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The Utility of Plain Radiography in the Evaluation of Degenerative Spine Disease

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The Utility of Plain Radiography in the Evaluation of Degenerative Spine Disease

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By

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The work described in this thesis is adapted from the following projects

Hommouri QM, Simpson AK, Rechtine G, Grauer JN.
Routine Imaging in the Spine Practice: A Questionnaire Study of the Utilization of Radiographs in the Evaluation of Spine Complaints. *Spine J*. 2007 Nov-Dec;7(6):745-7.

Hommouri Q, Haims AH, Simpson AK, Alqaqa A, Grauer JN.
The Utility of Dynamic Flexion/Extension Radiographs in the Initial Evaluation of the Degenerative Lumbar Spine. *Spine*. 2007 Oct 1;32(21):2361-4.

Simpson AK, Savino J, Whang P, Emerson JW, Grauer JN.
Assessment of Cervical Foramen with Oblique Radiographs: The Effect of Film Angle on Foraminal Area and the Ideal Oblique Imaging Angle. *J Spin Dis Tech. In Press.*

Simpson AK, Whang P, Jarisch A, Haims A, Grauer JN.
The Radiation Exposure Associated with Cervical and Lumbar Spine Radiographs.
J Spin Dis Tech. In Press.

Abstract

Study Designs: Questionnaire, Retrospective chart review, Cadaver study, and cross-sectional study.

Objectives: Assess current imaging practices; determine utility of accessory radiographic studies, including dynamic and oblique radiographs; calculate effective radiation doses of routine spine radiographs.

Summary of Background Data: Plain radiography is generally considered the initial imaging modality for evaluation of degenerative spine complaints. In addition to anteroposterior (AP) and lateral views, dynamic and oblique views may also be obtained. There is currently no data on imaging practices of spine specialists, the utility of these accessory radiographic views, or the radiation exposure patients receive as a result of various spine radiographs.

Methods: A questionnaire study was developed to determine current imaging practices; retrospective chart review and cadaver studies were performed to determine the utility of dynamic and oblique radiographs, respectively; a cross-sectional study was utilized to determine radiographic exposures.

Results: Imaging practices are varied amongst spine practitioners. The utility of dynamic films and cervical oblique films in the initial evaluation of spine complaints could not be supported. Radiation exposure from spine films is not negligible and lumbar films impart exposures an order of magnitude greater than corresponding cervical films.

Conclusions: Sophisticated cost-benefit analyses are necessary to establish appropriate guidelines for the use of plain radiographs in the evaluation of spine complaints.

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Introduction

Prevalence of Back and Neck Pain

The impact of back and neck pain on society has been evaluated by a number of studies. The National Health and Nutrition Examination Survey II (NHANES II) demonstrated the prevalence of back pain lasting greater than 2 weeks to be 16% for persons between 25 and 74 years of age.[1] Back pain is, in fact, the second most cited reason for physician visits, next to the common cold.[2]

Of the pain disorders, back pain is second only to headache as the most common cause of lost productive time, and results in the greatest total amount of lost work time.[3] It has been described that low back pain, specifically, results in more lost productivity than any other medical condition, and estimates of direct and indirect cost are around $50 billion per year in the United States alone.[4]

Fortunately, the majority of people who develop back pain will recover without intervention. A large Swedish study provided information about the natural history of back pain. In this study, 57% of patients with acute back pain recovered in 1 week, 90% in 6 weeks, and 95% in 12 weeks. At one-year follow-up, 1.2% remained out of work from disability.[5] The small percentage of patients that do not recover and progress to chronic back pain, defined as having duration greater than 12 weeks, account for the greatest societal costs.

Etiology of Back Pain Disorder

Back pain is often classified as either specific or non-specific. Specific low back pain is that which can be explained by a physical cause, such as injury, deformity, infection, or tumor.[6] In absence of other anatomic pathology, degenerative disc changes are not classified as a specific back pain cause, as many patients without symptoms can have evidence of degenerative disc disease on imaging studies. In fact, Boden *et al* demonstrated MRI evidence of disc degeneration or bulging in the lumbar spine in 35% of asymptomatic people between ages 20 and 39 years.[7] Specific back pain diagnoses account for only 15 to 20% of back complaints, while the majority of back problems will not have an identifiable physical cause.[8]

There are a multitude of potential etiologies for back pain symptomatology. Somatic pain can come from any of the structures of the spinal column (such as the intervertebral disc or apophyseal joints), as well as related muscles, tendons, and ligaments. This pain is often described as a deep dull pain, with greatest intensity over the involved anatomic area. This is clearly the most common cause of axial symptomatology. Viscerogenic pain may be referred to the spine from organs that share segmental innervation with this region. This pain is often poorly localized, and, in the lumbar spine, may be associated with GI symptoms. Back pain may also have a vascular etiology, and the prototypic cause of vasculogenic low back pain is an abdominal aortic aneurism. Although non-somatic causes of back pain are not common, these causes must be kept on the differential and potentially worked up if there is supporting evidence or no clear somatic cause.

Management of Back Pain

The key to clinical management of patients with back problems is an understanding of the natural history of back pain. The vast majority of patients with acute back pain will fully recover and resume normal activity within 4 to 6 weeks. The likelihood of recovery decreases, however, with the duration of back pain. The physician's objective is to return these patients to normal activity levels as quickly as their pain will allow. In doing so, diagnostic studies should be used sparingly and surgical intervention viewed as a last resort for back pain refractory to other treatment modalities.

For the purposes of developing evidence-based practice guidelines, non-specific LBP is classified based on duration of pain into acute (4 weeks or less), subacute (4 weeks to 12 weeks), and chronic (greater than 12 weeks).

In the acute stage of non-specific LBP, the physician's role is to provide information and reassurance to the patient, and encourage a self-care strategy. Return to normal activities as tolerated should be encouraged, as both bed rest and specific back strengthening exercises have been shown to be disadvantageous in the acute phase of non-specific LBP.[9] Over-the-counter(OTC) medications are recommended for pain relief, and acetaminophen is the first choice treatment.[10] Nonsteroidal anti-inflammatory drugs (NSAIDs) can be used when acetaminophen is inadequate, but they do carry an increased risk of side-effects.

Patients who continue to have pain after 4 weeks enter the sub-acute phase. The focus at this stage of back pain is proactive monitoring. The benefits of this strategy are better adaptation of treatment to changes in patient needs, and early detection of potential progression of symptoms that may indicate a specific diagnosis (development of radiculopathic pain indicating potential disc herniation). When low back pain persists for longer than 4 weeks, even in the absence of any “red flags”, such as change in neurologic exam or altered bladder/bowel habits, it is reasonable to obtain radiographs and refer patients to a specialist.

Diagnostic Imaging for Neck and Back Pain

Although plain radiographs are commonly obtained as the initial diagnostic imaging modality in the investigation of spinal complaints, there is little agreement concerning the appropriate radiographic series that should be obtained for any given patient presenting with back or neck pain. Currently, there is no standard for what series of radiographs should be taken by the primary care provider or spine specialist, either at initial presentation or preoperatively. The current perception is that most physicians obtain anteroposterior (AP) and lateral radiographs of the affected spinal region upon initial presentation and/or preoperatively.[11] These radiographic views give an overall structural roadmap, assess degeneration, demonstrate alignment, and potentially reveal fractures or lesions.

Additional radiographic views may also be considered. Dynamic flexion/extension (F/E) radiographs may be used to evaluate physiologic motion or reveal subtle dynamic instability, and for post-operative fusion assessment.[12-15] Oblique radiographs may be used to evaluate neural foramen in the cervical spine or provide direct visualization of the pars interarticularis in the lumbar spine.[16-18] Although these various radiographic techniques have been employed in the investigation of spinal complaints for many years, there has been little work on establishing their utility in the management of back and neck pain patients.

Dynamic (Flexion-Extension) Radiographs

The role of flexion-extension radiographs in the evaluation of cervical spine trauma patients has been well supported in the literature.[19,20] However, there has been significantly less attention to the utility of dynamic radiographs in the diagnosis and management of patients with degenerative spinal complaints. Recently, White *et al[21]* demonstrated that dynamic imaging in the initial evaluation of patients with degenerative cervical spine complaints revealed a new finding of spondylolisthesis in 1% of patients and a change in the severity of listhesis in 3% of their patient population. However, there were no changes in clinical management as a result of findings on the dynamic films. The results of this study led the authors to conclude that acquisition of flexion-extension radiographs was not merited in the evaluation of non-traumatic cervical complaints. In the lumbar spine, however, the utility of dynamic radiographs in the evaluation of degenerative disease has not been previously investigated.

Oblique Radiographs

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. Cervical foramina are formed 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.[22,23]

As cervical foramina are three-dimensional structures with an intrinsic angle of orientation, that angle must be reproduced by an oblique radiograph in order to view the foramen *en face* and 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° relative to the AP orientation, it has not been definitively established that this angle optimizes the view of the cervical foramina. Abel *et al[24]* compared oblique radiographs taken at 45º and 60º using both cadaveric specimens and human subjects. They demonstrated that the 60º "exaggerated oblique" radiographs provided better separation of the anterior and posterior elements and facilitated the visualization of the foramina**.** Marcelis *et al*[25] analyzed radiographs taken at 35°, 45°, and 55° and concluded that 55° oblique film provided better visualization of the lower cervical foramina than the traditional 45° view. No reports have determined the ideal oblique imaging angles for visualization of the various cervical foramina.

Radiation Risk from Spine Radiographs

While screening x-rays clearly play a critical role in the assessment of these patients, these diagnostic studies are not without their attendant risks. Medical exposure represents a major source of artificial ionizing radiation that accounts for a significant proportion of the collective dose received by the population. In particular, successful imaging of the spine involves the irradiation of large exposure fields that include multiple radiosensitive organs, and these relatively large doses may predispose these individuals to the development of malignancies and other hereditary defects.

This theory is supported by the results of multiple retrospective case series which have suggested that the lifetime risk of radiation-induced carcinogenesis attributable to spine x-rays is not negligible. For instance, children with scoliosis may exhibit a higher incidence of breast cancer and leukemia later in life because of the multiple spinal radiographic examinations that must be repeated over time in order to facilitate the proper management of these patients.[26-30] Even moderate radiation exposures have demonstrated increased cancer risk. In a large scale study utilizing the Canadian National Dose Registry, Ashmore et al demonstrated that the excess relative cancer risk is 3% for every 10 mSv, which is approximately the dose of a single abdominal CT scan.[31]

AP and lateral radiographs of the cervical and lumbar regions of the spine remain some of the most frequently performed radiographic studies. As with all plain radiographs, spine x-rays give rise to nonuniform, partial-body irradiation. Because of the different radiosensitivities exhibited by various organs, the collective risk attributable to a patient's radiation exposure is dependent upon the specific dose absorbed by each organ. Given the difficulty of accurately calculating these values, there continues to be a paucity of practical information that may be shared with patients regarding the total amount of radiation they are subjected to as a result of these diagnostic radiographs.

The diagnostic imaging of back and neck pain disorders continues to challenge primary care physicians and spine specialists alike. Despite the high prevalence of back pain, there is little evidence as to the appropriate imaging modalities and techniques that are of greatest utility when evaluating degenerative spinal complaints. Although dynamic radiographs and oblique films have been utilized by some clinicians for evaluating cervical and lumbar disease, there has been little evidence to support the role of these studies in the work-up of back pain.

This work will be presented in four chapters, each of which assesses a specific hypothesis. First, we defined current imaging practices used by spinal surgeons in the investigation of spinal complaints (**Chapter 1**), including the prevalence of dynamic studies and oblique radiographs. Second, we analyzed the value of dynamic radiographs (**Chapter 2**) and cervical oblique radiographs (**Chapter 3**) in the diagnosis and management of spinal complaints. Lastly, we sought to determine the radiation exposure that plain radiographs impart on patients (**Chapter 4**), so that we may account for both the benefit and risk of utilizing these imaging modalities.

CHAPTER 1 – Imaging Practices Questionnaire

Objective

To document current practice patterns of radiographic imaging during the initial presentation and preoperative evaluation of patients with spinal complaints using a questionnaire administered to spine specialists.

Methods

Questionnaire Development and Administration

A one page questionnaire was developed regarding the use of various radiographic films for regional spinal complaints (cervical, thoracic, and lumbar) at both the initial patient evaluation as well as preoperatively.

For each category, respondents were asked to check all of the four categories that applied: (1) No films, (2) AP/lateral, (3) F/E laterals, and (4) Obliques. Respondents who obtained AP/lateral images were also asked whether these films were taken supine or upright, and respondents who obtained F/E or oblique films were asked what percentage of time they believed that these images changed management.

Biographical questions were then asked about their surgical specialty (orthopedics or neurosurgery), whether or not they were fellowship trained, how long they had been in practice, in which state they practiced, and whether they did so in an academic or private practice setting. Then, the questionnaire was distributed to all participants of the "Disorders of the Spine" meeting (January 2006, Whistler, Canada). This population included both orthopaedic and neurosurgery spine surgeons.

Data Analysis

All data was compiled in Excel and described using frequency and percentage for categorical variables.

Results

Overview

Of the 173 participants and faculty to whom the questionnaire was distributed, 104 (60%) questionnaires were returned. 63% of the included questionnaires were completed by orthopaedic surgeons and 37% by neurosurgeons. 74% of these surgeons completed a spine fellowship. 44% practiced in an academic setting.

Utilization of Plain Films for Spinal Complaints

Cervical Spine

On initial presentation of a patient with cervical spinal complaints 88% of respondents obtained AP and lateral films, 43% obtained lateral F/E films, 8% obtained oblique films, and 10% did not obtain any plain films. During the preoperative evaluation of patients with cervical spine complaints, 93% of respondents obtained AP and lateral films, 70% obtained lateral F/E films, 16% obtained oblique films, and 4% did not obtain any plain films. (**Figure 1**)

Respondents who routinely obtained F/E views in the cervical spine believed that they made a difference in clinical management 19% of the time when obtained initially and 25% of the time when obtained preoperatively. Respondents who obtained oblique views in the cervical spine believed them to make a difference 20% of the time when obtained initially and 41% of the time when obtained preoperatively.

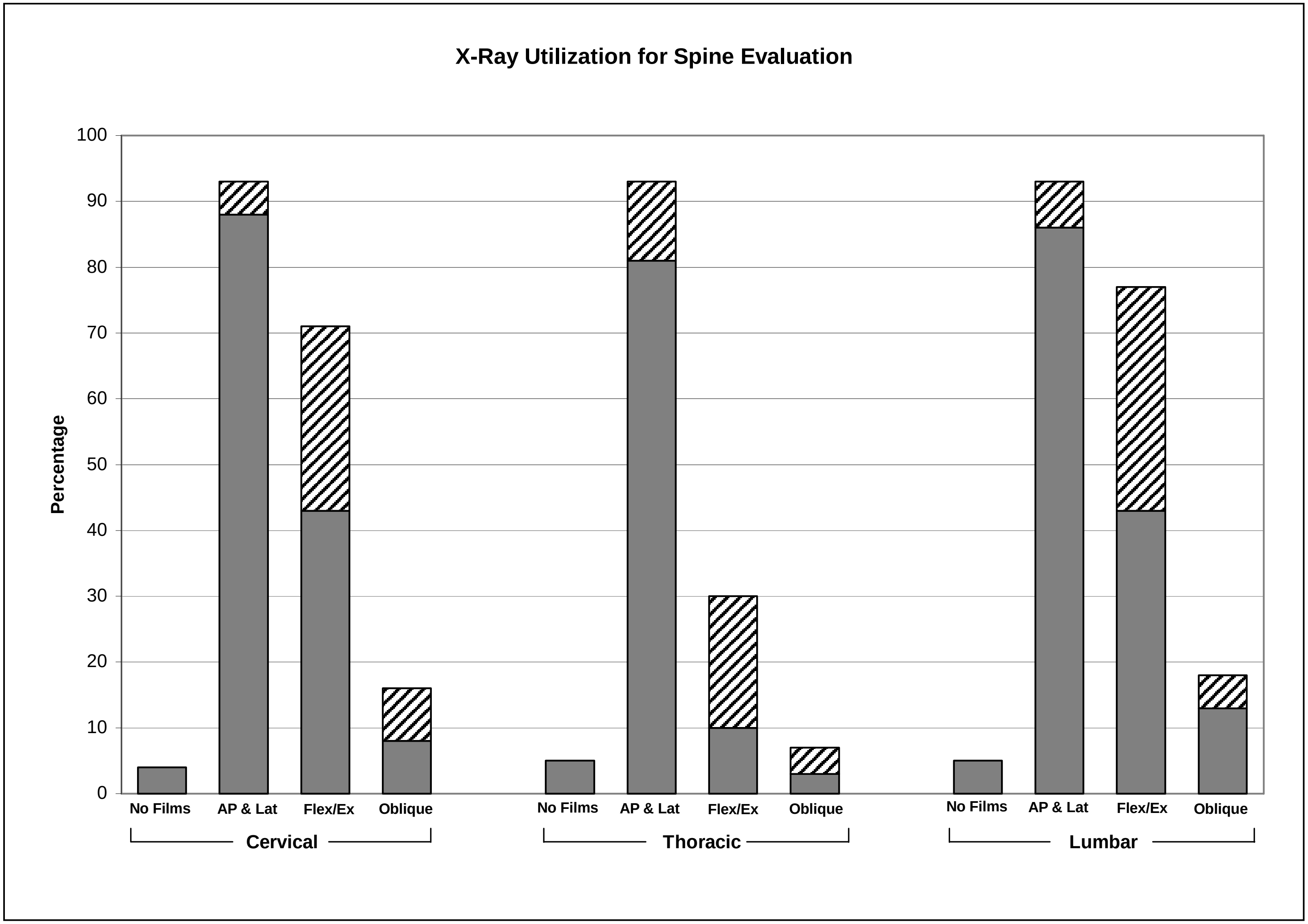

Figure 1 - Percentage of respondents who obtain no films, AP and lateral views, flexion/extension, and oblique views for each of the three spine regions, including cervical, thoracic, and lumbar. Percentages are further divided into those who obtain the films on initial presentation and those who only obtain these films prior to surgery.

Thoracic Spine

On initial presentation of a patient with thoracic spinal complaints 81% of respondents obtained AP and lateral films, 10% obtained lateral F/E films, 3% obtained oblique films, and 18% did not obtain any plain films. During the preoperative evaluation of patients with thoracic spine complaints, 93% of respondents obtained AP and lateral films, 30% obtained lateral F/E films, 7% obtained oblique films, and 5% did not obtain any plain films. (**Figure 1**)

Respondents who routinely obtained F/E views in the thoracic spine believed that they made a difference in clinical management 32% of the time when obtained initially and 35% of the time when obtained preoperatively. Respondents who obtained oblique views in the thoracic spine believed them to make a difference 17% of the time when obtained initially and 47% of the time when obtained preoperatively.

Lumbar Spine

On initial presentation of a patient with lumbar spinal complaints 86% of respondents obtained AP and lateral films, 43% obtained lateral F/E films, 13% obtained oblique films, and 10% did not obtain any plain films. During the preoperative evaluation of patients with lumbar spine complaints, 93% of respondents obtained AP and lateral films, 77% obtained lateral F/E films, 19% obtained oblique films, and 5% did not obtain any plain films. (**Figure 1**)

Respondents who routinely obtained F/E views in the lumbar spine believed that they made a difference in clinical management 28% of the time when obtained initially and 28% of the time when obtained preoperatively. Respondents who obtained oblique views in the lumbar spine believed them to make a difference 20% of the time when obtained initially and 42% of the time when obtained preoperatively.

Discussion

The results of this study confirm the impression that there is considerable variability in the initial and preoperative radiographic assessment of patients presenting to the spine surgeon with spinal complaints. Currently, there is no standard of care for obtaining imaging studies in the evaluation of degenerative spine disease. There are no clear recommendations to fall back upon from the literature for these practice patterns.

Radiograph utilization data is summarized in figure 1. One can see clearly that most spine surgeons in this study obtain some initial radiographic assessment mostly in the form of AP and Lateral films. A significant percentage of surgeons will obtain lateral F/E films at initial evaluation and an equal amount of surgeons will obtain them pre operativly. The same is true for obliques but with smaller percentages.

There are limitations to this study. As is the case with all survey studies, there exists a potential selection bias in the population of surgeons asked to complete this questionnaire. While there are relatively high percentages of academic (44%) and fellowship-trained (74%) surgeons in the surveyed population, we found no systematic differences in imaging practices based on these criteria. Also, survey studies rely upon surgeon approximations of practice which may not exactly reflect actual clinical practice. Finally, a limited number of surgeons were surveyed, but we did have a significant return rate of surveys circulated (60%) and do feel that this is an adequate cross section of practice patterns.

In summary, this study provides a measure of utilization of plain radiograph imaging for the spine surgeons. There does appear to be considerable variability in the initial and preoperative radiographic assessment of patients with spinal complaints without strong associations to surgeon demographics. As we embrace the modern day concept of evidence based medicine, such variations in practice seem hard to justify scientifically. Further studies of this topic could potentially lead to a standard of care for spinal imaging and help reduce potentially unnecessary radiographic imaging.

CHAPTER 2 – Utility of Flexion/Extension Films in the Lumbar Spine

Objective

To assess the utility of dynamic flexion/extension radiographs in the initial evaluation of the degenerative lumbar spine.

Methods

Patient population:

This study retrospectively reviewed the radiographic series of 390 consecutive patients, who visited our clinic between Sept 2003 and December 2004, with lumbar axial or radicular complaints. AP, neutral lateral, and dynamic lateral F/E lumbar radiographs had been obtained for each patient. This study review was approved by our institution's Human Investigations Committee.

Radiographs:

AP and lateral lumbar radiographs were taken with the patient in their natural posture. F/E lumbar films were taken by asking the patient to achieve his or her maximum effort at flexion and extension in the standing position.

All radiographs were reviewed by consensus of three examiners: one musculoskeletal radiologist, one spine surgeon, and one orthopaedic resident. The films were viewed using our center's digital radiography software (Synapse V3.0 by Fuji). All measurements were done using the program's digital measuring tools.

Standing AP and neutral lateral radiographs were initially reviewed for exclusion criteria. Patients with scoliosis of more than 30 degrees, spondylolisthesis of grade four or greater, evidence of fracture, or evidence of previous spinal surgery were excluded. These exclusion criteria were selected as it was believed that they would dictate the series of images which would be taken and/or obscure potential findings of dynamic radiographs.

AP views were only reviewed initially for exclusion criteria. The remaining observations were based on the lateral views, as the focus of the study was to identify additional information seen on dynamic lateral films relative to neutral lateral films**.** The lateral films were assessed for osteoarthritis, anterolisthesis or retrolisthesis, pars defects, and segmentation anomalies. Osteoarthritis was quantified as per Kellgren's classification (Table 1), and each level was assigned a grade, ranging from 0 to 4.[32] The amount of anterolisthesis or retrolisthesis was measured using computerized measuring tools. The measurement of spondylolisthesis was made by determining the relative anteroposterior distance between the posterior borders of adjacent vertebral bodies. A minimum measurement of 2mm was used to achieve this definition.

Grade	Criteria
0	Absence of degeneration in the disc
1	Minimal anterior osteophytosis
2	Definite anterior osteophytosis Possible narrowing of the disc space Some sclerosis of vertebral plates.
3	Moderate narrowing of the disc space Definite sclerosis of vertebral plates Osteophytosis.
4	Severe narrowing of the disc space Sclerosis of vertebral plates Multiple large osteophytes.

Table 1: Kellgren's classification adapted from *The epidemiology of chronic rheumatism; a symposium organized by the Council for International Organizations of Medical Science[4]s.*

F/E lateral films were then assessed for any additional information or any change in the amount of listhesis compared to the static radiographs. Change was defined as 2mm or greater. During the review, we did not quantify the amount of overall patient flexion or extension as we could not find consistent, reproducible measures and we had followed our clinical standard for obtaining these images.

For those patients in which F/E films provided additional information, we performed a chart review to determine whether clinical management was affected specifically by that additional information. We defined significant findings in this study as new findings or changes in findings revealed on dynamic films that resulted in changes to patient management.

Statistical analysis:

Intraobserver variability of the study group was assessed using Cohen's Kappa formula. A subset of 55 films were reviewed by the study group a second time, and comparison was made to their original assessment. The radiographs were reviewed by three observers, but the findings were recorded as the consensus of their reviews(meant to model a clinic environment), with the three reviewers essentially functioning as one. After collecting the data, the number of patients with change or new findings on F/E lateral radiographs was too few to warrant any meaningful statistical analysis. Descriptive analysis was believed to be most appropriate for this portion of the data.

Results

Of the 390 radiographic series from the period surveyed, 45 were excluded based on the criteria defined: nine for scoliosis, nine for fracture, twenty six for having had previous surgery, and one for spondyloptosis. Additionally, radiographic series of three patients could not be recalled from our digital archives for technical reasons. There were thus 342 cases for evaluation. There were 177 females (51.8%) and 165 males (48.2%). The mean age was 50.0 years (range 16 – 92).

Assessment of the AP and neutral lateral images allowed for a characterization of the patient population included in this series. The Kappa value for the amount of degeneration was found to be 0.61, consistent with substantial agreement.[33] The majority of cases reviewed demonstrated degenerative changes (Kellgren score greater than zero at one or more levels). These changes were seen in 270 of the patients (79.5%). The prevalence of degeneration was highest at the L4-L5 level, followed by L3-L4, and then closely by L5-S1. (Figure 1 and Table 2). Of note, there were 27 sacrilized L5 vertebrae (7.92%), 10 pars defects (2.92%), and 7 lumbaralized S1 vertebrae (2.04%). These numbers are of further relevance, as they affect the total number of L5-S1 disks reviewed.

	Grade 1	Grade 2	Grade 3	Grade 4	Total with degeneration	No degeneration
L1-L2	40	32	20	11	103	239
L2-L3	56	38	27	13	134	208
L3-L4	76	56	39	16	187	155
L4-L5	76	63	54	34	227	115
L5-S1	37	40	36	48	161	164

Table 2: Number of discs with degeneration broken down by level and grade of degeneration.

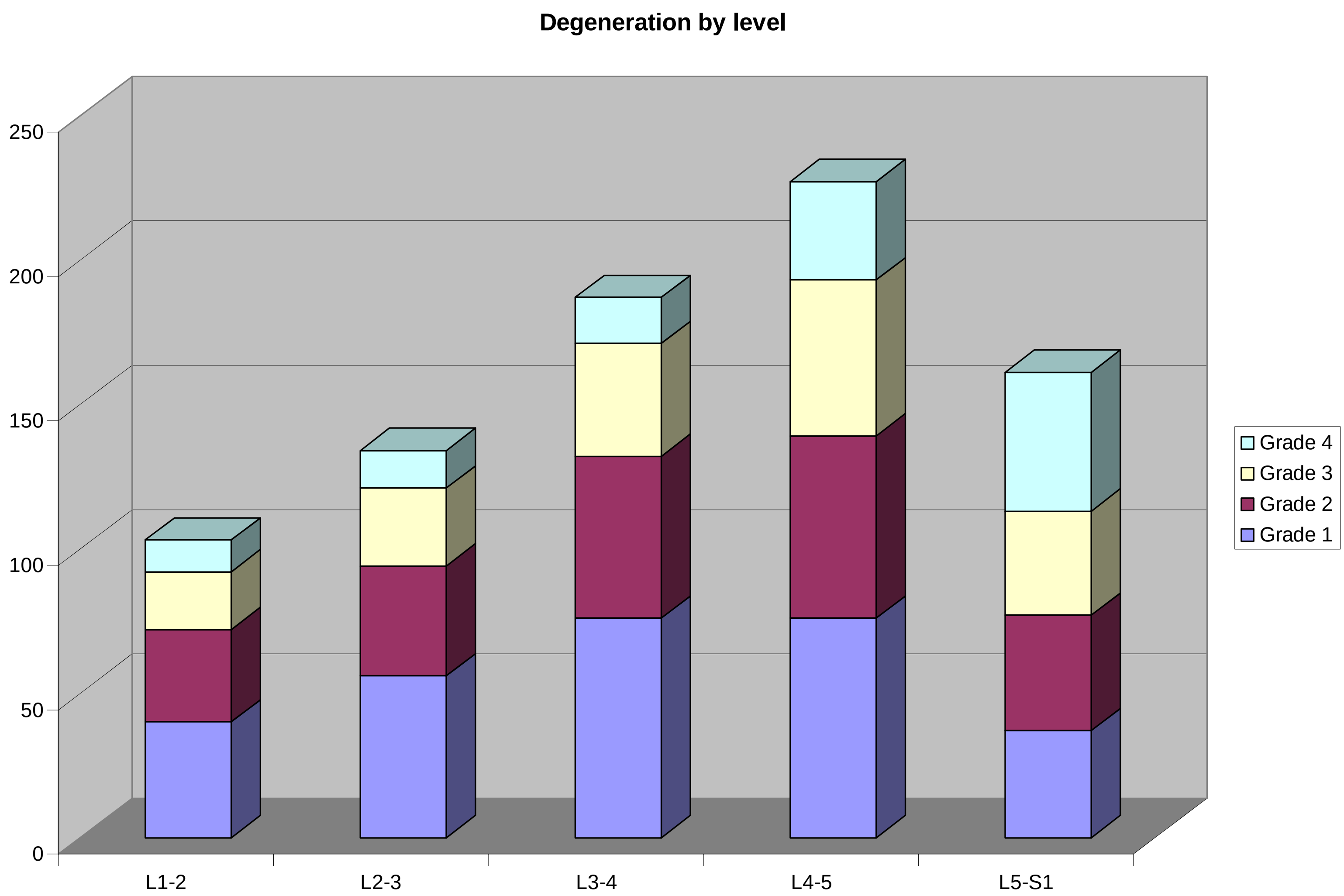

Figure 1 - Number of discs with degeneration broken down by level and grade of degeneration.

In terms of listhesis, 67 of the patients (20%) had anterolistheses: 54% of these were at L4-L5 and 31% at L5-S1. Listheses were Meyerding Grade I in 50 patients (75%), Grade II in 16 patients (24%), and Grade III in 1 patient (1%). An additional 46 patients (13%) had retrolistheses: 41% of these were at L4-L5 and 29% at L3-L4. 13 patients (4%) had both anterolisthesis and retrolisthesis at different levels.

Of the series reviewed, only 2 had new findings seen on dynamic F/E films that were not appreciated on the AP and neutral lateral films. One of these was a L3-L4 anterolisthesis of 3mm with flexion and the other was a L5-S1 retrolisthesis of 4mm with extension.

Fifteen additional series of radiographs were noted to have a change in the amount of listhesis on the dynamic F/E films compared to the neutral lateral films. Of these, 11 were changes in the amount of anterolisthesis and 5 were in the amount of retrolisthesis. These changes in listhesis ranged from 2-5mm (mean of 3.0mm). The changes in listhesis on flexion / extension did not result in changes of the Meyerding grade in any of the cases. Although a change in Meyerding grade unto itself is not defining of change in treatment, it is a marker of the fact that no large changes were seen.

A subsequent review of these patients' charts revealed no change in conservative management and no decision to go to surgery based solely on information from the F/E radiographs. Thus, no significant findings were seen on dynamic films.

Discussion

Plain spinal radiographs aid in the diagnosis of a number of different spinal pathologies: fractures, degeneration, instability, etc. AP and neutral lateral radiographic evaluation is recommended in all patients with lumbar symptomatology that persists beyond 4 to 6 weeks.[34] In addition to neutral films, a sizeable proportion of spine specialists routinely order dynamic flexion-extension views in this initial evaluation. While many surgeons believe that dynamic F/E radiographs contribute to clinical decision-making, the incidence of dynamic images leading to changes in patient management has previously not been well defined.

After reviewing the present cohort, only two cases out of the 342 reviewed had new findings with dynamic images and 15 cases demonstrated a minor change in the degree of the spondylolisthesis. These findings led to no change in conservative management and no decision to go to surgery based solely on information from the dynamic F/E radiographs.

Further, there is increased radiation with additional radiographic views. The amount of radiation exposure has decreased significantly with more advanced imaging techniques. Nevertheless, small doses of radiation exposure can still have long-term harmful effects, especially when considering the cumulative effect of radiation when obtaining multiple films with each follow-up or exacerbation of symptoms. There are also increased financial and temporal costs associated with obtaining additional radiographs.

This study does have limitations. The results are dictated by the population being studied. It is for that reason that we went to lengths defining baseline characteristics (degeneration, etc.) of this cohort. Additionally, this is a retrospective study. However, we were able to take advantage of the primary surgeon's practice of obtaining standing AP, neutral lateral, and dynamic F/E lumbar radiographs of all new patients presenting with lumbar-related complaints during the period of study collection to critically evaluate this practice.

There is some potential information that can be obtained from dynamic F/E lumbar radiographs, such as subtle instability. However we did not find the addition of these images to routine AP and neutral lateral images to effect clinical decisions in initial patient management of the cohort being studied. Thus, our study does not support the use of flexion-extension films in the initial evaluation of patients presenting with lumbar spine complaints from degenerative conditions. This study has thus led the senior spine surgeon to change his practice of routinely obtaining dynamic F/E radiographs for new patients with lumbar-related complaints. A critical evaluation of the potential role of dynamic F/E radiographs in patients with prior surgery, fracture, or other risk factor for instability, has not yet been performed. Further, the role of dynamic radiographs in the preoperative setting remains undefined.

CHAPTER 3 – Cervical Oblique Imaging and Film Angle Effects

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.

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 which 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 two layers of plexiglass which were marked in 5° increments to allow for precise positioning of the specimens during the radiographic assessment. **(Figure 1)**

Plain radiographs were obtained from 20° to 70° from AP orientation at 5 degree increments on both the left (RPO) and right (LPO) sides of the specimen, with the beam focused in the middle of the cervical spine. Two example radiographs demonstrate the cervical foramen as they appear at film angles of 45 **(Figure 2a)** and 55 degree **(Figure 2b)** oblique film angles. These x-rays were obtained with digital radiography software

(Synapse V3.0, Fuji Corp.) and all measurements were performed using the program's digital measuring tools.

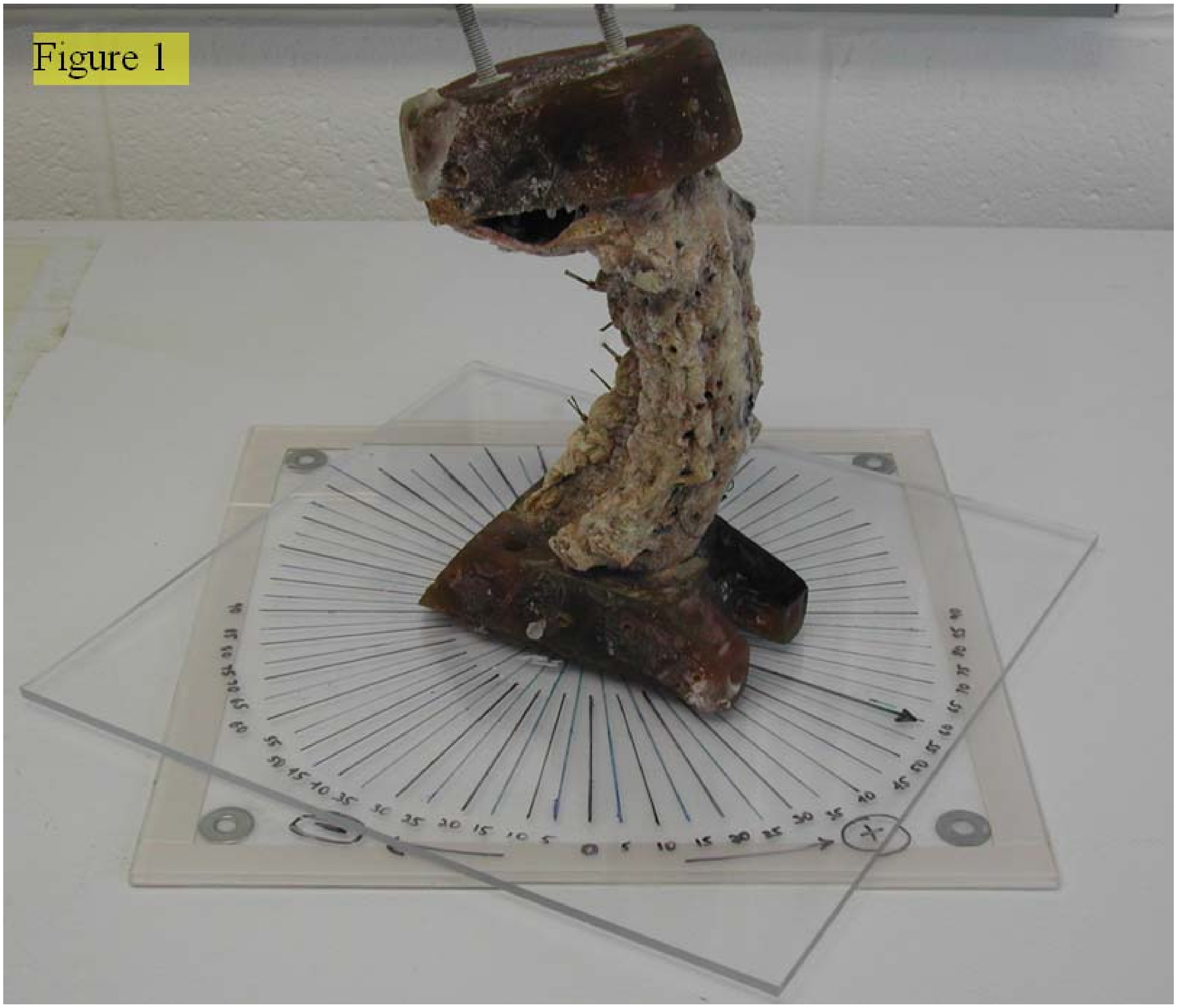

Figure 1 - : Cervical spine specimen frozen in neutral posture, positioned on rotating platform used for specimen orientation during oblique radiograph acquisition.

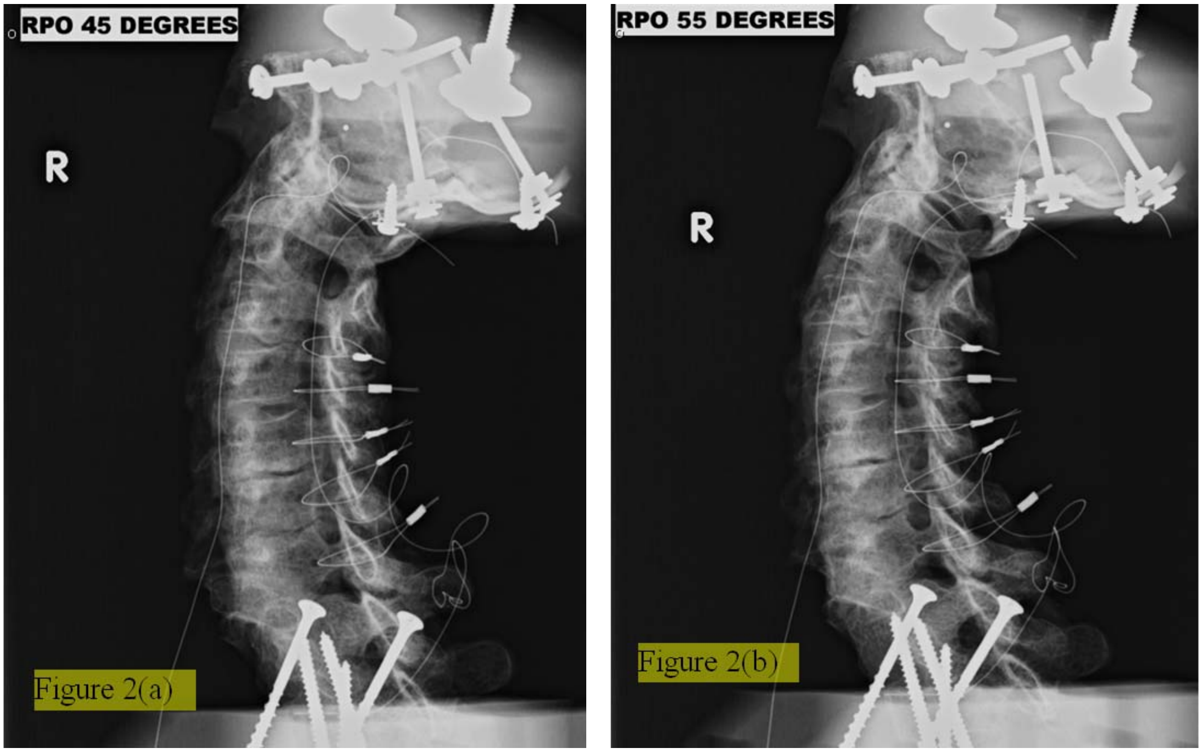

Figure 2 -Radiographs of specimen A obtained at 45 degree (a) and 55 degree (b) oblique film angles relative to the AP orientation.

Assessment of Foraminal Area

From these radiographs, the area of each foramen from C2-3 through C7-T1 was calculated for all of the specimens. Two separate techniques were utilized 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 orthopaedic research fellow made all measurements. Based on calculated interobserver reliabilities of the two methods, the measurement technique that exhibited greater reliability was utilized for assessment of the remaining specimens.

With the first method, the area was determined using the equation for area of an ovoid shape: π * (1/2) height * (1/2) width. Foraminal height was considered to be the maximum distance between the bony margins of the cephalad and caudad pedicles while 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.

Data Analysis and Statistical Methods

A priori analyses were performed on the values recorded by the three examiners to determine the interobserver reliabilities of the two 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 *et al* *[35]* was employed for grading ICCs: < 0.40 – poor; 0.40 to 0.59 – fair; 0.60 to 0.74 – good; > 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 (OLS) to characterize the relationship between these two 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° 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.

In order 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 to 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°. This data was 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 two methods of evaluating foraminal area revealed that multiplying the height and width resulted in good interobserver reliability (ICC 0.74; 95% confidence interval (CI) 0.64 to 0.82) whereas the values obtained with the freehand area measurement tool exhibited excellent reliability (ICC 0.83, 95% CI 0.75 to 0.89). Based on these findings, only the measurements from the freehand application were utilized to estimate foraminal area for the 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, right side) which demonstrates the relationships between the measured foraminal areas and the angles at which the oblique radiographs were obtained. **(Figure 3)** Eight of these plots were generated by measuring all of the foramina on both sides of the four specimens. The mean of the R^2 values for these quadratic fits was 0.81, with a standard deviation of 0.075.

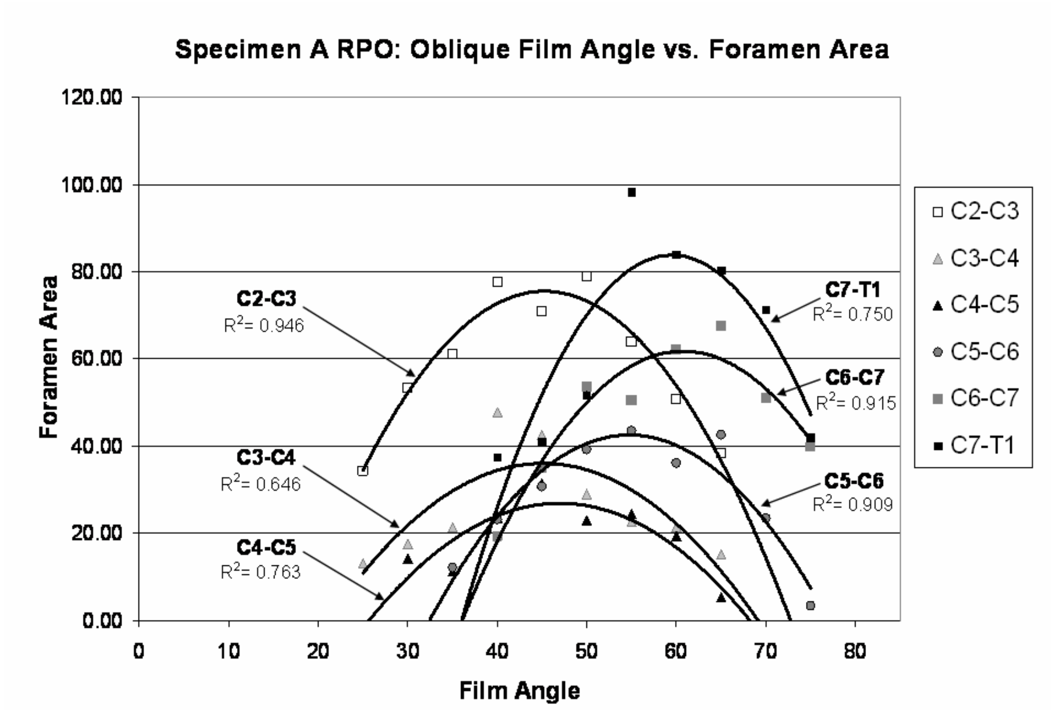

Figure 3: Film angle vs. foraminal area graph for specimen A, right side, which demonstrates the relationship between film angle and observed foraminal area for each cervical spine level

The mean optimal film angles (and the corresponding margin of error for a 95% confidence interval) for assessing foraminal area ranged from 46.3 ± 2.7° for the C2-C3 level to 56.1 ± 3.2° at C7-T1. **(Figure 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° deviations from the ideal film angle varied from 98.05 ± 0.54% at C2-C3 to 96.58 ± 0.76% at C7-T1, while for 10° deviations these averages decreased to 92.20 ± 2.17% at C2-C3 and 86.32 ± 3.04% at C7-T1. **(Figure 5)**

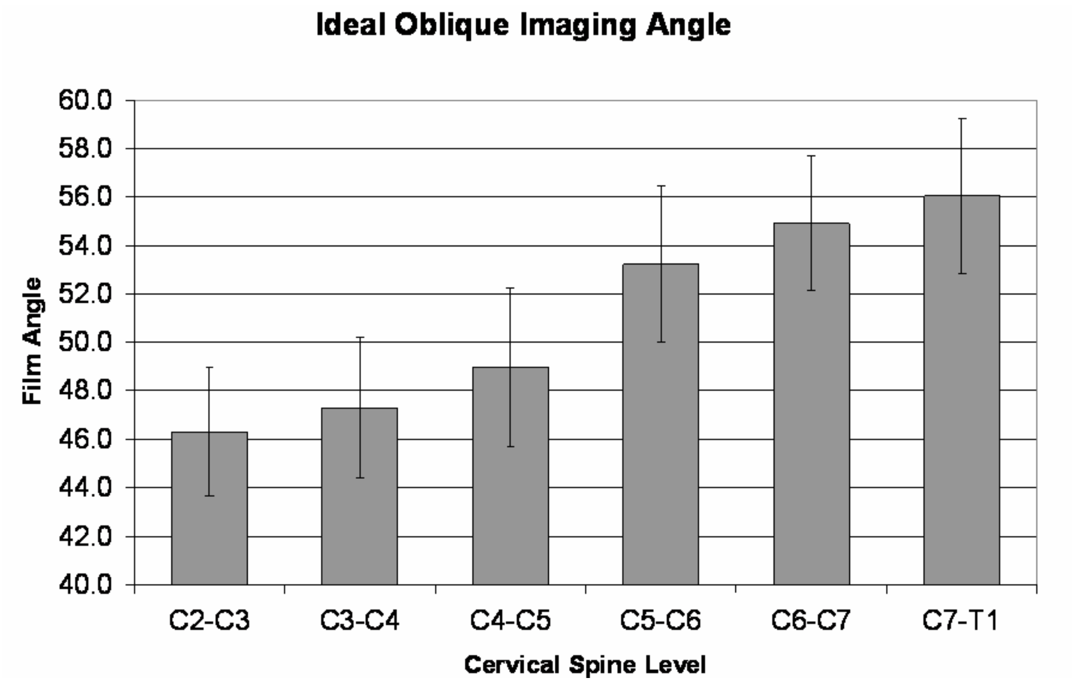

Figure 4: Mean optimal film angles (and 95% confidence intervals) for assessing foraminal area for each cervical spine level

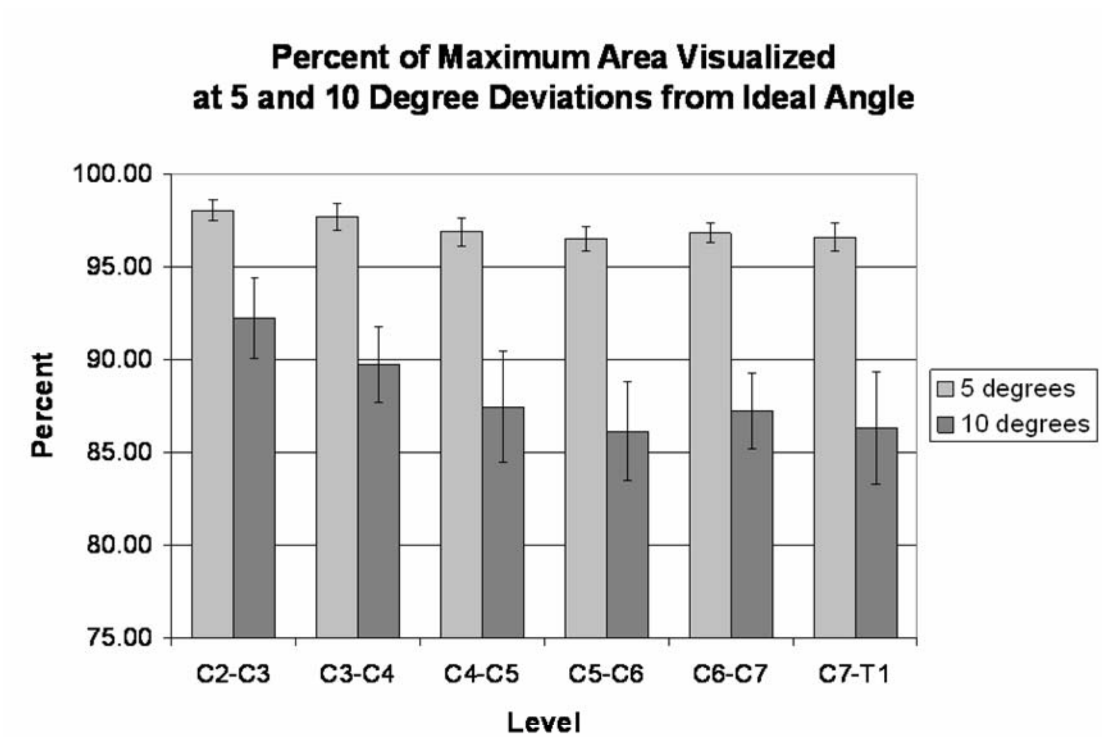

Figure 5: Percentage of the maximum observed area that could be visualized at 5° deviations from the ideal film angle for each cervical spine level

The smallest mean reductions in foraminal area, expressed as a percentage of the maximum value recorded for each level, were observed at film angles of 50° and 55° (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°. Thus, 52.4° 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. **(Figure 6)**

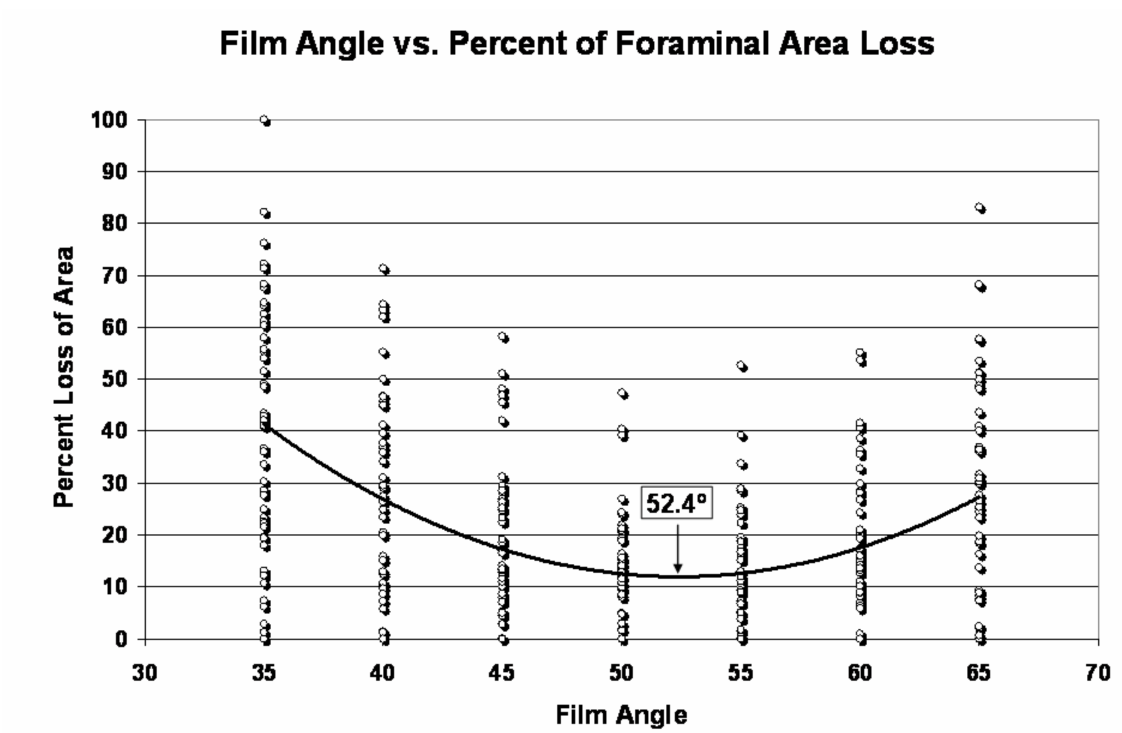

Figure 6: Scatter plot demonstrating percentage of observed foraminal area loss relative to the maximum observed area for every foramen at film angles between 35° and 65°

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 in order to assess foraminal patency. Although these films are typically oriented at approximately 45° 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 upon their location and that x-rays of greater obliquity (i.e. greater than 45°) may allow for more accurate estimates of foraminal area. [24, 25] 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 due 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 $46.3 \pm 2.7°$ while for the more caudal foramina the optimal film angles increased to a maximum of $56.1 \pm 3.2°$ 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*. In order 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° resulted in an apparent decrease in area of 7.8% at C2-3 and 13.7% at C7-T1. Because oblique radiographs are frequently acquired at a 45° 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°. The smallest overall losses across all of the foramina were observed at film angles of 50° and 55°, which gave rise to average area reductions of only 12.71% and 12.84%, respectively; these findings also indicated that 52.4° 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° with respect to the AP orientation in order to enhance the utility of oblique radiographs for evaluating cervical foramina.

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 (CT) 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 CT techniques.[36-39]

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 appear to exhibit specific angles of orientation that progressively increase relative to the AP plane from 46° at the C2-C3 level to 56° 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° in order to minimize the observed area lost when all of the foramina are assessed from a single x-ray.

CHAPTER 4 – Radiation Exposure from Spine Radiographs

Methods

The radiation that is required to generate clinical images is discussed in terms of the effective dose [E], a composite dosimetric value that is based on the total radiation absorbed by all of the exposed organs which are subsequently adjusted according to their respective radiosensitivities. In order to calculate these quantities, a number of terms must first be defined:

- Entrance dose [D] is the dose delivered from the ionizing radiation tube which is described in units of mGy; 1mGy is equivalent to 100 mrad/mrem/mSv.
- Dose-Area Product [DAP] is the product of the entrance skin dose and cross-sectional area of the x-ray beam. This value is used to evaluate the radiation exposure of the patient.
- Constant $[E/DAP]_{view,quality}$ is a conversion factor that takes into account the specific view and anatomic area involved (e.g. AP cervical, lateral lumbar, etc.) as well as the quality of the beam, which is influenced by variables such as applied potential (kV) and filtration. The conversion factor for a given view and anatomic region remains constant, and may be obtained from the National Radiological Safety Board NRPB-262 report.[40] The relevant $[E/DAP]_{view,quality}$ constants are listed in **Table 1**.
- Average area [A] is the area of the beam incident on the patient.
- Film area [FA] is the actual area of the film being used.

- Film area fraction [F] is the percentage of the actual film area that is taken up by the patient.
- Source-to-image distance [SID] is the distance from the radiation source to the film (or receiver) onto which the image is projected (**Figure 1**). The SID is generally standardized depending on the specific radiographic study that is being performed.
- Source-to-object distance [SOD] is the distance between the radiation source and the patient's tissue (Figure 1). The SOD is calculated by subtracting the length of the tissue that the beam passes through; for example, the SOD for a lateral cervical x-ray may be determined by subtracting the lateral dimension of the neck from the SID.

Table 1 - Values for $[E/DAP]_{view,quality}$ constant based on view and spine region.

	AP	Lateral
Cervical	0.22 mSv/(Gy-cm^2)	0.031 mSv/(Gy-cm^2)
Lumbar	0.22 mSv/(Gy-cm^2)	0.10 mSv/(Gy-cm^2)

Taken from NRPB report 262 (70 - 85 kV / 3 mm filtration which is a typical value)

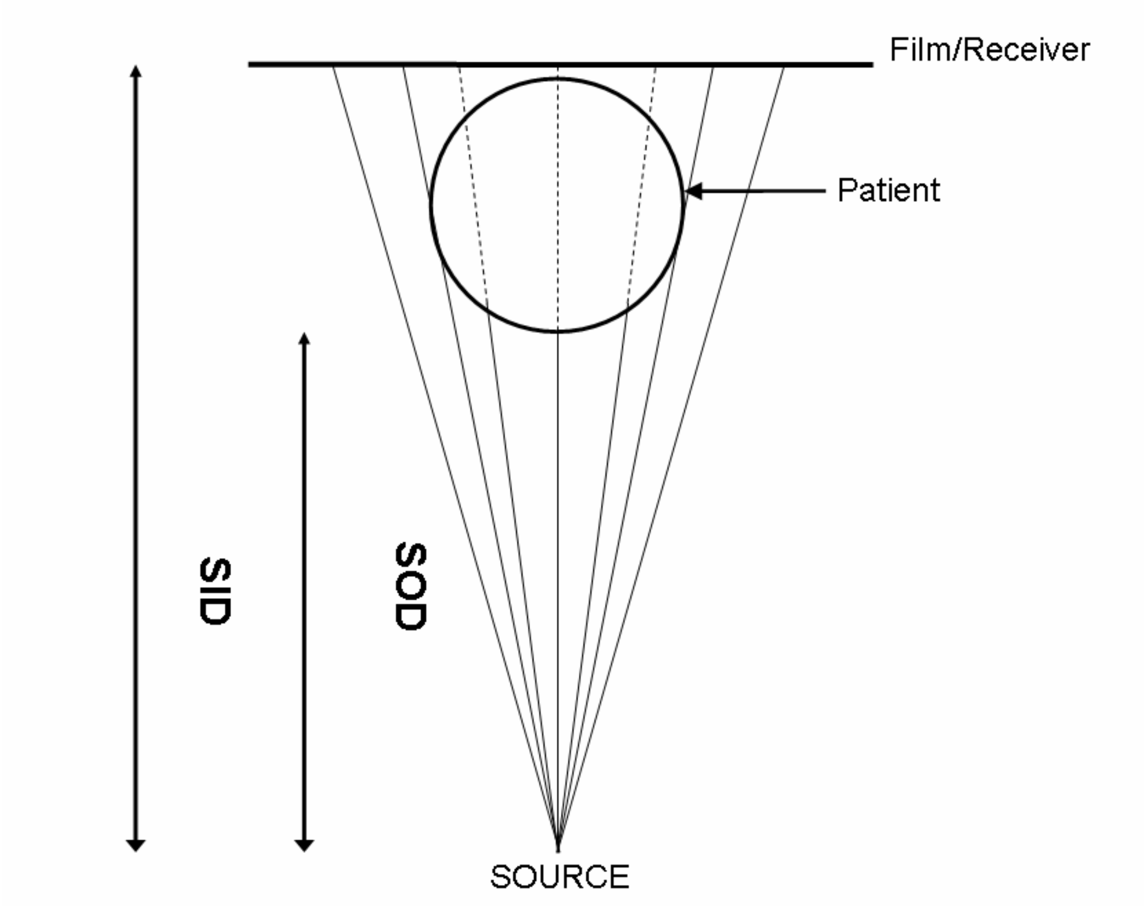

Figure 1. Schematic illustrating SID and SOD

The Effective Dose [E] is calculated by multiplying the Dose-Area Product [DAP] and the constant $[E/DAP]_{view,quality}$.

$$\mathbf{[E] = [DAP] \times [E/DAP]_{view,quality}}$$

The DAP is calculated by multiplying the Entrance Dose [D] by the Average area [A].

$$\mathbf{[DAP] = [D] \times [A]}$$

The entrance doses that were applied to our calculations represent the average values currently employed by the radiology department in our institution for each individual type of radiograph, each of which was based on the data recorded from 10 patients who had undergone that type of radiographic evaluation. The Average area [A] is the product of three factors: the actual film area [FA], the fraction of the film that is taken up by the patient [F], and another factor that accounts for the distance between the person and the film that is derived from the source-to-object distance [SOD] and the source-to-image distance [SID].

$$[A] = [FA] \times [F] \times [SOD/SID]^2$$

At our institution, the actual film areas used for cervical and lumbar radiographs are 25 x 30 cm and 35 x 43 cm, respectively. During these radiographic exams, the technologist has the ability to augment the radiation beam and expose less than the whole film area, a modification which may slightly alter the patient's effective dose. The fraction of the film taken up by the patient [F] was estimated from a review of 10 radiographic series for each specific view and region of the spine. While the SID is standardized in our radiology department, the SOD was determined by measuring the AP and lateral tissue dimensions of 10 patients undergoing spinal imaging; these values were subsequently subtracted from the respective SID values in order to estimate the SOD for each type of imaging study.

Results

We reviewed the imaging practices and protocols established by the radiology department of our institution for obtaining spinal radiographs. The average entrance doses [D] used in our clinic for cervical and lumbar radiographs are summarized in **Table 2**. The average AP and lateral tissue dimensions of patients undergoing spinal imaging were calculated in order to acquire the SID values for each of these views. According to our analysis, the average fraction of the film taken up by the patient [F] was approximately 0.8, i,e, the patient occupies approximately 80% of any given film.

The calculated effective doses [E] for these spinal radiographs are listed in **Table 3** along with the corresponding values presented by the National Radiological Protection Board (NRPB) of the United Kingdom.[41] Originally based on patient dose information collected in the 1990s, the NRPB estimates refer to the exposure acquired during a complete spinal evaluation consisting of AP and lateral images. For the purpose of comparison, the calculated effective doses for each of these spinal x-rays are also reported as a ratio of the combined effective dose of PA and lateral chest radiographs, which are known to result in a radiation exposure of approximately 0.15 mSv.[42]

Table 2 – Average values for Entrance Dose [D], SID, Tissue distance, and SOD.

	Entrance Dose[D] mGy	SID (in)	Tissue Distance (in)	SOD (in)
Cervical AP	1.2 mGy	40	5.7	34.3
Cervical Lateral	1.4 mGy	72	5.3	66.7
Lumbar AP	15 mGy	40	10.3	29.7
Lumbar Lateral	27 mGy	40	12.8	27.2

Table 3 - Calculated Effective Dose [*E*] values based on view and spine region.

	Calculated *E* (mSv)	Estimated *E* from NRPB for complete exam (AP + Lat) (mSv)	Equivalent number of Chest Radiographic Evaluations (0.15 mSv)
Cervical AP	0.12	0.064	~ 0.5 - 1
Cervical Lateral	0.02		
Lumbar AP	2.20	1.2	~ 10 - 25
Lumbar Lateral	1.50		

Discussion

Even with the development of advanced imaging modalities, plain radiographs still play an indispensable role in the diagnosis and treatment of patients with spinal pathology. Given the nearly ubiquitous nature of neck and low back symptoms, cervical and lumbar spine x-rays are being performed with increasing frequency; in addition to standard AP and lateral views, supplementary images such as oblique and flexion-extension films may also be informative in certain clinical scenarios. However, despite the widespread utilization of spinal radiographs by physicians of all specialties, there continues to be a significant degree of ambiguity regarding the radiation doses that patients are subjected to as a result of these studies. In order to perform appropriate risk-benefit analyses of current imaging practices, it is imperative that the amount of radiation imparted by these x-rays be accurately quantified.

This study describes a method for measuring the radiation exposure that occurs during the radiographic evaluation of the cervical and lumbar spines. In addition to involving a variety of constant values and formulas, the calculation of the radiation dose for a given imaging study is also influenced by institution-specific standards (e.g.

entrance radiation dose and source-to-image distance) and patient characteristics such as size. While these figures are unique to our institution, we believe that the effective doses recorded in this investigation are generally representative of most conventional spinal imaging techniques; nevertheless, in this report we have attempted to include a detailed description of our methodology so that other practitioners may independently determine the analogous radiation exposure values for their own institutions.

Another clinically relevant finding of this study is that in both the cervical and lumbar spines, the AP view resulted in greater radiation exposure to the patient than the corresponding lateral radiograph. Although lateral radiographs require greater entrance doses than AP views, the [E/DAP] constants for the lateral projections are orders of magnitude smaller than for the corresponding AP projections. These constants, which reflect the sensitivities of the exposed organs and the manner in which the organs are exposed from a particular radiographic view, demonstrate that the lateral views are less detrimental to radiosensitive organs. In our experience, physicians often order AP and lateral x-rays concurrently, but this practice may not be justified if a single view may provide sufficient clinical information. For example, in certain cases the follow-up radiographic evaluation of postoperative patients may only require a lateral image rather than a complete battery of films.

In addition, it is clear from this analysis that imaging of the lumbar spine gives rise to higher doses of radiation than imaging of the cervical spine. While the radiation exposure associated with cervical spine radiographs appears to be equivalent to that reported for chest films, the effective radiation doses of lumbar spine x-rays are approximately one order of magnitude greater than those of analogous images of the cervical spine. This difference in radiation exposure between these types of radiographic studies exists primarily because the larger soft tissue component surrounding the lumbar spine necessitates higher entrance doses in order to achieve adequate penetration; this also results in greater irradiation of the adjacent organs.

As we continue to critically assess the utility and cost-effectiveness of plain radiographs for the evaluation of spinal disorders, both primary care practitioners and spine specialists alike must become familiar with the amount of radiation patients are subjected to during these studies. By reporting the effective doses of cervical and lumbar radiographs, we hope that this information may become more accessible to clinicians, so that they may better educate their patients about the relative risks of these commonly ordered imaging studies; moreover, we believe that our methodology will allow clinicians to determine these values at their own institutions.

Summary Conclusions

Persistent non-specific back and neck pain presents a diagnostic challenge for primary care physicians and spine specialists alike. Most practitioners obtain plain radiographic films of the spine for persistent symptomatology before proceeding to advanced imaging modalities. The work presented here confirms the vast diversity of initial imaging regimens amongst physicians and demonstrates that many practitioners obtain supplemental film series (dynamic radiographs or oblique films) in addition to AP and lateral radiographs.

43% of respondents obtained dynamic flexion-extension films in the initial evaluation of degenerative cervical and lumbar spine complaints. Upon examining the utility of dynamic radiographs, we were unable to support their use in the initial management of lumbar spine disease. Previous work from this lab also found these dynamic images to be of little benefit in the initial evaluation of cervical spine disease. Given the findings from these studies, almost half of spine practitioners may be obtaining dynamic radiographs that have little impact on the clinical management of these patients.

Because a significant number of spine specialists also obtained oblique radiographs in the cervical spine to evaluate foraminal patency, we chose to critically evaluate the utility of these oblique films. Our results confirmed that there was significant variability in the observed foraminal area as a result of changes in the specific angle at which the radiograph is obtained. Although these films are commonly obtained at 45 degrees from the AP orientation, we found that film angles between 50 and 55 degrees were required in order to minimize the observed area lost when all of the foramina are assessed from a single x-ray. The accuracy of these oblique films is still unknown, however, as no previous studies have compared them to CT reconstructions, which have been shown to be the gold standard modality for measuring neuroforaminal dimensions.

The findings in the first three studies described here demonstrate the great variability in imaging practices and the lack of proven utility for many of the accessory radiographic studies that continue to be obtained by physicians. In the final chapter of this work, we investigated the radiation that patients receive from these radiographic studies and found radiation exposure levels to be more than trivial. Although cervical radiographs impart relatively moderate radiation doses, equivalent to that of a routine chest radiograph, lumbar films result in radiation exposures approximately 10 times that of corresponding cervical spine radiographs.

The collective findings described in these four studies make a strong argument for further critical analysis of our use of plain radiographs in the evaluation of cervical and lumbar spine symptoms. While standard AP and lateral views certainly have a role in providing an overall structural roadmap, assessing degeneration, alignment, and ruling out some pathologies, the use of accessory views may not be well supported. Given the risk of accumulating radiation exposure from these radiographs, more sophisticated cost-benefit analyses should be performed in order to establish appropriate guidelines for the use of plain radiographs in the evaluation of spine complaints.

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