The Assessment of Cervical Foramina With Oblique Radiographs: The Effect of Film Angle on Foraminal Area

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Study Design: Radiographic evaluation of cadaveric cervical spine specimens.

Objective: Assess reliability and reproducibility of foraminal dimensions obtained from cervical radiographs of varying obliquity and determine optimal angles for visualizing foramina at each cervical spine level.

Summary of Background Data: Oblique radiographs may be considered to assess cervical foraminal dimensions and are generally obtained 45 degrees from the anteroposterior (AP) orientation. Previous reports have suggested that foraminal area observed on these radiographs may be influenced by changes in obliquity so that certain film angles may be better suited for accurately assessing foramen size, depending on which level is being evaluated.

Methods: Radiographs of 4 human cadaveric cervical spines were obtained at 5-degree increments from 20 to 70 degrees relative to AP orientation, using both left and right sides of each specimen. Foraminal area was estimated by measuring height and width of each foramen and also with a freehand area measurement tool. Reliabilities of both methods were calculated. At each level, foraminal area was plotted against film angle and quadratic best-fit curves were used to determine the maximum area observed and the optimal angle of obliquity for assessment.

Results: Assessment of foraminal area using the height and width values was associated with good interobserver reliability, whereas the freehand method exhibited excellent reliability. The optimal film angles for calculating foraminal area increased from 46.3 degrees for C2-C3 to 56.1 degrees for C7-T1. The ideal film angle that minimized the overall error of measurement across the entire cervical spine was estimated to be 52.4 degrees.

Conclusions: Optimal angles for visualizing lower cervical foramina are larger than those for upper cervical spine. To minimize overall loss of foraminal area throughout the entire cervical spine, oblique cervical radiographs should be obtained at an angle of approximately 52 degrees from the AP orientation.

Key Words: cervical spine, intervertebral foramen, cervical radiographs, cadaver study

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Plain radiographs remain the most commonly used diagnostic imaging modality for evaluating patients with spinal complaints and may be useful for identifying fractures, tumors, or degenerative pathologies. In addition to standard anteroposterior (AP) and lateral x-rays, supplementary views such as dynamic lateral, odontoid, and oblique studies may be considered in certain situations.

Oblique views of the cervical spine are used to assess the patency of the intervertebral foramina and detect potential sites of nerve compression in individuals with suspected radiculopathy. In fact, a recent study demonstrated that as many as 8% of spine specialists routinely include cervical oblique x-rays as part of the initial battery of radiographic series when working up patients with degenerative cervical spine complaints.[1] Moreover, 16% obtained oblique views in the preoperative evaluation of these patients.

Cervical foramina are bordered by the uncovertebral joints anteromedially, the facet joints posterolaterally, and the pedicles of cephalad and caudad vertebrae superiorly and inferiorly. Degenerative changes involving any of these structures may result in compression of the cervical roots as they exit the foramen.[2,3]

As cervical foramina are 3-dimensional structures with an intrinsic angle of orientation, that angle must be reproduced by an oblique radiograph to view the foramen en face and to accurately estimate its dimensions. Any deviation from this specific orientation will result in an apparent foraminal opening that is smaller than the actual foraminal area.

Although cervical oblique x-rays are generally obtained with the film positioned 45 degrees relative to the AP orientation, it has not been definitively established that this angle optimizes the view of the cervical foramina. Abel[4] compared oblique radiographs taken at 45 and 60 degrees using both cadaveric specimens and human subjects. They demonstrated that the 60-degree "exaggerated oblique" radiographs provided better separation of the anterior and posterior elements and facilitated the visualization of the foramina. Marcelis et al[5] analyzed radiographs taken at 35, 45, and 55 degrees and concluded that 55-degree oblique film provided better visualization of the lower cervical foramina than the traditional 45-degree view.

To the best of our knowledge, no reports have determined the ideal oblique imaging angles for visualization of the various cervical foramina. The primary goals of this cadaveric study were to (1) calculate the reliability and reproducibility of the foraminal dimensions evident on cervical radiographs of varying obliquity, (2) determine the optimal film angles for evaluating the foramina at each cervical spine level, and (3) identify the ideal angle of orientation that provides the most representative visualization of all cervical foramina on a single radiograph.

MATERIALS AND METHODS

Specimen Preparation

Four fresh-frozen human cadaveric specimens, including the entire osteoligamentous cervical spine were mounted in resin at the levels of the occiput and the T2 vertebral body. AP and lateral x-rays were initially obtained for each specimen to rule out the presence of gross deformity, fracture, or other pathologic conditions that might obscure the boundaries of the foramina. The specimens were frozen in a neutral posture and were appropriately maintained in this state during all imaging to ensure that the foraminal dimensions would remain constant over time.

Radiographic Evaluation

The spines were placed upright on a revolving platform consisting of 2 layers of plexiglass, which were marked in 5-degree increments to allow for precise positioning of the specimens during the radiographic assessment (Fig. 1).

Plain radiographs were obtained from 20 to 70 degrees from AP orientation at 5-degree increments on both the left and right sides of the specimen. Two example radiographs demonstrate the cervical foramen as they appear at film angles of 45 (Fig. 2A) and 55-degree (Fig. 2B) oblique film angles. These x-rays were obtained with digital radiography software (Synapse V3.0, Fuji Corporation) and all measurements were performed using the program's digital measuring tools.

Assessment of Foraminal Area

From these radiographs, the area of each foramen from C2-C3 to C7-T1 was calculated for all of the specimens. Two separate techniques were used to estimate foraminal area as part of a pilot investigation involving one of the cervical spines. Three independent observers, including an attending spine surgeon, a spine fellow, and an orthopedic research fellow made all measurements. On the basis of the calculated interobserver reliabilities of the 2 methods, the measurement technique that exhibited greater reliability was used for assessment of the remaining specimens.

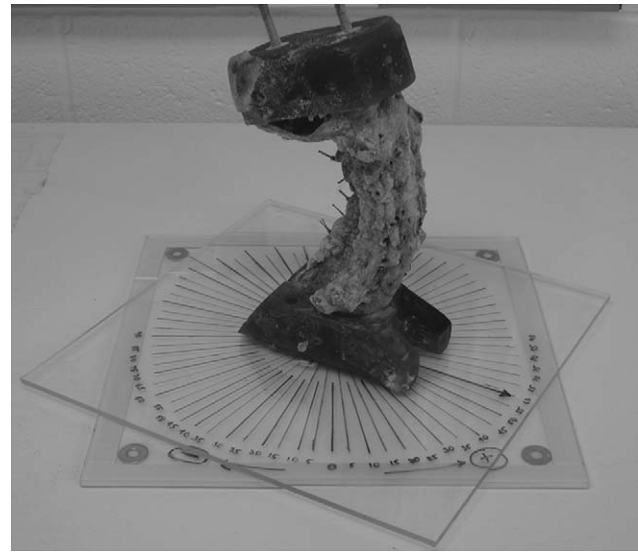

FIGURE 1. Cervical spine specimen frozen in neutral posture, positioned on rotating platform used for specimen orientation during oblique radiograph acquisition.

With the first method, the area was determined using the equation for area of an ovoid shape: $\pi \times (1/2)$ height $\times$ (1/2) width. Foraminal height was considered to be the maximum distance between the bony margins of the cephalad and caudad pedicles, whereas the width was measured at the point of greatest separation between anterior and posterior boundaries of the foramen. The second method for evaluating foraminal area required the use of a freehand area measurement function provided by the digital radiography software; with this tool, the operator manually traced the outline of the foramen and the area within that border was computed. For either approach, any foramina that could not be clearly visualized on the radiographs were not considered in the subsequent analysis.

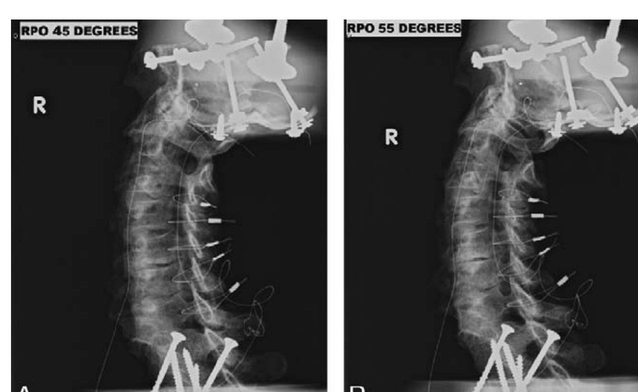

FIGURE 2. Radiographs of specimen A obtained at 45-degree (A) and 55-degree (B) oblique film angles relative to the AP orientation.

Data Analysis and Statistical Methods

A priori analyses were performed on the values recorded by the 3 examiners to determine the interobserver reliabilities of the 2 approaches described for assessing foraminal area. An intraclass correlation coefficient (ICC) represents a measure of interobserver reliability that reflects the relative homogeneity among raters with respect to the total variation; for each method, an ICC was derived using a 2-way random effects model and the consistency definition so that this statistic may be generalizable to all potential judges. For the purpose of comparison, the classification scheme of Fleiss[6] was employed for grading ICCs: <0.40—poor; 0.40 to 0.59—fair; 0.60 to 0.74—good; and >0.74—excellent.

For each foramen, the measured foraminal area was plotted against the film angles. Quadratic best-fit curves were then generated via ordinary least squares to characterize the relationship between these 2 variables. These models were used to estimate the maximum observed foraminal area and the corresponding film angle. This film angle, which would maximize observed foraminal area, was defined as the optimal film angle for visualizing a particular foramen, as this film orientation theoretically corresponds to an en face view of that foramen. The best-fit curve equations were also used to estimate the percent of the maximum area that would be seen on radiographs taken at 5 and 10-degree deviations from the optimal angle for that level. The values associated with the foramina of a given spinal level were averaged across all of the specimens and these means were reported with 95% confidence intervals (CIs).

To identify the single best angle of obliquity for visualizing all foramina across the entire cervical spine, we calculated the percentage of foraminal area lost at a given film angle relative to the maximum observed area. For every foramen, the foraminal area measured at a given film angle was compared with the maximum area observed for that foramen. The percentage of foraminal area lost was then plotted for every foramen for angles between 35 and 65 degrees. These data were then used to develop a quadratic best-fit line curve for these variables and determine the film angle at which foraminal area loss is minimized over all cervical spine levels and specimens.

RESULTS

A priori analyses of reliability for the 2 methods of evaluating foraminal area revealed that multiplying the height and width resulted in good interobserver reliability [ICC 0.74; 95% CI 0.64-0.82], whereas the values obtained with the freehand area measurement tool exhibited excellent reliability (ICC 0.83, 95% CI 0.75-0.89). On the basis of these findings, only the freehand application was used to estimate foraminal area for the remaining cervical spines.

For each foramen evaluated, foraminal area was plotted against the film angle and quadratic curves were fit to these points. An example is given for one of the specimens (specimen A, RPO), which demonstrates the relationships between the measured foraminal areas and the angles at which the oblique radiographs were obtained (Fig. 3). Eight of these plots were generated by measuring all of the foramina on both sides of the 4 specimens. The mean of the R^2 values for these quadratic fits was 0.81, with a standard deviation of 0.075, demonstrating that the curves generally provided very reasonable fits.

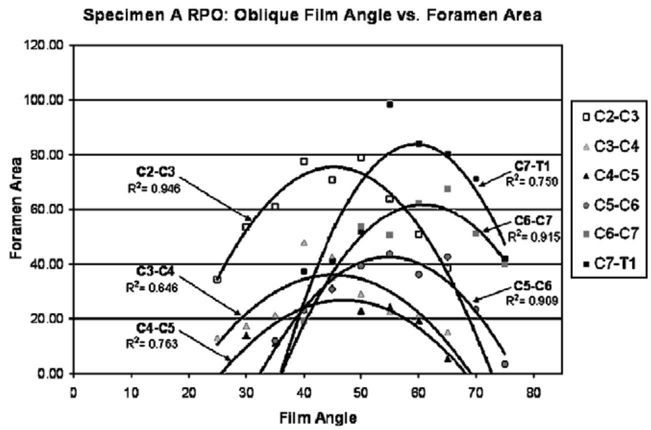

FIGURE 3. Film angle versus foraminal area graph for specimen A, right side, which demonstrates the relationship between film angle and observed foraminal area for each cervical spine level.

The mean optimal film angles (and the corresponding margin of error for a 95% CI) for assessing foraminal area ranged from 46.3 ± 2.7 degrees for the C2-C3 level to 56.1 ± 3.2 degrees at C7-T1 (Fig. 4). The average maximum foraminal area ranged from 66 mm^2 (C5-C6) to 103 mm^2 (C2-C3). The percentage of the maximum area that could be visualized at 5-degree deviations from the ideal film angle varied from 98.05% ± 0.54% at C2-C3 to 96.58% ± 0.76% at C7-T1, whereas for 10-degree deviations these averages decreased to 92.20% ± 2.17% at C2-C3 and 86.32% ± 3.04% at C7-T1 (Fig. 5).

The smallest mean reductions in foraminal area, expressed as a percentage of the maximum value recorded

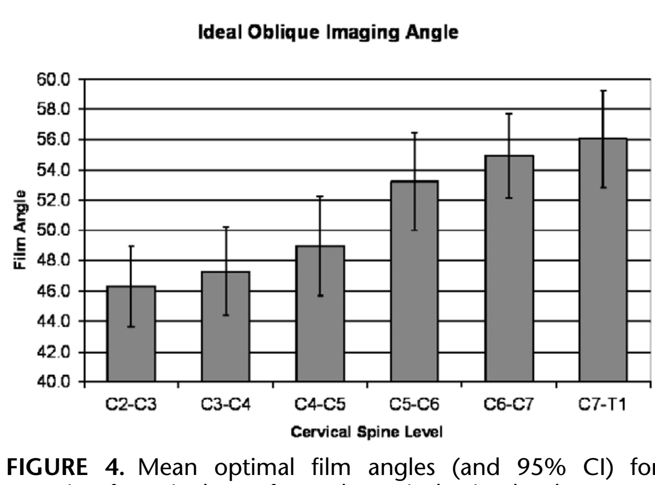

FIGURE 4. Mean optimal film angles (and 95% CI) for assessing foraminal area for each cervical spine level.

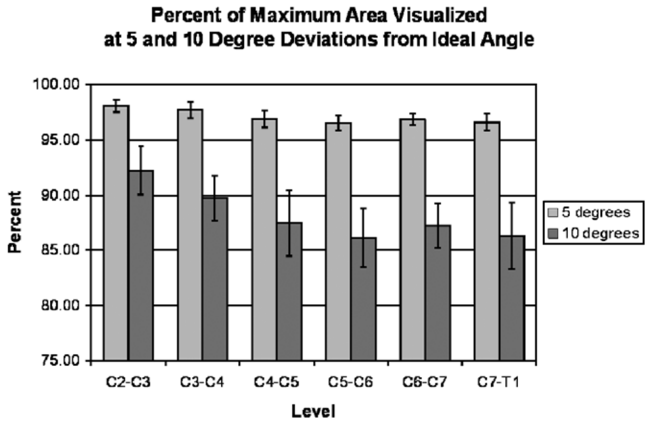

FIGURE 5. Percentage of the maximum observed area that could be visualized at 5-degree deviations from the ideal film angle for each cervical spine level.

for each level, were observed at film angles of 50 and 55 degrees (12.71% and 12.84%, respectively). The lowest point on the curve expressing the average percent reduction in foraminal area as a function of the film angle occurred at 52.4 degrees. Thus, 52.4 degrees may be considered the optimal orientation for obtaining oblique radiographs because the loss of total observed foraminal area across the entire cervical spine was minimized at this angle (Fig. 6).

DISCUSSION

Plain radiographs play an indispensable role in the diagnosis and treatment of cervical spine pathology. We have previously reported that 8% of spine specialists obtain oblique radiographs during the initial evaluation of patients with suspected degeneration of the cervical spine to assess the status of the foramina. Although these films are typically oriented at approximately 45 degrees from the AP view, there continues to be a paucity of data regarding the effects of any changes in obliquity on the assessment of foraminal size. Further, the angle that best facilitates the visualization of cervical foramina remains unknown.

A number of observational studies have suggested that different film angles may be preferable for certain foramina depending on their location, and that x-rays of greater obliquity (ie, greater than 45 degrees) may allow for more accurate estimates of foraminal area.[4,5] We performed a quantitative radiographic analysis of several cadaveric specimens in an attempt to (1) ascertain the optimal film angles for imaging of the neuroforamina at each level of the cervical spine and (2) identify the ideal angle for an oblique x-ray that minimizes the overall error of measurement owing to any variation in foraminal orientation, thereby offering the best view of all the cervical foramina.

Our results confirm that the optimal angles for viewing cervical foramina vary according to the level of the spine that is being considered. Specifically, the C2-C3 foramina were best visualized at 46.3 ± 2.7 degrees, whereas for the more caudal foramina the optimal film angles increased to a maximum of 56.1 ± 3.2 degrees at C7-T1. The divergence of these angles throughout the cervical spine is consistent with earlier studies that also noted that each individual neuroforamen exhibits a unique orientation. Because of this variation in foraminal orientation, different film angles are required to effectively evaluate the foramina of the upper and lower cervical regions.

Given the diverse orientations of the cervical foramina with their discrete optimal film angles, it is unlikely that any single oblique x-ray would be able to present every foramen en face. To understand the effect of film angle on the validity of this radiographic assessment, we calculated the apparent loss of foraminal area that occurred when the film angles deviated from the optimal orientation. In our analysis, altering the angle of obliquity by 10 degrees resulted in an apparent decrease in area of 7.8% at C2-C3 and 13.7% at C7-T1. Because oblique radiographs are frequently acquired at a 45 degrees angle, which is outside the range of optimal values estimated in this investigation, it is likely that many of these x-rays will significantly underestimate the true area of the foramina, especially those located in the lower cervical spine.

We also sought to establish the ideal angle of obliquity for imaging the entire cervical spine by documenting the percent loss in total foraminal area associated with each orientation between 35 and 65 degrees. The smallest overall losses across all of the foramina were observed at film angles of 50 and 55 degrees, which gave rise to average area reductions of only 12.71% and 12.84%, respectively; these findings also indicated that 52.4 degrees may represent the ideal angle for minimizing the error of measurement that occurs when the foramina are not viewed exactly in line with the radiation source. Taking into account the inconsistencies inherent to the acquisition of spinal x-rays, we recommend that patients be positioned at an angle between 50 and 55 degrees with respect to the AP orientation to enhance the utility of oblique radiographs for evaluating cervical foramina.

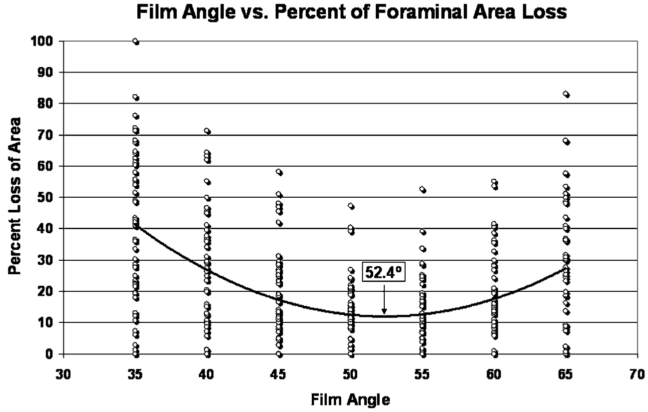

FIGURE 6. Scatter plot demonstrating percentage of observed foraminal area loss relative to the maximum observed area for every foramen at film angles between 35 and 65 degrees.

There are limitations to this study that clearly merit further discussion. Although we examined the changes in foraminal area evident at a range of oblique film angles, we did not incorporate the variable of superior-inferior angulation into our analysis. It is possible that targeting the x-ray beam in a more cephalad or caudad direction may influence the extent to which the foramina may be visualized with oblique radiographs. In addition, we did not determine the accuracy of the foraminal dimensions measured from these oblique radiographs. Previous reports have confirmed that of all the advanced imaging modalities that may be used to assess cervical foramina, computed tomography most closely approximates the values obtained from cadaver dissections; however, to the best of our knowledge no studies have determined the accuracy of oblique radiographs for calculating foraminal area to that of either anatomic data or computed tomography techniques.[7–10]

We believe that this is the first study to characterize the variability in foraminal area that exists because of differences in the orientation of oblique films. This radiographic evaluation of multiple cervical spine specimens revealed that the foramina seem to exhibit specific angles of orientation that progressively increase relative to the AP plane from 46 degrees at the C2-C3 level to 56 degrees at the thoracolumbar junction. As a result of these discrepancies, there is no single oblique view that is able to visualize every foramen en face; nevertheless, these findings suggest that oblique radiographs should be obtained using a film angle close to 52 degrees to minimize the observed area lost when all of the foramina are assessed from a single x-ray.

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