

# The Segments and the Inferior Boundaries of the Odontoid Process of C2 Based on the Magnetic Resonance Imaging Study

## C2 Odontoid Çıkıntının Segmentleri ve Inferior Sınırlarının Manyetik Rezonans Görüntüleme Temel Alınarak Belirlenmesi

### ABSTRACT

**AIM:** The aims of this clinical study were to describe the segments and the inferior boundaries of the odontoid process as regards the embryological development of C2 based on the magnetic resonance imaging finding.

**MATERIAL and METHODS:** Cranial and cervical magnetic resonance images including occiput, C1, and C2, and those obtained for different reasons such as evaluation of cranial and upper cervical pathology were re-evaluated for this study. Synchondroses around the odontoid process were accepted as the boundaries between the neural arch and the body of C2.

**RESULTS:** Thirty cases were included for this study. Fifteen of these were adult cases and the remaining 15 were in pediatric cases. Apicodental, dentocentral, neurocentral, and dentoneural synchondrotic articulations were clear, especially under the ages of 3 years. The dentocentral synchondrosis was found well below the line drawn through the level of superior articulating facets.

**CONCLUSION:** This study demonstrated that the inferior boundary of the odontoid process is not located at the level of superior articulating facets. The real border between the odontoid process and the body of C2 is located well below the level of the superior articulating facets because of the location of the dentocentral synchondrotic articulation. This level should be considered in the classification of C2 fractures.

**KEY WORDS:** Odontoid process, Dentocentral synchonrosis, The boundaries of the odontoid process

### ÖZ

**AMAÇ:** Odontoid segmentleri ve inferior sınırlarının embriyolojik gelişme aşamaları temel alınarak MR (Manyetik Rezonans) ile belirlenmesidir.

**YÖNTEM ve GEREÇ:** Oksiput, C1 ve C2'yi içine alan, kraniyal ve üst servikal değişik patolojileri incelemek amacıyla çekilen detaylı ince kesitleride içeren manyetik rezonans tetkikleri tekrar incelendi. Odontoid ile C2 korpusu ve nöral arkus arasındaki sinkondrotik eklemler odontoid'in inferior sınırları olarak tesbit edildi.

**BULGULAR:** Bu çalışma 30 olguyu kapsamaktadır. Bu olgulardan 15'i erişkin yaş grubunda iken geri kalan 15 olgu çocukluk yaş grubundaydı. Üç yaşın altındaki olgularda apikodental, dentosantral, nörosantral ve dentonöral sinkondrotik eklemler belirgindi. Dentosantral sinkondrosis süperior artiküler fasetler hizasından çekilen hattın altında kalıyordu.

**SONUÇ:** Bu çalışma bize odontoid'in inferior sınırının superior artiküler fasetler hizasında olmadığını göstermektedir. Odontoid ve C2 cismi arasındaki sınır süperior artiküler faset seviyesinin daha aşağısında kalmaktadır, çünkü dentosantral sinkondrosis faset seviyesinin altında yerleşiktir. C2 kırıklarının sınıflandırılmasında bu göz önünde bulundurulmalıdır.

**ANAHTAR SÖZCÜKLER:** : Odontoid çıkıntı, Dentosantral sinkondrosis, Odontoid çıkıntının sınırları

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## INTRODUCTION

The second cervical vertebra is unique in terms of anatomical shape, function, and biomechanical properties (2,3). The functions of the head such as flexion, extension, lateral bending, and lateral rotation is related to the anatomical function of C2 and its odontoid process. C2 is also the largest among the members of upper cervical spine (2). It consists of a body, paired pedicles, lateral masses (superior articulating facets, pars interarticularis, and inferior articulating facets), laminae, and bifid spinous process (2,3,5,12). Other members of the upper cervical spine include the foramen magnum, paired occipital condyles and C1 (5,9). This segment serves as a transitional zone between the rigid calvarium and flexible lower cervical spine (2,3,5,12).

The odontoid process of C2 projects upward from the superior roof of the body, and differs it from the others (2,5,12). In embryological developmental stages, C2 forms from four bones separated by synchondrotical articulations and consisting of four ossification centers (two of them are located in the neural arches bilaterally, 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 until the end of the ossification process (2). These cartilaginous articulations are named dentocentral (separating odontoid from the body) and neurocentral synchondrosis (separating odontoid and body from neural arches) (2,7). Synchondroses among the neural arches, body, and odontoid process fuse at 3 to 6 years (2). After the age of 6 years, the odontoid process fuses with the body and the neural arches (2). In adult age, the remnant of the dentocentral synchondrosis can be imaged by magnetic resonance as a hypointense ring between the inferior end of the odontoid and the superior roof of the body of C2. This structure is located in the cancellous bone, and should be accepted as the inferior border of the odontoid process in adults. The anatomical level of dentocentral synchondrosis is well below the superior articulating facets and the indentation of the transverse ligament to the posterior aspect of the odontoid process.

C2 fractures make up a large percentage of all cervical injuries. The fractures of the odontoid process are relatively common among C2 fractures.

Anderson and D'Alonzo (1) classified odontoid fractures into three types. Type I occurs through the upper part of the odontoid process, probably as a result of an avulsion at the insertion of the alar ligament. Type II fractures occur at the junction of the odontoid process with the vertebral body. Type III extends down into the body of the axis. In this classification, the level of superior articulating facets of the odontoid process is accepted as the border between the odontoid process and the body of C2. However, during embryological development there is a dentocentral synchondrotic articulation between the odontoid process and the body of C2. In adult ages, the remnant of dentocentral synchondrosis should be accepted as the inferior boundary of the odontoid process of C2.

The aims of this clinical study were to describe the segments and the inferior boundary of the odontoid process the embryological development of C2 based on the MRI study. Using MR images, we will describe the remnant of dentocentral synchondrosis. This remnant is located between the inferior border of the odontoid process and the body of C2.

## MATERIALS and METHODS

The study population consisted of 15 adults (8 males aged between 18 and 71 years, and 7 females aged between 22 and 68 years) and 15 pediatric cases (9 males aged between 1 and 17 years, and 6 females aged between 2 and 15 years). The upper cervical spine of all patients was examined by using magnetic resonance imaging (MRI).

Neuroradiological images were obtained for the evaluation of other suspicious pathologies. Were selected images from the upper cervical and thin slice MRI.

Magnetic resonance images were obtained using a 1.0-tesla unit (General Electric) with a neck and/or head surface coil. The MR imaging protocol for the upper cervical region included 3-mm sagittal T1-weighted (TR 600 msec, TE 20 msec) and T2-weighted turbo spin-echo (TR 2500 msec, TE 80 msec) sequences.

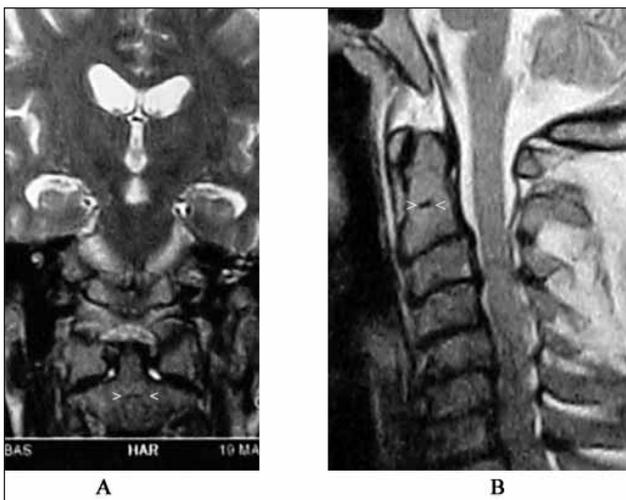
Lateral and anterior odontoid radiographs were obtained in all patients. All patients also underwent Oc-C2 computerized scanning with sagittal reconstructions. Coronal MR Images were obtained in all patients. Midsagittal and midcoronal MR images were scanned and converted into digital

images by using a 3.2 megapixel digital camera (Sony, Japan). All digital images were copied into the hard-disc of a computer (Vestel Asteo computer, Turkey).

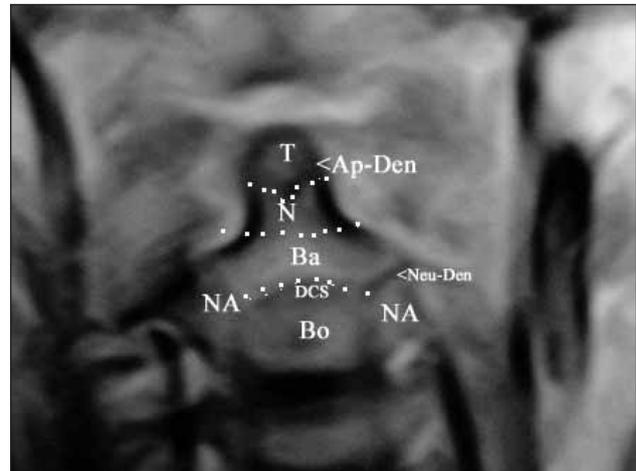
The first stage of the study was the evaluation of the patients under the age of 3 years. Synchondrotic articulations were investigated with MRI. These articulations were as follows; apicodental synchondrosis, dentocentral synchondrosis, neurodental synchondrosis, and neurocentral synchondrosis. The neurodental, dentocentral and neurocentral synchondrosis were selected as inferior boundaries of the odontoid process. The dentocentral synchondrosis is located between the border of odontoid process and the body of C2. The neurocentral synchondrosis is located between the neural arch and the body of C2 and the neurodental synchondrosis is located between the neural arch and the odontoid process. The appearance of the remnant of the dentocentral synchondrosis is shown in Figure 1. Apicodental, dentocentral and neurocentral synchondroses are shown in Figure 2. The parts of C2 are shown in Figure 3.

**RESULTS**

Dentocentral synchondrosis in the pediatric age and its remnant in adult ages were demonstrated in all cases by using sagittal images of MRI.



**Figure 1:** A. Coronal T2-weighted magnetic resonance imaging in a 63-year-old adult shows the remnant of dentocentral synchondrosis. This remnant should be accepted as the inferior boundary of the odontoid process (arrow shows the remnant of the dentocentral synchondrosis). B. Sagittal T2-weighted magnetic resonance imaging of an adult case shows the remnant of the dentocentral synchondrosis of C2 (arrow shows the remnant of the dentocentral synchondrosis).

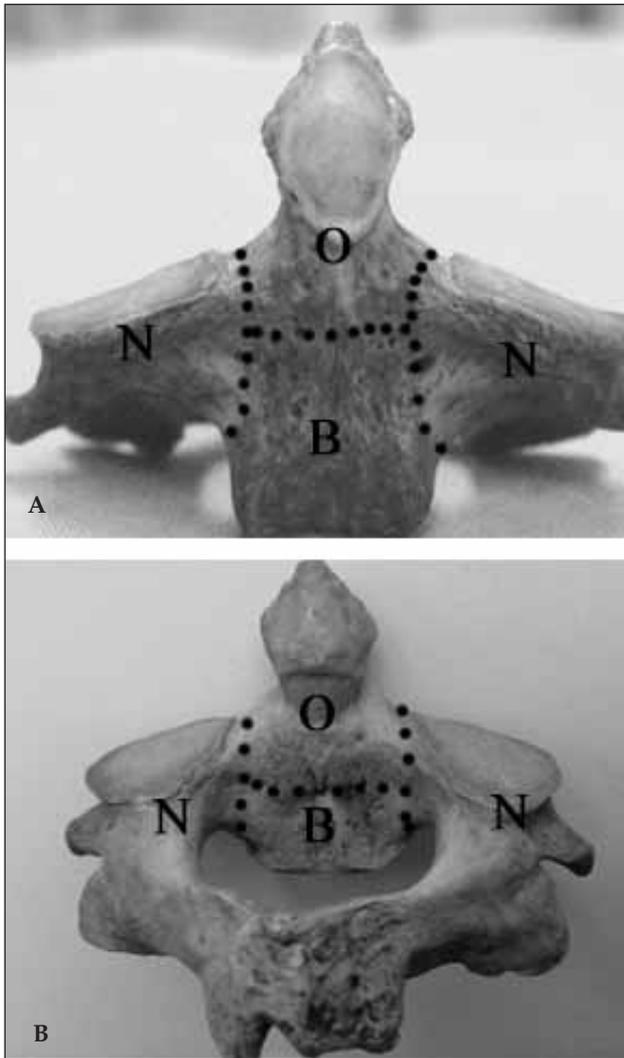


**Figure 2:** Coronal T1-weighted magnetic resonance imaging of a pediatric case shows the segments of the odontoid process (T: Tip of the odontoid, N: The neck of the odontoid, Ba: The base of the odontoid, Bo: The body of C2, Ap-Den: Apicodental synchondrosis Neu-Den: Neurodental synchondrosis, dotted areas mark the borders of the segments of the odontoid process).

Dentocentral and apicodental synchondroses have different locations than the other synchondroses. The apicodental synchondrosis is located in the odontoid process. The dentocentral synchondrosis is located between the odontoid process and the body of C2. In other words, the dentocentral synchondrosis is located at the superior border of the body of C2 and inferior border of the odontoid process.

In the pediatric cases under the age of 3 years, the appearance of apicodental synchondrosis was very clear. At the same time, the appearance of dentocentral synchondrosis was also very clear in cases under the age of 3 years. Synchondrotic articulations were seen as hypointense bands in T1-weighted MRI in all cases (Figure 2). These articulations were seen as hyperintense bands in T2-weighted MRI.

The synchondrotic articulations were not seen in all adult cases. The remnant of dentocentral synchondrosis can only be seen in sagittal and coronal MR images (Figure 1). The image characteristics can be described as follows; in T1-weighted MRI, these articulations can be imagined as hypointense circular disc (Figure 2). In T2-weighted MRI they were seen as hyperintense discs. In the pediatric ages, the dentocentral synchondrosis was accepted as the border of odontoid process with the body of C2. In the same way the remnant of the



**Figure 3: A.** This figure taken from a cadaver C2 shows the parts of C2 in antero-posterior view (O: Odontoid process, N: Neural arc, B: Body of C2).

**B.** This figure taken from a cadaver C2 shows the parts of C2 in postero-anterior view (O: Odontoid process, N: Neural arc, B: Body of C2).

dentocentral synchondrosis should be accepted as the border of the odontoid process and the body of C2 (Figure 1). In all cases the location of the remnant of dentocentral synchondrosis was well below the line drawn through the superior articulating facets.

We divided the odontoid process of C2 into three segments according to the synchondrotic articulations. The first segment is the tip of the odontoid process. This segment is located in the upper portion of the odontoid process. The border of this segment is the apicodental synchondrosis. It is impossible to see the apicodental synchondrosis in

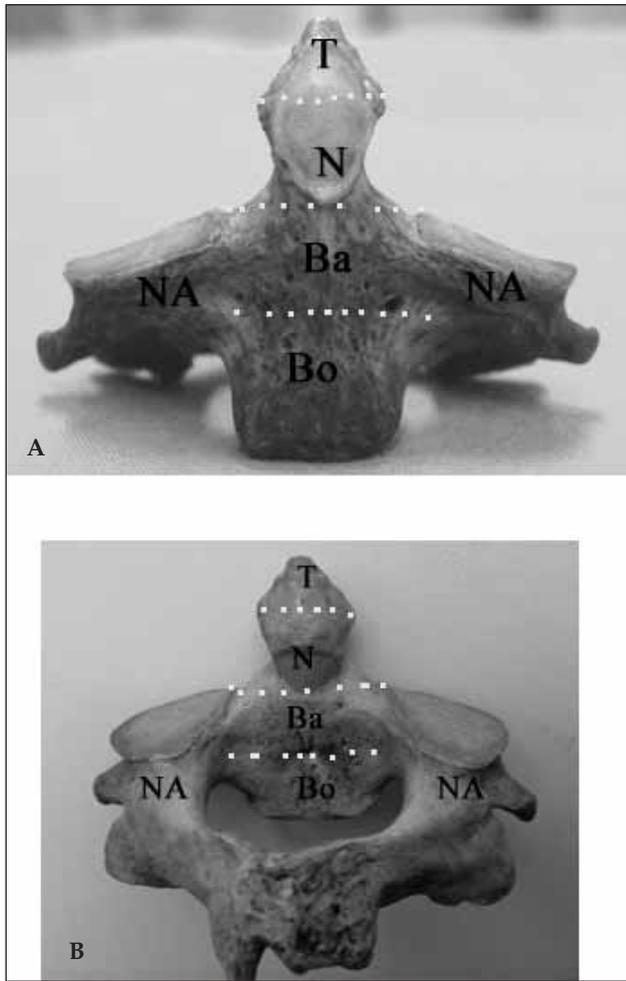
the adult ages. The border of the tip of the odontoid is therefore an imaginary line drawn through the upper portion of the odontoid at these ages. The second portion is the neck of the odontoid process. This segment begins from the end of the tip of the odontoid process to the line drawn through the superior articulating facets. According to our study, the odontoid process ends at the remnant of dentocentral synchondrosis. This line should therefore not be accepted as the junction of the odontoid with the body of C2. This area should be accepted as the neck of the odontoid segment. The last segment in our study is the base of the odontoid process. This segment starts at the line drawn through the level of superior articulating facets to the remnant of dentocentral synchondrosis. The inferior portion from the dentocentral synchondrosis should be accepted as the body of C2 (Figure 4).

The lateral borders of the odontoid process were very clear in the pediatric ages because of the neurodental synchondrosis located between the neural arc and the base of the odontoid process. We divided this synchondrosis into two segments. The first segment is the neurocentral synchondrosis. This synchondrosis is located between the neural arc and the body of C2. The second segment is the neurodental synchondrosis. This segment is located between the neural arc and the base of the odontoid process. In adult ages, this is an imaginary line drawn horizontally lateral to the odontoid process bilaterally. This line passes from the pedicle of C2.

## DISCUSSION

Fractures of the odontoid process make up a large percentage of odontoid process pathologies. Odontoid fractures were first described by Lambotte in 1894. Following this description, odontoid fractures were treated by non-surgical treatment modalities for a long time. Mixter and Osgood first surgically treated cases with odontoid fractures (posterior fixation with wiring) in 1910 (4).

De Morgues and Fischer first classified odontoid fractures as base and the neck fractures of the odontoid process in 1972 (12). After this classification Anderson and D'Alanzo proposed a new classification system that is widely used in neurosurgical practice in the world (1). This classification system described three fracture types. The original description of odontoid fractures according to Anderson and D'Alanzo classification



**Figure 4:** A. This figure taken from a cadaver C2 shows the segments of the odontoid process in antero-posterior view (T: Tip of the odontoid process, N: Neck of the odontoid process, Ba: Base of the odontoid process, Bo: Body of C2, NA: Neural arc, dotted areas mark the borders of the segments of the odontoid process) B. This figure taken from a cadaver C2 shows the segments of the odontoid process in posterior-anterior view (T: Tip of the odontoid process, N: Neck of the odontoid process, Ba: Base of the odontoid process, Bo: Body of C2, NA: Neural arc, dotted areas mark the borders of the segments of the odontoid process)

can be addressed as follows. Type I fracture occurs through the upper part of the odontoid process, probably as a result of an avulsion at the insertion of the alar ligament. Type II fractures occur at the junction of the odontoid process with the vertebral body. Type III extends down into the body of the atlas. The mentioned descriptions reflect the original description of Anderson and D’Alanzo. At the first glance, there seems to be no problem for these descriptions. In fact, there are some anatomical problems with Type II and Type III fractures of the

odontoid process. The area of Type II fracture is a horizontal line drawn through the upper border of the superior articulating facets of the axis. Anderson and D’Alanzo and some other authors described this line is the junction of the odontoid process with the body of C2. The same classification described the fractures that pass below this level as body of C2 fractures (Type III fractures). It is necessary to know the inferior boundary of the odontoid process to accept these descriptions. In this clinical study, we described the inferior boundary of the odontoid process as the remnant of dentocentral synchondrosis by using MRI. According to our study, the imaginary line drawn through the upper border of the superior articulating facets of the axis is not the junction of the odontoid process and the body of C2. The remnant of the dentocentral synchondrosis is well below this level. At the same time, the fractures passing under this horizontal line should not be accepted as the body of C2 fracture because of the location of the dentocentral synchondrosis remnant.

Stillerman et al (12), in their classical monograph, defined the line at the level of the superior articulating facets as the synchondrosis and stated that the majority of odontoid fractures involve this line where the odontoid process fuses with the body of C2. In fact, this line is just the border between the neck and the base of the odontoid segment, and the real dentocentral synchondrosis is located between the base of the odontoid and the body of C2, and more below the neck of the odontoid.

The external surface anatomy of C2 had been studied and well-described previously in many anatomical studies (2,3,6,9,10,11). The internal anatomy of the vertebral bones, especially the internal trabecular anatomy of C2 was studied in only a few published articles regarding the aspect of biomechanical properties and segmental anatomy (2, 8). It is necessary to know the internal anatomy of C2 for proper diagnosis, description and classification.

MRI is a useful neuroradiological diagnostic tool in the investigation of the internal cancellous anatomy of the vertebral bones in living subjects at different ages. Our study revealed that MRI has a high capability to demonstrate the remnant of the dentocentral synchondrosis in both coronal and sagittal images. CT with bone window can show the cortical bone structure in the odontoid and body segments. It is however difficult to distinguish the

remnant of neurocentral synchondrotic articulations; the remnant of dentocentral synchondrosis was seen as a hypointense disc in T1-weighted images located midline between the space of odontoid and the body of C2. In T2-weighted MR images, this area was seen as a hypointense area.

This clinical study demonstrated that the remnant of the dentocentral synchondrosis is located well below the superior articulating facets and can be imagined by sagittal and coronal magnetic resonance images. This remnant can be seen in pediatric patients, adults, and even in the elderly. The localization and level of the remnant of the dentocentral synchondrosis is not only important as an anatomical detail but it is also extremely important from the clinical perspective aspect because of odontoid and C2 fractures. The odontoid segment may be divided into three segments according to the localization of the dentocentral synchondrosis. The first segment is the tip of the odontoid. This segment is separated from the second segment of the odontoid (the neck) by the apicodental synchondrosis. The neck of the odontoid process lies between the apicodental synchondrosis and the level of the superior articulating facets. The third segment connects the neck to the body of C2 via the dentocentral synchondrosis, and can be named the base of the odontoid segment. This segment also fuses with the neural arches bilaterally.

In the stage of embryological development and in pediatric ages the inferior boundary of the odontoid process was formed by the synchondrotic articulations between the parts of C2 based on the magnetic resonance imaging findings.

The neural arc, the body and the odontoid process are three main parts of C2. The odontoid process makes articulations with all these structures. The dentocentral synchondrosis is located between the inferior end of the odontoid process and superior border of the body of C2. In pediatric ages it is very clear and easy to distinguish this articulation. In adult ages, with the regression of dentocentral synchondrosis the remnant of dentocentral synchondrosis appears. This remnant is very important in the description of the inferior boundary of the odontoid process in adult ages. Another synchondrosis is the neurodental syndchondrosis. This synchondrosis is located between the inferolateral boundary of odontoid process and the neural arc. In pediatric ages this articulation is very

clear, but in the adult ages it disappears. The imaginary line drawn medial border of the superior articulating facets can be accepted as the inferolateral boundary of the odontoid process. This area is generally accepted as the pedicle of C2.

According to our description of the inferior boundary of the odontoid process of C2 based on the synchondrotic articulations between the parts of C2, it is necessary to re-describe the location of the fracture of the odontoid process. As mentioned previously we divided the odontoid process into three segments. The first segment is the apical segment or the tip of the odontoid process. This segment starts at the tip of the odontoid process and ends at the apicodental synchondrosis in pediatric ages. In adult ages, this level is just an imaginary line drawn horizontally at the superior part of the odontoid process. Type I fractures of odontoid process are seen in this location. The second segment is the neck of the odontoid process. This segment begins from the apicodental synchondrosis in pediatric ages and imaginary line in adults as mentioned above. This segment ends at the imaginary line drawn through the superior end of the superior articulating process. Some authors have mistakenly described this segment as the junction of the odontoid process with the body of C2. Actually this is just inside part of the odontoid process. The fractures seen in this location are accepted as Type II fractures. After our description, these fractures can be accepted as the neck fractures of the odontoid process. The third and the last segment of the odontoid process is the base of the odontoid process. This segment is located between the imaginary line drawn at the superior level of the superior articulating process and the dentocentral synchondrosis in pediatric ages. In adult ages the inferior level can be described as the remnant of the dentocentral synchondrosis. This remnant can be seen in MRI as described previously in this text. The fractures in this segment can be described as the base fractures of the odontoid process. According to our description of the inferior boundary of the odontoid process, the fractures seen in this location are not the C2 body fractures, as the body of C2 is located under the level of the dentocentral synchondrosis remnant.

#### CONCLUSION

Based on the localization of the dentocentral synchondrosis, the odontoid process of C2 can be divided into three segments as mentioned above; the

tip, the neck, and the base. The base of the odontoid process begins from the level of superior articulating facets, and ends at the level of the remnant of the dentocentral synchondrosis. The level of superior articulating facets should be considered as a border inside the odontoid process separating the neck from the base of the odontoid segments. Fractures of the odontoid process should be redefined according to this evaluation.

#### REFERENCES

1. Anderson LD, D'Alonzo RT: Fractures of the odontoid process of the axis. *J Bone and Joint Surg* 56: 1663-1674, 1974
2. Cokluk C, Aydin K, Rakunt C, Iyigun O, Onder A: The borders of the odontoid process of C2 in adults and in children including the estimation of odontoid/body ratio. *Eur Spine J* 15: 278-782, 2006
3. Cokluk C, Takayasu M, Yoshida J: Pedicle fracture of the axis: Report of two cases and review of the literature. *Clin Neurol Neurosurg* 107: 136-39, 2005
4. Dickman CA, Greene KA, Sonntag VKH: Injuries involving the transverse atlantal ligament: Classification and treatment guidelines based upon experience with 39 injuries. *Neurosurg* 38: 44-50, 1996
5. Doherty BJ, Heggeness MH: Quantitative anatomy of the second cervical vertebra. *Spine* 20: 513-517, 1995
6. Ebraheim NA, Fow J, Xu R, Yeasting RA: The location of the pedicle and pars interarticularis in the axis. *Spine* 26: 34-37, 2001
7. Garton HJL, Park P, Papadopoulos SM: Fracture dislocation of the neurocentral synchondroses of the axis. Case illustration. *J Neurosurg Spine* 96: 350, 2002
8. Heggeness MH, Doherty BJ: The trabecular anatomy of the axis. *Spine* 4: 1945-1949, 1993
9. Koebke J: Morphological and functional studies on the odontoid process of the human axis. *Anat Embryol (Berl)* 155: 197-208, 1979
10. Mandel IM, Kambach BJ, Petersilge CA, Johnstone B, Yoo JU: Morphologic consideration of C2 isthmus dimensions for the placement of transarticular screws. *Spine* 25: 1542-1547, 2000
11. Schaffler MB, Alson MD, Heller JG, Garfin SR: Morphology of the dens. A quantitative study. *Spine* 17: 738-743, 1992
12. Stillerman CB, Roy RS, Weiss MH: Cervical spine injuries: Diagnosis and management. In Wilkins RH and Rengachary SS eds. *Neurosurgery*. 2nd ed. New York: McGraw-Hill, 1996: 2875- 2904