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# The assessment of cervical foraminal area on oblique radiographs as compared to computed tomography

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# The Assessment of Cervical Foraminal Area on Oblique Radiographs as Compared to Computed Tomography

A Thesis Submitted to the
Yale University School of Medicine
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Medicine

by

Jennifer Marie Sabino

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**Abstract**

Cervical oblique radiographs are often obtained to evaluate the patency of the intervertebral foramina. Previous work has demonstrated that computed tomography (CT), particularly oblique reconstructions of the spine, allows for the accurate measurement of foraminal dimensions. Although oblique radiographs are routinely ordered by practitioners for this reason, there are currently no studies that have directly compared these measurements to those derived from CT scans. The purpose of this study was to establish any correlation between the dimensions of cervical foramina assessed from oblique radiographs to those observed on CT scans.

Radiographs of four fresh-frozen cadaveric cervical spine specimens were obtained at an angle of 50 degrees. Using digital measurement tools, the foraminal height, width and cross-sectional area were calculated at each level between C2-C3 and C7-T1. CT scans were subsequently performed so that these values could also be acquired from 50 degree oblique reconstructions.

Statistical analyses revealed excellent inter-observer reliabilities for radiographs and CT scans (ICC 0.91 and 0.99 for height, 0.90 and 0.97 for width, and 0.84 and 0.92 for area). For the two imaging modalities, the Pearson correlation coefficients for height, width, and area were 0.439, 0.871, and 0.899; which corresponds to a moderate correlation for height and strong correlations for width and area. The only significant differences ($p<0.05$) between CT and radiograph measurements were for height at the C6/C7 and C7/T1, for width at the C5/6, and for area at the C2/3. Based on these findings, we believe that oblique radiographs provide reasonably accurate estimates of intervertebral foraminal dimensionsfor the initial evaluation of the cervical spine.

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## Introduction

*Cervical Radiculopathy – Epidemiology*

Cervical radiculopathy occurs as a result of irritation of the nerve roots as they exit the spine though the foramina. This condition may arise from any number of acute or chronic pathologic disorders including inflammation, compression, and dynamic instability; overall, spondylosis accounts for approximately 70% of these cases while an additional 20% are related to the presence of intervertebral disc herniations (1).

In a large, population-based study published by Radhakrishnan *et al.*, the incidence of cervical radiculopathy was reported to be 0.1% with a slightly greater predilection for men (107.3 per 100,000) than women (63.4 per 100,000) (1). Although the mean age at the time of diagnosis was 47.9 years, the peak incidence was determined to be in the sixth decade of life which appeared to decline after the age of 60. Previous investigators have also demonstrated that the more distal nerve roots are more commonly affected than those of the proximal cervical spine. In the series of Yoss *et al.*, the frequency of C7 nerve root involvement was 67% compared to 2%, 19%, and 10%, for the C5, C6, and C8 levels, respectively (2).

In the majority of instances, cervical radiculopathy is not able to be linked to a specific incident. According to the aforementioned study, only 20% of subjects were able to identify an inciting event; the most common mechanism reported by these individuals was some type of physical exertion (e.g. shoveling snow) followed by trauma which was usually sustained as a consequence of a motor vehicle accident. In this population the onset of cervical radiculopathy was classified as acute (less than four weeks), subacute (four to eight weeks), or insidious (greater than eight weeks) in 50.1%, 24.1%, and 25.8% of cases, respectively, with a mean duration of symptoms prior to diagnosis of approximately 40 days (median – 15 days) (1). In general, disc herniations are thought to be associated with a more rapid onset of symptoms than spondylosis which is characterized by a more insidious clinical course (2).

Pain is an almost universal finding of cervical radiculopathy, occurring in 97.5% of patients (1). The nature of this pain is often inscrutable and may be described as dull, aching, or sharp. In another large study including over 800 individuals, the most common presenting symptoms and signs were arm pain (99.4%), sensory deficits (85.2%), neck pain (79.7%), hyporeflexia (71.2%), and motor deficits (68%) (3). While cervical radiculopathy is typically limited to one upper extremity, bilateral symptoms may be experienced if multiple roots are involved. Unfortunately, the diagnosis of this condition is complicated by the inconsistent presentation of these patients who may exhibit all or none of these symptoms to varying degrees.

*Diagnosis: History and Physical Exam*

As with any type of spinal pathology, the diagnostic workup of an individual who exhibits clinical findings suggestive of cervical radiculopathy should include a thorough history and physical examination focusing on the neck and neurologic system (4). Other pathologic conditions that should be considered in the differential diagnosis are upper extremity nerve entrapment syndromes, brachial plexus disorders, peripheral neuropathies, and musculoskeletal injuries. While most of these etiologies are relatively benign, it is critical to establish the correct diagnosis so that the treatment of more serious cervical spine-related problems may be initiated without delay.

*Diagnosis – Imaging Modalities*

In order to institute the most appropriate therapies for these individuals, the diagnosis of cervical radiculopathy should be confirmed with appropriate imaging techniques such as plain radiographs, computed tomography (CT) and magnetic resonance imaging (MRI). Longitudinal studies have shown that cervical spondylosis tends to progress over time so that degenerative changes are nearly ubiquitous among asymptomatic patients over the age of 60, especially in the lower cervical levels. For this reason, any abnormalities noted on these images should be carefully correlated with the clinical data obtained from the history and physical examination to ensure that these pathologic lesions represent the source of the patient's symptoms (4).

The cervical neuroforamina are ovoid-shaped canals that are oriented approximately 45 degrees from the mid-sagittal plane. They are bordered superiorly and inferiorly by the pedicles of the adjacent vertebrae, anteromedially by the uncovertebral joint, posterolaterally by the facet joint. These foramina are approximately 9 mm in height and 4 mm in width, although these values may vary among the different regions of the cervical spine (4). The nerve roots enter the canal at approximately the same level as their origin so that they follow a nearly horizontal trajectory through the foramina. Because compression of the cervical roots frequently occurs at this point, an accurate assessment of foraminal dimensions and their patency may be of significant interest to practitioners..

Multiple authors have attempted to elucidate the relationship between foraminal dimensions and nerve root compression. Using a manual cursor measurement tool to assess CT images and a computer digitizer for cryomicrotome analysis, Inufusa *et al.* reported a 15% reduction in foraminal size during extension such that cadaveric spines frozen in this position exhibited a nerve root compression rate of 33.3% compared to 21% for specimens maintained in the neutral alignment (5). In contrast, the foraminal dimensions of flexed spines were 12% larger than those calculated for cervical extension so that the incidence of root compression decreased to only 15.4% in this position. In this study, the compressed nerves were associated with significantly smaller foraminal width and cross-sectional area, suggesting that any decrease in foraminal dimensions as seen on cervical images may be a reliable indicator of root compression.

The utility of a particular imaging modality for corroborating the diagnosis of cervical radiculopathy is largely dependent upon its sensitivity and specificity for detecting the compressive lesion (6). At this time the most appropriate algorithm for imaging individuals with suspected neural compression remains a matter of some debate; while the literature supports the routine screening of patients with CT scans in the setting of cervical trauma, the imaging protocol for those with degenerative conditions remains less clear.

*Plain Radiography*

Conventional radiographs are usually acquired as part of the diagnostic evaluation of patients with cervical complaints because they are inexpensive, readily available, and are useful for visualizing spondylosis, instability, fractures and other traumatic injuries. A cervical spine series nearly always includes anteroposterior (AP) and lateral x-rays but oblique views (i.e. oriented approximately 45 degrees from the mid-sagittal plane) may also be valuable for visualizing the intervertebral foramen (7, 8). A recent survey indicated that 8% of spine surgeons typically order oblique radiographs when performing their initial assessment of the cervical spine and 16% will include them for patients undergoing operative intervention for spondylotic conditions (9).

Oblique radiographs are normally obtained with the subject turned 45 degrees with respect to the x-ray beam; nevertheless, it has previously been shown that this may not the optimal orientation for visualizing the cervical foramina. Marcelis *et al.* found that 55 degrees,allowed for a more accurate measurement of foraminal size, especially in the lower cervical spine (10). Simpson *et al.* determined the ideal angle that maximized foraminal area across the entire cervical spine to be 52 degrees and concluded that any deviation from this point by more than five degrees in either direction significantly increased the percent error at all levels (11).

Even though oblique radiographs are frequently completed for the purpose of inspecting the foramina, the diagnostic accuracy of these films has not yet been definitively established (12, 13). In one large series, oblique x-rays revealed an obvious abnormality in only 86.6% of patients with cervical radiculopathy (1). Based on the results of 1118 cervical foramina that were evaluated with myelography, oblique radiographs acquired at an angle of 45 degrees gave rise to positive and negative predictive values of 56% and 87%, respectively, for clinically significant nerve root compression (7). Because of the relatively poor sensitivity and specificity of plain x-rays, many practitioners elect to order additional imaging studies in an attempt to confirm the diagnosis of cervical radiculopathy.

*Computed Tomography*

Computed tomography (CT) may be indispensable for assessing cervical spine anatomy and is currently regarded as the gold standard imaging study for evaluating the intervertebral foramina because it provides cross-sectional views of the osseous structures that border the nerve roots (14, 15). Multiple investigators have shown that the foraminal dimensions calculated from CT data are analogous to those derived from cadaveric dissections. (5, 16,17). Three-dimensional reconstructions may be preferable to conventional CT for this application because these images are more orthogonal to the foramina and are not affected by the angle of the gantry, resulting in improved interobserver variability (18). Stockley *et al.* reported that oblique CT reconstructions correctly predicted bony compression of the nerve roots in 75% of the subjects in their series (19). Despite these advantages, CT is relatively time-consuming, expensive, and generates greater amounts of ionizing radiation than plain x-rays.

*Magnetic Resonance Imaging and Myelography*

Magnetic resonance imaging (MRI) is another strategy that is regularly employed to examine the neuroformina of the cervical spine (20, 21). MRI depicts the intervertebral discs, neural elements, and vessels in great detail without subjecting these individuals to any radiation exposure. However, this technique is less effective for delineating the bony margins of the foramina compared to CT and their dimensions may be underestimated because of the confounding effects of magnetic susceptibility which refers to the disparate magnetization of various tissues, leading to distortion of the image at the interface between different structures (20, 22, 23). Tien *et al.* noted that the diameters of the upper cervical foramina may be reduced by up to 25% with gradient-echo MRI (22). Tsuruda *et al.* also demonstrated that cervical foramina may appear to be 8% to 27% smaller on MRI compared to CT (23). In addition, MRI is not as accessible as other types of imaging and its costs may be more prohibitive so that in most cases MRI is not considered to be a first-line modality for cervical radiculopathy.

Myelography is another diagnostic procedure during which contrast is injected into the thecal sac to outline the nerve root sleeve which permits any potential sources of compression to be identified. The technique is often combined with CT so that intradural processes may be differentiated from extrinsic deformation of the neural elements. CT myelography is an excellent alternative for patients who are not candidates for MRI because of pacemakers or other metallic implants. Myelography is both extremely sensitive and specific for detecting compressive pathology with an accuracy rate approaching 95% when compared to the findings documented during subsequent surgical intervention (24). Since myelograms are more invasive than other imaging studies and are associated with a variety of short and long term complications, this modality has largely been supplanted by MRI for visualizing the contents of the spinal canal.

*Conservative Treatment*

According to the natural history of this disease, the majority of patients with cervical radiculopathy will note gradual resolution of their symptoms with little or no formal treatments; even individuals who experience recurrent symptoms will likely exhibit a benign, self-limited course. Nevertheless, further intervention may be warranted if these complaints persist or become increasingly debilitating.

The conservative management of cervical radiculopathy consists of medications such as nonsteroidal anti-inflammatories (NSAIDs) in conjunction with a supervised physical therapy program emphasizing active mobilization of the spine and strengthening exercises targeting compensatory neck muscles (25). While cervical traction may also bring about symptomatic relief of nerve root compression by separating the vertebrae and expanding intervertebral joint space, two independent metaanalyses of randomized clinical trials assessing these types of regimens failed to reveal any clear benefits for cervical radiculopathy (26, 27).

Epidural injections may also be a viable option for individuals with radicular symptoms refractory to these more conservative measures. Cervical injections may be performed using either an interlaminar or transforaminal technique. Slipman *et al.* showed that treatment with fluoroscopically-guided selective nerve root blocks yielded good to excellent outcomes in 60% of patients characterized by marked improvements in pain control and decreased utilization of analgesic medications (28). Given the significant adverse events that may occur as a result of cervical injections (e.g. injury to the spinal cord or neural elements with the risk of permanent neurologic deficits), the relative benefits of these procedures must be carefully weighed against their potential hazards (27). Alternative therapies including acupuncture and chiropractic manipulations have also been advocated for cervical radiculopathy but the efficacies of these treatments have not yet been adequately validated.

*Surgical Treatment*

Surgical intervention for cervical radiculopathy may be reasonable to consider for patients who present with neurologic involvement or those who have exhausted all conservative measures, provided that they also display corresponding evidence of nerve root compression on advanced imaging studies. Depending on a number of different factors including the location of the pathology, the number of affected levels, and the sagittal alignment of the spinal column, compressive lesions may either be addressed by completing a discectomy and fusion through an anterior cervical approach or by performing a posterior laminoforaminotomy. In a recent Cochrane review of the existing literature regarding the results of operative treatment for cervical radiculopathy, subjects who underwent surgery exhibited greater improvements in pain, weakness, and sensory loss at four months compared to those who were managed nonoperatively; however, at one year there were no significant differences between these two cohorts (29).

**Statement of Purpose**

The purpose of this cadaveric study was to assess the correlation cervical foramina dimensions from oblique radiographs to those measured from the "gold standard" imaging modality of oblique CT reconstructions. To the best of this author's knowledge, no prior studies have made this direct comparison. The information obtained from this assessment will provide clinically useful information as plain films are routinely used as first line diagnostic imaging tools in assessing the cervical spine.

## Methods

### *Specimen Preparation*

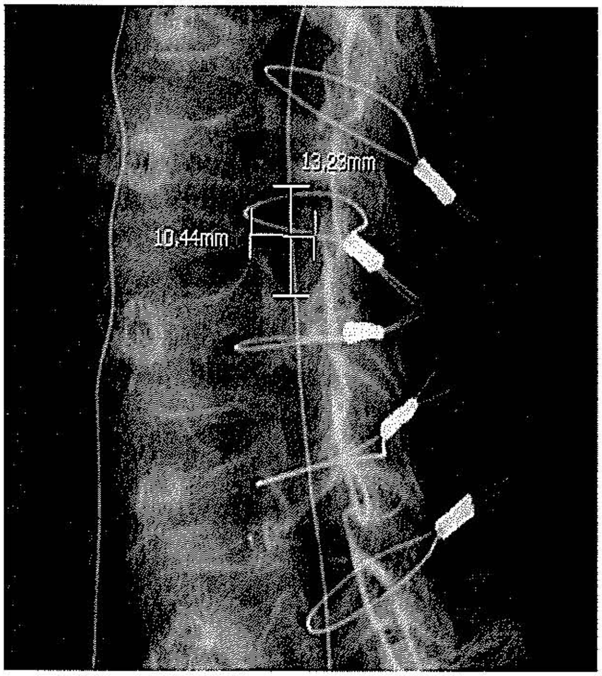
Four fresh-frozen human cervical spine specimens (occiput to T2) stripped of non-ligamentous soft tissues were obtained. The specimens had been used previously for non-destructive flexion / extension testing and were mounted in resin blocks at the occiput and at T2. Anteroposterior (AP) and lateral radiographs were taken to verify that there were no gross deformities, fractures, or other abnormalities which might obscure assessment of the foraminal dimensions. Mounting did not obscure the foramina to be measured. The specimens were frozen in neutral posture and were kept frozen during radiographic and CT evaluations to ensure that foraminal size would remain constant throughout the study.

### *Foramen Assessment from Radiographs*

Bilateral oblique plain films were obtained of each specimen at 50 degrees from the AP orientation. The spines were placed upright on a marked turntable and rotated to ensure this angle of orientation. This angle was selected based on a previous work that identified this angle of obliquity to maximize perceived cervical foraminal cross-sectional area on oblique radiographs and thus to best represent their size (11).

The radiographs were reviewed and assessed with measurement tools on our institution's digital radiography software (Synapse V3.0 , FujiFilm USA). Intervertebral foramina were measured bilaterally from C2-3 through C7-T1; 48 total intervertebral foramens were evaluated. If a foramen could not be well visualized for a given level for any reason, no measurement was taken.

Three parameters were measured for each foramen: height, width, and cross-sectional area. Foraminal height was measured as the greatest distance between the bony margins of the cephalad and caudad pedicles. Foraminal width was bounded anteriorly by the uncovertebral joint and posteriorly by the zygoapophyseal joint (**Figure 1a**). These measurements were made with the distance tool and reported in millimeters. Foraminal cross-sectional area was bounded by the above noted landmarks (**Figure 1b**). This measurement was traced with the freehand area tool and reported in square millimeters. All measurements for both radiographs and reconstructed CT scans were repeated by three observers, including an attending spine surgeon, a spine fellow, and an orthopedic research fellow.



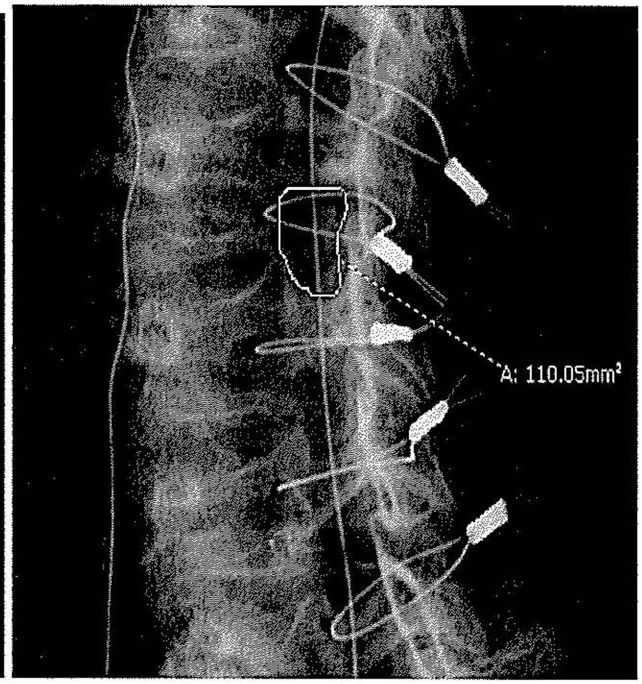




**Figure 1a** (left): Oblique radiograph with height and width measurements using Synapse.
**Figure 2b** (right): Oblique radiograph at 50 degrees with freehand area measurements using Synapse

The magnification factor of the radiographs was calculated using the calibration function in TraumaCad software (Orthocrat ltd. Petach-Tikva, Isreal). An OrthoMark (Orthocrat ltd. Petach-Tikva, Isreal) steel sphere of known diameter (25 mm) was placed on the turntable at the same distance from the x-ray source as the cadaveric specimens. Plain radiographs were taken of the sphere. The diameter of the sphere was measured on the radiograph using the TraumaCad calibration tool and was found to be 30.3mm. The maginification factor was calculated by dividing the radiographic measurement by the true diameter (magnification factor = 30.3mm/25mm = 1.212). The original measurements were divide by the magnification factor to give the corrected measurements. The corrected measurements were subsequently compared to the measurements taken from the reconstructed CT scans as described in the next section.

*Foramen Assessment from CT Oblique Reconstructions*

Following the plain films, 2mm axial CT images were acquired on a GE LightSpeed 16 Scanner (GE Healthcare system, Piscataway, NJ). Images were stored in our institution's digital archive system (Synapse/PACS, FujiFilm USA) and subsequently converted into oblique reconstructions using the multi-planar reconstruction software tools. These reconstructions were made at 50 degrees from the AP orientation to match optimized angles used for the plain radiographs (**Figure 2a and b**).

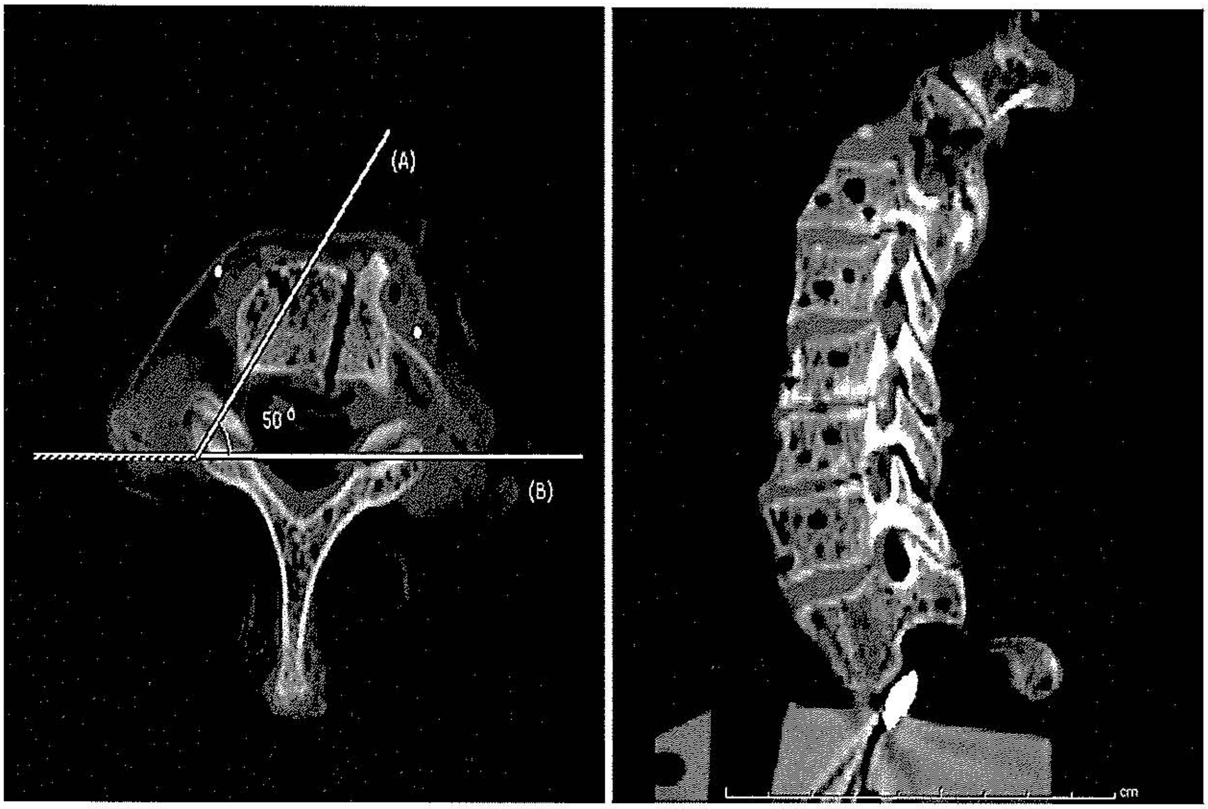



**Figure 2a** (left): Axial image used to reconstruct images for foraminal measurement where (A) is the 50 degree slice to the coronal plane (B).

**Figure 2b** (right): 50 degree reconstruction

The slices used to measure each foramen corresponded to the narrowest point in the foraminal canal on each side. A similar method was used by Inufusa *et al.* when measuring foraminal dimensions in the lumbar spine (5) and oblique reformations were found to present the best view of the foramen (18).

Measurements were made with similar techniques to those used for plain film assessments. Foraminal height was measured as the greatest distance between the bony margins of the cephalad and caudad pedicles. Foraminal width was measured as the distance between the uncovertebral joint anteriorly and the zygoapophyseal joint a 2-way random effects model and the consistency definition. The random effects model is interpreted as having the ability to be generalized to all possible judges. The following classification scheme was used for ICC: $< 0.40$ = poor; 0.40 – 0.59 = fair; 0.60 – 0.74 = good; $> 0.74$ = excellent (30, 31).

Once excellent correlation was established using one specimen, the dimensions of the remaining three specimens were measured. Mean values of height, width, and cross-sectional area with 95% confidence intervals were calculated from all measurements at each level. The radiograph data was multiplied by the inverse of the calculated magnification factor to account for radiographic magnification.

To compare the foraminal dimensions measured on the oblique radiographs to the dimensions measured from the CT reconstructions, a Pearson's correlation was performed to evaluate the linear relationship between two variables. The correlation coefficient is represented as a range from +1 to -1, with +1 indicating a perfect positive correlation between the radiographic area and the CT area. Values between +1 and -1 represent the strength and direction of the linear relationship between the two variables. The correlation between the radiographic and CT foraminal measurements was considered statistically significant at two-sided alpha at $p<0.05$. Correlation coefficients between 0.1 and 0.3 represent small correlation, 0.3 and 0.5, medium correlation, and 0.5 and 0.9, large correlation, although this classification is somewhat arbitrary and should not be observed too strictly (32, 33).

The mean values for height, width, and area at all levels were tested using a two tailed Student's T-test to determine whether there was a statistically significant difference in means found by radiograph and CT. The variables were considered paired because two different types of measurements were preformed on the same foramen. A Student's t-test determines whether the means of two normally distributed populations differ, using the standard deviation of the samples rather than the precisely known value. Measurement differences were determined to be statistically significant at $p < 0.05$.

**Results**

*Measurement Reliability*

The a-priori analyses of inter-observer reliability for three readers for foraminal height, width, and cross-sectional area on one specimen demonstrated excellent inter-observer reliability for radiographs, ICC 0.91 (95% confidence interval (CI) 0.61 to 0.99), 0.90 (95% CI 0.58 to 0.99), and 0.84 (95% CI 0.58 to 0.98), respecively. Similarly, excellent inter-obesrver raliablility was seen for height, width, and cross-sectional area for CT, 0.99 (95% CI 0.96 to 0.99), 0.97 (95% CI 0.88 to 0.99), and 0.92 (95% CI 0.67 to 0.99).

Based on this analysis, the digital measurement tool from Synapse was found to be a reliable, and this method was preformed on the foramina on both sides of the remaining three specimens at each cervical level.

*Foraminal Dimensions Comparison*

The magnification factor for the radiographs was found to be 1.212 using the method described above. All dimensions measured on the radiographs were multiplied by the inverse of this factor to correct for radiographic magnification. As a result, all radiographic dimensions reported in this section incorporate this correction factor .

As described earlier, the 50 degree angle of obliquity used was the 5 degree interval that most approximated the ideal angle for optimizing foraminal area (11). The mean foraminal height, width, and area found by radiograph and by CT were plotted to compare values found by each imaging modality at each cervical level (**Figure 4, 5, and 6**).

| | Radiograph | CT | P-value |
|---|---|---|---|
| Height (mm) | | | |
| C2-C3 | 11.9 +/- 1.0 | 11.0 +/- 1.2 | 0.396 |
| C3-C4 | 9.6 +/- 0.8 | 10.0 +/- 0.7 | 0.291 |
| C4-C5 | 9.9 +/- 0.9 | 10.2 +/- 1.0 | 0.739 |
| C5-C6 | 9.0 +/- 1.3 | 10.5 +/- 0.5 | 0.121 |
| *C6-C7* | 9.7 +/- 0.8 | 11.2 +/- 1.0 | **0.027** |
| *C7-T1* | 8.7 +/- 0.7 | 10.5 +/- 0.7 | **0.008** |
| Width (mm) | | | |
| C2-C3 | 7.8 +/- 0.9 | 7.9 +/- 1.3 | 0.655 |
| C3-C4 | 5.8 +/- 1.3 | 5.9 +/- 0.5 | 0.299 |
| C4-C5 | 5.7 +/- 0.8 | 5.9 +/- 0.6 | 0.652 |
| *C5-C6* | 4.6 +/- 0.7 | 5.8 +/- 0.6 | **0.042** |
| C6-C7 | 5.7 +/- 0.7 | 5.9 +/- 0.4 | 0.557 |
| C7-T1 | 5.9 +/- 0.8 | 7.0 +/- 0.6 | 0.096 |
| Area ($mm^2$) | | | |
| *C2-C3* | 79.3 +/- 8.2 | 69.4 +/- 6.6 | **0.036** |
| C3-C4 | 56.0 +/- 11.4 | 52.1 +/- 12.4 | 0.779 |
| C4-C5 | 58.2 +/- 16.2 | 56.5 +/- 11.6 | 0.721 |
| C5-C6 | 53.6 +/- 12.2 | 47.0 +/- 11.1 | 0.526 |
| C6-C7 | 64.5 +/- 9.6 | 59.7 +/- 10.9 | 0.349 |
| C7-T1 | 67.3 +/- 12.5 | 69.7 +/- 11.2 | 0.709 |

**Table 1**: Radiograph data with magnification correction and CT data with 95% confidence intervals

*Foraminal Height*

Mean foraminal height for both radiograph and CT scans can be seen in **Figure 4**. At each level the mean (± 95% confidence interval) measurements from both sides of each specimen can be seen in **Table 1**. At levels C6/7 and C7/T1 the CT measurements were significantly greater than xray (p=0.027 and p=0.008, respectively). No statistical difference was found at any other level (p>0.121 for all). The Pearson's correlation of the radiographic foraminal height and the CT reconstruction areas was found to be 0.439 (p>0.05), representing medium correlation.

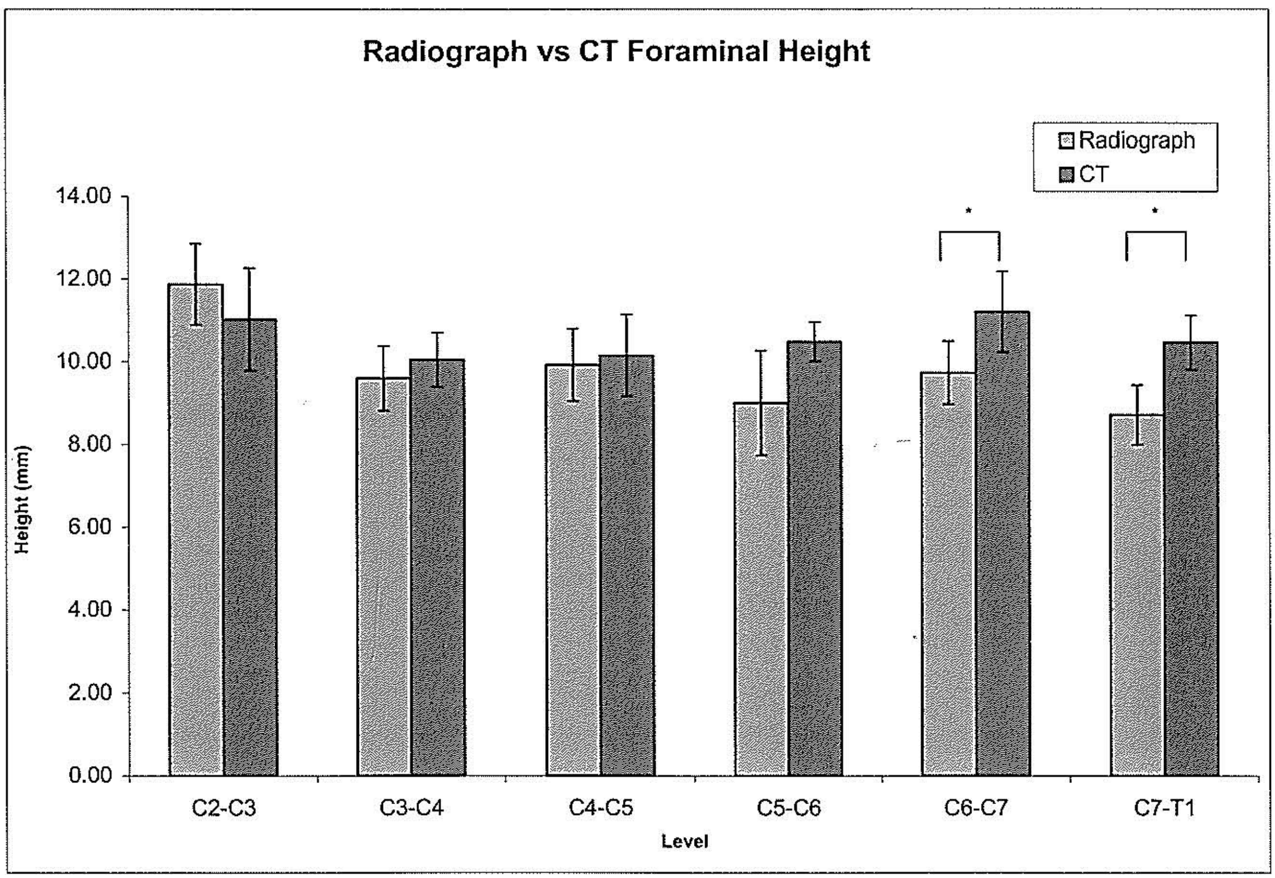



**Figure 4**: Radiograph vs CT Foraminal height graph with 95% CI error bars.
(*) indicate that there is a significant difference between the two values (p<0.05)

*Foraminal Width*

Mean foraminal width for both radiograph and CT scans can be seen in **Figure 5**. At each level the mean measurements from both sides of each specimen can be seen in **Table 1**. At level C5/6 the CT measurements were significantly greater than xray ($p=0.042$). No statistical difference was found at any other level ($p>0.096$ for all). The Pearson's correlation for width was 0.871 ($p<0.001$), representing large positive correlation.

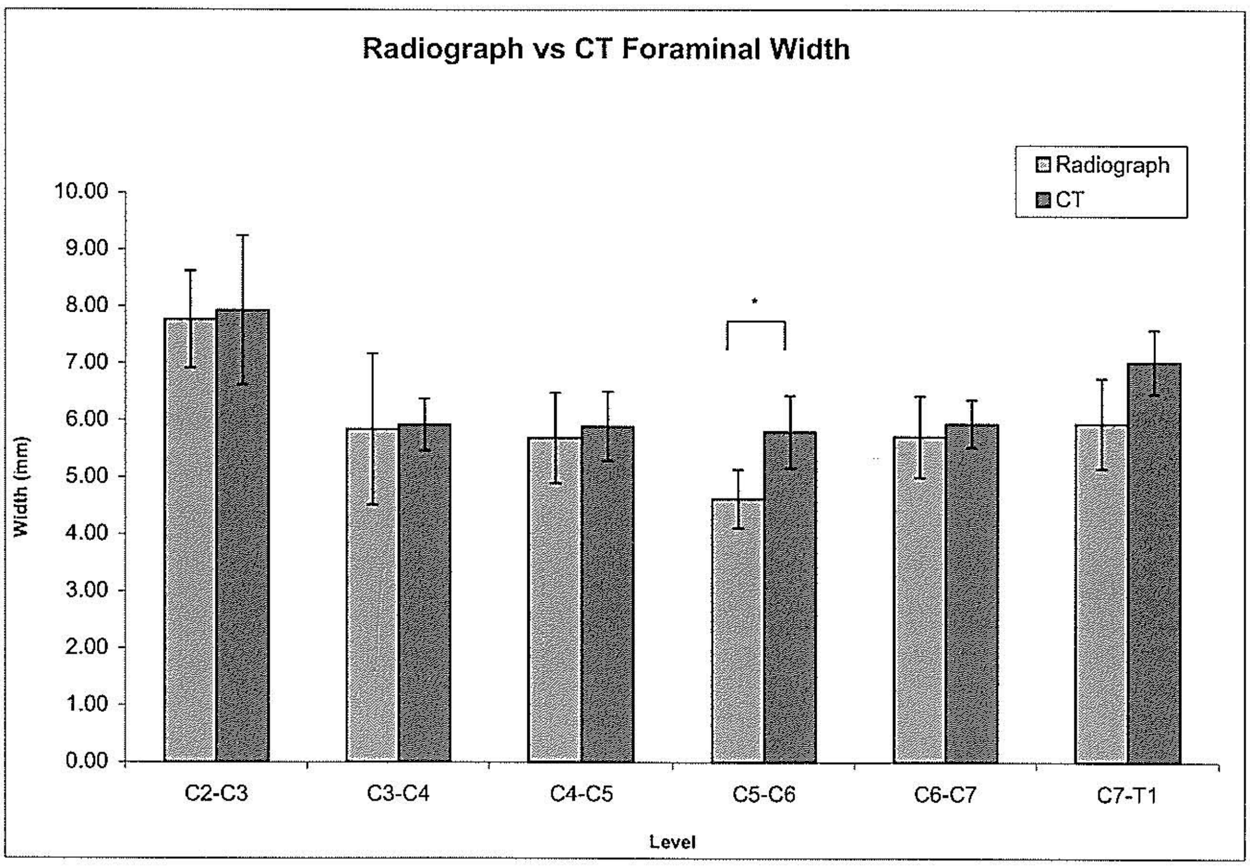



**Figure 5**: Radiograph vs CT Foraminal width graph with 95% CI error bars.
(*) indicate that there is a significant difference between the two values ($p<0.05$)

*Foraminal Area*

Mean foraminal area for both radiograph and CT scans can be seen in **Figure 6**. At each level the mean measurements from both sides of each specimen can be seen in **Table 1**. At level C2/3 the radiograph measurements were significantly greater than CT ($p=0.036$). No statistical difference was found at any other level ($p>0.349$ for all). The Pearson's correlation for width was 0.899 ($p<0.001$), representing large positive correlation.

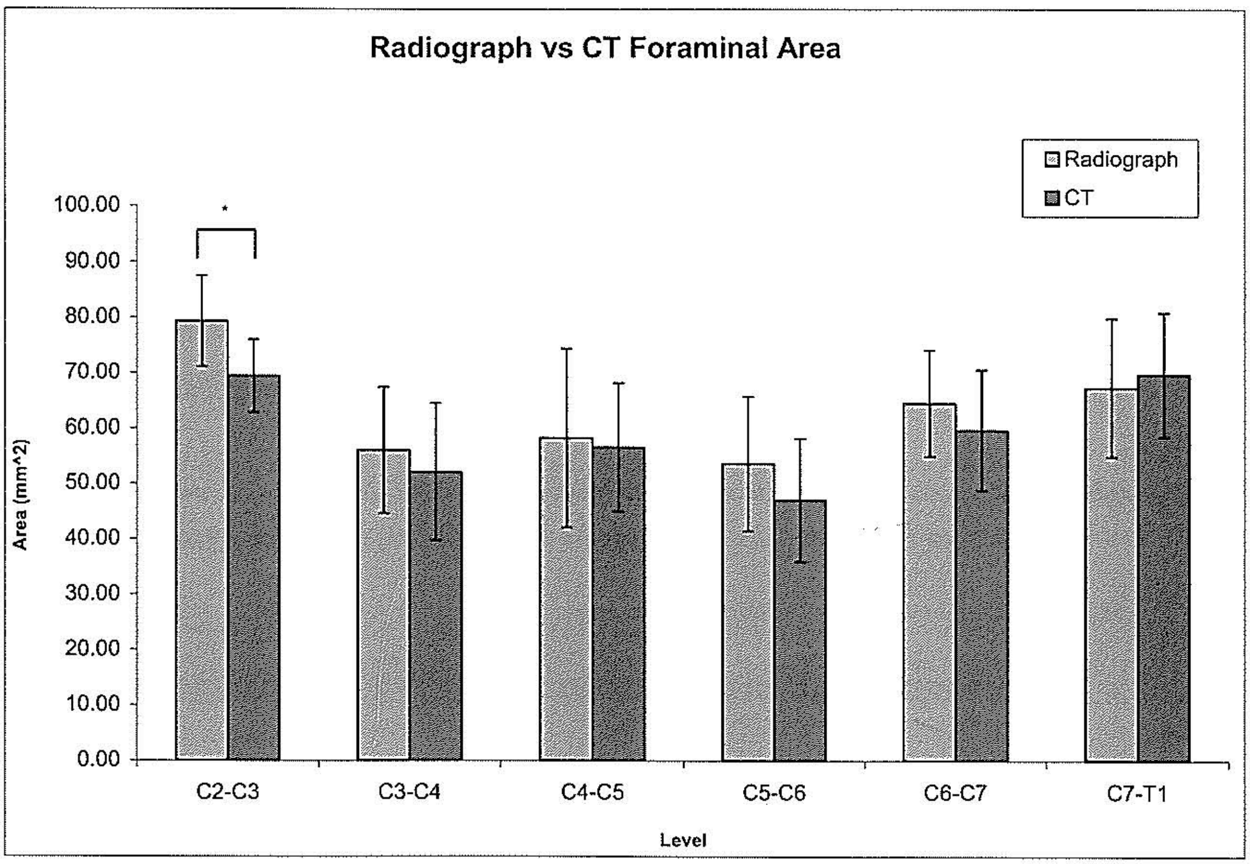



**Figure 6**: Radiograph vs CT Foraminal Area graph with 95% CI error bars.
(*) indicate that there is a significant difference between the two values ($p<0.05$)

**Discussion**

Oblique radiographs are a potential imaging modality to assess intervertebral foramina. Such films are convenient, rapidly acquired, and impart minimal radiation related risk to the patient. 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 in order to assess the status of the foramina and 16% as part of preoperative evaluations (9). Although these films are frequently acquired, there continues to be a paucity of data regarding the accuracy of oblique radiographs for the assessment of foraminal dimensions.

This study compared the foraminal height, width, and cross-sectional area determined from oblique radiographs to that of oblique CT reconstructions; the data indicated significant positive correlations in all parameters between these two modalities. Pearson's correlation coefficient was 0.439, 0.871, and 0.899 for height, width, and cross-sectional area, respectively. These results demonstrate medium correlation for height and strong correlation for width and area according to guidelines suggested by Cohen *et al* (33). The highest correlations were found in width and cross-sectional area. There parameters are the most clinically relevant because foraminal narrowing and resulting nerve compression usually result in overgrowth of the facets causing decreases in width and area but not necessarily height.

In general, there was no statistical difference between measurements determined from radiographs and those from CT when radiographic measurements were corrected for radiographic magnification by a factor of 1.212. The only statistical differences found were at levels C6-C7 and C7-T1 for height, C5-C6 for width, and C2-C3 for area. The slight disparity, where it exists may the result of partial volume averaging, a phenomenon in which the soft tissue to bone margins are partially obscured in CT. The differences may also be attributed to deviation from the ideal angle at each specific level, which varies from 46.3 degrees for C2-C3 to 56.1 degrees for C7-T1 (11). Slight differences may also be the result of error from straying from the ideal angle or ignoring the superior inferior angulation of the foramina.

Previous work by Simpson *et al.* examined radiographs at varying angles of obliquity in an effort to determine the most favorable angle for visualizing the intervertebral foramina; visualization, as defined by maximal foraminal area, found that an angle of obliquity of 52.4 degrees optimized the foraminal dimensions measured on plain radiographs (11). Taking into account the inconsistencies inherent in taking spinal radiographs secondary to problems with patient positioning, it is unlikely that this exact angle be used. This study further supports the conclusions made by the aforementioned study that straying slightly from this ideal angle, not greater than five degrees in either direction, will still result in a good correlation between radiographic and CT interpretations of foraminal size and not cause significant underestimations of foraminal size in radiographic measurements. Given the results of this and the current study, it appears that oblique radiographs acquired in these projections provide both optimal visualization and accurate foraminal assessment.

There are limitations to this study that clearly merit further discussion. While it is accepted that CT is the gold standard for depicting bony margins, this author found no studies directly comparing measurements from CT reconstructions to their anatomic counterparts at any level of the spine. CT is likely considered the gold standard for imaging suspected nerve root compression at the neural foramen for its well documented ability to image bone as well as soft tissue, a short coming of plain films and MRI. Further study should be aimed at determining the margin of error inherent in imaging bony margins using CT. However, previous reports have confirmed that CT most support findings in cadaveric studies, even though a direct correlations have not been made, and their ability to image more than just bony anatomy is well proven (16, 17, 18, 34). In addition, we did not determine the accuracy of foraminal dimensions measured from these oblique radiographs as compared to anatomic cadaveric measurements. A useful study would correlate oblique radiographs, CT, and MRI imaging with anatomic studies to find overall margins of error for foraminal cross-sectional area.

Methods for measuring the foraminal cross-sectional area in the literature include using the freehand drawing tool on the imaging software to trace the approximate outline of the foramen and using a circular shape to approximate its margins. This group has also used an ellipse to approximate the shape of the foramina. We followed the freehand measurement method when designing our experimental method because it was the most well documented and exhibited the best inter-observer correlation. We found an excellent inter-observer correlation coefficient for height, width and area, representing excellent inter-observer correlation for both imaging modalities. However, this method has inherent flaws. The measurement of each foramen is not standardized and the borders are highly subjective to the observer. Also, once excellent inter-observer correlation was found on one specimen, the remaining specimens were measured by one observer. More accurate measurements might have been taken by all three.

We examined the changes in foraminal area evident at an oblique film angle that closely approximated the ideal angle that maximized foraminal area; however, 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.

**Conclusions**

The results of our study confirm that cervical oblique radiography represents an acceptable and accurate diagnostic modality for the initial assessment of foraminal anatomy. Overall, the radiographic measurements were similar and highly correlated to CT measurements. This suggests that oblique cervical radiography may represent an accurate diagnostic modality for the initial assessment of foraminal anatomy. CT is clearly the gold standard for imaging bony structures and will continue to be essential for preoperative planning and when better characterize positive finding from oblique radiographs. However, it is possible that by oblique radiographs can provide accurate measurements of the intervertebral foraminal dimensions for the initial evaluation of nerve root compression and thus reduce further testing and radiation exposure by limiting the need for CT in certain patients

Given the results of previous work, the authors of this study continue to advocate that films be obtained at 50 to 55 degrees, as these angles provide optimal visualization. However, it is important to note that further research needs to be undertaken to determine specific errors of margin for these imaging modalities to ensure accurate correlation with anatomic models. This investigation will aid in deciding whether to expose patients to further radiation through preliminary imaging.

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