ORIGINAL RESEARCH

Lead Foil Compensating Filters and their Impact on Reducing Radiation Exposure for Cervical Spine X-rays

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ABSTRACT

OBJECTIVE: To assess the amount of X-ray exposure that is reduced with the utilization of lead foil compensating filters (LFCF), which can be used when taking cervical X-rays.

MATERIALS AND METHODS: Seven types of LFCF were evaluated in a clinical practice. A radiation physicist from the Alabama Department of Public Health conducted the dosimetric readings in this study. Each set of readings was conducted with the X-ray equipment setup to take nasium, vertex and lateral cervical radiographs. Different X-ray factors were utilized with each type of LFCF to simulate patients with various body types.

RESULTS: The nasium LFCF reduced overall exposure by an average of 65% with a reduction of 97% to the majority of the skull and part of the eyes. The vertex LFCF reduced overall radiation by an average of 78%, while the lateral cervical filter reduced exposure by an average of 75%.

CONCLUSION: The utilization of LFCF in clinical practice can be useful for significantly reducing radiographic exposure for cervical X-rays, while helping to improve film quality for the purpose of spinal biomechanical assessment.

Key Words:

Lead foil compensating filter, radiation exposure, Orthospinology, upper cervical, chiropractic, subluxation

Introduction

Lead foil compensating filters (LFCF) have been used by Grostic-based upper cervical chiropractors for over 50 years to reduce exposure to ionizing radiation while helping to increase X-ray film quality. The Grostic Procedure (also referred to as Orthospinology) is a method of adjusting the upper cervical spine, which is based on the clinical research and teaching of the late Dr. John Francis Grostic. The Procedure employs a method of X-ray analysis that quantifies the lateral and rotational misalignments between atlas and axis as well as atlas and occiput. The analytical procedure examines the spatial orientation of the atlas, the geometry of the articulating surfaces, and the misalignment configuration to arrive at an effective correction vector. The X-ray analysis is the real core of the procedure and Grostic felt that chiropractors should lead the way in radiographic quality and patient safety. He was one of the first in the profession to advocate the use of LFCF, high kilovolts peak (kVp) technique, and aligned X-ray equipment as a part of his training courses in the Grostic Procedure.

The use of LFCF causes the skull to appear more radiopaque by attenuating the radiographic beam to the head. This helps the doctor construct the central skull line with the use of template or computer-aided digitization analysis by enabling the lateral edge of the skull to become more distinct (Figure 1). This is a critical procedure necessary in the Orthospinology X-ray analysis and has been shown to have a high degree of inter- and intra-examiner reliability,[1-3] with the exception of one study.[4] The Sigler and Howe study showed poor inter and intra-examiner reliability for measuring atlas laterality, although this study's protocol has been challenged.[5,6] However, when the same data was applied to the adjustment vector it was found to be extremely reliable from a clinical standpoint.[6]

Chiropractors who utilize upper cervical specific methods may use LFCF with the nasium (frontal plane), vertex (transverse plane) and lateral cervical X-rays. The nasium is an anterior to posterior (A-P) film (Figure 2) that is taken with the central ray angulated along the plane of the atlas vertebra as it sits in the sagittal plane (S-line). As a result, the lower cervical spine

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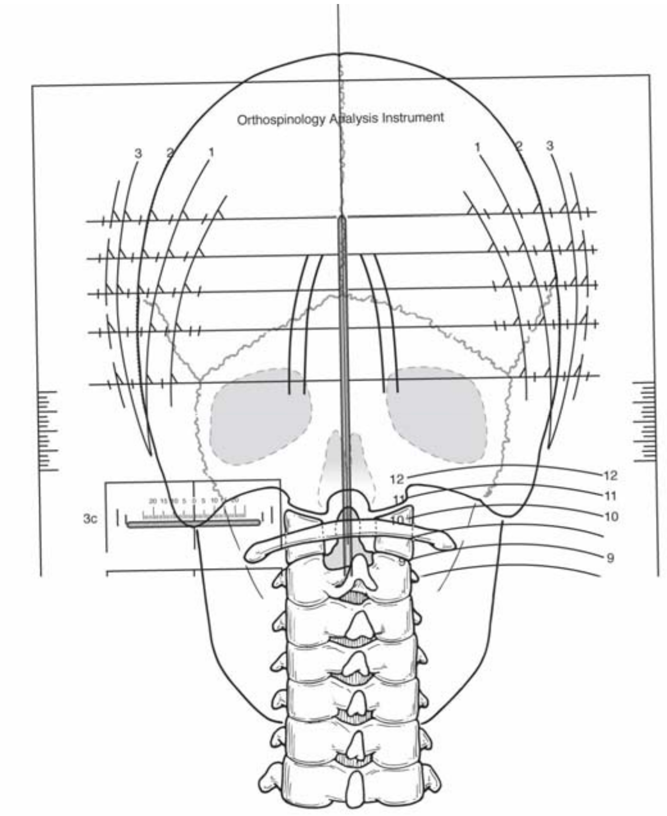

Figure 1: X-ray Mensuration Template

may be hard to visualize in cases where the central ray has to be angulated significantly in the caudal direction. LFCF improve the uniformity of the radiographic image by compensating for differences in body thickness and/or density. For example, the nasium filter can be used to prevent the skull and upper cervical vertebrae from appearing too dark, while allowing the lower cervical region to be visualized with a greater X-ray beam penetration. Many upper cervical chiropractors utilize "split screens" to accomplish the same purpose. This type of cassette has two or three separate screens with each having a different speed to accomplish the above stated goal. However, these split screens essentially attenuate the X-ray beam after it goes through the patient, as opposed to LFCF that reduce the exposure before the beam penetrates the patient.

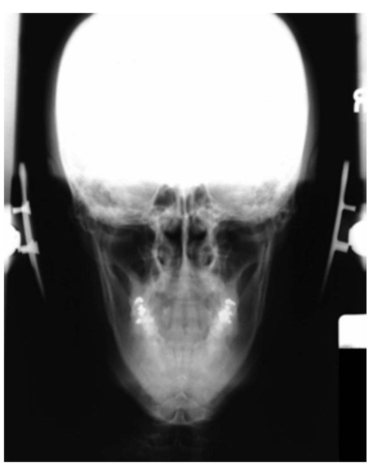

Figure 2: Nasium Radiograph with LFCF

The primary purpose of the vertex view (Figure 3) is to evaluate the occipito-atlanto-axial articulations in the transverse plane, so it is unnecessary to radiate the majority of the head and neck. A LFCF may be used for the lateral cervical X-ray with large patients who have relatively short and/or thick necks. Attenuating the beam to the region above the slope of the trapezius muscle can be helpful with visualizing the lower cervical vertebrae without "burning out" the mid to upper cervical spine.

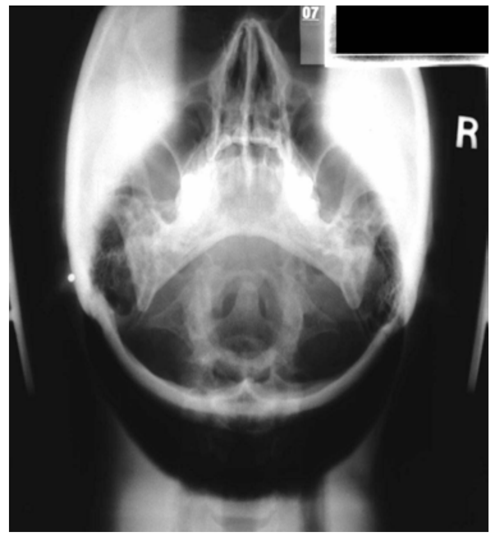

Figure 3: Vertex Radiograph with LFCF

Ionizing radiation can be defined as radiation in which an individual particle carries enough energy to ionize an atom or molecule. That is, to completely remove an electron from its orbit. Ionizing radiation can come in various forms such as: electromagnetic, ultraviolet light, X-rays, and gamma rays. Heavy metal filtration for spinal X-rays has been reported in the literature to show significant reduction in exposure and increasing film quality.[7-12] These filters are placed on the front of the collimator and are not to be confused with added and/or inherent filtration that is located within the machine and X-ray tube housing. Compensating filters also benefit patients by attenuating a much higher percentage of low-energy versus high-energy X-rays. Low-energy photons have longer wavelengths than high-energy X-rays, which cause them to have low penetrating power and most of these photons will add to the dose absorbed by the patient. Consequently, low-energy X-rays tend to interact with whole atoms, while high-energy photons generally interact with nuclei.[13] Low-energy photons also contribute to scatter radiation and result in a slight degree of film fog, which results in a general graying of the radiograph.

Hinson collected data to determine the amount of exposure that would be reduced with the use of LFCF before conducting his pilot study on patients suffering with trigeminal neuralgia.[14] Low (70) kVp technique was used in his evaluation because a high-frequency X-ray machine was used. Many chiropractors utilizing upper cervical methods use a range of 80 to 90 kVp for the cervical views. Hinson's nasium LFCF was found to reduce the dosimetric readings, in milliroentgens (mR), by 89%. Dr. Roderic Rochester has also conducted a preliminary study that assessed the effectiveness of his LFCF used in taking the nasium view.[6] Rochester enlisted the aid of the Georgia Department of Human Resources to conduct the dosimetric measurements. The evaluation involved each region of the nasium LFCF being specifically tested. The upper part of the filter, which attenuates the beam to the majority of the skull and part of the eyes, was found to reduce exposure (in milliRems) by 95%. The second portion that covers from the base of the skull to the mid cervical region was found to reduced radiation by 90%. Grostic and Dickholtz have also reported reductions of 90% and 78%, respectively, with the use of nasium LFCF.[6]

The *Roentgen* is the unit of radiation exposure or intensity; *Rad* stands for *r*adiation *a*bsorbed *d*ose as it relates to the patient; and *Rem* stands for *r*ad *e*quivalent *m*an, which is the unit of dose equivalent or occupational exposure. There is a subtle difference among these three units; however, in diagnostic radiology they have almost the same value. This present study set out to objectively assess the degree that the author's LFCF reduced exposure when taking nasium, vertex and lateral cervical X-rays.

Materials and Methods

Nasium Filters

Each LFCF is made of one-eighth inch white plexiglas that is seven inches wide by approximately three inches tall (Figure 4). Each layer of lead foil that is applied to the filter has a thickness of approximately 0.003". The lead foil is manufactured by 3M as a tape, which makes it easy to apply to the plexiglas. Lead is preferred because to get the equivalent of 0.003" lead foil filtration would require the use of over three millimeters of aluminum. Four types of nasium LFCF were used in this study. The entire surface of each filter is covered with one layer of lead foil. Filter #1 has two additional layers of foil added from the top of the filter down about two inches. The one inch portion of the lower filter that has only one layer of foil, attenuates the primary beam from the mid cervical region up to just below the cranial parietal sutures. This is accomplished by placing the filter about three quarters of an inch below the center horizontal line on the collimator.

Figure 4: Nasium filter affixed to collimator

This lower filtration region helps prevent the upper cervical vertebrae from being "burned out" on the image. The extra layers on the superior aspect of the filters provide additional attenuation of the primary beam to allow the skull to appear more radiopaque. This also protects brain tissue and part of the eyes. Filters #2 and #3 have three and four extra layers, respectively. Filter #4 has two layers of foil that cover the entire filter and four additional layers for the upper portion of the LFCF. Magnetic tape is placed on the lateral edge of all filters that enables them to be affixed to the front of the metallic aspect of the collimator.

Vertex Filters

This study examined two types of vertex LFCF that will be referred to as #1 and #2 (Figure 5). The overall dimensions of the #1 vertex filter are seven and one-quarter inches wide by six inches tall. This filter has a symmetrical hole cut out in the center with a diameter of one and one-eighth inch. This opening allows an unattenuated window for viewing the atlas. From the top of the center hole up to the superior aspect of the filter is a five-eighths of an inch channel that has only one layer of lead foil that is present with both vertex filters. This is to prevent the ethmoid region from being "burned out" on the film, which is an important anatomical structure used in the Orthospinology analysis. This layer of foil also provides protection for the medial portion of the eyes. However, this channel only descends from the top of the filter down one and three-quarters of an inch for the #1 LFCF. The region below this channel is continuous with the remainder of the filter, which includes four additional layers of lead foil. The #2 filter's overall dimensions are seven inches wide by six and three-eighths inches tall. The center hole of this filter has a diameter of one and five-sixteenths of an inch. This second filter is typically used for extra large patients. All LFCF are covered with a thin layer of clear laminate to protect the foil from handling.

Figure 5: Vertex filter affixed to collimator

Lateral Cervical Filter

The size of this LFCF is seven inches wide by approximately three inches tall, and it is covered by one layer of lead foil. This filter is only used for patients with large and relatively short necks to prevent the mid to upper cervical spine from appearing too dark on the film. This filter is placed in an angular fashion on the collimator so that the region above the trapezius muscle will have the X-ray beam attenuated. A filter with two layers of foil is used rarely with extremely large patients, but this LFCF was not tested in this study.

Data Collection

A senior radiation physicist from the X-ray Compliance Branch Office of Radiation Control carried out the dosimetric readings in the author's practice. The physicist works for the State of Alabama Department of Public Health (ADPH). The dosimeter utilized in this study was a mdh Industries, Inc. Model 1015 X-ray monitor with a six centimeter cubed ion chamber. This dosimeter has a +/- 15% error rate for its readings. The X-ray equipment was setup with a focal film distance of 41.5" for the nasium and vertex exposures, and 71" for the lateral cervical view. The source to test stand distance was 23" for the nasium and vertex exposures, and 52" for the lateral cervical view. The focal spot to the center of the ion chamber probe was 35" for the nasium and vertex exposures and 65" for the lateral cervical view. The factors and calculations obtained in this study were based on a 13 centimeter patient.

Two to three exposures were taken and recorded for each X-ray setup and set of factors. All exposures were taken at 82 kVp. The first set of exposures was taken without a LFCF for each milliamperes per second (mAs) setting. Each nasium LFCF was then magnetically attached to the collimator and the respective exposures were taken with the ion chamber probe directed at the bottom portion of the filter. The same procedure as followed with the ion chamber probe directed at the upper portion of the LFCF. A similar protocol was followed for the vertex LFCF exposures, except the ion chamber probe was directed at the superior/central channel and then the main part of the filter. The readings for the lateral cervical LFCF were simply taken with and without the filter.

Results

Table 1 reveals the collected data for simulated nasium X-rays taken at various mAs settings with different LFCF. Average dosimetric readings were calculated and recorded as well as exposure at skin entrance, which is represented with the acronym ESE. A coverage ratio was calculated for the nasium LFCF so that it could be determined how regions of the filters reduced exposure to the overall film (Table 2). This was determined by obtaining measurements of the coverage region of each aspect of the filter by studying actual nasium X-rays from the doctor's practice, as well as from low exposure radiographs taken with only a LFCF (Figure 6). After averaging the data for all four LFCF, the nasium filters reduced overall exposure by 65% for each A-P cervical X-ray (Table 2). The upper region of the filter reduced exposure to the majority of the skull by an average of 97%, while the lower section reduced radiation by 82% to the region from the lower occiput to the mid cervical spine (Table 1).

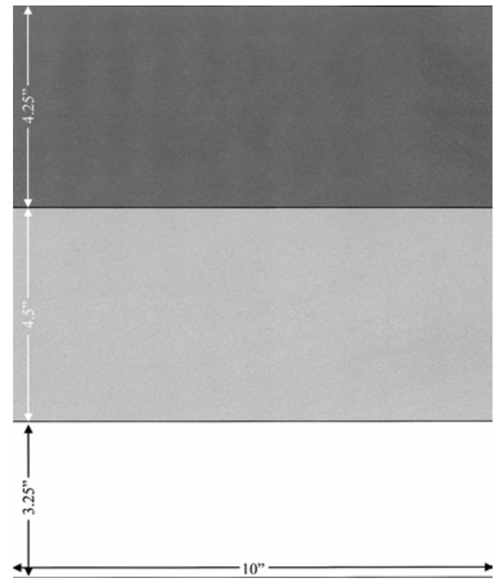

Figure 6: Nasium LFCF coverage ratio

Table 3 reveals dosimetric readings for simulated vertex X-rays taken at various mAs settings with either a #1 or #2 vertex LFCF. A coverage ratio was determined for each vertex LFCF (Figures 7 and 8). This enabled the determination of how each region of the filter reduced exposure to the overall X-ray (Tables 4 and 5). After averaging the data for both LFCF, the vertex filters reduced overall exposure by 78% for this X-ray view (Tables 4 and 5). Table 6 shows the dosimetric readings with and without the lateral cervical LFCF. A coverage ratio was also determined for the lateral cervical LFCF (Figure 9). This LFCF was shown to reduce overall exposure in milliroentgens by 75% for the lateral cervical view (Table 7).

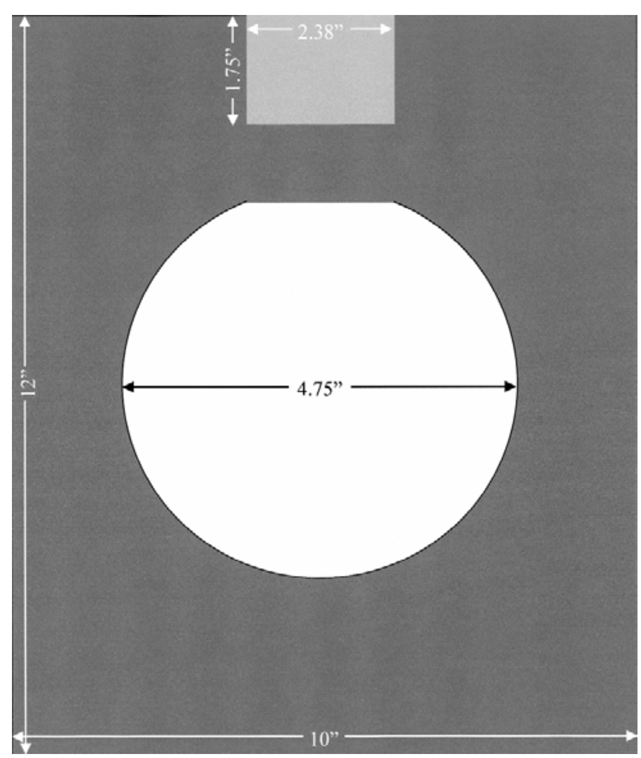

Figure 7: Vertex #1 LFCF coverage ratio

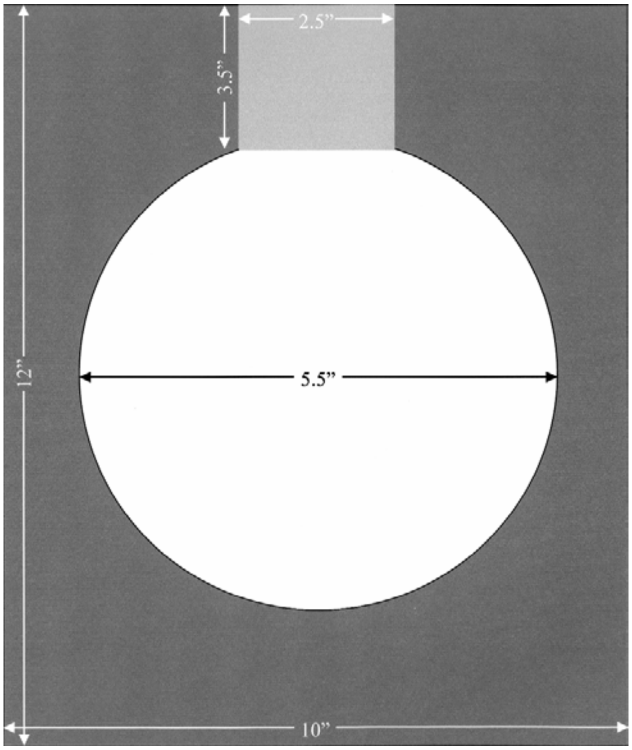

Figure 8: Vertex #2 LFCF coverage ratio

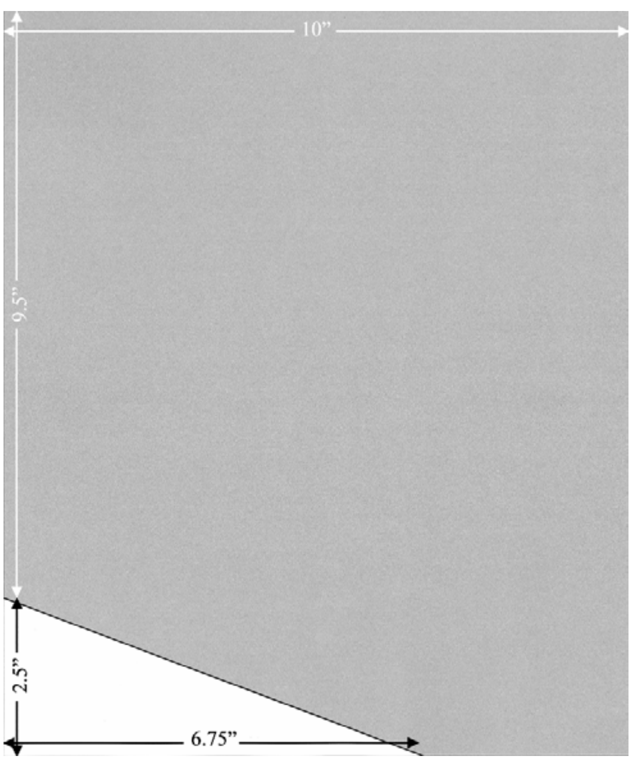

Figure 9: Lateral cervical LFCF coverage ratio

Discussion

The data in this study reveals an average exposure of 36 mR ESE for the nasium view when the LFCF is utilized. Averaging the two types of vertex filters revealed 39 mR ESE per film. This paper reports an average of 13 mR utilized for the lateral cervical view when the LFCF is used. The ADPH X-ray Compliance Branch Office of Radiation Control has collected data from 409 chiropractic office inspections over the period of 8/12/99 to 11/18/04. The average A-P cervical was reported to be 89 mR ESE; however, no data had been collected for the lateral cervical view.[15] One may surmise that these dosimetric readings are on the low side since they are obtained from each doctor’s X-ray machine after the doctor reports his/her typical A-P cervical radiographic machine settings. Since the doctor is undergoing a state regulatory inspection he/she may not report factors used for medium to large patients. The data collected from this present study reports dosimetric readings from a cross-section of different types of patients. Since no data is available from the ADPH for the lateral cervical view, it will be estimated that the average dosimetric readings will be the same as the A-P view. For the sake of comparison, a standard A-P and lateral cervical series would typically require the patient to be exposed to 178 mR based, in part, on ADPH data.

The basic radiographic protocol for the Orthospinology procedure requires a lateral cervical, nasium and vertex views. This study reveals an average exposure of 88 mR ESE for these three views; with a possible addition of 75 mR on average for a nasium and vertex post X-ray taken after the initial adjustment. If the latter protocol is utilized this would equate to 163 mR compared to 178 mR for a standard two view series. However, it may be argued that this does not provide an accurate comparison since the Orthospinology series lacks a standard A-P cervical view for pathological evaluation. The addition of an A-P cervical view to the Orthospinology series would bring the estimated total to as little as 136 mR or as high as 211 mR. The 48 mR ESE dosimetric reading for the A-P cervical view is obtained from the 10 mAs setting from Table 1. A 10 mAs setting would be used for a moderately large patient in the author’s practice.

It should be noted that the exposures in this study were taken at 82 kVp since this is the protocol of the doctor’s practice. This may explain, in part, the relatively low dosimetric reading for the A-P cervical view. In reality, the 48 mR exposure is an overestimate since a lateral cervical LFCF is utilized to cover at least one-third of the A-P open mouth radiograph. This is done to provide a limited amount of shielding to the skull and eyes. The Orthospinology protocol[16] recommends a standard A-P open mouth view (or possibly lower cervical view) for the following reasons:

- if the nasium is taken with a moderate to high S-line
- if the doctor suspects a pathology or does not feel that the other views are sufficient
- if the superior surface of the axis body and/or axis spinous process is not clearly visible

The incidence of significant pathological findings on spinal X-rays is considered to be rare, but it is posited that this should not be the only purpose for using this diagnostic assessment. Amevo et al.[17] have commented on improving the diagnostic value of X-rays with biomechanical analysis, although a segment of the chiropractic profession and even some insurance company guidelines have indicated that this type of radiographic assessment is not important or valid.[18,19]

However, a study by Harger et al.[20] revealed that 51% of chiropractors routinely take X-rays for biomechanical and postural assessment. It was also found that 63% of doctors of chiropractic utilize radiographic mensuration to locate spinal subluxations. It may be surmised that based on this data, X-ray analysis for the purpose of assessing the biomechanical component of spinal dysfunction is within the standard of care for the chiropractic profession and is further supported by clinical practice guidelines.[21,22]

The issue of X-ray safety is further addressed in the author's practice with the utilization of high film/screen speed (>600) combinations, shielding (gonadal and lead apron) and moderately high (82) kVp technique for patients' cervical X-rays. Increasing film screen speed from 250 to 800 can reduce mAs settings by almost 70%, with minimal impact on image quality. Hellström et al.[23] refute the idea that an 800-speed film system is too fast for many types of radiographic assessment. Increasing kVp by 15% can also reduce the required mAs by 50%. This represents the difference between taking a radiograph at 80 kVp compared to 70 kVp, and the loss of contrast is minimal. Increasing kVp also decreases the amount of low-energy photons that are emitted from the machine as discussed previously.

A paper from the National Cancer Institute presents data showing that head and neck X-rays do not present a significant risk in patients developing thyroid cancer.[24] Keske et al.[25] compared the risk of radiation exposure of various radiographic examinations with the induction of cancer and genetic diseases. It was found that the highest risk values were attributed to small bowel enema radiography and lumbar myelography; while the lowest values were found for cervical spine, paranasal sinuses and upper thigh X-rays.

One paper has provided detailed estimates of the cancer risks from diagnostic X-rays, although the authors admitted that the calculations involved a number of assumptions primarily based on the linear no-threshold (LNT) theory.[26] The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) proposed the LNT theory[27] after observing the effects of the atomic bomb explosions in Hiroshima and Nagasaki, Japan. Studies of survivors showed a linear relationship between cancer mortality and high doses of radiation.[28,29] Government agencies have adopted this theory as it proposes that there are no safe levels of ionizing radiation.[30] However, there is little scientific evidence to support this contention, particularly when it is applied to relatively low levels of radiation.[31-35] Japanese studies have been conducted on the life expectancy of atomic bomb survivors who suffered relatively low amounts of radiation. The data revealed that the life expectancy of the exposed population turned out to be higher than those of the control group with no unusual genetic defects found in their children.[36-38] However, Cologne and Preston[39] have reported conflicting data related to some of these issues.

This may be explained by a hypothesis called radiation hormesis, which states how low levels of radiation are not only safe but actually provide a health benefit.[40] Hormesis is an effect where something (e.g., fat-soluble vitamins, alcohol, sunlight) acts like a healthy stimulant in small doses, but it is toxic or damaging in large amounts. It is conjectured that a low dose of a toxin (in this case radiation) may jump start certain repair mechanisms in the body, and these mechanisms are efficient enough that they not only neutralize the toxin's effect but even repair other defects not caused by the toxin. Large doses of radiation have been clearly shown to cause a greater incidence of health problems as evidenced by epidemiological studies. However, humans live in a radioactive world as radiation is a part of our natural environment. Natural background radiation comes from three primary sources: cosmic radiation, external terrestrial sources, and radon. Interestingly, international standards allow exposure to be as much as 5,000 mrems per year for those who work with and around radioactive material.[41] It should be noted that the purpose of this paper was not to provide a full discussion of this hypothesis.

Indeed, the preponderance of the evidence indicates that the inherent risk to the patient from taking appropriate cervical spine radiographs appears to be quite low. However, doctors should err on the side of caution and limit the amount of exposure to their patients when possible. An additional benefit of using LFCF is the potential of providing clearer X-rays by reducing scatter radiation, while enhancing certain structures for the purpose of analysis. It is proposed that each doctor should ask the following questions before taking X-rays of their patients:

> Does the potential yield of information justify the exposure?
>
> Will the outcome of the study affect the treatment or management of the case?
>
> Are less hazardous, equally reliable techniques available?

Conclusion

The utilization of LFCF can be useful by significantly reducing radiographic exposure for cervical X-rays. A secondary benefit may be the improvement in film quality for cervical biomechanical assessment. This protocol represents a viable radiographic procedure that can benefit both doctor and patient.

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Table 1. Average Dosimetric Readings for Nasium View

Filtration	#1 Filter @ 10 mAs		#2 Filter @ 15 mAs		#3 Filter @ 25 mAs		#4 Filter @ 40 mAs	
	mR	ESE (mR)	mR	ESE (mR)	mR	ESE (mR)	mR	ESE (mR)
None	44.9	48	66.7	72	109.5	120	172	180
Middle filtration	9.20	10	14.7	16	21.9	24	18.4	19
% reduction	80%	79%	78%	78%	80%	80%	89%	89%
Top filtration	2.0	2.4	2.3	2.4	4.30	4.3	3.70	3.8
% reduction	96%	95%	97%	97%	96%	96%	98%	98%

Table 2. Lead Foil Coverage Ratios and Dosimetric Readings for Nasium View

Foil coverage ratios	#1 Filter @ 10 mAs		#2 Filter @ 15 mAs		#3 Filter @ 25 mAs		#4 Filter @ 40 mAs	
	mR	ESE (mR)	mR	ESE (mR)	mR	ESE (mR)	mR	ESE (mR)
No filtration (27%)	12.2	13	18.1	19.4	29.7	32.4	46.6	48.6
Middle filtration (38%)	3.5	3.8	5.5	6.1	8.2	9.1	6.9	7.2
Top filtration (35%)	0.7	0.8	0.8	0.8	1.5	1.5	1.3	1.3
Total mR	16.4	17.6	24.4	26.3	39.4	43	54.8	57.1
Overall reduction	64%	63%	63%	64%	64%	64%	68%	68%

Table 3. Average Dosimetric Readings for Vertex View

Filtration	#1 Filter @ 16.6 mAs		#1 Filter @ 30 mAs		#2 Filter @ 40 mAs		#2 Filter @ 50 mAs	
	mR	ESE (mR)	mR	ESE (mR)	mR	ESE (mR)	mR	ESE (mR)
None	73.2	80	126.5	135	175.5	185	219.5	240
Ethmoid filtration	9.7	10.5	16.8	18	32.9	36	42.3	46
% reduction	87%	87%	87%	87%	81%	81%	81%	81%
Skull/neck filtration	1.5	1.7	2.9	3.2	15.2	16.0	19.4	22
% reduction	98%	98%	98%	98%	91%	91%	91%	91%

Table 4. Lead Foil Coverage Ratios and Dosimetric Readings for #1 Vertex LFCF

Foil coverage ratios	#1 Filter @ 16.6 mAs		#1 Filter @ 30 mAs	
	mR	(mR)	mR	ESE (mR)
No filtration (15%)	10.7	12	18.5	20.3
Ethmoid filtration (3%)	0.3	0.3	0.5	0.5
Skull/neck filtration (82%)	1.2	1.4	2.4	2.6
Total mR	12.2	13.7	21.5	23.4
Overall reduction	83%	83%	83%	83%

Table 5. Lead Foil Coverage Ratios and Dosimetric Readings for #2 Vertex LFCF

Foil coverage ratios	#2 Filter @ 40 mAs		#2 Filter @ 50 mAs	
	mR	(mR)	mR	ESE (mR)
No filtration (20%)	34.4	37	43	48
Ethmoid filtration (7%)	2.5	2.5	3.2	3.2
Skull/neck filtration (73%)	11.1	11.7	14.1	16.1
Total mR	48	51.2	60.3	67.3
Overall reduction	73%	72%	73%	72%

Table 6. Average Dosimetric Readings for Lateral Cervical View

	25 mAs	50 mAs
Filtration	mR	mR
None	35.7	67.8
Neck/skull filtration	6.5	13.7
% reduction	82%	80%

Table 7. Lead Foil Coverage Ratios and Dosimetric Readings for Lat. Cerv. View

	25 mAs	50 mAs
Foil coverage ratios	mR	mR
No filtration (7%)	2.5	4.8
Filtration (93%)	6.1	12.7
Total mR	8.6	17.5
Overall reduction	76%	74%