Oblique Radiographs Compared Favorably With Computed Tomography Images in Assessing Cervical Foraminal Area

Christopher P. Miller, MD, Jennifer Sabino, MD, Jesse E. Bible, MD, Peter G. Whang, MD, and Jonathan N. Grauer, MD

Abstract

Oblique radiographs are often ordered to evaluate the patency of cervical intervertebral foramina. Previous studies have shown that computed tomography (CT) provides accurate measurements of foraminal dimensions. Up until now, no study has directly compared the diagnostic utility of oblique radiographs and CT.

We conducted a study to quantify the correlation between cervical foramina dimensions measured on oblique radiographs and on CT scans. Heights, widths, and cross-sectional areas were evaluated at every level from C2–C3 through C7–T1 using both oblique radiographs and oblique CT reconstructions. Both measurements were performed at a 50% oblique angle.

Interreliability and intrareliability statistics for radiographs and CT were 0.91 and 0.99 for height, 0.90 and 0.97 for width, and 0.84 and 0.92 for area. Pearson correlation coefficients for height, width, and area were 0.439, 0.871, and 0.899, respectively.

Oblique radiographs of the cervical spine provide accurate estimates of intervertebral foraminal dimensions—estimates similar to those generated from CT reconstructions. Thus, these radiographs may serve as an acceptable first-line imaging study for initial assessment of patients suspected of having nerve root compression that precludes the higher cost and radiation exposure associated with CT scans.

Dr. Miller is Resident Physician, Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut.

Dr. Sabino is Resident Physician, Department of Surgery, Walter Reed Army Medical Center, Washington, DC.

Dr. Bible is Resident Physician, Department of Orthopaedics, Vanderbilt University School of Medicine, Nashville, Tennessee.

Dr. Whang is Associate Professor, and Dr. Grauer is Associate Professor, Department of Orthopaedics and Rehabilitation, Yale University School of Medicine.

Address correspondence to: Jonathan N. Grauer, MD, Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, PO Box 208071, New Haven, CT 06520-8071 (tel, 203-737-7463; fax, 203-785-7132; e-mail, jonathan.grauer@yale.edu).

Am J Orthop. 2011;40(5):241-245.

Several imaging techniques are used routinely to evaluate patients with cervical spine conditions. In particular, these studies may be useful for visualizing degenerative changes—such as osteophyte formation, disk space narrowing, and foraminal stenosis—that may place these individuals at risk for compression of the neural elements. Plain radiographs, which are inexpensive and readily accessible, are often obtained in these situations. In addition to standard anteroposterior (AP) and lateral views, oblique views (views oriented approximately 45° with respect to the midsagittal plane) also may be included in a cervical spine series to assess the intervertebral foramina.[1,2] In a survey published in 2007, 8% of 104 spine surgeons reported typically ordering oblique radiographs of the cervical spine as part of the initial battery of imaging studies, and 16% reported obtaining these films when considering operative intervention for spondylotic conditions.[3]

In contrast, computed tomography (CT) is widely believed to be the gold standard for depicting the intervertebral foramina; it clearly delineates the bony margins of these structures and better characterizes osteophytes and neural structures.[4,5] Multiple investigators have found that foraminal dimensions estimated from CT studies were similar to the anatomical data derived from cadaveric dissections.[6-8] Three-dimensional reconstructions may be preferred over conventional CT for this application because these images are more orthogonal to the foramina and are not as dependent on the angle of the gantry, resulting in improved interobserver variability.[9] Stockley and colleagues[10] reported that oblique CT reconstructions correctly predicted symptomatic nerve compression secondary to bony entrapment in 75% of the patients in their series.

Oblique radiographs are often obtained for inspection of the foramina; however, the diagnostic accuracy of these films has not been established definitively.[11,12] CT, with oblique reconstructions, offers multiplanar views of the foramina; however this modality may not be appropriate as a first-line imaging technique for the diagnostic workup of individuals with compressive pathology of the cervical spine, as it is relatively time consuming and expensive and generates more ionizing radiation than plain radiographs do.[13,14] To date, the relationship between foraminal dimensions on oblique radiographs

Table. Radiography Data With Magnification Correction and Computed Tomography Data With 95% Confidence Intervals (CI)

Spine Level	Radiography Mean	Radiography 95% CI	Computed Tomography Mean	Computed Tomography 95% CI	*P* value
Height, mm					
C2–C3	11.9	1.0	11.0	1.2	.396
C3–C4	9.6	0.8	10.0	0.7	.291
C4–C5	9.9	0.9	10.2	1.0	.739
C5–C6	9.0	1.3	10.5	0.5	.121
C6–C7	9.7	0.8	11.2	1.0	.027[a]
C7–T1	8.7	0.7	10.5	0.7	.008[a]
Width, mm					
C2–C3	7.8	0.9	7.9	1.3	.655
C3–C4	5.8	1.3	5.9	0.5	.299
C4–C5	5.7	0.8	5.9	0.6	.652
C5–C6	4.6	0.7	5.8	0.6	.042[a]
C6–C7	5.7	0.7	5.9	0.4	.557
C7–T1	5.9	0.8	7.0	0.6	.096
Area, mm^2					
C2–C3	79.3	8.2	69.4	6.6	.036[a]
C3–C4	56.0	11.4	52.1	12.4	.779
C4–C5	58.2	16.2	56.5	11.6	.721
C5–C6	53.6	12.2	47.0	11.1	.526
C6–C7	64.5	9.6	59.7	10.9	.349
C7–T1	67.3	12.5	69.7	11.2	.709

[a]Statistically significant.

and those calculated from CT scans has not been elucidated in comparative investigations. The purpose of the present cadaveric study was to quantify the degree of correlation between these 2 methods for measuring various foraminal parameters.

Materials and Methods

Specimen Preparation

Four fresh-frozen human cadaveric cervical spines that had previously been subjected to atraumatic biomechanical testing were stripped of all nonligamentous soft tissues and mounted in resin blocks at the levels of the occiput and T2 vertebral body. AP and lateral radiographs were initially obtained to verify that there were no gross deformities, fractures, or other anatomical abnormalities that might obscure visualization of the foramina. Specimens were frozen in neutral alignment and were maintained in this position during the ensuing radiographic and CT imaging to ensure that the foraminal dimensions remained constant throughout the study.

Radiographic Assessment of Cervical Foramina

The cervical spines were placed upright on a marked turntable so that oblique radiographs could be obtained bilaterally at an angle of 50° from the AP plane, based on previous data confirming that this orientation maximized the foraminal area on these films.[15] For each specimen, both foramina from C2–C3 to C7–T1 were inspected, for a total of 48 structures in this series. The left C2–C3 and C3–C4 foramina from 1 cadaveric specimen were not clearly visible on both radiographs and CT and were therefore excluded from subsequent analysis.

Using the measurement tools in our institution's digital radiography software (Synapse V3.0, FujiFilm USA, Valhalla, New York), we assessed 3 discrete parameters for each foramen: height, width, and cross-sectional area. Foraminal height was defined as the farthest distance between the bony margins of the cephalad and caudal pedicles, and foraminal width was bounded anteriorly by the uncovertebral joint and posteriorly by the zygoapophyseal joint (Figure 1A); both dimensions were calculated with the distance function and were reported in millimeters. Cross-sectional area was determined by tracing the space demarcated by these landmarks with the freehand instrument and was expressed in square millimeters (Figure 1B). Each plain film and each CT scan were reviewed by 3 independent observers—an attending spine surgeon, a spine surgery fellow, and an orthopedic research fellow.

The magnification factor of the radiographs was calculated with a calibration application (TraumaCad; Orthocrat, Petach-Tikva, Israel). An OrthoMark (Orthocrat) steel sphere of known diameter (25 mm) was placed on the turntable the same distance away from the x-ray source as the cadaveric specimens. The apparent diameter of the sphere on the radiograph

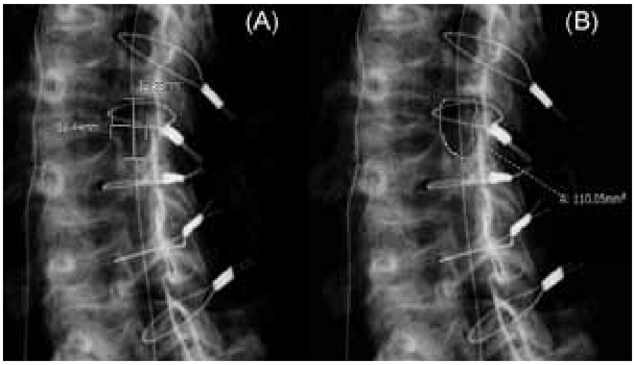

Figure 1. (A) Calculation of foraminal height and width from oblique radiograph of cadaveric specimen using digital radiography software. (B) Calculation of foraminal area using digital freehand measurement tool.

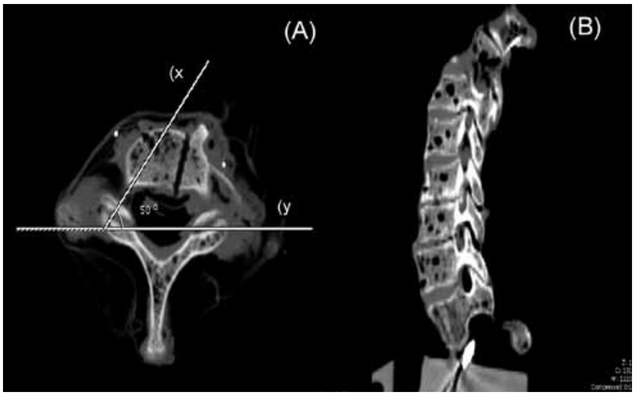

Figure 2. Axial (A) and sagittal (B) computed tomography reconstructions angled 50° with respect to coronal plane (y-axis).

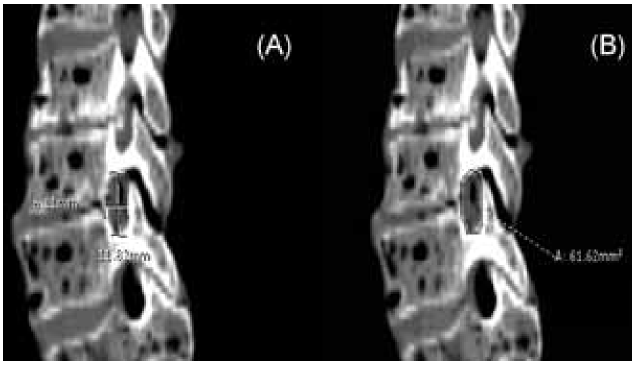

Figure 3. (A) Calculation of foraminal height and width from oblique computed tomography image using digital radiography software. (B) Calculation of foraminal area using freehand measurement tool.

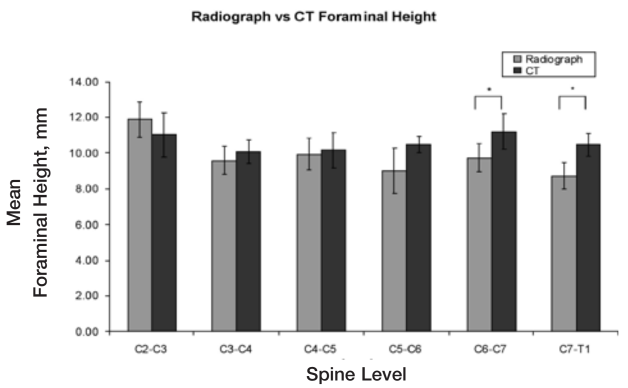

Figure 4. Graph comparing mean foraminal heights (millimeters) derived from oblique radiographs and computed tomography reconstructions. Error bars represent 95% confidence intervals; asterisk indicates significant ($P<.05$) difference between corresponding values.

(30.3 mm) was divided by the true diameter (25 mm) to determine the magnification factor (1.212). All the values recorded from the oblique films were divided by this magnification factor before comparison with the CT data.

Foraminal Assessment From CT Oblique Reconstructions

After the radiographs were completed, thin-cut (2-mm) axial CT images of the cervical spines were generated using a GE LightSpeed 16 Scanner (GE Healthcare, Piscataway, New Jersey) and stored in a digital archive system (Synapse/PACS, FujiFilm USA) so that they could be converted into oblique reconstructions angled 50° from the AP plane, similar to the orientation of the radiographs (Figure 2). As with the plain radiographs, the CT images were measured for height, width, and cross-sectional area, including the narrowest point of each foramen, according to a validated technique described for the lumbar spine (Figure 3).[6,9]

Data Analysis and Statistical Methods

After the data were compiled, statistical testing was performed using SPSS 17.00 software (SPSS Inc, Chicago, Illinois). A priori analyses of parameters were completed to determine the interobserver reliabilities of the 3 examiners for both the oblique radiographs and the CT reconstructions. Intraclass correlation coefficients (ICCs) were also derived from a 2-way random effects model in conjunction with the consistency definition, which reflects the ability of these findings to be generalized to all possible judges. ICCs were interpreted according to a classification scheme of <0.40 (poor), 0.40 to 0.59 (fair), 0.60 to 0.74 (good), and >0.74 (excellent).[16,17]

For both imaging techniques, mean values for foraminal height, width, and cross-sectional area (with 95% confidence intervals [CIs]) were calculated for each level of the spine and were compared using a 2-tailed paired *t* test. The Pearson correlation coefficient was used to depict the linear relationship between the measurements obtained from radiographs and those generated from CT reconstructions: 0.1 to 0.3 (small correlation), 0.3 to 0.5 (medium correlation), and 0.5 to 0.9 (strong correlation).[18] Statistical significance was defined as $P<.05$.

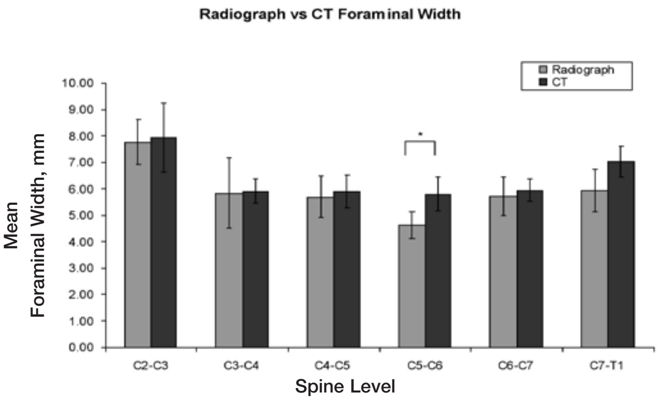

Figure 5. Graph comparing mean foraminal widths (millimeters) derived from oblique radiographs and computed tomography reconstructions. Error bars represent 95% confidence intervals; asterisk indicates significant (*P*<.05) difference between corresponding values.

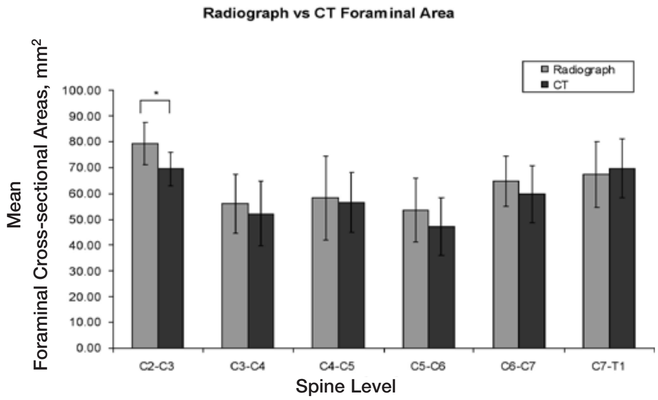

Figure 6. Graph comparing mean foraminal cross-sectional areas (square millimeters) derived from oblique radiographs and computed tomography reconstructions. Error bars represent 95% confidence intervals; asterisk indicates significant (*P*<.05) difference between corresponding values.

Results

Measurement Reliability

The a priori analyses of the measurements from radiographs of a single specimen revealed excellent interobserver reliabilities for foraminal height, width, and cross-sectional area; the ICCs for these parameters were 0.91 (95% CI, 0.61–0.99), 0.90 (95% CI, 0.58–0.99), and 0.84 (95% CI, 0.58–0.98), respectively. The corresponding values from CT images also exhibited excellent interobserver reliabilities, with ICCs of 0.99 (95% CI, 0.96–0.99), 0.97 (95% CI, 0.88–0.99), and 0.92 (95% CI, 0.67–0.99) for height, width, and cross-sectional area, respectively.

Foraminal Height

For each level of the cervical spine, the mean foraminal heights (and 95% CIs) were determined from the oblique radiographs and CT reconstructions. These heights are listed in the Table and presented graphically in Figure 4. At C6–C7 and C7–T1, the CT values were significantly larger than those estimated from the radiographs (*P* = .027 and *P* = .008, respectively), with no other statistically significant differences observed for any of the more proximal foramina. The Pearson correlation coefficient between the mean height data collected with these 2 techniques was 0.439 (*P* = .378).

Foraminal Width

The mean foraminal widths, determined from the oblique radiographs and CT reconstructions, are listed in the Table and presented graphically in Figure 5. The only significant difference between CT and radiographic measurements was at C5–C6 (*P* = .042). The Pearson correlation coefficient between the mean width data was 0.871 (*P* = .024), indicative of a strong association.

Foraminal Cross-Sectional Area

The mean foraminal areas calculated from the oblique radiographs and CT reconstructions are listed in the Table and presented graphically in Figure 6. Aside from the C2–C3 foramen, for which the mean cross-sectional area assessed from the radiographs was significantly (*P* = .036) larger than that measured from the CT images, there were no statistically significant differences between these modalities at any level of the cervical spine. Again, a strong association between the mean widths was reflected by a Pearson correlation coefficient of 0.899 (*P* = .015).

Discussion

Oblique radiographs and CT scans are regularly obtained to facilitate diagnostic evaluation and preoperative assessment of patients with degenerative conditions of the cervical spine. Although both imaging modalities may be used to visualize the cervical foramina, each technique has its relative advantages and disadvantages. Radiographs are usually less expensive and more easily accessible than CT images, but there is still some debate regarding the accuracy of oblique radiographs for depicting the patency of foramina. In contrast, CT reconstructions provide multiplanar views of the bony anatomy, which allow for more precise measurement of foraminal dimensions; unfortunately, these studies are more costly than plain films. In addition, though newer protocols are consistently decreasing the required dose of radiation, they do subject patients to considerably more ionizing radiation—which according to a recent report may be more than 68 times larger than the exposure generated from a series of cervical radiographs.[13,14] The purpose of our investigation was to compare the height, width, and cross-sectional area of the cervical foramina on oblique radiographs and CT images of cadaveric specimens.

Analysis of these data sets revealed significant positive correlations between the mean values obtained from the radiographs and the CT scans. The Pearson correlation coefficients for width and cross-sectional area were 0.871 and 0.899, respectively, with both indicating a strong positive correlation according to the guidelines proposed by Cohen.[18] It has been suggested that these 2 parameters are the most clinically relevant, as foraminal narrowing with resultant nerve compression usually occurs secondary to facet hypertrophy and uncovertebral osteophytes, which are more likely to diminish the width and total area of these structures but not necessarily their height.[19]

The only statistically significant discrepancies between radiographic and CT values were found at C6–C7 and C7–T1 for height, at C5–C6 for width, and at C2–C3 for cross-sectional area. These disparities may be attributed in part to unavoidable deviations from the optimal angle for visualizing the foramina at each level, which has been shown to range from 46.3° at C2–C3 to 56.1° at C7–T1.[15] Furthermore, the mean widths at C5–C6 and mean areas at C2–C3 varied by only 1 mm and 10 mm^2, respectively. Although these differences were statistically significant, we believe that the minor deviations exhibited by these 2 imaging modalities are not clinically relevant and would not be expected to alter the decision making of the practitioners reviewing these studies.

The limitations of this study clearly merit discussion. For practical purposes, images were obtained with specimens positioned approximately 50° relative to the midsagittal plane. In the previously cited investigation,[15] we demonstrated that an angle of 52.4° maximized the total size of the foramina across the entire cervical spine on oblique radiographs; however, maintaining the film cassette within 5° of this "ideal" orientation did not give rise to any significant increases in the percentage error. In addition, we did not take into account the potential effects of angulation in other planes on these results. For instance, it is conceivable that adjusting the x-ray beam more cephalad or caudad may also determine to what extent the foramina may be visualized on oblique radiographs or CT reconstructions such that their appearance may be distorted on these images. Finally, because the foramina of these cervical spine specimens were not directly measured, it was not possible to quantify the accuracy of the radiographic and CT readings with the true anatomical measurements. Although no one has reported a study comparing the foraminal dimensions apparent on oblique radiographs with those derived from cadaveric dissections, previous reports have confirmed that CT approximates these anatomical values more closely than other advanced imaging modalities.[7,8,10,20]

Conclusion

In conclusion, we believe that the present study is the first to characterize the diagnostic utility of oblique radiographs and CT reconstructions for assessing the cervical foramina. Although CT is widely accepted as the gold standard for viewing the bony structures of the cervical spine, the significant correlation between these 2 modalities suggests that plain radiographs may be the most appropriate imaging study for initial evaluation of patients with suspected nerve root compression, as they are likely to provide sufficient spatial information about the foramina and in many cases may preclude the need for CT scans—which not only are more expensive than radiographs but also are known to expose patients to more substantial amounts of ionizing radiation.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

References

1. Abel MS. The exaggerated supine oblique view of the cervical spine. *Skeletal Radiol.* 1982;8(3):213-219.
2. Pyhtinen J, Laitinen J. Cervical intervertebral foramen narrowing and myelographic nerve root sleeve deformities. *Neuroradiology*. 1993;35(8):596-597.
3. Hammouri QM, Simpson AK, Grauer JN, Rechtine G. From the imaging department: a questionnaire study of the use of radiographs in the evaluation of spine complaints. *Spine J.* 2007;7(6):745-747.
4. Lee BC, Kazam E, Newman AD. Computed tomography of the spine and spinal cord. *Radiology.* 1978;128(1):95-102.
5. Modic MT, Ross JS, Masaryk TJ. Imaging of degenerative disease of the cervical spine. *Clin Orthop.* 1989;(239):109-120.
6. Inufusa A, An HS, Lim TH, Hasegawa T, Haughton VM, Nowicki BH. Anatomic changes of the spinal canal and intervertebral foramen associated with flexion-extension movement. *Spine.* 1996;21(21):2412-2420.
7. Kitagawa T, Fujiwara A, Kobayashi N, Saiki K, Tamai K, Saotome K. Morphologic changes in the cervical neural foramen due to flexion and extension: in vivo imaging study. *Spine.* 2004;29(24):2821-2825.
8. Pech P, Daniels DL, Williams AL, Haughton VM. The cervical neural foramina: correlation of microtomy and CT anatomy. *Radiology.* 1985;155(1):143-146.
9. Roberts CC, McDaniel NT, Krupinski EA, Erly WK. Oblique reformation in cervical spine computed tomography: a new look at an old friend. *Spine.* 2003;28(2):167-170.
10. Stockley I, Getty CJ, Dixon AK, Glaves I, Euinton HA, Barrington NA. Lumbar lateral canal entrapment: clinical, radiculographic and computed tomographic findings. *Clin Radiol.* 1988;39(2):144-149.
11. Mink JH, Gordon RE, Deutsch AL. The cervical spine: radiologist's perspective. *Phys Med Rehabil Clin North Am.* 2003;14(3):493-548, vi.
12. Polston DW. Cervical radiculopathy. *Neurol Clin.* 2007;25(2):373-385.
13. Biswas D, Bible JE, Bohan M, Simpson AK, Whang PG, Grauer JN. Radiation exposure from musculoskeletal computerized tomographic scans. *J Bone Joint Surg Am.* 2009;91(8):1882-1889.
14. Simpson AK, Whang PG, Jonisch A, Haims A, Grauer JN. The radiation exposure associated with cervical and lumbar spine radiographs. *J Spinal Disord Tech.* 2008;21(6):409-412.
15. Simpson AK, Sabino J, Whang P, Emerson JW, Grauer JN. The assessment of cervical foramina with oblique radiographs: the effect of film angle on foraminal area. *J Spinal Disord Tech.* 2009;22(1):21-25.
16. Cohen J, Cohen P. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1983.
17. Fleiss JL. *Statistical Methods for Rates and Proportions*. 2nd ed. New York, NY: Wiley; 1981.
18. Cohen J. *Statistical Power Analysis for the Behavioral Sciences.* 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
19. Tanaka N, Fujimoto Y, An HS, Ikuta Y, Yasuda M. The anatomic relation among the nerve roots, intervertebral foramina, and intervertebral discs of the cervical spine. *Spine.* 2000;25(3):286-291.
20. Rauschning W, Bergström K, Pech P. Correlative craniospinal anatomy studies by computed tomography and cryomicrotomy. *J Comput Assist Tomogr.* 1983;7(1):9-13.

This paper will be judged for the Resident Writer's Award.