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1.Abstract
Cervical spinal column can anatomically be divided into two parts as upper and lower cervical spine. Upper cervical spine consists of the foramen magnum, paired occipital condyle, atlas and axis. C2 (axis) is the largest structure with its unique shape and function in the part of upper cervical spine. The pars interarticularis and the pedicle are differently located in axis in comparison with other cervical vertebrates. These two parts of the axis may be confused because of their unique anatomical localization. The pedicle of axis is the portion beneath the superior articulating facet and anteromedial to the transverse foramen. In the other hand, the pars interarticularis or isthmus of C2 is the narrower portion between the superior and inferior articulating facets. Fracture located at the pedicle of axis is extremely rare. The publications are still at the case presentation level. The presumed mechanism of injury is axial compression occurring in association with an asymmetrical lateral or rotatory component of the atlas on axis. Computerized tomography images with bone window and three-dimensional reconstruction are the gold standard in the neuroradiologicaldiagnosing and demontration of the fracture. There is no specific clinical symptom and finding for this fracture. The neck pain may probably be present and the only symptom in the patient with unilateral pedicle fracture. In the management of axis pedicle fracture, it is important to know the patient's age, the presence of neurological deficit, the association of additional fracture and ligament damage, and the presence of the criteria of instability. Isolated single-sided pedicle fractures are usually stabile fracture. There is no need for surgical treatment in such patients.

Key Words: C2 pedicle fractures, axis fractures, axis fracture classification, pedicle of axis.

2. Background

Regional cervical column fractures of the spine are frequently encountered pathological condition in the practice of neurosurgical traumatic emergency (1). The ratio of isolated axis fractures among the cervical spinal column fractures had been reported as 14-20% in the publishedliterature. The most common type is the odontoid process fractures(2-5). In the other hand, pedicle fractures of axis are very rare pathology and had uncommonlybeen reported in the medical literature (1, 2, 6, 7).

The upper cervical spine consists of the foramen magnum, paired occipital condyles, C1, and C2 (8, 9). This segment serves as a transitional zone between the rigid calvarium and the flexible lover cervical spine (8, 9). C2 is the largest structure with its unique shape and function in this part (10). It consists of a body, paired pedicles, lateral masses (superior articulating facets, pars interarticularis, and inferior articulating facets), lamina, and bifid spinous process (8, 9).

At birth, the odontoid is separated from the body of C2 by a cartilaginous band called the dentocentralsynchondrosis and the odontoid process projects from the level of this synchondrosis(10). The dentocentralsynchondrosis sits well below the level of the superior articulating facets. The body is the most inferior segment of the C2 vertebra. The superior border of this segment is formed by the dentocentralsynchondrosis. This line is also the inferior border of the odontoid. The lateral border is formed by the neurocentralsynchondrosis. The neural arches are hemistructures located bilaterally. They fuse posteriorly via the spinous process. This portion includes the pedicle, superior and inferior articulating facets, transverse foramen, pars interarticularis, lamina and spinous process. The C2 pedicle connects the neural arches to the base of the odontoid and the body of C2 via the ossification of the neurocentralsynchondrosis. The place of the C2 pedicle is more anteriorly located as compared with other vertebrates (10).

The odontoid process of C2 projects upward from the superior roof of the body, and makes it different from others (8, 9, 10). In embryological developmental stages, C2 forms from four bones separated by synchondrotic articulations and consisting of four ossifications centers (two of them are bilaterally located in the neural arches, one of them is located in the body, and one is located in the odontoid process). The borders of the odontoid process are well demarcated by these cartilaginous articulations during prenatal and postnatal development of C2. These cartilaginous articulations are named as dentocentral(separating odontoid from the body), and neurocentralsynchondrosis (separating odontoid and body from neural arches) (10, 11). Synchondroses among the neural arches, body, and odontoid process fuse at 3 to 6 years of ages. After the ages of 6 years, odontoid process fuses with the body and the neural arches. In the adult age, the remnant of dentocentralsynchondrosismay be imagined by magnetic resonance imaging technique as a hypointense ring between the inferior end of the odontoid and the superior roof of the body of C2. This sutructure is located in the cancellous bone, and should be accepted as the inferior border of the odontoid process in adults. The anatomical level of dentocentralsynchondrosis is well below from the superior articulating facets and the indentation of the transverse ligament onto the posterior aspect of the odontoid process.

The pedicle of vertebrae is a short segment that connects the dorsal elements with the body of the vertebrae (12, 13). It is important to know the exact location of the C2 pedicle. The pedicle of C2 vertebra is located medially beneath the superior facet and anteromedial to the transverse foramen (1). It is also important to clarify the location of the pars interarticularis and pedicle. Pars interarticularis or isthmus is the narrower portion between the superior and inferior facets. This portion is located posteromedial to the transverse foramen (14). In the clinical practice, the distinguishing of these two anatomical locations is extremely important in the correct description and diagnosing of the axis fractures.

3. Description of Upper Cervical Spine

Cervical spinal column anatomically can be divided two part as upper and lower cervical spine. Upper cervical spine consists of the foramen magnum, paired occipital condyles, atlas and axis. This part is more flexible in comparison with the lower cervical spine. Biomechanically the portion of the upper cervical spine may be described as transitional zone between rigid calvarium and flexible lower portion of cervical spine (C3-C7) (1, 5). Different and specific anatomic shape of occipital condyle, atlas and axis, and the ligamentous structures of this zone are responsible for elasticity and flexibility of this portion (5, 15). The second cervical vertebra is also named as axis. It is the largest vertebra of cervical spine (5, 15). The location, shape, anatomical and biomechanical characteristics of C2 makes it unique and different among the cervical spinal column vertebrates (5, 15).

4. Description of the Pedicle

The pars interarticularis and the pedicle are differently located in axis in comparison with other vertebrae. These two parts can be confused in the axis because of their unique anatomical localization. The pedicle is a specific segment of a vertebra that connects the posterior segments with the body. In thoracic and lumbar part of the vertebral column this segment is very clear. In the other hand, the portion located between the superior and inferior facets is named as pars interarticularis. This segment also named as isthmus of vertebrae (14). The location of pedicle is shown in Figure 1. In the axis, the superior articulating facet is located more anterior to the inferior articulating facet (12, 13, 14, 16). This unique anatomical difference of C2 makes confusion in the clinical practice in terms of diagnosing and nomenclature of axis pedicle fracture. Our previously published reports clearly described the location of the axis pedicle (1, 10).Ebraheim et al. (14), Mandel et al. (13), Gehweiller et al. (17), and Cokluk et al. (1)clearly described the exact location of axis pedicle. According to his description, the pedicle of axis is the portion beneath the superior facet and anteromedial to the transverse foramen. In the other hand, the pars interarticularis or isthmus of axis is the narrower portion between the superior and inferior articulating facets (Figure 1).Benzel et al. (12, 16) described that the axis pedicle is located more ventrally and medially then the pedicle at lower cervical levels, and it forms a posterolateral extension of the vertebral body connecting it with its superior articulating process. Borne t al. (18), considered that the exact anatomic pedicle of axis can be described as the narrower portion joining the complex vertebral body-odontoid base to the superior articulating process and the isthmus is the portion located between the superior and inferior facets.

5. Developmentof Axis After Birth

In the ages of infancy and early childhood, it can be seen the incomplete ossification including odontoid, body and neural arches of axis. Four bony structures can be determined as dens, body and two neural arches (19). The segments of C2 based on embryological segments are shown in Figure 2. The pedicles of axis are bilaterally located between the neural arches and the body of C2. The neural arches are bilaterally joined with the bony structures of the odontoid-body complex at the neurocentralsyncondrosis (19, 20). In this region of axis, the completing of the bony fusion is seen at the 6 years of age. After this age, the pedicle completely turns into a bone structure (Figure 2). During the period of development, traumatic fractures involving the synchondrotic articulation between dens, body, and neural arches had been well described (1, 19, 21, 22, 23).

6. Incidence of Pedicle Fractures of Axis

Fracture located at the pedicle of axis is extremely rare. The publications are still at the level of case presentations. Borne et al (18), reported 18 cases of pedicle fractures of C2. The authors concluded that these lesions are more correctly called "pedicle-isthmus" fractures. The authors also presented a technique of screw fixation. This surgical technique was found to be a simple and safe method of repair for such kind of fractures. Signoret at al. (7) reported three patients in whom a fractured odontoid process was associated with a fracture of superior articular process of the axis. The possible mechanism of injury was suggested as forced lateral flexion for this fracture. Craig and Hodgson (6) reported nine cases of superior facet fractures of the axis vertebra. In seven cases, there were associated odontoid fractures. They described the appearance of the fracture in a direction of coronal or sagittal planes. The authors stated that computerized tomographic scanning has been found to be particularly helpful in diagnosing these fractures. Hadley et al (2) reported two cases in 107 axis fractures.

7. Mechanism of Injury

Mechanism of injury is complex. Impact forced applied to the head are transmitted to the spine via the lateral mass of axis through the occipital condyle and the lateral mass of C1. Large amount of mechanical forces are generally absorbed by the flexibility, elasticity and tensile strength of the cranial and upper cervical structures along the transmitting way (1). These multidirectional vector forces are divided into two parts at the level of occipital condyles according to the direction and the site of the applying forces. There is a close relationship between the position of the head and occipital condyles, and the direction of the traumatic vector forces (1). The presumed mechanism of injury is axial compression occurring in association with an asymmetrical lateral or rotatory component of the atlas on axis (1).

8. Diagnosing of Axis Pedicle Fractures

Diagnosis of the pedicle fractures on plain radiography is difficult. In separated fractures,the plain radiography may show the fractured line. In the other hand, in non-displaced fractures plain X-ray usually does not show any findings to delineate a pedicle fracture. Computerized tomography images with bone window and three-dimensional reconstruction are the gold standard in the neuroradiological diagnosing of fracture (Figure 3). Magnetic resonance imaging is not a best diagnostic modality to delineate fractures whereas it is important to show a spinal cord injury and

related structures such as intervertebral disc and ligamentous components (Figure 4). Three-dimensional reconstruction of upper cervical region may provide the understanding and comprehension of the pathology (Figure 5).

9. Clinical Symptoms

There is no specific clinical symptom and finding for the clinical diagnosing of the pedicle fracture. The neck pain may probably be present and the only symptom in the patient with unilateral pedicle fracture of axis. In suspected cases, computerized tomography of the upper cervical spine with bone window is mandatory to obtain neuroradiological diagnosing.

10. Classification of C2 Fractures

We propose a classification based on postnatal developmental segments of the axis. This structure includes three main parts at the birth; the odontoid segment, the body and the neural arches. We used these segments as the main determinants for the basic classification of C2 fractures. This classification includes four types of the fractures; odontoid, body, pedicle and neural arch fractures. Neural arch fractures cover superior and inferior articulating facet, pars interarticularis, lamina and spinous process fractures.

During the developmental process, the segments of C2 are separated from each other by synchondroses articulations (11). The odontoid process is joined to the body and neural arches via the dentocental and neurocentalsyncondrosis respectively (11). The neurocentralsynchondrosis connects the neural arches to the base of the odontoid and the body of C2. This portion is the pedicle of C2 and gradually ossifies into a bony structure.

The odontoid segment develops from two portions; the apical and body portions. According to this classification, odontoid fractures should be divided into two groups as apical fractures and body fractures. But, the odontoid process is not only an anatomical structure but also a very important and specific functional structure (9). Because of this, the classification of odontoid process should be made according to both of embryological and functional properties. Anderson and D'Alanzo (24) have classified the odontoid fractures into three groups. This classification is the most commonly used in neurosurgical practice. For these reasons, we divided odontoid fractures into three groups. The first group is apical portion fractures, the second group is middle portion fractures and the third group includes base fractures. The exact mechanism of odontoid fractures is unknown. However, it consists of a complex mechanism of flexion, extension, and rotation (25, 26).

The C2 pedicle connects the neural arches to the base of the odontoid and the body of C2 via the ossification of the neurocentralsynchondrosis. The location of the C2 pedicle is anteriorly located as compared with other vertebrae (12, 13, 14). The fractures located between the odontoid process and superior articular facets should be classified as pedicle fractures. Pedicle fractures result from a lateral flexion force occurring in association with a rotated position of C1 on C2 (16, 27).

The pars interarticularis fractures are also known as hangman's fractures. Schneider (28) at al reported eight cases of hangman's fractures from motor vehicular accidents and described the mechanism of injury. In such cases, the location of the fracture is the pars interarticularis of the neural arch. Francis (29) and Effendi (30) classified these fractures. Recently, Levine and Edwards (31) modified a classification system, categorizing these fractures based on degree of displacement on lateral cervical spine radiographs and on mechanical stability. The mechanism of this injury is hyperextension with concomitant axial loading (32).

Benzel(16) classified axis body fractures according to orientation of the fracture line. Type I was described as a coronal oriented vertical fracture; Type II was a sagittal oriented vertical fracture and Type III a horizontal rostral fracture. In this classification, the horizontal fracture is rostral located in the C2 body and is the same injury as the previously described Type III odontoid process fracture of Anderson and D'Alanzo. This classification is complex and difficult to use in clinical practice. Fujimura (32) described axis body fractures by the type of bony injury depicted in radiographic images into the four types; avulsion, transverse, burst, and sagittal fractures.

The nomenclature and classification of axis fractures are important because of the frequency of occurrence and clinical importance. We propose a new classification method based on the postnatal developmental model of axis. The segments such as odontoid, body, pedicle and pars interarticularis are clear and it is easy to use in clinical practice.

11. Revised Patient Population:

Previously two cases with traumatic axis pedicle fracture were reported. Up to that date, an additional five cases were treated for axis pedicle fracture. Conservative treatment methods were selected in three of these patients while the other two cases were treated by surgical methods. Posterior pedicle screw fixation is the gold standard in the surgical treatment. Table 1

shows the published C2 pedicle fracture cases in the literature.

Authors	Year	Number of Cases	Details
Borne et al. (18)	1984	18	C2 pedicle fracture
Hadley et al. (2)	1985	2	C2 pedicle fracture
Craig and Hodgson (6)	1991	7	Including C2 superior articulating facets fractures
Cokluk et al. (1)	2005	2	C2 pedicle fracture (Revised number of patients was found as 7 including previously published two cases)

Table 1. The summary of the reported cases of pedicle fractures of C2.

12. Management of C2 Pedicle Fractures:

In the management of axis pedicle fracture, it is important that the patient's age, presence of neurological deficit, additional fracture, ligament damage, and instability of the fracture. Isolated single-sided pedicle fractures are usually fractured in the form of non-fragmented fissures. Such kinds of fractures are stabile fractures of C2. There is no need for surgical treatment in such patients. Simple cervical collar with 30 days follow-up followed by direct radiography is suitable. Computed tomography is sufficient after three months of fracture formation to demonstrate detailed bone healing. The same treatment can be applied in elderly patients with unilateral pedicle fracture. Posterior pedicle screw application is the ideal treatment for patients with bilateral complete pedicle fracture. The separation of the anterior elements from the posterior elements in the bilateral pedicle fractures should be treated with internal fixation methods. Use of simple cervical collar for one month after surgery is sufficient. In the cases of pedicle fracture together with odontoid fracture, only pedicle screw application will not be sufficient for treatment. It is sufficient to use an external cervical collar in the unilateral pedicle fracture accompanied by a Type I odontoid fracture. C1-2 posterior fixation is appropriate for the treatment of unilateral or bilateral pedicle fractures associated with Type II odontoid fractures (Figure 6 and 7). In the cases of Type III odontoid fractures accompanied by a unilateral pedicle fracture, in the other hand the age of the patient under 70 years old, the Halo Coat can be accepted as sufficient treatment. Patients over 70 years of age should be treated with C1-2 posterior fixation techniques.

13. Conclusion:

The pedicle and the pars interarticularis of the axis may be confused because of their unique anatomical localization. The pedicle of axis is the portion beneath the superior articulating facet and anteromedial to the transverse foramen but the pars interarticularis or isthmus of C2 is the narrower portion between the superior and inferior articulating facets. The pedicle fracture of axis is extremely rare. In this study, it is proposed a classification system based on postnatal developmental segments of the axis. In this classification system, the axis was divided into three parts as odontoid, body and neural arches. The neurocentralsynchondrosis connects the neural arches to the base of the odontoid and the body of C2. This portion is the pedicle of C2 in adults. This classification includes four types of the fractures; odontoid, body, pedicle and neural arch fractures. Neural arch fractures cover superior and inferior articulating facet, pars interarticularis, lamina and spinous process fractures.Computerized tomography images with bone window and three-dimensional reconstruction are the gold standard in the neuroradiological diagnosing of fracture. C1-2 posterior fixation is appropriate for the treatment of unilateral or bilateral pedicle fractures associated with Type II odontoid fractures. The separation of the anterior elements from the posterior elements in the bilateral pedicle fractures should also be treated with internal fixation methods.

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Figure Legends:

Figure 1. This figure shows the location of the pedicle and pars interarticularis (OP: Odontoid process, C: Corpus, P: Pedicle, SAF: Superior articulating facet, F: foramen of transversarium, PIA: Pars inetrarticularis, IAF: Inferior articulating facets, NA: Neural arch, SP: Spinous process).

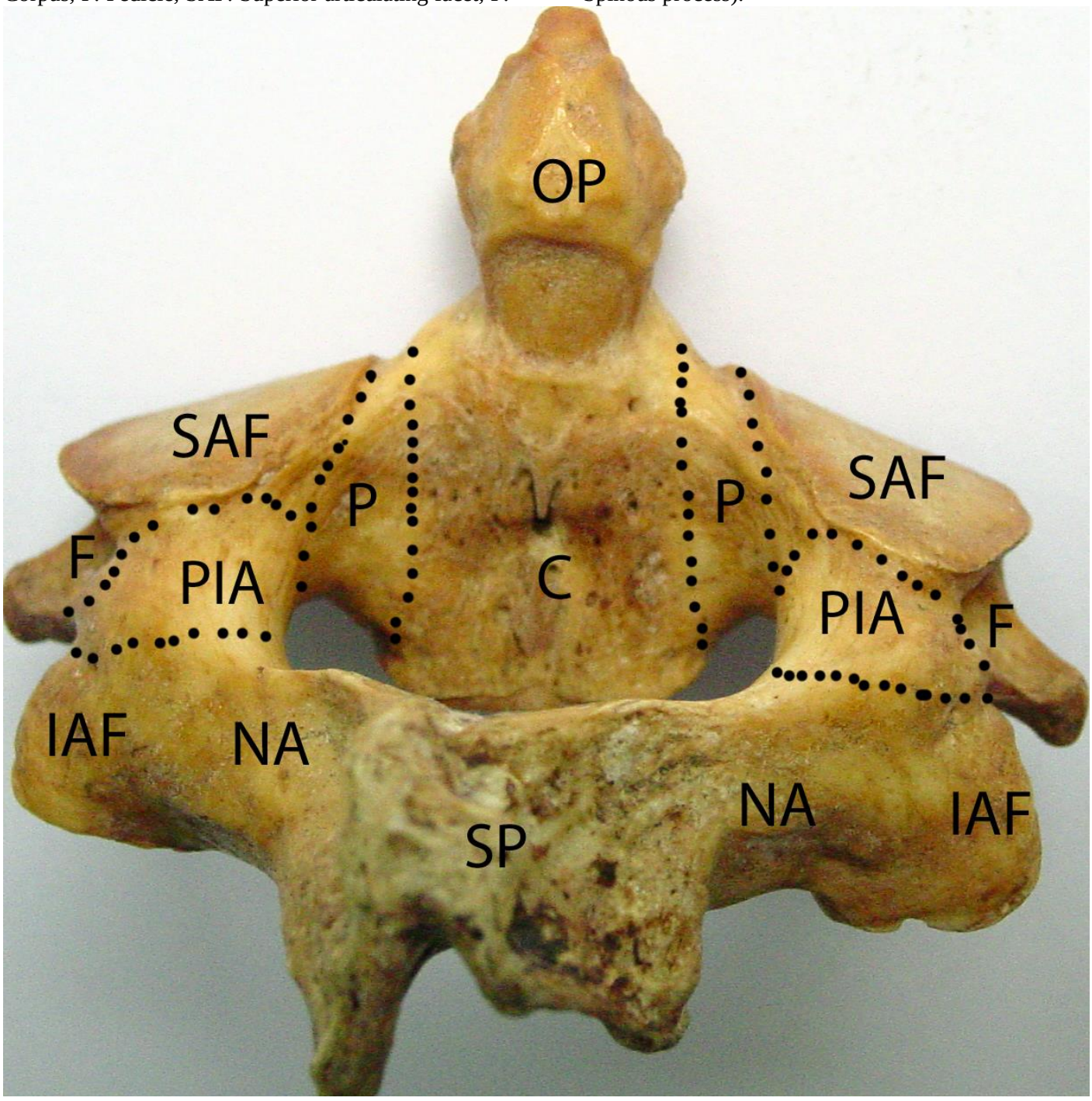

Figure 2. This figure shows the segments of the axis based on the embryological segments of the C2 (O: Odontoid, C: Corpus, SAF: Superior articulating facet, F: Foramen of transversarium, PIA: Pars inetrarticularis, IAF: Inferior articulating facets, NA: Neural arch, SP: Spinous process).

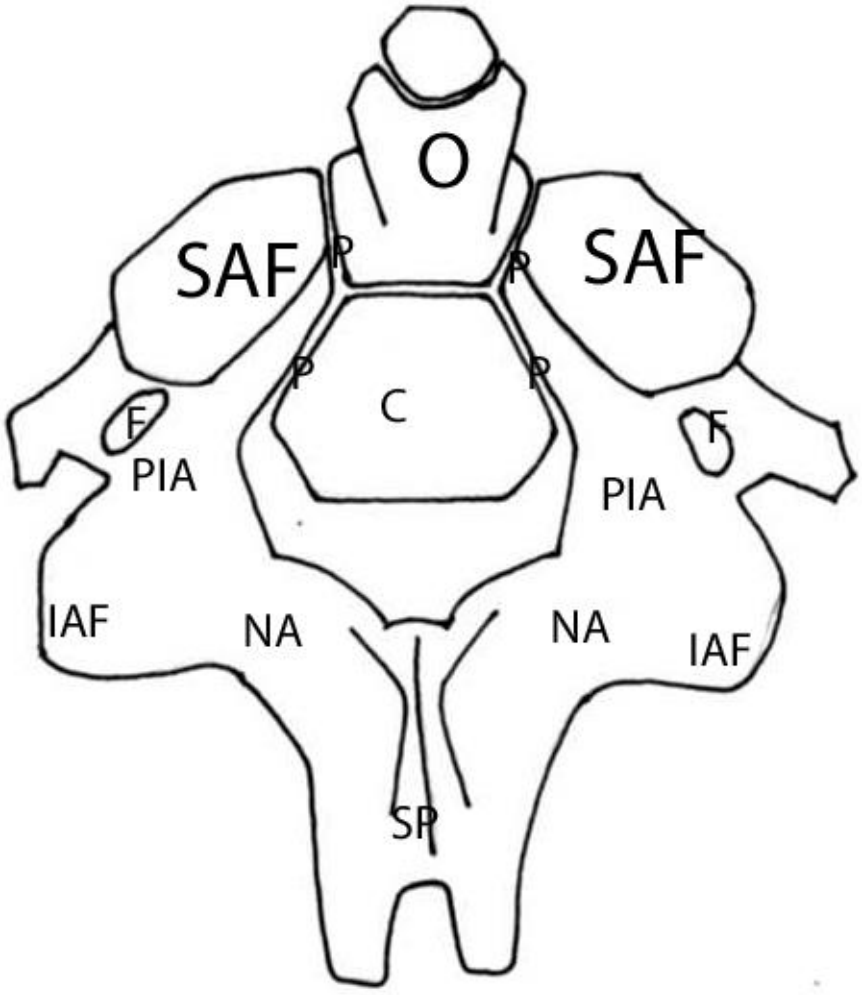

Figure 3. Axial computerized tomography section of C2 shows right pedicle fracture of axis (arrows show the pedicle fracture line).

Figure 4. Sagittal T2 weighted images of magnetic resonance imaging of cervical region shows Type II odontoid process fracture (arrow shows the fracture line).

Figure 5. Three-dimensional computerized imaging of upper cervical region shows odontoid and pedicle fracture of C2 (OP: Odontoid process, OF: Odontoid Fracture, PF: Pedicle fracture).

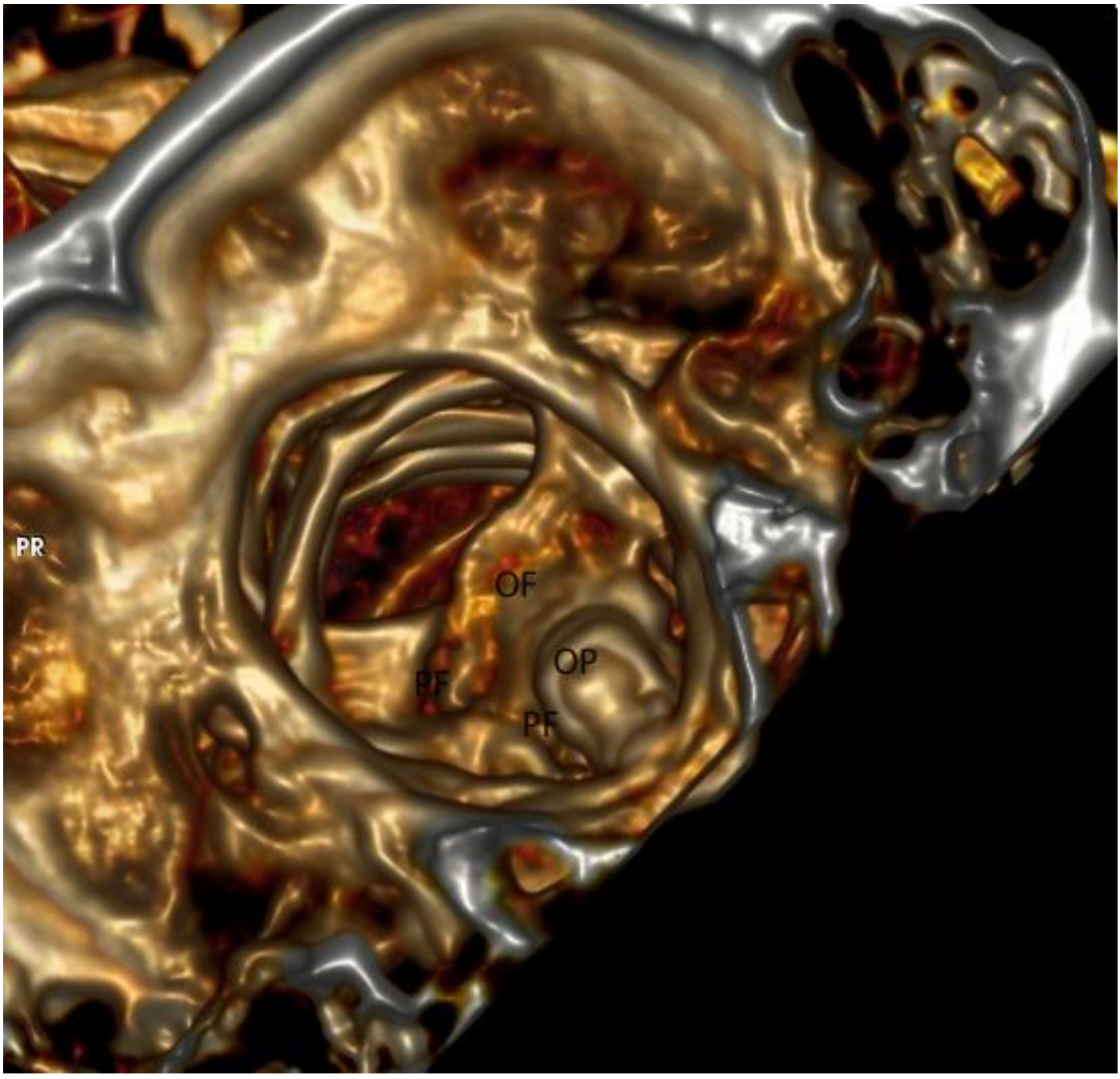

Figure 6. Axial spiral computerized tomography image shows the trajectory of C1 lateral mass and C2 pedicle screws (OC: Occipital condyle, C1: atlas, C2: axis, C1-PS: C1 lateral mass screw, C2-PS: C2 pedicle screw).

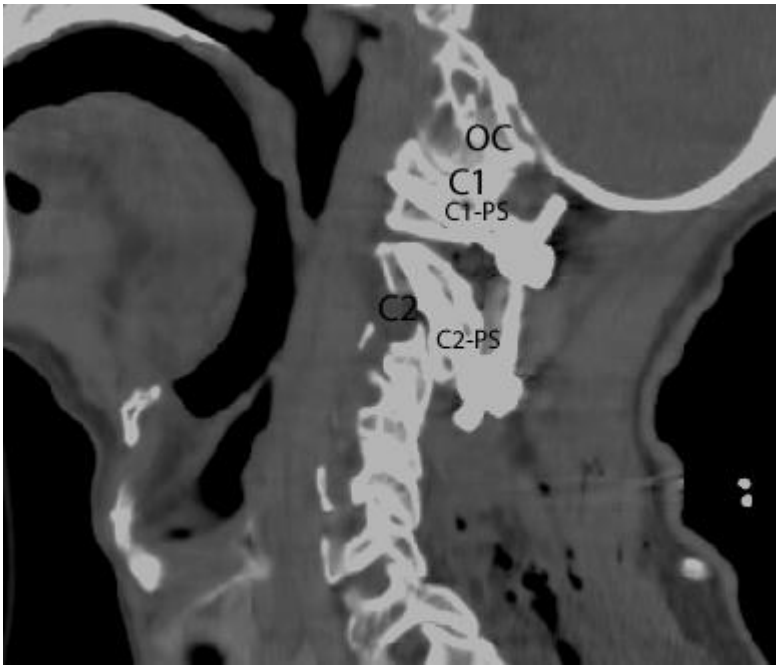

Figure 7. Three-dimensional computerized imaging of upper cervical region shows the location of C1 lateral mass and C2 pedicle screws (C1: Atlas, OF: Odontoid fracture, PF: Pedicle fracture, C1-PS: C1 lateral mass screw, C2-PS: C2 pedicle screw).