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# Radiography and Clinical Decision-Making in Chiropractic

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## Abstract

The concern over x-ray exposure risks can overshadow the potential benefit of radiography, especially in cases where manual therapy is employed. Spinal malalignment cannot be accurately visualized without imaging. Manual therapy and the load tolerances of injured spinal tissues raise different criteria for the use of x-rays for spinal disorders than in medical practice. Current regulatory bodies rely on radiography risk assessments based on Linear-No-Threshold (LNT) risk models. There is a need to consider radiography guidelines for chiropractic which are different from those for medical practice. Radiography practice guidelines are summaries dominated by frequentist interpretations in the analysis of data from studies. In contrast, clinicians often employ a pseudo-Bayesian form of reasoning during the clinical decision-making process. The overrepresentation of frequentist perspectives in evidence-based practice guidelines alter decision-making away from practical assessment of a patient's needs, toward an overly cautious standard applied to patients without regard to their risk/benefit likelihoods relating to radiography. Guidelines for radiography in chiropractic to fully assess the condition of the spine and spinal alignment prior to manual therapy, especially with high velocity, low amplitude spinal manipulation (HVLA-SM), should necessarily differ from those used in medical practice.



## Keywords

x-rays, radiology, manipulation, spinal, bayes theorem, chiropractic, clinical decision-making


## Introduction

In the chiropractic profession, there has long been disagreements over when to employ radiographic imaging.[1] From its earliest days, the chiropractic profession has concentrated on the correction of vertebral subluxations and spinal health.[2] Many definitions have been proposed for vertebral subluxation, most of which include biomechanical alterations of alignment and motion of the spine that can cause harmful effects.[3] Manual therapy for the spine employed by chiropractors can include various types of movement, but spinal adjustment/manipulation (SM) in the form of high velocity, low amplitude (HVLA) manual techniques is the most common form of treatment in chiropractic.[4-6]

Published evidence suggests that mild to moderate transient adverse reactions occur in about 50% of patients after chiropractic and other forms of SM,[7,8] but severe adverse reactions associated with SM such as cauda equine syndrome or stroke are extremely rare.[9,10] Further, we are aware of no studies that compare adverse events or benefits of manual therapy in patients with radiographs to manual therapy in patients without radiographs.

Evidence-based guidelines are an important component of x-ray utilization in practice. The current prevailing radiographic practice guidelines recommend against radiographic imaging in most patients with musculoskeletal complaints under age 65 for the first 4– 6 weeks of care since most patients do not present with red flags conditions (e.g., fracture, dislocation, pathology, infection, and prolonged steroid use).[11-13] Guidelines since 1994 come to similar conclusions.[14] While there is little controversy over the concept that imaging should

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be used in the presence of red flags, red flags conditions are not present in most patients who seek chiropractic care for spinal pain.[15] Following radiographic guidelines based on red flags can limit the diagnostic information chiropractic practitioners would be able to gather on patients prior to manual therapy. The implications of such radiographic guidelines are that manual therapy is acceptable without pre-treatment radiographs and that in the absence of red flags, radiographs are not required to prevent adverse events or improve outcomes.

There are also guidelines in chiropractic that do not restrict x-ray indications to red flags conditions. The ICA Best Practice Guidelines take a completely different perspective, stating that radiography is part of the routine standard of practice in chiropractic for children and adults and is used primarily for biomechanical reasons rather than primarily for red flags indications.[16] Another guideline that has been put forth in chiropractic is the Practice Chiropractors' Committee on Radiology Protocol (PCCRP), which also states that radiology in chiropractic is primarily for biomechanical assessment of spinal subluxation, as well as for other health concerns such as degenerative changes, instabilities, soft tissue injuries, fractures, and pathologies.[17] The more restrictive red flags basis for radiography guidelines in chiropractic, however, is considered the evidence-based best practice in peer-reviewed published literature.[11]

Chiropractors most frequently treat patients for musculoskeletal pain, as well as for biomechanical reasons, supportive care for recurrent symptoms, and maintenance or wellness care and optimizing function.[18] Maintenance care is intended to prevent episodes of musculoskeletal pain or deterioration of a chronic recurrent condition, or to improve biomechanically compromised articulations of the spine.[19,20] Some research has suggested chiropractic care can improve non-pain conditions such as reduced or asymmetrical spinal range of motion,[21] vertigo,[22] muscle hypertonicity,[23] elbow position sense,[24] as well as somatosensory processing at the cortical level.[25] The goals of chiropractic care, therefore, are not necessarily confined to the treatment of musculoskeletal complaints. It is logical that chiropractic care administered for different purposes may influence the decision to use radiography prior to manual therapy since the length of care or number of treatments may vary with the goals of care. Hence, radiographic guidelines for purposes beyond musculoskeletal complaints may require different considerations than the currently prevailing symptom-based, red flags guidelines.

In this overview and commentary, we discuss the clinical relevance of radiographs in chiropractic care. We argue for different radiography guidelines for chiropractors than for a medical professional not intervening with manual therapy. However, the development of a framework to guide clinical decision-making necessarily requires the interpretation of evidence from diverse and, at times, contradictory sources. It is our belief that the radiography guidelines for chiropractic would benefit from a consideration of the following four areas of concern: An updated approach to assessing radiologic risk for very low levels of exposure during x-ray imaging; biological plausibility of improved outcomes and reduced risks from radiographic spinal assessment prior to manual therapy; alternative interpretations of research for evidence-based medicine and guidelines development; and different statistical frameworks for interpreting evidence using both frequentist and Bayesian approaches.

## Methods

This is an unsystematic narrative overview and commentary as described by Green et al.[26] We express a particular point of view based on our experiences and review of the evidence. Our synthesis of references likely demonstrates this bias.

## Discussion

### *Biological Plausibility*

Red flags radiology guidelines suggest that there has not been enough research to predict the need for radiography for musculoskeletal complaints beyond red flags conditions or complications in care. The risk of radiation exposure and the expense of the procedure is generally assumed under those guidelines to be greater than the known need for radiography in most cases in chiropractic care. So, if radiographs are to be considered in chiropractic beyond special circumstances, there must at minimum be a biologically plausible connection between chiropractic treatment based on radiographic assessment and the potential for improved patient outcomes. "A biologically plausible association is one for which a reasonable mechanism can be hypothesized, but for which no (or little) biologic evidence may exist."[27] Therefore, we must show that biomechanical assessments using radiographs are relevant to a person's health care, and that such assessments may meaningfully change chiropractic treatment and outcomes.

*Alignment and Health.* For radiographic imaging to play a meaningful role in pre-manual therapy decision-making, radiographic spinal alignment assessment must be clinically valid. A number of studies have reported the clinical significance and optimal configuration for spinal alignment, especially in the sagittal plane.[28-31] However, "Each patient's spine status and shape is unique, even if general rules apply to most."[28] The relationship between sagittal radiographic parameters and Health Related Quality of Life has also been explored, with improved sagittal parameters (after surgery) associated with better outcomes.[30] Although these studies have mostly focused on surgical outcomes, there is reason to consider these parameters for non-operative treatment as well.

Balanced alignment is a major contributor to spinal health. Sagittal balance compensatory mechanisms from the upper spine to the knees are well studied and generally predictable. To fully analyze the relationship between the spine, pelvis, and lower extremities, standing lateral radiographs of the full spine, pelvis, and lower extremities are needed.[30] These mechanisms should also be of interest to non-surgical practitioners in spine care. A significant percentage of people with adult spinal deformity (abnormal spinal curvature/alignment) never seek treatment, but for those that do, non-operative treatment can often be beneficial.[31] Spinal manipulation is an option for non-operative treatment of patients with adult spinal deformities, depending on the severity and type of deformity.[32]

Any alteration in the equilibrium of ideal sagittal balance instigates malalignment and its compensations, meaning sagittal malalignment is not limited to surgery for adult spinal deformity.[29] Its mechanisms are part of most spinal disorders and the radiographic assessment of sagittal malalignment is an essential part of the examination of patients with spinal disorders.[29] Ideal spine models, however, must allow for variations due to age. Sagittal spinal alignment changes as children grow, especially in the cervicothoracic, thoracolumbar, and lumbosacral transition areas.[33] For this and other reasons, our discussion will focus on adults.

Adverse effects from malalignment are not limited to the regional sagittal configurations. Grivas et al. indicate that under load, ligaments deform or elongate (i.e., creep), which "is particularly important to joint injury" because "excessive creep could result in laxity of the joint thus predisposing it to further injury."[34] Creep deformation of the ligaments occurs as a result of either constant or cyclically repetitive loading.[35] Such deformation leads to intersegmental and regional malalignments, which can produce further unbalanced ligament loading with resultant changes in the instantaneous axis of rotation, and predisposes the spine to degenerative changes of the disc and facets.[36]

The term "buckling" describes the deformation or warping from a forceful overload, either rapidly or gradually. There are several types of buckling that occur in the spine, both segmentally and those involving several vertebral motion segments, which can be associated with pain.[37,38] Spinal alignment distortions from segmental and regional buckling, vertebral translations, and rotations are revealed through imaging, particularly in weight-bearing radiography. Once there is damage causing buckling, translations, and rotations, that area of the spine is weaker and more easily fails under forces significantly lower than the original injurious loads.[39] Injury mechanisms are complex, as are the various injury remnants of distorted alignment visible on spinal imaging. Radiographic imaging can provide evidence of the physiologic age of past spinal injuries, may help discern the likely types of trauma historically experienced by that individual, and provide a record of the state of the spine.[40] Radiographs allow assessment of vertebral alignment, comparison of vertebral body and disc space size, assessment of bone density and architecture, and gross evaluation of soft tissue structures.[14]

*Biomechanics of Malalignment and Manual Therapy.* Manual therapy for adult spinal deformities and musculoskeletal symptoms involves forces applied to affect the damaged joints of the spine where spinal buckling and creep deformation is often present. Triano[38] described the biomechanics of spinal buckling behavior as a model of the manipulable lesion. He stated that the biomechanical patterns of SM form a systematic characterization of manual procedures. He also described SM as using controlled forces applied to the spine designed to "unbuckle" motion segments.[38] Herzog[41] described HVLA treatments as causing deformations of the spine and surrounding soft tissues. Applying manual therapy vectors of force to the spine specifically to deform the spinal structure in order to unbuckle motion segments is compromised without imaging, as the direction of the needed vectors of corrective force cannot be accurately determined by other means. But the magnitude of force is also a consideration.

High velocity, low amplitude spinal manipulation force measurements on adults or patient simulators reach different peak amplitudes, depending upon the type of SM employed, the method of force measurement, the area of the spine being treated, and the individuals delivering and receiving the SM. Published research shows a wide range of force measurements, from 41 to 889 N in one study.[38] Another study found mean posterior to anterior forces at T3 to be 364 N ± 106 N.[42] Lateral to medial peak cervical forces were found in another study to be 99-140 N, whereas posterior to anterior T4 transverse process forces were 399 N ± 119 N, and sacro-iliac joint prone drop method revealed peak forces of 328 N ± 78 N.[43] Triano summarized his findings for lumbar spine mammillary push move SM to average 500 N in the lateral decubitus position.[44] Owens et al.[45] found peak force loads that ranged from 399 N for "light" force side posture lumbar adjustments to 744 N for "heavy" force prone adjustments using the Gonstead technique, but some forces were as high as 1400 N. Another study found peak force magnitudes with means of 863 N for one participant and 1044 N for the second participant, from thrusts on the thoracic transverse process on male adults, with some thrusts reaching above 1300 N.[46]

Healthy structure is generally compatible with the upper limits of these force loads from HVLA/SM maneuvers.[38] However, once injured, the spine can be further injured under loads much lower than those in healthy individuals. The best available spinal load tolerance data are mostly from human cadaver specimens and porcine segments. Repeated shear loads to the lumbar spine of 1200 N led to a Grade 1 listhesis in one study,[47] with shear strength up to failure levels in human lumbar specimens ranging from 600 to 3200 N. These data suggest that the higher end peak forces of HVLA/SM may be enough to cause further damage to a buckle-deformed spine if the force is applied in an inappropriate direction.

Injuries can occur when excessive forces are applied to healthy tissues or when lesser forces are applied to abnormally weak tissues.[47] Comparing the results from measurements recorded in matching spinal regions, the upper levels of reported lumbar spine peak forces of HVLA/SM exceed the lower levels of reported shear strength in non-buckled lumbar spines, let alone previously injured spines. Therefore, it is reasonable to consider imaging to procure evidence of the condition of the underlying lumbar spine, as well as to aid in determining the appropriate direction (opposite any direction of creep deformation or buckling) of applied forces prior to performing HVLA/SM.

Most of the published experiments on the force thresholds needed to injure the cervical spine involve compression, whiplash, or other motor vehicle-type injuries. As a result, it is difficult to compare HVLA/SM treatment forces to known cervical spine injury load tolerances. As a common example, the threshold for mild (no fractures) whiplash injuries reportedly is slightly above 6 mph.[48] The post-injury residual deformities in the cervical spine, however, follow patterns of buckling in various forms, as well as translations and rotations.[49]

The combined effects of genetic inheritance, aging, and loading history can influence the strength of spinal tissues to such an extent that it is difficult to specify the likely strength of an individual's spine.[50] The risk of injury depends on tissue weakness as much as peak loading,[50] so precise force measurements are not required to reduce risk for HVLA/SM. Imaging assessment informs the clinician about the appropriate magnitude and direction of specific forces that might be generated by HVLA/SM. Precautionary imaging is an effort to both provide appropriate care and to avoid inappropriate care, especially in older patients, patients with a history of degenerative joint disease, as well as those with even a distant history of injuries to the spine region in question.

*Subclinical Malalignment.* The earliest sign of spinal joint injury is a subtle increase of neutral zone displacement of the vertebra, which can occur with few observable anatomic lesions.[51] The neutral zone is the laxity seen in physiological intervertebral motion met by minimal resistance.[52] Further motion increase within the neutral zone is a sign of the progression of injury. Therefore, subtle changes in intervertebral displacement, even in the absence of gross injury, are themselves potential signs of early injury. There is currently no other way to assess such changes without weight bearing or dynamic imaging. However, spinal malalignment can be found in otherwise asymptomatic patients and some small intersegmental displacement may be a normal variant. Yet, standards for disability ratings and instability only describe relatively large inter-articular displacements, insensitive to subtle neutral zone displacements from early injury.

Displacements from facet capsule tears, ligament laxity, and disc derangement are all likely consequences of shear, compression, and torsional loading failures.[50] Shear and torsion force directions are also the most common HVLA/SM forces. For example, if one pushes posterior to anterior on L5 where a measureable subclinical retrolisthesis of L4 on L5 exists,[53] there is a potential for further injury to L4-5 articular soft tissues due to the weakness of the discs, capsules, and/or ligaments that originally caused the pre-existing retrolisthesis. Similarly, in the presence of spondylolisthesis, spondylolysis, or anterolisthesis in any spine region, posterior to anterior shear force should be avoided at that level. It is, therefore, clinically meaningful to have imaging evidence of such abnormalities prior to applying any kind of posterior to anterior, axial rotation or compressive loads to that region. Another example of similar pre-treatment concern is the radiographic vacuum sign in the disc at a spondylolisthesis segment, which is indicative of instability.[54] One should look for those types of malalignments and signs of instability prior to spinal manipulation if the history and/or physical examination suggest past or present spinal injury.

Translations and rotations seen on radiographic examinations of mid-range flexion and extension are also associated with intervertebral injuries.[55] Neutral and functional radiography provide several signs of intervertebral instability including degenerative changes, translations, and rotations.[56] Intervertebral displacement seen on neutral weight-bearing radiographs, such as less than 3 mm of retrolisthesis or mildly increased or decreased motion at an intervertebral level on bending radiographs, could be observable variations in neutral zone positions that are signs of mild to moderate injury.

When it comes to HVLA/SM, the notions of a target point of ideal positioning and specific force application also support a precautionary imaging assessment to determine the ideal position. In an article by Evans and Breen,[57] short lever specificity was indicated over long lever HVLA/SM techniques for mechanically efficient cavitation production. They suggest that specific and efficient cavitation is best attained with a pre-thrust position in which the target joint is specifically positioned into its own neutral zone motion. Imaging can improve the choice of targeting neutral zone displacements and joint plane analysis.

In terms of safe force application, Triano[44] published minimum criteria for safety and competence when applying HVLA/SM forces.[44] He listed requirements for differential diagnosis including identifying a subluxation and co-morbid conditions, ruling out non-musculoskeletal and serious conditions, and monitoring response to treatment. Radiographic imaging is also useful for these differential assessments, as well as for allowing the clinician to obtain more insight into the disruption of structure and function.

Specific movement during HVLA/SM should involve a pre-thrust position in the neutral zone of the targeted spinal articulation(s) and the muscular resistance should be at a minimum.[57] Considering the axiom "above all do no harm," particularly in light of the minimal to non-existent risks of appropriately limited, very low level exposure radiography (discussed later), argues for the importance of imaging to ensure HVLA/SM is conducted in a manner which maximizes efficacy and minimizes potential harm.

Clinical decision-making should not, however, be based solely on the assumed mechanism of injury implied from findings on plain radiographs.[14] The history of injury or symptom onset, type of symptoms, and physical signs from examination[58] are important aspects of patient management.

But the pattern of spinal column derangement seen on imaging contributes significantly to the appropriate diagnosis and therefore can influence the decision to apply potentially therapeutic forces to the spine**.**

*Anomalies.* Radiographs can also be useful for finding spinal and pelvic anomalies, which are common and may potentially alter manual therapy force intervention strategies.[59,60] Beck et al.[59] found that 847 full spine radiographs revealed anomalies in 68% of the patients.[59] They noted that some anomalies found may not alter chiropractic adjustment or treatment strategies, but that some may have profound effects. In order to be important, an anomaly found on a radiograph must have clinical relevance. The anomalies noted in that study that in our opinion may alter HVLM/SM strategies are listed below by percentage of patients found in that study and can only be identified with imaging: spondylolisthesis (8%), DJD (24%), transitional segments (10%), posterior ponticle (14%), blocked vertebra (1%), facet tropism (1%), abdominal aortic aneurism (1%), and DISH (1%).[59]"

## Clinical Decision-Making Based on Frequentist Versus Bayesian Principles

Accurate interpretation of research is a necessary part of both an evidenced-based decision-making framework and to develop guidelines for imaging. Two common frameworks for interpreting research and updating one's beliefs based on new data are the frequentist and Bayesian approaches to statistical inference. Both frequentist and Bayesian methods of reasoning can be used to inform clinical decisions made regarding the use of radiographic imaging. However, using typical frequentist approaches such as simple *P* value heuristics to determine whether a research finding is real or not, a clinician often may not be able to conclude how justified a particular decision is prior to a planned action, nor how credible a hypothetical approach might be prior to its administration. Frequentist statistical testing typically measures the impact of an intervention in a specific sample of patients and reports out a general average treatment effect for all participants as the main finding. Such an analysis does not typically consider the relationship between individual patient details or practitioner skill and expected efficacy, which is vital information when making treatment decisions. This recognition has led some to argue that the results of frequentist findings alone usually cannot adequately answer the question "Based on the existing evidence, what is the probability of the truth of a particular belief?"[61]

The guidelines on radiographic usage in patients with musculoskeletal pain rely mainly on studies using frequentist data analysis (e.g., null hypothesis significance testing). For example, there is little association between contemporaneous spinal-related symptoms and the presence or absence of significant spinal radiographic findings, leading to the conclusion that imaging is not clinically relevant for typical spinal pain cases without red flags. But such a standard implicitly accepts the notion that we should only provide services (e.g., X-ray imaging) if they have been shown to have a statistically significant impact for the population as a whole on average. We suggest an alternative decision-making framework to employ, specifically for the chiropractic clinician deciding whether to utilize radiography on a given patient, prior to administering manual treatment.

Asking a question like: "is there a correlation between radiographic findings and symptoms," clinically speaking, may not be the best way to frame the issue for clinical decision-making for individual patients. Patients present to chiropractic offices and typically indicate their symptoms, including pain and relevant history. Instead of beginning with the presumption of zero relationship between symptoms and radiographic findings, the implicit null hypothesis to be rejected employed in the vast majority of published literature, we suggest practitioners consider a Bayesian framework for decision-making. In this instance, a frequentist might argue that, on average, a radiograph will not identify the cause of spinal-related symptoms in a general population of patients, and therefore, will not meaningfully add to the diagnosis of a particular patient.[13] However, Bayesian reasoning would include other known factors in the presumed likelihood (formally known as "priors") of a relationship between imaging and injury identification, such as the patient's history and information about the types of conditions encountered in similar patient populations. When these factors are taken into account to adjust our "priors," it may increase the a priori probability that a radiograph would provide clinically relevant information for that individual patient.

According to Johnson et al., "Clinicians regularly use the Bayesian framework when considering the utility of a diagnostic test. Using information from a patient history and physical examination, clinicians construct a pre-test probability of disease (equivalent to a prior)."[62] McCrossin affirms this idea: "Clinicians are natural Bayesians when it comes to diagnosis. They have to be. The alternative approach might be to use the methods of classical hypothesis testing, but probably only once."[63] Both the frequentist and Bayesian approaches are valid and useful in the appropriate setting, although they differ both methodologically and philosophically. The frequentist approach is by far the most common in the published medical literature and as a result may be more often applied in guidelines for clinical settings. However, as discussed above, clinicians themselves frequently apply Bayesian reasoning in the process of diagnosis without the benefit of any formal training in Bayesian statistics and inference.[64]

Although it is true that a radiograph will often not, by itself, identify the cause of spinal-related symptoms in a given population of patients, it can also be true that a substantial subset of chiropractic patients will benefit from receiving treatment informed from a radiograph. Relevant radiographic information can be useful in preventing harm to injured areas and for guiding the direction or application of manual care.

Comparing the extraordinarily low to possibly non-existent risk of very low-level x-ray exposure with the reasonably high likelihood of benefits from radiography in many patients, raises the importance of questioning the prevailing imaging guidelines based on red flags.

A clinician's confidence in the probability that a pre-manual therapy radiograph will contribute clinically relevant information may be increased using other relevant information to update their Bayesian priors. By combining information from studies on the nature of spinal deformities and malalignment with patient information like age, history, and physical findings at the likely site of care, we can further increase the expected utility of pre-treatment imaging. Additionally, a knowledge of which areas of the spine that most frequently have specific anomalies or weaknesses can further increase the probability that we will find the results of radiographic examination to be clinically meaningful.

It is not our position that the Bayesian approach to diagnosis is without faults. There is subjectivity in our assessment of the odds of a patient having a particular disorder. But replacing the subjectivity of the Bayesian framework of decision-making with frequentist approaches in clinical practice is to exclude clinical judgment and context from patient care.[64] As compared to a case where no imaging is used, properly applied imaging offers unique information about that patient's condition that cannot be observed otherwise.

## Outcome Measurements

A common argument against radiographic structural assessment early in chiropractic care is that imaging does not result in better outcomes. Such an assertion may not be correct. Using upper cervical radiographs, Erikson and Owens[65] showed that chiropractic patients who had an improvement of 30% in their atlas alignment also had greater improvements in their pain than those who did not achieve that magnitude of malalignment reduction. Rochester[66] found that those chiropractic patients who had an improvement of 50% or greater in atlas malalignment also required less care for their condition. These studies, although limited, suggest that not only may outcomes be improved as found on radiographic measurements, but also costs for care may possibly be reduced by the improvement in spinal alignment. Further research is needed to determine the effects that imaging may have on outcomes and costs in chiropractic.

Though malalignment and hypomobility have both been recognized features of the chiropractic subluxation paradigm, hypomobility has received much more attention in chiropractic than malalignment in recent years.[67] It is also known that symptom improvement can occur without alignment improvement. But we have described the importance of structural alignment, and also note that radiographic measurement methods can be reliable.[68-74] The radiographic measurement of scoliosis,[75] adult spinal deformity,[32] and intervertebral instability[76] continue to play fundamental roles in spinal evaluation, for example. We are also aware of 3 articles that have reported that spinal alignment improved after SM,[65,66,77] but the evidence that SM alone can improve spinal alignment is limited. Further research on how best to improve spinal malalignment is needed and would be consistent with current trends in medical research.

It seems obvious that in order to measurably change alignment, forces must be applied. It is unlikely, however, that the optimum direction to apply forces to improve alignment would be achieved without imaging or by chance. Radiographic imaging allows the measurement of the magnitude and direction of intersegmental and regional malalignment not offered by non–imaging-based procedures.[53,78-80] Additionally, if a force is repeatedly applied in a direction that would increase spinal malalignment, it is logical that this may cause harm and should be avoided whenever possible.

## Putting Radiographic Findings into Perspective

Catastrophizing radiographic findings can lead to psychological detriment in patients with spine-related symptoms. When reporting radiographic findings, clinicians need to be sensitive to the potential negative effect on patients,[81] although the same is true for the results of other tests such as physical and laboratory findings.

It is also worth noting that the location of likely spinal derangements should first be determined during historical and physical examinations. Radiographs should supplement those examination findings after it is determined that the patient is a good candidate for manual therapy intervention which would best be applied incorporating findings from imaging.

## Health Risks of Very Low Level Radiation Diagnostic X-Rays

One cannot discuss the use of radiography without addressing the main concern for its usage, which is the purported health risk. To understand the concern over radiation, exposure first requires an understanding of the Linear-No-Threshold hypothesis of risk modeling. As briefly described by Sacks et al., "The Linear-No-Threshold (LNT) assumption is over 70 years old and holds that all ionizing radiation exposure leaves cumulative effects, all of which are harmful regardless of how low the dose or dose rate is."[82] Models used to predict risks of radiation exposures, including very low levels of radiation for the production of x-rays, are based mainly on the studies of Japanese atomic bomb survivors.[83]

It is important to note that there is a great deal of published literature that supports the LNT premise, which advocates restricted clinical use of radiography. However, the validity of the LNT hypothesis has been repeatedly questioned, with many arguing that the theory should be abandoned altogether.[82,84-88]

It is also important to note that most of the effects of radiation in biology were not well understood even 30 years ago and a great deal of what we know about radiation's effect on humans has emerged relatively recently.[89] In contrast to the LNT assumption, radiation at low levels appears to cause biologic effects different than, and not linearly related to, those at higher levels.

To address the biological effects of radiation, a brief review of terms is appropriate. In the scientific literature, the "dose" of radiation is expressed in different forms. In this discussion, we will use the "effective dose" expressed in units of millisieverts (mSv) since that is a common measure of the health effect of low levels of ionizing radiation on the human body.

The Health Physics Society (HPS), a non-profit organization dedicated since 1956 to radiation safety, has concluded that "below levels of about 100 mSv above background from all sources combined, the observed radiation effects in people are not statistically different from zero"; and that "the LNT hypothesis cannot provide reliable projections of future cancer incidence from low level radiation exposures.[90]" The HPS further stated that "The references to 100 mSv in this position statement should not be construed as implying that health effects are well established for doses exceeding 100 mSv. Considerable uncertainties remain for stochastic effects of radiation exposure between 100 mSv and 1000 mSv."[90]

The French Academy of Sciences and the French National Academy of Medicine have also weighed in on this debate about very low levels of radiation exposure. In their joint statement, they stated that the LNT assumption "…should not be used without precaution for assessing by extrapolation the risks associated with low (<100 mSv) and even more so, with very low doses (<10 mSv), especially for benefit-risk assessments imposed on radiologists…."[91]

The LNT assumption is one possible model by which radiation exposure may be considered.[92] Two other noteworthy models include the hormesis model and the threshold model.[93] The "unscientific and forced LNT default model" is reportedly based mainly on seriously flawed epidemiological studies.[93] The hormesis model suggests overall reduced stochastic risks at very low levels of ionizing radiation exposure with increased stochastic risks to exposures at higher levels. The threshold model, on the other hand, suggests that no significant change in risks to radiation exposures may occur until a certain threshold is met. Stochastic responses to radiation generally have a U or J shape curve under the hormesis model, where low doses stimulate immune responses and high doses inhibit them.[94] Others have presented convincing evidence in support of the hormesis model in great detail.[95]

Much of the interpretation of the data used to initially adopt the LNT assumption has been found to be faulty and subject to ideological motivations.[96] For instance, early studies used in support of the LNT assumption about the effects of low radiation doses were shown to actually be relatively high dose exposure levels.[96] Interestingly, a contemporaneous prospective study of 40,000 subjects also showed that low dose medical exposures in pregnancies did not result in increased leukemia in the exposed children.[97] The recommendation to replace the threshold model with the LNT hypothesis reportedly was integrated into regulations and science, at least partially, by inappropriately appealing to authority of the times in the late 1950s due to fear of effects of radiation fallout and nuclear testing and other radiation exposures that were not well understood.[96] The bulk of the studies used to model stochastic risks from radiation involves Hiroshima and Nagasaki atomic bomb survivors, forming the basis for the BEIR (Biological Effects of Ionizing Radiation) reports. However, re-evaluation of the data from the 1950s observations and additional data covering a 40 year period after those bombings support a hormetic, J-shaped curve response to radiation exposures, rather than a linear dose response model.[96] Contrary to the LNT assumption, radiation doses below 100 to 200 mSv are thought by some to likely be beneficial and not harmful.[98] The LNT model is only theoretical and has never been empirically or conclusively demonstrated.[98]

Ricci and Tharmalingam[99] further describe the historical and scientific foundational errors of the LNT risk model assumptions since its inception dating back to 1946. Ricci and Tharmalingam state: "We show that linear interpolations are incorrect because both the biological and epidemiological evidence for thresholds or other non-linearities, are more than substantial. We discuss why the LNT model suffers from misspecification errors, multiple testing, and other biases. Moreover, its use by regulatory agencies conflates vague assertions of scientific causation, by conjecturing the LNT, for administrative ease of use."

Ring et al.[100] also point out that using the LNT model for radiation near background levels cannot provide reliable risk projections: "The aggregation of very low individual doses over extended time periods is inappropriate, and in particular, the calculation of the number of cancer deaths based on collective effective doses from trivial individual doses should be avoided." They further note that the HPS recently addressed the Environmental Protection Agency (EPA), urging them to discontinue their reliance on the LNT risk modeling for low dose exposures. The HPS reportedly stated that the EPA's position on this matter was inconsistent with international organizations and that it tended to foment public fear unnecessarily.

To put radiation exposure risk into perspective (even under the LNT assumption), an illustration is put forth that approximates the risk of an exposure of 100 people to 100 mSv of ionizing radiation. Over a lifetime, approximately one of those 100 people would be expected to develop cancer from that radiation exposure, whereas it would be expected that approximately 42 of them would develop cancer from other causes.[101] 100 mSv is considered a low dose exposure, even though it is over 40 times the worldwide average yearly background radiation exposure level. Furthermore, even the largest epidemiological studies cannot reliably distinguish between low risk and zero risk of very low dose exposures in the range of naturally occurring background radiation.[102] The worldwide average of naturally occurring background ionizing radiation from food, water, air, ground, and cosmic sources is 2.4 mSv,[103] whereas in the United States background ionizing radiation averages 3.1 mSv.[104] Typical diagnostic x-rays are usually much lower exposures than natural background radiation. Radiobiological knowledge is lacking regarding the biologic response to such low exposures, therefore, estimates of risks of very low-level exposures are extrapolated from studies of high dose exposures.[102] For those reasons, the model basis for extrapolation in estimating risks from studies, makes the known shortfalls of the LNT hypothesis even more concerning when it comes to establishing policy for exposures like diagnostic x-ray usage.

Mettler et al.[105] placed the average effective doses for various radiological procedures at 0.2, 1.0, and 1.5 mSv for the cervical, thoracic, and lumbar spines, respectively, while noting that reported ranges varied from 0.07 to 0.3, 0.6 to 1.4, and 0.5 to 1.5 mSv, respectively. Those dose levels are consistent with the UNSCEAR 2000 estimates of x-ray series examinations of the cervical, thoracic, and lumbar regions.[103] The levels of radiation exposure from spine x-rays are, therefore, well under background levels in most cases. In fact, the estimates of risks of the effective dose from ionizing radiation for such spine x-ray diagnostic examinations are too small to be observed or may be non-existent, as stated by the HPS.[90]

It is important to restate that this commentary focuses on diagnostic x-ray usage in adults. There are unique considerations for the care of children and the use of diagnostic x-ray. The effects, for example, of ionizing radiation from various sources on IQ and school performance, solid cancers and leukemia for in-utero and childhood low dose exposures are commonly studied, often with mixed results concerning relative risks.[106,107] Specifically regarding pediatric diagnostic x-ray radiation, a recent meta-analysis systematic review of epidemiological studies published from 2000 to 2019 including 24 studies found no increased risks of all cancers, leukemia, and brain tumors after pre-natal x-ray or CT exposures. For post-natal exposures, there were some increased risks for leukemia and brain tumors after CT exposures, but no increased risks of all cancers after x-ray exposure.[108] Pediatric considerations regarding diagnostic x-rays are complex and therefore will be left to specific review of that subject by others.

The assessment of risk related to radiation exposure from chiropractic radiography needs reconsideration. Some regard the LNT hypothesis as a useful tool due to its mathematical simplicity, even if it is scientifically unproven.[109] However, the historically accepted belief that radiation at very low levels is a significant risk factor does not reflect the latest evidence. Additionally, in the very near future ultrasensitive imaging technology will produce extremely low radiation x-rays, which will reduce clinical radiation exposures to approximately 400 times lower than the already very low level that current technology allows.[110] When that technology is clinically available the exposure levels will be so low that the concern over radiation risks will have even less practical relevance.

Regarding risk, there are two types worth considering: the risk of harm from administering a procedure vs the risk of losing potential benefits of said procedure. While writing in the 2017 article in the Journal of Nuclear Medicine, Siegel et al. indicated that the LNT hypothesis tends to promote “radiophobia” while ignoring “the myriad benefits of imaging,” and “... leading to actual risks far greater than the hypothetical carcinogenic risk purportedly avoided.”[85]

We hope that the perspectives offered here prompt a careful re-examination of radiographic guidelines which affect the physician’s ability to provide optimal care in exchange for avoiding the assumed risks associated with x-ray. We recognize that there is no absolutely “safe” default position, so in each case the clinician should be given reasonable latitude to render care in the best interest of the patient. We suggest that if the often-misunderstood benefits vs health risks of radiation exposure were not as significant a part of this debate, neither would there be as much attention applied to other potential shortcomings associated with radiography.

## Imaging Guidelines—An Alternative Perspective

The imaging guidelines for chiropractic practice put forth by Bussières et al. in a series of articles, address important questions about the use of imaging in chiropractic. The first question Bussières et al.[11] posed was: “Does ionizing radiation from radiography carry a potential risk to patients?”[11] The potential risks of conventional radiographs were briefly discussed by Bussières et al., concluding that: “In summary, this report concludes that ionizing radiation is dangerous even at low doses and that there are no safe limits.”[12] We suggest that their conclusion is likely erroneous and that it greatly influences their recommendations.

Importantly, the original literature review related to radiation risk in the Bussières et al. articles is based on several references, the dates of which ranged from 1986 to 2007. Those references used models for risk primarily based on the LNT hypothesis. Bussières et al.[111] also defend their use of the LNT hypothesis to predict radiation risk in a letter to the editor rebutting a commentary in JCCA[112] primarily citing the BEIR VII report from the National Academy of Sciences and their support of the LNT hypothesis.

The BEIR VII report was based primarily on data from epidemiology studies on atomic bomb survivors, medical radiation exposure, workers in nuclear and radiation industries, and environmental radiation exposures like Three Mile Island and Chernobyl.[113] We have already discussed the difficulties in studying and the lack of reliable evidence for predicting the effects of very low level diagnostic radiation. Additionally, there are many reasons that compromise the relevance of extrapolating health effects of these populations to the use of medical x-ray for diagnosis purposes. For instance, Japanese survivors being exposed to whole-body radiation and fallout and being in a poor health environment with malnourishment and hazards created by the bombs along with psychological terror make them a very different population compared to the average patient in these times.[113] There reportedly is little scientific disagreement that instantaneous exposures to the Japanese survivors over 100 mSv had detrimental effects. However, for exposures of less than 100 mSv increased cancer incidence cannot be confidently identified, even in those survivors in that exceedingly poor environment.[113]

The United States EPA also relies on the LNT dose response model to regulate radiation exposure to humans.[114] But Cardarelli and Ulsh[115] wrote that it is time to move beyond the LNT risk assessments used in the BEIR VII report and by the EPA, and provided scientific basis for discontinuing its use. They also admit that although the LNT based regulatory agency policies were controversial from the beginning, the LNT assumption has significant institutional inertia. They further state: "In summary, two influential pieces of evidence relied upon by the BEIR VII Committee (the LSS cohort and the 15-country study) no longer support the LNT model based on the latest scientific literature."

Calabrese summarizes the errors resulting from the implementation and continued use of the LNT assumption by writing: "Thus, cancer risk assessment has a poorly appreciated, complex and seriously flawed history that has undermined policies and practices of regulatory agencies in the U.S. and worldwide to the present time."[116]

Bussières et al. also list a number of notable limitations in their guidelines development approach. One such concern they included: "It could be argued that our process, however extensive, did not include a sufficient number of chiropractic named technique representatives and a sufficient number of other health professions dealing with musculoskeletal disorders. Users of specific chiropractic techniques that rely on the routine use of radiography for the purpose of elaborating a plan of treatment should have a particular interest in imaging guidelines development."[11] They reportedly invited 2 specific chiropractic technique representatives that fit their description above, but one declined and the other did not follow through with the process. We agree with Bussieres et al. that the views of those types of technique approaches are not well represented in their guideline process or conclusions. They state that "…the need to confirm pathology, to follow the evolution of a pathology possibly affecting therapy, or to identify a clinically suspected contraindication to manipulative therapy are the best-documented reasons" for taking x-rays.[13] We also find those reasons to be important, in addition to our suggested indications for radiographic assessment for the application of manual spine therapy forces.

There are several motivations driving the increase in guideline development: cutting costs, health care financing arrangements, variations in health services, and the transition toward more multidisciplinary practice.[117] There are certainly benefits from evidence-based medicine (EBM) and practice guidelines, but there are disadvantages as well. Saarni and Gylling, in an article in the Journal of Medical Ethics ask whether EBM guidelines are a solution to rationing or politics disguised as science.[118] They discuss the problems with applying EBM guidelines to individual cases and the potentially deleterious effect it can have on professionalism in practice. In a 2010 review of the imaging guidelines of different countries, Koes et al.[119] noted that there were discrepancies regarding diagnostic recommendations for spinal manipulation for low back pain, such as the French guidelines recommending imaging prior to spinal manipulations.[119] This conflict, in our view, is a matter of concern. As Bussières et al. state: "Future research is needed to validate the content of the proposed diagnostic imaging guideline."[11]

### *Points of Agreement*

The authors are in agreement with many of the positions and opinions held by most radiographic guidelines. For instance, patient management should include published science whenever possible. Taking x-rays should not be rote or routine. There must be indications based on patient findings and knowledge about the nature of the patient's condition for the use of x-ray in practice. Findings on radiographs do not contemporaneously predict symptoms well. Additionally, proper care and management of the chiropractic patient is based on more than just radiographic findings. We recognize the importance of other points of view and vigorous discussion in a profession.

## Limitations

As we described earlier, this is a biased commentary and unsystematic narrative overview and presentation of references. There is also little to no research that deals with chiropractic comparing treatment with and without radiographs. What research is available about the differences in outcomes related to the use of radiography pertains to usual medical care, which is not pertinent to spinal manipulation/adjustment treatment. The lack of such research leaves little evidence upon which to base a position on this topic directly, therefore, we are forced to infer based on available evidence and clinical experience, which might lead to errors in judgment.

We may also err in our interpretations and proposed applications of research on this subject. The collective experience between the two lead authors of over 75 years of chiropractic practice could influence their impartiality and bias this discussion.

## Summary

We suggest that the potential benefit of information taken from spinal radiographs and the use of Bayesian decision-making will lead to meaningful changes in treatment strategies in chiropractic compared to current prevailing imaging guidelines. We are not suggesting radiography be used as a screening tool. We are instead suggesting that patients that present for chiropractic treatment with signs of biomechanical dysfunction of the spine, including vertebral subluxations/manipulable lesions, will often be better served by including a radiographic assessment of the region of concern prior to manual spine therapy, especially when using HVLA/SM. We also suggest that the well-informed clinician is in the best position to make that decision.

Imaging is part of the assessment to fully understand the nature of spinal conditions, apply the appropriate forces for manual therapy, and prevent a worsening of their condition from the treatment itself. Guidelines including current research that reflect a balanced risk assessment of diagnostic radiography, not based on the LNT assumption, would more appropriately inform practicing chiropractors. However, we recognize that in the rapidly changing world of current scientific literature, guidelines begin to become obsolete before they can be published, putting guideline makers in a difficult position. A manual therapy is different than a medication and imaging guidelines for chiropractic and medical care should reflect those differences. While guidelines are needed, they have distinct limitations.

Further research into the forces of different types of manual therapy and load tolerances of previously injured spinal joints is needed. We also encourage our universities to explore all the methods of imaging to assist chiropractic applications for spinal disorders, both those that use radiation and those that do not. We seek an open-minded approach to the current literature and to safe and plausible therapeutic approaches to spinal deformity treatment. We hope those approaches may eventually provide a reasonable bridge between those who see imaging's role applied strictly following red flags guidelines and those who view its role as primarily for biomechanical assessment.

## Conclusion

Our positions are not in full agreement with current prevailing imaging guidelines for chiropractic practice. However, the view that very low-level radiation x-rays lack significant health risks is supported by substantial published science and expert opinion. There is a need for radiology guidelines specific to the practice of chiropractic and necessarily unlike those for the practice of medicine. There is also need for a more balanced look at the clinical decision-making process from more than a frequentist interpretation of research findings to include Bayesian principles. Imaging of the biomechanical distortions of the spine prior to manual therapy is an acknowledgment of malalignment and its effect on the human structure. Understanding the force involved in manual therapy/HVLA/SM and load tolerances of injured spinal regions is a pre-requisite to the decision-making process for appropriate treatment of individual patients.

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