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대한영상의학회지

Anterior Atlantodental and Posterior Atlantodental Intervals on Plain Radiography, Multidetector CT, and MRI[1]

경추부위의 단순방사선, Multidetector CT, MRI 검사에서의 전환추-축추 간격과 후환추-축추 간격[1]

Kibo Yoon, MD[2], Seung Woo Cha, MD[1], Jeong Ah Ryu, MD[1], Dong Woo Park, MD[1], Seunghun Lee, MD[2], Kyung Bin Joo, MD[2]

[1]Department of Radiology, Hanyang University Guri Hospital, Hanyang University College of Medicine, Guri, Korea
[2]Department of Radiology, Hanyang University Seoul Hospital, Hanyang University College of Medicine, Seoul, Korea

Purpose: To determine the normal values of the anterior atlantodental interval (AADI) and posterior atlantodental interval (PADI) on plain radiography, multidetector CT (MDCT) and MRI, as well as the dural sac width and spinal cord diameter at the atlantoaxial joint level on MRI.
Materials and Methods: In total, 60 subjects underwent plain radiography, MRI and MDCT. We obtained values for AADI and PADI on plain radiography, MDCT, and MRI, and for dural sac width and spinal cord diameter on MRI. Two radiologists independently measured each value and a consensus was reached.
Results: The average AADI was 1.5 ± 0.5 mm on plain radiography, 1.4 ± 0.3 mm on MDCT, and 1.6 ± 0.5 mm on MRI. The average PADI was 20.6 ± 2.4 mm on plain radiography, 18.0 ± 2.1 mm on MDCT, and 17.7 ± 1.9 mm on MRI. The dural sac width was 13.7 ± 1.8 mm, and the spinal cord diameter was 7.8 ± 0.7 mm. Interobserver agreement was 0.701–0.927 and intraobserver agreement was 0.681–0.937.
Conclusion: AADI values obtained on MDCT are significantly lower than those obtained on plain radiography or MRI. PADI values obtained on plain radiography are significantly higher than those obtained on MDCT or MRI. The dural sac width is most closely correlated with PADI values on MDCT. PADI seems to be easier to measure, more relevant, and clinically useful than AADI.

Index terms
Atlantoaxial Joint
Cervical Vertebrae
Plain Radiography
Multidetector Computed Tomography
Magnetic Resonance Imaging

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Corresponding author: Jeong Ah Ryu, MD
Department of Radiology, Hanyang University Guri Hospital, Hanyang University College of Medicine, 153 Gyeongchun-ro, Guri 471-701, Korea.
Tel. 82-31-560-2594 Fax. 82-31-560-2551
E-mail: ryuja@hanyang.ac.kr

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INTRODUCTION

The atlantoaxial joint is frequently affected by trauma, arthropathies, and neoplasm, and it has been the subject of many investigations to diagnose instability (1-5). Since Coutts' investigation in 1934 (6), the anterior atlantodental interval (AADI) has been recognized as the most sensitive gauge of atlantoaxial displacement (6, 7). The posterior atlantodental interval (PADI) contains nerve roots, the spinal cord and arteries (8), and it may be a more direct measure of neurological risk. Previously studies have shown a close correlation between PADI in plain radiography and clinical findings (9-14). Recently, the multidetector CT (MDCT) scan has replaced plain radiography as the primary radiological examination type in emergency situations in many hospitals, including our institution. It has been considered the standard modality for the diagnosis of cervical spine injuries (15-20). More recent studies have claimed that the MRI should be used for complete cervical clearance in all blunt trauma patients (16-19). However, the normal reference values of AADI and PADI on MDCT and MRI have not yet been established, despite several studies (21-24). In the present work, we aimed to determine the normal values of AADI and PADI on plain radiography, MDCT and MRI, as well as the dural sac width and spinal cord diameter at the atlantoaxial joint level on MRI.

MATERIALS AND METHODS

The study was approved by the Institutional Review Board of our hospital. Informed consent and patient approval were not obtained from the research subjects because the study was non-therapeutic and retrospective.

Subjects

We searched our electronic medical record system and found 14607 consecutive patients who visited the department of orthopedic surgery at our institution between July 2008 and August 2012 with a complaint of back pain. Among them, we found 1719 patients who were evaluated with L-spine MRI with cervical screening MRI, and who were discharged from the hospital without a diagnosis of cervical spine injury or upper cervical spondylosis. Among the subjects, we selected those between 20 and 55 years of age. We evaluated the patients' cervicothoracic screening MRI, and excluded anyone with cervical developmental abnormalities, diseases of the lower cervical spine affecting more than one disc level, infectious spondylodiskitis, or a tumorous condition of the cervical spine. We also reviewed the patients' electronic medical records and excluded anyone with a previous history of cervical injury or operation, rheumatoid arthritis, or ankylosing spondylitis. Of the remaining 211 subjects, 68 underwent all of the three examinations: plain radiography consisting of anteroposterior, lateral and open-mouth views, cervical spine MDCT scan with multiplanar reconstructions, and cervical screening MRI consisting of T2-weighted sagittal images. We also excluded eight subjects because their plain radiography, MDCT, and MRI were not performed within one month of the first hospital visit. In the end, sixty subjects (35 men, 25 women, mean age 37 years, range 20–55 years) were included in this study.

Imaging

Plain radiography of the cervical spine consisted of three views; anteroposterior, open mouth, and lateral. We evaluated all three images; however, measurements were only performed on the lateral view. The images were taken at a 1.75 m (six feet) standard tube distance, with the central beam directed at the level of the thyroid cartilage, and the patient sitting upright with his or her head in a neutral position. Plain radiography was carried out within one month of the first hospital visit.

MDCT of the cervical spine was performed in the neutral position without intravenous contrast enhancement using a 16 channel-MDCT scanner (Sensation 16, Siemens Medical Systems, Erlangen, Germany), with the following standard protocol: 16 × 0.75 mm collimation with 1-mm-thick sections, 0.5-mm overlap, and pitch of 0.89. Axial images were reconstructed at 1 mm, and reconstructions in both sagittal and coronal planes were obtained from the 1 mm axial reconstructions, reformatted to 3-mm thickness every 3 mm through the entire cervical spine. A 180-mm field of view (FOV), 512 × 512 matrix, 120 kVp, and 100 mAs were routinely used. The images were analyzed using a preset bone window setting [level 500 Hounsfield unit (HU), width 2500 HU]. The MDCT was taken within one month of the first hospital visit. We used mid-sagittal reconstruction images for measurement.

The MRI of the cervical spine was performed using a 1.5 Tesla MR Scanner (1.5-T Genesis Signa Advantage scanner, General Electric, Milwaukee, WI, USA), with a spine coil, in a supine neutral position. A T2-weighted fast spin echo sequence in the sagittal plain was obtained, and we used a mid-sagittal image for measurement. The MRI included the entire cervical spine, from the brain stem to the T3 vertebra, with settings of repetition time/echo time 4000/120 ms, inversion time 160 ms, flip angle 90°, slice thickness 3.0 mm, interslice gap 0.1 mm, number of slices 15, FOV 240 × 240 mm^2, voxel size 0.8 × 0.5 × 1.0 mm^3, and echo train length 30. The MRI was performed within one month of the first hospital visit.

Measurements

We obtained a total of 8 measurements on each patient using a Picture Archiving and Communication System (PACS) workstation, which consisted of the following: AADI on plain radiography, PADI on plain radiography, AADI on MDCT, PADI on MDCT, AADI on MRI, PADI on MRI, dural sac width on MRI, and spinal cord diameter on MRI.

AADI was measured from the posteroinferior aspect of the anterior arch of the atlas, to the adjacent anterior surface of odontoid process, at a level just superior to the attachment of the deep portion of the anterior atlantoaxial ligament, as used in Hinck's investigation (7). PADI was measured from the posterior surface of the odontoid process to the anterior edge of the posterior ring of the atlas, along the transverse axis of the ring of the atlas, according to the definition by Boden et al. (9). That is the same definition as the space available for the spinal cord at the C1–C2 level in a recent publication (Fig. 1) (11).

We defined dural sac width as the distance from the inner surface of the anterior wall of the dural sac to the inner surface of the posterior wall of the dural sac as measured perpendicular to the long axis of the dural sac at the level of the ring of the atlas. We defined the spinal cord diameter as the whole thickness of the spinal cord measured perpendicular to the long axis of the spinal cord at the same level.

We magnified all of the original images three-fold to select the most accurate measuring points, and made the measurements with the electronic cursor of the PACS workstation. Although the values were figured to the hundredth of a millimeter in the PACS station, we calculated the resolution of the images provided by the 2K monitors to be above 0.1 mm. The calculated in-plane resolution achievable from the technical parameters was limited to 0.3 mm in MDCT and 0.5 mm in MRI, based on the pixel number and FOV. Measured values were rounded to the nearest tenth of a millimeter.

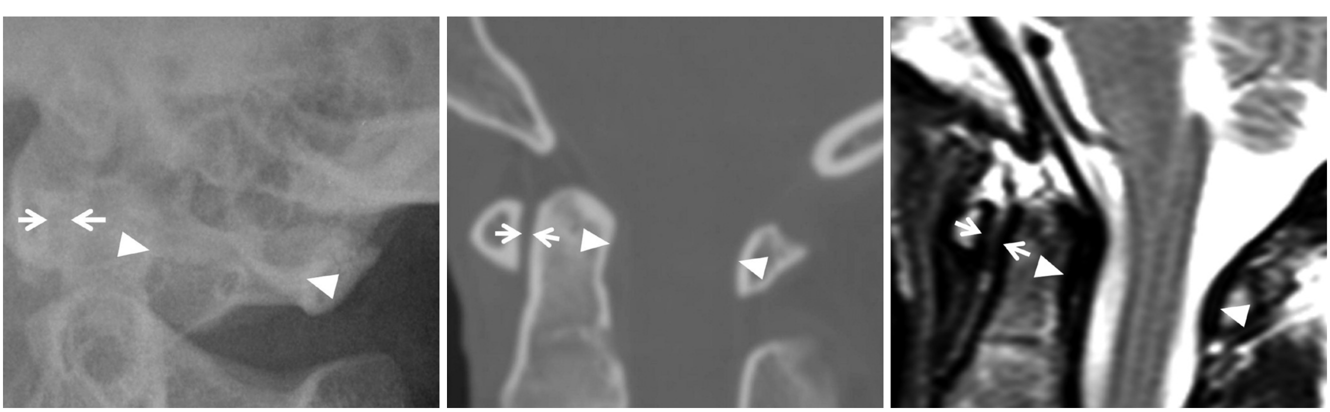
Statistical Analysis

Two radiologists (with 3 and 12 years of experience) measured AADI and PADI on the 60 plain radiographs, MDCT, and MRI independently. These were completely deidentified and presented in random order. With these data, we evaluated the interobserver, and intraobserver agreement. For comparing intraobserver and interobserver agreement, we used the intraclass correlation coefficient as described by Shrout and Fleiss (25). One month later, three radiologists (with 3, 12, and 17 years of experience) measured the AADI and PADI on all the images by consensus, and the dural sac widths and spinal cord diameters on MRI were also measured by consensus. These consensus measures were used in all the analyses. We calculated the mean values, standard deviation of the AADI and PADI values using one-way analysis of variance, and Pearson's correlation methods. SPSS 17.0 (SPSS Inc., Chicago, IL, USA) was used to analyze data and a p value of ≤ 0.05 was taken to indicate statistical significance. Finally, we used Microsoft Office Excel software to draw graphs of the 60 pairs of AADI and PADI data to detect any differences between the values obtained by the three modalities.

RESULTS

AADI on Plain Radiography, MDCT, and MRI

The average AADI values were 1.5 ± 0.5 (range of 0.7–2.8) mm on plain radiography, 1.4 ± 0.3 (0.9–2.6) mm on MDCT, and 1.6 ± 0.5 (0.5–2.7) mm on MRI (Table 1). We found that none of the values of plain radiography, MDCT or MRI exceeded 3 mm, and only 9 and 10 of the 60 sets of values exceeded 2 mm for AADI on plain radiography and MRI, respectively. In



A B C

Fig. 1. Anterior atlantodental interval (AADI) and posterior atlantodental interval (PADI) on plain radiography, multidetector CT (MDCT), and MRI.
A. A representative normal subject shows AADI (distance between white arrows) and PADI (distance between arrowheads) on plain radiography.
B. A representative normal subject shows AADI (distance between white arrows) and PADI (distance between arrowheads) on MDCT.
C. A representative normal subject shows AADI (distance between white arrows) and PADI (distance between arrowheads) on MRI.

Table 1. Parameters of the AADI and PADI in the Study Population (mm)

	Plain Radiography	MDCT	MRI
AADI			
Range	0.7–2.8	0.9–2.3	0.5–2.7
Mean	1.5	1.4	1.6
Standard deviation	0.5	0.3	0.5
Interobserver agreement	0.789	0.797	0.701
Intraobserver agreement	0.707	0.801	0.681
PADI			
Range	13.3–27.7	13.0–23.7	13.8–23.6
Mean	20.6	18.0	17.7
Standard deviation	2.4	2.1	1.9
Interobserver agreement	0.927	0.915	0.760
Intraobserver agreement	0.879	0.937	0.857

Note.—AADI = anterior atlantodental interval, MDCT = multidetector CT, PADI = posterior atlantodental interval

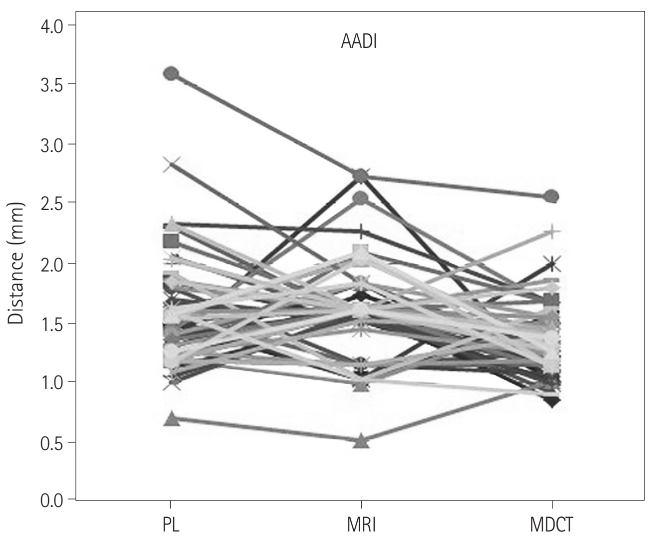


Fig. 2. AADI on plain radiography, MDCT, and MRI. The differences and tendencies of the AADI values measured on plain radiography, MDCT, and MRI can be seen. AADI on MDCT is significantly below that on plain radiography and MRI ($p < 0.05$).
Note.—AADI = anterior atlantodental interval, MDCT = multidetector CT, PL = plain radiography

addition, on MDCT, only one of the 60 subjects yielded values exceeding 2 mm for AADI. AADI on MDCT was significantly smaller than on plain radiography or MRI ($p < 0.05$) (Fig. 2). Interobserver and intraobserver agreement were: on plain radiography, 0.789 and 0.707; on MDCT, 0.797 and 0.801; and on MRI, 0.701 and 0.681, respectively.

We found our data are in good agreement with previous reports. In the recent literature, AADI on MDCT is reported to be 1.83 ± 0.46 mm in men and 1.63 ± 0.43 in women (22), and AADI on MRI is reported to be 2.29 ± 0.47 mm (23). These results agree with our finding that AADI on MDCT is smaller than AADI on MRI. The AADI on MRI had a larger standard deviation than on MDCT, as large as on plain radiography. This could be due to the relatively large pixel size of MRI, which may not accurately represent the small AADI, or due to a chemical shift artifact in the bony cortex and inner bone marrow fat and outer cartilage, or the indeterminate bony margin of the zero signal of the cortical bone itself (8). Also, we used only T2-weighted midsagittal images, and the differentiation of bone from ligamentous structures can be obscure on T2-weighted images.

PADI on Plain Radiography, MDCT, and MRI

Average PADI values were 20.6 ± 2.4 (range of 13.3–27.7) mm on plain radiography, 18.0 ± 2.1 (13.0–23.7) mm on MDCT, and 17.7 ± 1.9 (13.8–23.6) mm on MRI (Table 1). The PADI on plain radiography was higher than on MDCT or MRI ($p < 0.05$) (Fig. 3). Interobserver and intraobserver agreement were: on plain radiography, 0.927 and 0.879; on MDCT, 0.915 and 0.937; and on MRI, 0.760 and 0.857, respectively.

A recently reported normative PADI value was 20.6 ± 2.6 (15–28) mm (11), very similar to our result. In another study, PADI showed good agreement with postsurgical neurological recovery in rheumatoid arthritis patients (9). On plain radiography, PADI measured larger than on MDCT and MRI, and that may be due to the magnification on the image at the 1.75 m standard tube distance. MDCT and MRI do not magnify images, and they yielded very similar PADI values.

Dural Sac Width and Spinal Cord Diameter on MRI

Average dural sac width was 13.7 ± 1.8 (range of 9.9–20.0) mm and the average spinal cord diameter was 7.8 ± 0.7 (range of 6.2–9.3) mm. Dural sac width is known to vary with position. Dvorak et al. (24) reported that in a patient group with known atlantoaxial instability, the mean diameter of the spinal cord was 7.4 mm in the neutral position and 6.5 mm in flexion, and that a spinal cord diameter, in cervical flexion, of less than 6 mm was a risk factor for neurological deficits. In the statistical analysis, the dural sac width most strongly correlated with PADI on MDCT.

DISCUSSION

Identifying and diagnosing instability in imaging studies is clinically important but very challenging. Many studies have focused a great deal of attention on diagnosing atlantoaxial instability. While an increased AADI provides indirect evidence there may be instability, it is possible that this increase is fixed, and in the absence of neural compression, the segment may be completely stable. An abnormal AADI does not necessarily imply neurological abnormality. PADI narrowing also does not direct imply neurological abnormalities. The narrowing of the PADI can lead to vascular compromise of the anterior spinal artery, vertebral artery, and basilar artery, even without direct compression of spinal cord (8). The value of PADI has been reported to be correlated with the presence and severity of paralysis, and was the most important predictor of the potential for neurological recovery after surgery in rheumatoid arthritis patients (9).

However, there are no established normal values of the AADI and PADI in MDCT and MRI yet. Currently, MDCT and MRI are preferred for critical evaluations because of their ability to detect bone and soft tissue lesions of the atlantoaxial joint (2, 8, 9, 12). MDCT is considered to be very available, efficient, and accurate for cervical spine blunt trauma in order to exclude unstable injuries (15, 20). MRI shows the spinal cord itself, and the visualization of the cord allows clinicians to determine whether the cord is at risk for, or compressed. MRI can also reveal isolated ligamentous injury, spinal cord contusion, and complex injuries of the occipitoatlantal joint capsule and craniocervical ligaments (16-19). However, MRI does not permit close cardiovascular monitoring and ventilation support of the traumatized patients during data acquisition (17). Although the actual measurement of the AADI and PADI is inconsequential in MRI, the relation of the AADI and PADI among plain radiography, MDCT, and MRI may help us to decide which patient should undergo an MRI, in spite of the long data acquisition time and troublesome manual ventilation support. So, we tried to find any tendency and relation of AADI and PADI among the three imaging modalities.

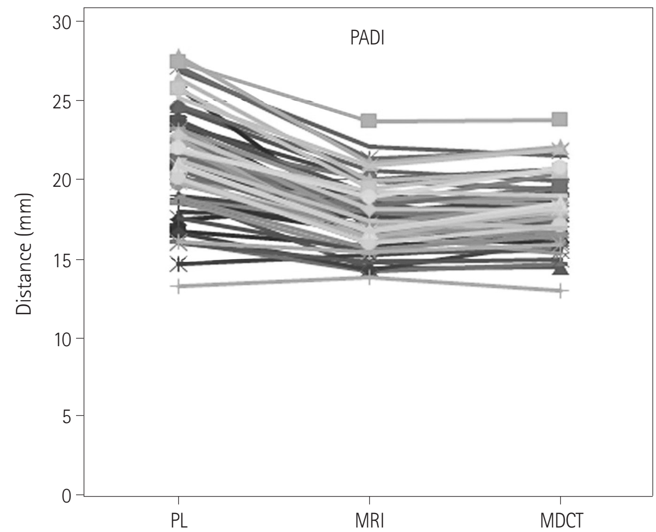


Fig. 3. PADI on plain radiography, MDCT, and MRI. The differences and tendencies of PADI values measured on plain radiography, MDCT, and MRI can be seen. PADI on plain radiography is significantly larger than on MDCT and MRI ($p < 0.05$).
Note.—MDCT = multidetector CT, PADI = posterior atlantodental interval, PL = plain radiography

The most accurate method to measure AADI and PADI among plain radiography, MDCT, and MRI is MDCT because the definition of AADI and PADI is based on the diameter between cortical bone surface of odontoid process and atlas. Plain radiography is not only inevitably larger than MDCT due to magnification on the image but also less efficient for measuring the distance of the complex anatomy of the cervical spine. And MRI has a disadvantage in the discrimination of the boundary of cortical bone and ligament. However, there have been no previous reports about the correlation between AADI and PADI on MRI and a comparison with plain radiography and MDCT. In our study, the data of AADI and PADI on plain radiography and MDCT show good agreement with previous reports. Also, AADI on MDCT is significantly smaller than on plain radiography and MRI, and PADI on plain radiography is significantly larger than those on MDCT and MRI. AADI and PADI on MRI are similar to those on MDCT.

PADI of less than 14 mm was associated with the presence of paralysis, and in another study, severe stenosis was defined as a

PADI not exceeding 13 mm (11). In that study, the definition of PADI was based on plain radiography. In our study, PADI values obtained on MDCT were significantly lower than those obtained on plain radiography. So, the same numerical value of 14 mm can be applied to MDCT. Also, PADI was easier to measure than AADI, thanks to its large size. And, the dural sac width was closely correlated with PADI on the MDCT, which may imply that PADI is a direct indicator of the neurological risk, making it more relevant and clinically useful. However, a large scale test should be done in the future to confirm the findings.

There were some limitations in our study. First, the patients had undergone plain radiography and MRI of the cervical spine as part of routine evaluation of their lumbar spine or for screening of the cervical spine. Hence, there were only T2-weighted images for most of the patients. MR sequences may have influenced the measurements because of the extent of bony cortex-ligament discrimination and chemical shift artifacts, and single sagittal T2-weighted images may not give an accurate determination of measurements, especially if the patient is rotated, or has curvature. Post-processing to obtain the mid-sagittal image may decrease resolution especially with the small measurement of AADI. Second, there is difficulty in deciding what to measure, due to the confusing superimposition and complexity of the radiographic anatomy of the cervicocranium and the inherent granularity of radiographic images, as in AADI (7). Third, the AADI and PADI measurements may have been affected by the change of position, as we took the plain radiographs of the cervical spine in a neutral sitting position, and MDCT and MRI in a neutral supine position. This alone could make the differences in measurements found in this study or be the real reason, rather than one study being less accurate.

In summary, AADI values obtained on MDCT are significantly lower than those obtained on plain radiography or MRI. PADI values obtained on plain radiography are significantly higher than those obtained on MDCT or MRI. Dural sac width is most closely correlated with PADI values on MDCT. Finally, PADI seems to be easier to measure, more relevant, and more clinically useful than AADI.

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경추부위의 단순방사선, Multidetector CT, MRI 검사에서의 전환추-축추 간격과 후환추-축추 간격[1]

윤기보[2] · 차승우[1] · 류정아[1] · 박동우[1] · 이승훈[2] · 주경빈[2]

목적: Multidetector CT (이하 MDCT)와 MRI에서 전환추-축추 간격(anterior atlantodental interval; 이하 AADI)과 후환추-축추 간격(posterior atlantodental interval; 이하 PADI)의 정상 수치를 구하고자 하였다.

대상과 방법: 경추부위의 단순방사선검사, MDCT, MRI를 모두 시행한 60명(남성: 35명, 여성: 25명)의 환자를 대상으로 하였으며 각각의 AADI, PADI를 구하였다. MRI상 환추축성 관절(atlantoaxial joint) 위치에서 경막주머니 너비와 척수 직경을 구하였다. 두 명의 영상의학과 의사가 독립적으로 측정을 하였으며 세 명이 합의하여 측정하였다.

결과: 평균 AADI의 수치는 단순방사선검사상 1.5 ± 0.5 mm, MDCT상 1.4 ± 0.3 mm, MRI상 1.6 ± 0.5 mm였다. 평균 PADI의 수치는 단순방사선검사상 20.6 ± 2.4 mm, MDCT상 18.0 ± 2.1 mm, MRI상 17.7 ± 1.9 mm였다. 환추축성 관절에서 평균 경막주머니 너비는 13.7 ± 1.8 mm, 평균 척수 직경은 7.8 ± 0.7 mm였다. 관찰자간일치도는 0.701~0.927, 관찰자내일치도는 0.681~0.937이었다.

결론: MDCT에서 전환추-축추 간격 수치는 단순방사선검사나 MRI에서 얻은 수치보다 의미있게 작았다. 단순방사선검사에서 후환추-축추 간격은 MDCT나 MRI에서 얻은 수치보다 의미있게 컸다. 환추축성 관절에서 경막주머니 너비는 MDCT의 후환추-축추 간격과 가장 연관성이 있었다. 후환추-축추 간격은 전환추-축추 간격보다 더 쉽게 측정가능하며 유용하게 생각된다.

[1]한양대학교 의과대학 구리병원 영상의학과, [2]한양대학교 의과대학 한양대학교병원 영상의학과