in exactly verifying the origin of the horizontal arteries as the contrast medium in most specimens had disappeared during the excision but the contrast medium covered the wall of the internal carotid artery in many instances and there was a direct connection between the wall and the horizontal arteries.

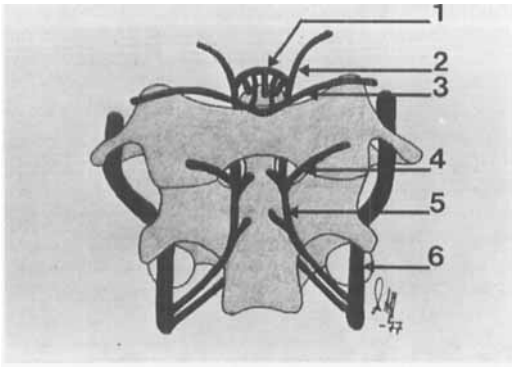

Figure 5. Anterior aspect of the atlas and axis with arteries.

1. *Apical arcade.*
2. *Posterior horizontal artery.*
3. *Superior anterior horizontal artery.*
4. *Inferior anterior horizontal artery.*
5. *Anterior ascending artery.*
6. *Vertebral artery.*

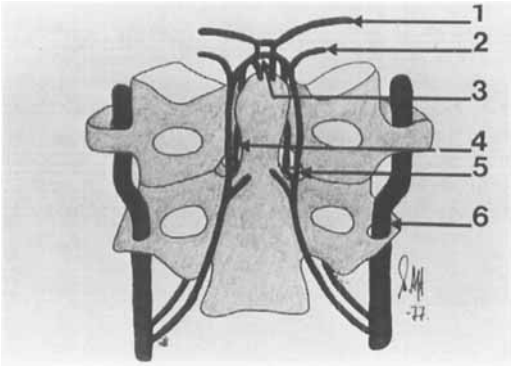

Figure 6. Posterior aspect of the body of the axis, odontoid process and massa lateralis of the atlas with the lamina of the atlas and axis cut.

1. *Superior anterior horizontal artery.*
2. *Posterior horizontal artery.*
3. *Apical arcade.*
4. *Anterior ascending artery.*
5. *Posterior ascending artery.*
6. *Vertebral artery.*

Paired anterior ascending arteries
(Figures 5, 7 and 10)

These arteries branched off from the vertebral arteries immediately caudal to the axis. Their course was cephaled on the anterolateral surface of the axis and near the base of the odontoid process each artery gave a branch which penetrated into the odontoid within which it then ran posteriorly and cephalad branching eventually into a network of fine arteries.

The anterior ascending arteries continued their course on the anterolateral surface of the odontoid and over the apex of this they joined and, anastomosing also with branches from the posterior ascending arteries, they here formed the apical arcade.

Paired posterior ascending arteries
(Figures 6, 7, 10 and 11).

The posterior ascending arteries branched off from the vertebral arteries at the same level as the anterior ascending arteries. The posterior ascending artery ran cephalad on the posterolateral surface of the axis giving off branches to the body of this vertebra. At the base of

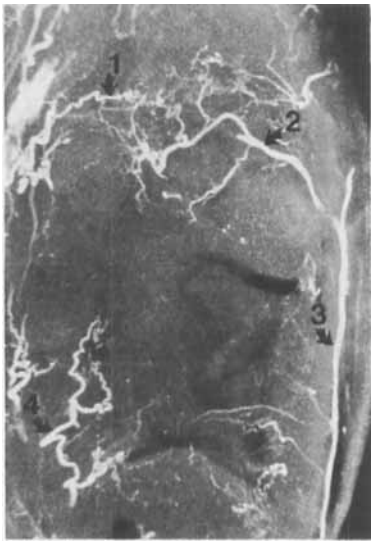

Figure 7. Sagittal section through the upper cervical spine. Radiograph of Spalteholtz preparation. (cf. Figure 4 a, no. 1, slice thickness 5 mm).

1. *Anastomosing artery between the superior anterior horizontal artery and the apical arcade.*
2. *Part of the apical arcade.*
3. *Posterior ascending artery.*
4. *Part of the anterior ascending artery.*

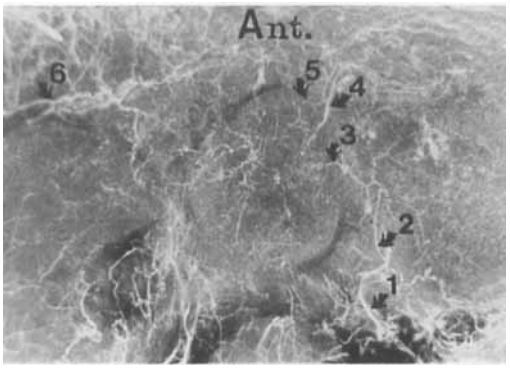

Figure 8. Horizontal section through the base of the odontoid process. Radiograph of Spalteholtz preparation. (cf. Figure 4 c, no. 3; slice thickness 12 mm). The odontoid process is in the centre of the picture. Seen from above and posteriorly.

1. *Posterior ascending artery.*
2. *Branch from the posterior ascending artery which runs along the accessory ligament to the lateral aspect of the odontoid base, where it*
3. *penetrates the bone and divides into an arterial network.*
4. *Anterior ascending artery.*
5. *An anterior artery penetrating into the odontoid process.*
6. *Inferior anterior horizontal artery.*

the odontoid process one branch turned off and slightly caudad to the transverse ligament it penetrated into the odontoid within which it then divided into a number of small branches. Each of the paired posterior ascending arteries also gave off one branch which ran along the accessory ligament to the insertions laterally on the base of the odontoid where it penetrated into the bone. The posterior ascending arteries continuing in a cephalad direction passed posterior to the alar ligaments on top of which they turned medially and anteriorly. Joining the apical arcade they contributed to the formation of a vascular network round the tip of the odontoid and the alar ligaments. There were thus anastomoses connecting all the four ascending arteries. From this apical network branches were given off which descended into the odontoid within which further divisions occurred.

In this investigation it proved impossible to demonstrate any vessels penetrating into the odontoid process within the circumscribed region of the insertion of the alar ligaments.

Anterior horizontal arteries
(Figures 5, 6, 7 and 8)

These vessels, two on each side, one inferior and one superior, ran horizontally on the anterior surface of the atlas. The inferior horizontal arteries anastomosed under the anterior lamina of the atlas with the ipsilateral anterior ascending artery. The superior horizontal arteries anastomosed with each other in the midline, and moreover, gave off branches which penetrated the atlanto-occipital membrane and established contact with the apical vascular network.

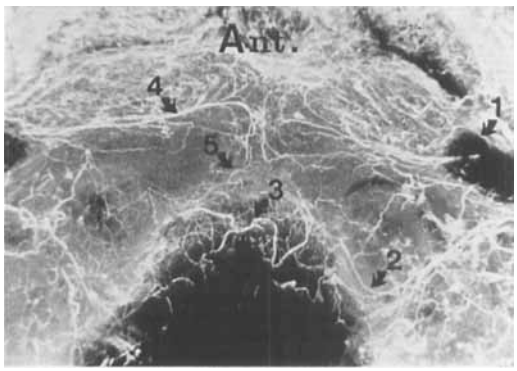

Figure 9. Horizontal section through the uppermost part of the cervical spine. Radiograph of Spalteholtz preparation. (cf. Figure 4 c, no. 1; slice thickness 12 mm). Seen from above and posteriorly.

1. *Internal carotid artery.*
2. *Posterior horizontal artery (branch from the ascending pharyngeal artery).*
3. *Apical arcade.*
4. *Superior anterior horizontal artery.*
5. *Anastomosing branch from the superior anterior horizontal artery and the supra-odontoid arteries.*
6. *Capsular artery.*

Posterior horizontal arteries
(Figures 5, 6 and 9)

These arteries branching off from the ascending pharyngeal artery and running horizontally through the canalis hypoglossi of the occipital condyle at the level of the foramen magnum turned anteriorly and downwards and reached the apex of the odontoid process where they linked up with the apical vascular network.

Intraosseous anastomoses
(Figures 8, 10 and 11)

The arteries entering the odontoid process at its base anastomosed inside the odontoid with those arteries entering the odontoid at its apex. The interior of the odontoid process was the site of a rich anastomotic network of arteries.

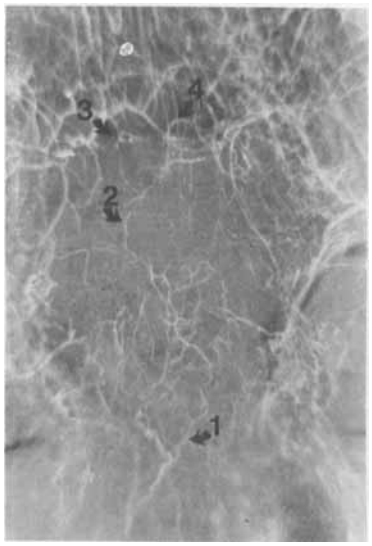

Figure 11. Frontal longitudinal section. Radiograph of Spalteholtz preparation. (cf. Figure 4 b, no. 1; slice thickness 10 mm).

1. *An anterior artery penetrating the base of the odontoid process dividing into a fine anastomosing network.*
2. *Anastomosing artery between the basal and apical arteries.*

3 and 4. Arteries penetrating the apex.

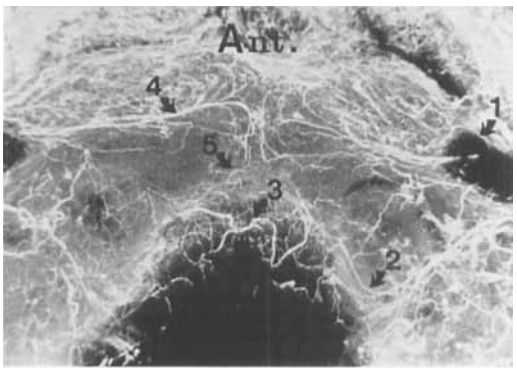

Figure 10. Sagittal section through the odontoid process. Radiograph of Spalteholtz preparation. (cf. Figure 4 a, no. 3, slice thickness 5 mm).

1. *Transverse section through the apical arcade.*
2. *Apical artery penetrating into the odontoid process.*
3. *An anterior artery penetrating the base of the odontoid process. Note the rich anastomosing network within the odontoid process and the anastomosing arteries between the apical and basal arteries.*

There were arteries running along with the accessory and apical ligaments penetrating into the odontoid process. No arteries could be seen to run into the bone from the interior of these ligaments. Vessels from the apical arcade ran along the alar ligament without penetrating the odontoid bone.

DISCUSSION

From this investigation it has thus become evident that the odontoid process is in the centre of a rich network of arteries. Arteries were seen to penetrate into the odontoid around its base and at its apex. Vascular connections were demonstrated between ligament and bone except in the case of the alar ligaments. No arteries could be observed to traverse into the odontoid at the insertions of these ligaments. The failure to demon-

strate this may simply be a matter of technique and be related to the contrast medium used. However, it should be mentioned that a good filling of arteries was present in the arteries around the ligament as well as in the intraosseous area bordering the zone where the ligament inserts. In the translucent specimens it was impossible to detect any arteries and random histologic sections have not revealed any signs of vascular supply in this special region of ligamentous attachment. On the other hand, vascular connections were observed between the inside of the odontoid process and the vessels running along the apical and accessory ligaments. In studies of the vascular supply between ligaments and bone it has previously been demonstrated (Moseley & Goldie 1963, Peterson et al. 1974, Björkström 1976, personal communication) that vascular connections exist and the present observations coincide with those made in previous investigations.

The arterial arcade above the odontoid process has previously been described to have its origin in the anterior and posterior ascending arteries. In this investigation, however, it was demonstrated that the arcade receives arterial branches from other sources as well, such as for example, the ascending pharyngeal artery, a branch of the external carotid artery and those arteries, apparently branches of the internal carotid artery, which penetrate the membrana atlantooccipitalis. Thus, the intraosseous arterial supply of the odontoid process is not entirely dependent on the anterior and posterior ascending arteries. This investigation has made clear that in cases of high odontoid fractures with or without interfragmentary dislocation the arterial supply need not necessarily be damaged to an extent that the superior part of the odontoid process looses its blood supply as there are sources other than the anterior and posterior ascending arteries. This problem is the subject of further study.

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