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Bright Facet Sign and its Association with Demographic and Clinical Variables

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Abstract

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DC, Palmer University, 1982

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Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

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Abstract

Low back pain has a significant impact on global public health and economics. The bright facet sign (BFS), a common finding on magnetic resonance imaging (MRI) of the lumbar spine, is associated with low back pain. While degenerative joint disease (DJD) affects low back pain, its presence appears independent of the BFS at the disc and facet joints at the same spinal level. Increased BMI, considered a risk factor for DJD, has an inverse association with the BFS. The independent relationship of DJD and the BFS is poorly understood and may represent a previously unreported pain pathway. In this nested case-control quantitative study, based on an accepted conceptual framework, 350 lumbar MRI studies on symptomatic patients with historic and anthropomorphic data related to low back pain were analyzed using Spearman's Rho and Multivariate Logistic Regression to examine any associations between the BFS at 3 spinal levels and the independent variables age, race/ethnicity, physical activity, BMI, trauma, low back pain, and DJD. The findings revealed significant associations between the BFS and the duration of pain, age, and gender at 1 or more spinal levels, the BFS and BMI and degenerative facet disease (DFD) at all 3 spinal levels, and no association between the BFS and degenerative disc disease (DDD). These results, contrary to current medical constructs where BMI, DFD, and DDD are considered predictive of low back pain, facilitate an improved understanding of joint function and contribute to the current body of knowledge related to low back pain. An understanding of the BFS as it relates to DJD and low back pain will assist clinicians with the early detection of spinal degeneration and the mitigation of pain and suffering, contributing to positive social change.

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Dedication

My first teachers were my greatest educators. My mother, Josephine Longmuir, nee Gallanger, taught me the value of good manners, responsibility, and that hard work should always be a source of pride. She loved me very much and supported all my dreams. My father, Andrew Longmuir showed me strength, insight, and by example, that being a man is much more than being a grown up. He is my hero.

Robert Longmuir, my father's eldest brother, was a mentor. A natural teacher, he taught me gentleness and determination. The patience he showed while trying to teach his tone-deaf nephew to play the piano seemed limitless. I miss him dearly.

For their love, guidance, and encouragement, I am eternally grateful. As a small token of my appreciation, I dedicate this work.

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Every path to a doctoral degree is filled with important individuals who deserve special recognition. When that path also involves the collection and management of original patient data, the contributions of those individuals become all the more significant. I would like to acknowledge those who have assisted me through this research project. First, let me express my appreciation to Dr. Joseph Robare, chair of my doctoral committee, who was supportive and guided me through this writing. I would like to thank the members of my dissertation committee, Dr. Shana Morrell and Dr. Roland Thorpe, who provided valuable guidance and offered collegial support through the process.

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Chapter 1: Introduction to the Study

Introduction

Low back pain is a common and costly problem, both domestically and globally (Maniakis & Gray, 2000). In the United States, low back pain is responsible for up to 148 million lost work days annually, with an estimated loss of $28 billion in productivity (Maetzel & Lai, 2002; Pai & Sundaram, 2004). With a 65% prevalence among the adult population world-wide (Papageorgiou, Croft, Ferry, Jayson, & Silman, 1995), low back pain has a significant impact upon world public health (Maniakis & Gray).

The Bright Facet Sign (BFS), a radiologic marker found on MRI scans, had been determined to be a common advanced imaging finding among patients seeking care for low back pain (Czervionke & Fenton, 2008; Longmuir & Conley, 2008). The BFS has been shown by Longmuir and Conley (2008) to be independent of degenerative changes at the disc and facet at the same spinal level, while showing a statistically significant association between degenerative facet changes at the next spinal level superior and two levels superior to the degenerative facet disease and two levels inferior to the presence of degenerative disc disease (DJD). Subjects with a BFS have a mean body mass index (BMI) 25% lower than those without a BFS (Longmuir & Conley, 2008). The mechanisms responsible for the production of the BFS might lead to a better understanding of lumbar facet joint function and could contribute significantly to the current body of knowledge related to low back pain. This may lead to a modification of treatment protocols, provide a mechanism for earlier detection of degenerative joint

disease, and contribute to positive social change by reducing the low back-related pain and suffering.

The goal of this study was to examine the relationship of the BFS to DJD and the independent variables associated with both to improve the understanding of the physiologic relationships. An increased understanding of these relationships could contribute to the current body of knowledge on the causes of low back pain. This in turn could contribute to improved identification and treatment options for low back pain.

In this introductory chapter, I begin with a summary of the research literature relating to the scope of the BFS. I discuss a gap in the current literature and present the problem, which the study addressed. The purpose of the study is explained and the research questions and hypotheses are stated. I introduce magnetic resonance imaging (MRI) as the diagnostic modality of choice. There are limitations to my proposed study and they, along with its assumptions are discussed. Finally, I will present the significance of this investigation and provide a detailed chapter summary.

Background

Radiographic signs are used by healthcare practitioners to describe and summarize findings encountered on patient plain film x-ray, MRI, and computerized tomography (CT). Signs serve as shorthand expressions by which abnormal findings may be categorized and connected by member of the radiological community to a disease presentation. There is a shortage of peer-reviewed literature related to the significance of increased (bright) signal, which suggests an increased volume of joint fluid, within the facet joints on water-sensitive FSE (fast spin echo) T2-weighted magnetic resonance

images of the lumbar spine. Although discussions among peers have caused debate, only recently have a definition (Longmuir & Conley, 2008) and associations between the presence of low back pain and the BFS appeared in refereed journals (Czervionke & Fenton, 2008; Friedrich et al., 2007; Yang & Yang, 2005).

The BFS is homogeneous in density and variable in size. Its margins are contained within the articular margins of the facet resulting in a rectilinear shape. Subjacent bony erosive changes are not present and there is an absence of capsular distention often associated with bacterial infection. There is no evidence of juxta-articular mass lesion and according to Longmuir and Conley (2008), Yang and Yang (2005), and Friedrich et al. (2007), there is an absence of extra-articular fluid accumulation with the BFS. In contrast, Czervionke and Fenton (2008) maintain that a supplementary accumulation of extra-articular fluid is part of the BFS and is plainly visualized when an MRI fat suppression technique is added to the FSE T2-weighted imaging sequence.

The association between back pain and degenerative facet disease is supported in the literature (Borenstein, 2000; Jarvik & Deyo, 2002). There are, however, gaps in the literature regarding the BFS. Because early lumbar facet degeneration is marked by hyperemia and inflammatory infiltrate (synovitis), a causative relationship between degenerative facet disease and a bright facet response would be a logical assumption (Longmuir & Conley, 2008). A statistically significant relationship exists between the BFS and degenerative facet changes at the next spinal level superior, and two levels superior to DJD, and two levels inferior to the presence of degenerative disc disease (Longmuir & Conley). Individuals with a BFS have a mean BMI of 28.97, 25% less than

the 36.25 mean BMI of those without a BFS (Longmuir & Conley). It is not known if the bright facet appearance occurs with equal prevalence among members of different ethnicities, genders and ages. Only a single study approaches these topics (Longmuir & Conley) and there is currently very little data available.

Problem Statement

Nonspecific low back pain is a common problem (Borenstein, 2000). Seventy to eighty percent of the adult population in the United States will experience low back pain at some time during their life (Biering-Sorensen, 1984; Frymoyer, Pope, & Clement, 1983; Kelsey, Golden, & Mundt, 1990). In the United States, low back pain is responsible for up to 148 million lost work days annually, with an estimated loss of $28 billion in productivity (Maetzel & Li, 2002; Pai & Sundaram, 2004).

The association between back pain and degenerative facet disease is supported in the literature (Borenstein, 2000; Fujiwara et al., 2000; Jarvik & Deyo, 2002). Because early lumbar facet degeneration is marked by hyperemia and the presence of inflammatory infiltrate (fluid), a causative relationship between degenerative facet disease and the bright facet response, described on magnetic resonance imaging of the low back, would be logical (Longmuir & Conley, 2008). A bright intra-articular lumbar response on MRI is considered a finding. It becomes a sign when multiple observers, using the same description and the same search criteria, consistently identify it. It has been reported that an undefined, statistically significant relationship exists between the presence of the BFS and degenerative joint disease (DJD) of the lumbar disc and facets (Longmuir & Conley, 2008). However, the distribution of the BFS described by

Longmuir and Conley (2008), Marcondes César et al., (2011) and Yang and Yang (2005) is independent of degenerative change at the disc and facet joints at the same level. Czervionke and Fenton, (2008) and Yang and Yang have argued that a strong relationship between the BFS and low back symptomatology exists, but this currently remains undocumented. Elucidation of a previously unreported pathway a causative physiological mechanism of the BFS and low back pain would be useful for the early identification and treatment of low back pain.

Purpose of the Study

The BFS has a statistically significant association with DJD and low back pain (Czervionke & Fenton, 2008; Yang & Yang, 2005). Paradoxically, the BFS also has a statistically significant association with patients with low BMI (Longmuir & Conley, 2008). This is unexpected, because increased age (Medsger & Masi, 1985; Sack, 1995) and obesity are both considered strong predictors of DJD (Sabharwal & Christelis, 2010; Karnik & Kanekar, 2012). The low back pain associated with the BFS may belong to a different physiological pathway than the pain associated with DJD and by extension, its risk factors of advancing age and obesity. A previously unreported pathway between the causative physiological mechanism of the BFS and low back pain may exist that would clarify this association. An exploration of the relationships that exist between the BFS and its associations with the independent variables of age, race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration may lead to a better understanding of such a pathway.

If such an alternate pathway did exist, it would contribute significantly to the body of knowledge of low back pain. The discovery of such a pathway could lead to the earlier detection of degenerative lumbar findings, resulting in the modification of treatment protocols for low back pain. The early detection of degenerative spinal disease could contribute to positive social change by reducing the pain and suffering related to low back pain. The physiology of bright facets may help account for gender, anthropometric and race disparities in low back pain. Considering the global prevalence of low back pain, the direct and indirect health costs, and loss of productivity, an improved understanding of the pathophysiology of low back pain may lead to positive social change through a reduction in health care costs, decreased morbidity, and improved quality of life. The purpose of this study was to explore the frequency of the BFS, a dependent variable, and its relationship to the covariates of BMI, DJD, race/ethnicity, gender, low back pain, physical activity, and trauma, after adjusting for age.

Research Questions and Hypotheses

There were two research questions guiding this research. The questions including null and alternative hypothesis were:

Research Question 1

Is there an association between the dependent variable Bright Facet Sign and the independent variable degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and degenerative joint disease.

Research Question 2

Is there an association between the dependent variable Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the BFS and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Conceptual Framework

The conceptual framework for this study was based on the physiologic mechanisms associated with low back pain and interpretation in the literature of the meaning of the BFS. According to musculoskeletal radiologist, Dr. Bryan Hosler, plain film radiography, CT, MRI, and diagnostic ultrasound are standards of investigational imaging used to confirm the presence of normal structures and to exclude abnormal findings, which may be attributed to variations of normal anatomy or disease (B. Hosler, personal communication, May 7, 2014). Healthcare providers use diagnostic imaging to determine the source of subjective low back pain before recommending treatment to reduce its interference with patient comfort and productivity.

Alterations in structure or function produced by disease help to explain subjective low back pain. Many of these alterations, when visualized by a provider are known as "signs" (Eisenberg, 1983). It is common medical practice to abbreviate physical examination and radiographic findings by a descriptive eponym that portrays a relationship with an identifiable pattern of disease. In Chapter 2, I provide a more detailed description of the identification and naming of signs and the relationship those signs have to the identification and treatment of the causes of subjective pain. The BFS is so named because its high signal appearance on specialized MRI sequences is bright white and its location is confined to an intra-articular compartment of the lumbar facet joints. Prior to the naming of the BFS by Longmuir and Conley (2008), only Czervioke and Fenton (2008) and Yang and Yang (2005) argued in the literature that a strong relationship between the BFS and low back pain exists.

The objective and frequent appearance of increased signal on FSE T2-weighted MR scans of the lumbar facet joint has validated the use of the radiographic term BFS (Longmuir & Conley, 2008; Yang & Yang, 2005). A meaningful relationship was noted in the literature between the BFS and pain (Czervionke & Fenton, 2008; Yang & Yang) and degenerative articular changes and body habitus (Longmuir & Conley). However, the nature of this relationship is poorly understood and not well represented in the literature.

Nature of the Study

I performed a quantitative observational investigation, using the nested case-control design, to evaluate MRI studies for the presence, or absence, of the BFS and

associations with the independent variables of age, race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration. Three hundred and fifty MRI scans were independently reviewed by residency-trained and board certified radiologists, sufficient to provide academic rigor. A detailed sample size computation of 350 MRI scans is provided in Chapter 3. This number also provided a convenient cut-off point by corresponding to the anticipated average monthly patient volume at the three participating advanced imaging facilities.

Because all participants in this study were symptomatic, a comparison to enrolled asymptomatic participants was not possible. Since medical ethics allows only symptomatic patients to be eligible for advanced imaging, prescreening of the images was used to admit equal numbers of patients both with, and without, BFS to the investigation. This provided a comparison group and added power to the study. The cohort, therefore consisted of patients who were symptomatic, while the nested case control used participants with BFS as cases, and those without as controls.

I invited a cohort of adult men and women to participate from a stream of symptomatic patients referred to an MRI facility for noncontrasted lumbar spine imaging. Exclusionary criteria limited study participation. These were individuals referred for advanced lumbar spine imaging by primary health care providers as part of their usual clinical work-up for low back pain. The cost of performing the study was assumed by the insurance benefits to which each participant was entitled.

Possible Types and Sources of Information or Data

Recruited board certified radiologists reviewed the lumbar MRI scans of qualified participants at advanced imaging facilities located within Hurst, Texas; Overland Park, Kansas; and Phoenix, Arizona. I conducted an analysis of introductory patient questionnaires to provide historical health information, the patients' chief complaints, orthopedic and neurological findings, and demographic information. I also accessed the medical records from the office of the referring health practitioner were used to confirm the presence, or absence of pre-existing disease.

Definitions

Age: Measured in months and generally recognized as a major risk factor for DJD, however DJD is not necessarily a consequence of the aging process (Mankin, Brandt, & Shulman, 1986; Tsang, 1990).

B_0: The strong external magnetic field of an MRI unit (Blake, Hochman & Edelman, 2003).

Body Mass Index (BMI): Expressed in kg/m^2, it is defined as the body mass of an individual expressed in kilograms divided by the square of their height in meters (Freedman & Sherry, 2009).

Bright Facet Sign (BFS) - The presence of increased intra-articular signal with a lumbar facet articulation on a T2-weighted image in the absence of discernible pathology (Longmuir & Conley, 2008).

Degenerative Cascade - a series of three progressive clinical stages, 1. Dysfunction, the earliest phase where rotational injury to the disc leads to a loss of

normal function. Minimal pathological or anatomical changes may be noted 2. Instability, the second phase where disc height is compromised, the annulus fibrosis of the disc bulges circumferentially, and the contents of the disc become decreased. Ligamentous laxity at the facet joints becomes apparent along with thinning of the articular cartilage and denuding of the facet surfaces. This results in a three-joint complex with abnormal motion, and 3. Restabilization, whereby fibrotic changes in the facet joints and disc give rise to bony sclerosis and hypertrophic changes which reduce intersegmental motion and tend toward stabilization of the motor unit (Suri et al., 2011) .

Degenerative Joint Disease (DJD) - Osteoarthritis with the presumption of involvement of a diarthrodial articulation. When osteoarthritis occurs in the spine it may involve the intervertebral discs, facet joints, uncovertebral, costotransverse or costovertebral joints. Of these, degenerative disease of the disc (DDD) and facet articulations (DFD) are the most symptomatically significant (Farfan, 1980).

Diarthrodial Joint - A joint defined by a synovial cavity containing opposing bony surfaces lined with hyaline cartilage and lubricated by synovial fluid. Rotary motion of the articulation is characteristic (Stedman, 2013).

Echo Time (TE) - One half the time interval between successive 90- and 180-degree pulses in a spin-echo magnetic resonance imaging sequence, making TE the primary determinant of differences in the contrast of a T2-weighted image (Blake, Hochman & Edelman, 2003).

Effusion - The escape of fluid into a tissue or anatomical space, such as a joint (Stedman, 2013). Pathologically important, as the contents of the effused joint fluid may vary significantly from normal joint fluid (Segami et al., 2002).

Equilibrium - A stable state where the sum of all forces acting on each particle is zero (Blake, Hochman, & Edelman, 2003).

Fast Spin Echo (FSE) - A facet echo pulse sequence characterized by a series of rapidly applied 180° rephasing pulses and multiple echoes, changing the phase encoding gradient for each echo (Blake, Hochman, & Edelman, 2003).

Fat Suppression - A common method by which MRI signal from fat tissue is suppressed. By using one of three techniques, fat saturation; inversion-recovery; or opposed-phase imaging, the competing subtle signals created by other tissue types are readily apparent (Delfaut, Beltran, Johnson, Rousseau, Marchandise, & Cotten, 1999).

Gapped Facet - An articular facet surface that moves away from its partner facet. Joint separation secondary to denuding of the articular cartilage and laxity of the capsular ligament resulting in a widening of the facet joint space (Kirkaldy-Willis & Farfan, 1983).

Grading Degenerative Disc Disease (DDD) - A classification system for the gross morphology of lumbar intervertebral disc degeneration was developed in the form of a simple algorithm using contemporary MRI technique by Pfirrmann, Metzdorf, Zanetti, Hodler & Boos, (2001). The system is comprehensive and has been adopted for both research and clinical purposes (Adams & Roughley, 2006; Kim, Yoon, Li, Park &

Hutton, 2005; Modic & Ross, 2007). It consists of five grades I-V which is defined in Table 1.

Table 1

Pfirrmann et al. (2001), Classification of Disc Degeneration

Grade	Structure	Nucleus and Annulus	Signal Intensity	Disc Height
I	Homogeneous, bright white	Clear	Hyperintense, isointense to CSF	Normal
II	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to CSF	Normal
III	Inhomogeneous, gray	Unclear	Intermediate	Normal to ↓
IV	Inhomogeneous, gray to black	Lost	Intermediate to hypointense	Normal to ↓↓
V	Inhomogeneous, black	Lost	Hypointense	Collapsed

Note. Adapted from Pfirrmann, C. W. A., Metzdorf, A., Zanetti, M., Hodler, J., & Boos, N. (2001). Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine*. 26(17), 1873-1878.

Grading Degenerative Facet Disease (DFD)- An established classification system (Pfirrmann et al, 1999) for the morphology of lumbar facet joint degeneration was

developed by Grogan et al. (1997). It relies on four grades of articular cartilage degeneration to categorize the extent of the osteoarthritic change and is described as follows:

Grade 1: Uniformly thick cartilage covers the articular surfaces completely. The interspace between the cartilage layers covering each articular process is well-defined by a uniform dark band of low MR signal intensity.

Grade 2: Cartilage covers the entire surface of the articular processes but with eroded or irregular regions evident. The interspace is irregular in pattern in the posterior aspects and not crescentic.

Grade 3: Cartilage incompletely covers the articular surfaces with regions of the underlying bone exposed to the joint space.

Grade 4: Cartilage is absent except for traces on the articular surface. Voids are present and are characterized by low MR signal intensity.

High Signal Intensity - An accumulation of bright pixels on a magnetic resonance image. Water demonstrates a high intensity on T2-weighted images and fat demonstrates a high signal intensity on T1-weighted images (Blake, Hochman & Edelman, 2003).

Joint Instability - The most common and well-accepted assessment of instability has been based on the radiographic observations of Knutson (1944) who defined instability as 3 or more mm of anterior translation measured between flexion and extension lumbar radiographs (Pope, Ogon, & Okawa, 1999).

Longitudinal Relaxation - The return of longitudinal magnetization to its equilibrium value after excitation, which requires an exchange of energy between the nuclear spins and the lattice (Herzog, 1995).

Low Back Pain - Discomfort between the costal margins and the gluteal folds, with or without sciatica (Friedrich et al., 2007). It is considered chronic when it persists for 12 weeks for more (Chou, 2011).

Low Signal Intensity - An accumulation of dark pixels on a magnetic resonance image. Water demonstrates a low intensity on T1-weighted images and fat demonstrates a low signal intensity on T2-weighted images. Cortical bone is consistently low signal on both T1- and T2-weighted images (Blake, Hochman & Edelman, 2003).

Magic Angle Phenomenon - Usually seen in tendons and ligaments that are oriented at 54.74° to the main magnetic field. Signal from water molecules associated with the tendon collagen fibers is not normally seen because of dipolar interactions that result in very short T2 times (Blake, Hochman, & Edelman, 2003).

Magnetic Resonance Imaging (MRI) - An imaging modality which relies upon magnetic atomic nuclei (protons) which align themselves in a strong magnetic field, absorb energy from pulsed radiofrequency, and emit radiofrequency signals as the excitation decays. These signals vary with the proton density and the relaxation times of the tissue. A tomographic image is constructed form the emitted signal information and displayed on a computer monitor. Magnetic resonance imaging is a standard of investigational modalities (Madan, Rai, & Harley, 2003) and commonly used to evaluate

abnormalities of the lumbar spine (Shi, Schweitzer, Carrino, & Parker, 2002). Nagashima and coworkers (2010) consider it discriminatory and clinically useful for the longitudinal evaluation of degenerative disc disease.

Main Magnetic Field (B_0) - The strong external magnetic field of the MRI unit. It has strength measure in gauss (G) and tesla (T). One tesla is equal to 10,000 gauss. In comparison the earth's magnetic field is approximately 0.5 gauss. Consequently a .3-T MRI magnet is about 6,000 times the strength of the earth's magnetic field (Blake, Hochman, & Edelman, 2003).

Obesity - An abnormal or excessive fat accumulation that may impair health. BMI is the most useful population-level measure of obesity as it is the same for both sexes and for all ages of adults. A BMI greater than, or equal to 30 $kg/^{m2}$ denotes obesity (World Health Organization, 2013). Obesity is considered a strong predictor of DJD (Karnik & Kanekar, 2012; Sabharwal & Christelis, 2010).

Osteoarthritis - The most common of the arthritides it is categorized into primary (or idiopathic) and secondary forms based on the identification of an underlying condition or traumatic event. The triad of osteophyte formation, reactive sclerosis and joint narrowing are characteristic (Marchiori, 2005; pg. 525).

Physical Activity - Any bodily movement produced by skeletal muscles that requires energy expenditure (World Health Organization, 2014).

Race/Ethnicity - A self-selected identity chosen by each study participant based on the categories provided by the U.S. Office of Management and Budget (OMB). Six such categories are recognized: White, Black or African American, Hispanic, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander (OMB, 2010).

Radiofrequency (RF) - An electromagnetic wave with a frequency in the electromagnetic spectrum in the 1-100 megahertz range. This is the same general range as those frequencies used for the transmission of radio and television signals (Blake, Hochman & Edelman, 2003).

Repetition Time (TR) - The time internal between successive 90-degree pulses in a basic spin-echo sequence. TR is the primary determinant of T1 relaxation. Longer repetition times reduce T1-dependent image contrast (Blake, Hochman, & Edelman, 2003).

Sign - A descriptive shorthand phrase, a few words that convey a complete mental picture of a particular radiographic or MRI finding that often serves to refine a differential diagnosis (Stedman, 2013).

Spin-echo (SE) - The most common and basic of the imaging pulse sequences. Lengthening and shortening of the pulses (spin) and listening (echo) times contributes to either the T1-weighted (short) or T2-weighted (Long), or intermediate-density weighted images. Spin-echo sequences use pulse angles of 90 degrees (Blake, Hochman, & Edelman, 2003).

Synovitis - Inflammation of a synovial membrane. It is usually painful, particularly when joint motion is involved (Stedman, 2013).

T1-weighted - A magnetic resonance imaging term used to describe the time required for 63% of the excited hydrogen nuclei to undergo longitudinal relaxation. The time depends on the strength of the external magnet and the chemical environment of the hydrogen protons. T1-weighted images are fat sensitive and generally provide good anatomical detail (Herzog, 1995).

T2-weighted - A magnetic resonance imaging term used to describe the time required for 63% of the excited hydrogen nuclei to undergo transverse relaxation. The time depends on the strength of the external magnet and chemical environment of the hydrogen protons. T2-weighted images are water sensitive and are generally grainy in appearance when compared with T1-weighted images. Since most disease processes have associated edema, T2-weighted images are sensitive for many disease processes (Herzog, 1995).

Transverse Relaxation - The length of time during which excited protons reach equilibrium or go out of phase with each other (Blake, Hochman, & Edelman, 2003).

Assumptions

All of the subjects to be examined and subsequently included in this study were reportedly symptomatic. I assumed that clinical indications adequately justified lumbar MRI examination. There was no mechanism in place for me to exclude malingering subjects. Although every effort was made to enforce research objectivity and the strict

standards associated with radiographic record keeping, this investigation relied on self-reported data. The MRI technologists at each of the participating facilities were instructed to read the questions aloud to each subject and elicit a verbal response. This helped to assure the completion of each worksheet, while reinforcing the necessity of a complete and truthful response.

Each of the experienced musculoskeletal radiologists participating in this study as readers were required to read and familiarize themselves with the Training Program for Bright Facet Data Collection that I compiled. This program is located in the Appendix and contains multiple FSE T2-weighted MR images showing bright facet responses in both the axial and sagittal planes. Additionally, there is a written definition of the bright facet response and a sample data collection instrument with which to become familiar.

For purposes of grading, the bright facet responses were divided into 5 separate categories, Grades 0 through 4 as developed by Longmuir and Conley (2008). I therefore assumed the MRI readers understood what they were looking for, and had an understanding of the appearance and grading of the BFS. I assumed that bias can influence the outcome of the study, and steps needed to be taken to reduce the biases of all radiologists involved. To support the objectivity of the study, I did not participate as an MRI reader. To impart rigor to the study the established grading systems of Pfirrmann et al. (2001) were used to evaluate for the presence of degenerative disc disease, and the Grogan et al. (1999) method were used to grade degenerative facet changes. Separate readers were used to access the grading of a BFS and the grading of degenerative joint disease. This decreased the tendency of a single reader to ascribe the presence or absence

of a BFS to a degenerative joint finding. Accuracy of the data was enhanced by independent verification of all transcribed patient information to the Excel format, assuming an absence of transcription errors.

Scope and Delimitations

Subjects for this investigation were referred for MRI examination of the lumbar spine by a primary care provider (DC, DO, FNP, MD) for diagnostic purposes. The expense associated with MR examination is significant, necessitating the use of symptomatic individuals already in need of advanced imaging. No examinations were made solely for this research. Each subject was at least 18 years of age and able to give written informed consent in English. To qualify for inclusion in the study, each subject had to be available to complete all acquisitions of the lumbar MR examination. Deception was not used as part of this research protocol. There were no placebo conditions and recommendations for patient care were not made.

All lumbar MRI studies were complete, of good technical quality, and performed without contrast enhancement using the established imaging protocol of T1 and T2 FSE sagittal and axial images. Contraindications to MRI examination as determined by the Medical Director at each participating facility included, however were not limited to: seizure disorder, ferromagnetic surgical appliances, aneurysm clips, eye or ear implants, shrapnel, and metal fragments.

Limitations

Because of their ubiquitousness, it was not possible to control for the presence of non-steroidal anti-inflammatory agents (NSAIDs). NSAIDs fall primarily into three main

categories: ibuprofen, (e.g., brand names such as Advil, Motrin, and Nuprin), naproxen (e.g. brand names such as Aleve and Naprosyn) and COX-2 inhibitors (e.g. brand names such as Bextra and Celebrex). The sustained concentration of NSAIDs in synovial fluid is recognized in the literature (Day, McLachian, Graham, & Williams, 1999). NSAIDs are known to decrease the synthesis of prostaglandins in synovial fluid. This could in turn influence the accumulation of intraarticular fluid, which accounts for the BFS.

Reviewer bias may take several forms among radiologists and may occur when an MRI reviewer is inappropriately blinded, or made aware of study findings before a final diagnostic decision has been made (Sica, 2006). Of particular concern is this instance is a form of potential reviewer bias that may be inferred by any inter-professional relationship shared by the myself and the MRI readers. The Past President of the Kansas State Board of Healing Arts, Dr. Raymond N. Conley, maintains that radiology residents are encouraged to think logically and emulate the problem-solving thought processes of their department chairs (R. Conley, personal communication, February 21, 2014). This may result in a lack of diagnostic diversity, should both a former chair and former resident both participate as MRI readers. Similarly, colleagues at the same MR imaging center, or who have shared a previous work place, may develop diagnostic film-reading traits that result in a tendency toward group-think (B. Hosler, personal communication, February 16, 2014).

Patients sometimes have selective recollection and may exaggerate symptoms, particularly when third-party reimbursement is involved (Derring, 2002). Differences in reporting accuracy are more often associated with a failure to report information, than to

exaggerate (Aschengrau & Seage, III, 2008, pg 271). In case-control studies, recall bias can bias an association away from, or toward a null hypothesis. Although recall bias can be minimized through the use of preexisting medical records for the necessary study data, its presence cannot be completely excluded (Coughlin, 1990).

Significance

This research is an extension of a previous inquiry conducted by Longmuir and Conley (2008) which introduced the diagnostic imaging eponym BFS and determined it to be a common imaging finding among patients seeking care for low back pain. In the cited study, I showed the BFS to be independent of degenerative changes at the disc and facet at the same level, while also demonstrating a statistical association between degenerative facet changes at the next spinal level superior and two levels superior to DJD and two levels inferior to the presence of degenerative disc disease. Perhaps most significantly, subjects with a BFS were found to have a mean BMI of 28.97, 25% less than the 36.25 mean BMI of those with similar symptoms, however, without a BFS.

Obesity is a known risk factor for degenerative remodeling of the weight-bearing articulations of the human body (Felson, 1996). The increased load-bearing generated by a high BMI would, in turn, elevate intra-articular pressure and challenge the redistribution of forces across the joint surfaces. This would serve to accelerate the degenerative process throughout the lower lumbar spine (Kalichman, Guermazi, Li, & Hunter, 2009). It is counter-intuitive that subjects in the Longmuir and Conley (2008) study with a BFS were found to have a mean BMI of 28.97, 25% less than the 36.25 mean BMI of those without a BFS.

Czervionke and Fenton, (2008) and Yang and Yang, (2005) have argued that a strong relationship between the BFS and low back symptomatology exists, therefore, an unrecognized pathway between the causative physiological mechanism of the BFS and low back pain may also exist. The body of literature relating to this field would benefit significantly from the clarification of such a causative physiological mechanism. A larger nested case-control study, such as I have done here, could help explain the association between common low back pain and the BFS and satisfy the gap in the current literature. Further, there is a paradoxical association between increased BMI and the BFS, as it involves the presence of DJD. The mechanisms responsible for the production of the BFS might lead to a better understanding of diarthrodial joint function. This could also contribute significantly to the current body of knowledge related to low back pain. In turn, this could lead to modification of treatment protocols and provide a mechanism for earlier detection of degenerative joint disease which could contribute to positive social change by reducing the pain and suffering related to low back pain. It is not known if the bright facet appearance occurs with equal prevalence among members of different races, ethnicities, genders and ages, as only a single study approaches these topics (Longmuir & Conley, 2008) as there is very little data available.

Low back pain is not evenly distributed throughout the population (Andersson, Ingemar, Ejlertsson, Leden, & Rosenberg, 1993). It is not known if the bright facet appearance occurs with equal prevalence among members of different ethnicities, genders and body types as only a single study approaches these topics (Longmuir & Conley, 2008) as there is very little data available. If disparities exist, the physiology of

bright facets may help to account for them. Considering that seventy to 80% of the adult population in the United States will experience low back pain at some time during their life (Biering-Sorensen, 1984; Frymoyer, Pope, & Clement, 1983; Kelsey, Golden, & Mundt, 1990), and that in the United States low back pain is responsible for an estimated annual loss of $28 billion in productivity (Maetzel & Li, 2002; Pai & Sundaram, 2004), low back pain presents a significant public health burden.

The mechanisms responsible for the production of the BFS might lead to a better understanding of diarthrodial joint function. This could also contribute significantly to the current body of knowledge related to low back pain. In turn, this could lead to modification of treatment protocols and also provide a mechanism for earlier detection of degenerative joint disease which in turn could contribute to positive social change by reducing pain and suffering related to low back pain. The physiology of bright facets may help account for disparities in low back pain. Considering the global prevalence of low back pain, the direct and indirect health costs, and loss of manpower, an improved understanding of the pathophysiology may lead to positive social change.

Summary

Low back pain is a common and costly global problem. MRI examination of the low back is the gold standard of investigational modalities for musculoskeletal disease processes (Madan, Rai, & Harley, 2003) and has been shown useful in the detection and grading of the BFS (Longmuir & Conley, 2008). An association between the BFS and low back pain is recognized in the literature (Yang & Yang, 2005). An association between the BFS and DJD is also recognized in the literature (Czervionke & Fenton,

2008). It is the weight bearing joints that are the most commonly affected by degenerative joint disease (Fujiwara et al., 2000) and of these, the facet and intervertebral joints of the lumbar spine are among the clinically significant (Farfan, 1980). Obesity is considered a strong predictor of DJD (Karnik & Kanekar, 2012; Sabharwal & Christelis, 2010;). However, it is decreased BMI, not considered a risk factor for DJD, that has been shown to have a statistically significant association with the BFS (Longmuir & Conley, 2008). An alternate pathway, apart from the conventional risk factors for wear-and-tear, which associate BFS with low back pain is implied.

Synovitis, marked by hyperemia and inflammatory synovial infiltrate, could account for the BFS (Chaput, Padon, Rush, Lenehan, & Rahm, 2007; Czervionke & Fenton, 2008). Since early lumbar facet degeneration is marked by such intra-articular changes (Jacobson, Girish, Jiang, & Sabb, 2008; Kirkaldy-Willis, & Farfan, 1983) then a causative relationship between degenerative facet disease and a bright facet response would be logical. However, this is contradicted by the BFS distributions described by Longmuir and Conley (2008), Yang and Yang (2005) and Marcondes César, Yonezaki, Ueno, Valesin Filho, and Reis Rodrigues (2011), which found the BFS to be independent of degenerative changes at the disc and facet at the same level. A previously undiscovered pathway between the causative mechanism of the BFS and low back pain may exist to facilitate such an association. Such a pathway could result in the modification of current treatment protocols for low back pain and contribute to positive social change by helping to reduce individual pain and the growing economic burden.

In Chapter 2, I review the literature to define the BFS, its frequency and known associations. There is a discussion on those anatomical and physiological factors, which can simulate a BFS. A review of the existing literature is included to facilitate an understanding of the many risk factors and physiological processes that help contribute to the presence of increased intra-articular fluid and a BFS. The conceptual framework of this research is discussed and takes into account the diversity of imaging findings and the deductive processes required to formulate a radiographic diagnosis. Routine healthcare practice requires specialty practitioners to adopt radiographic signs to create a didactic and lasting mental image of the significant characteristics of a disease process in order to formulate a working diagnosis. This concept is discussed in detail. The BFS exists in the literature because it is needed. Now further research is needed to establish its risk factors and the physiological pathway that associates it with low back pain.

In Chapter 3, I present my research design and its connection to my research questions. The research population is defined and inclusionary and exclusionary criteria are introduced to help define the experimental sample. In Chapter 3, procedures for recruitment, participation and data collection are presented. The data collection instruments are detailed and a data analysis plan is discussed. Threats to internal and external validity are reviewed and ethical procedures for the treatment of participants and their data are described. Finally, I conclude with a summary of the investigational design and method of inquiry.

Chapter 2: Literature Review

Introduction

Nonspecific low back pain is a common condition (Borenstein, 2000) and is defined by Friedrich et al. (2007) as pain between the costal margins and the gluteal folds. With a 65% lifetime prevalence among the adult population (Papageorgiou, Croft, Ferry, Jayson, & Silman, 1995), low back pain has a significant impact upon world public health (Maniakis & Gray, 2000). In the United States, low back pain is responsible for up to 148 million lost work days annually, with an estimated loss of $28 billion in productivity (Maetzel & Li, 2002; Pai & Sundaram, 2004). Seventy to eighty percent of individuals will experience an episode of low back pain during their adult life (Kelsey, Golden & Mundt, 1990).

An association between low back pain and lumbar degenerative joint change at both the disc and facet level is supported in the literature (Borenstein; Fujiwara et al., 2000; Jarvik & Deyo, 2002). A statistical relationship exists between the BFS and DJD of the lumbar disc (Longmuir & Conley, 2008; Yang & Yang, 2005) and facet articulations (Czervionke & Fenton, 2008; Longmuir & Conley; Young Cho, Murovic, & Park, 2009) and patients with low BMI. The aim of this study is to identify associations between the BFS and the independent variables of age, race/ethnicity, physical activity, BMI, trauma, low back pain and degenerative joint disease at the facet and intervertebral disc level. Since low back pain is often associated with the wear-and-tear of DJD and its risk factors of high BMI, low physical activity, and age; the purpose of this study is explore a

pathway of low back pain that involves the BFS as a potential intermediary, thereby providing a target for new and perhaps more effective low back pain treatments.

This literature review begins with a review of the theories and physiological constructs guiding this research. This includes a summation of what is understood about the BFS, its current associations, and those physiological characteristics that help frame the course and direction of this inquiry. I examined the selection of magnetic resonance imaging (MRI) as the modality of choice and outline salient information on spinal degenerative joint disease. Finally, I consider the literature pertaining to the explanatory variables as they relate to the pathophysiology of the human spine.

Literature Search Strategy

The purpose of the literature review search was to present studies relating to the description, associated findings, and significance of the BFS, spinal osteoarthritis at the facet and intervertebral disc joints, lumbar facet articular fluid, and relationships that exist between lumbar facet effusion and age, race/ethnicity, physical activity, BMI, trauma, and low back pain. I performed a search of pertinent literature using several databases including CINAHL Plus, EMBASE, MANTIS, and MEDLINE through the available resources of Walden Library and the Seabury Learning Resource Center at the Southern California University of Health Sciences. I specified only those articles in refereed journals dated between the years of 2003 through present. I employed key words *back pain, BMI, bright facet, degenerative changes, degenerative facet, diagnostic imaging, disc disease, race/ethnicity, facet, facet fluid, facet joint, hydroarthrosis, inflammation, instability, intervertebral disc, low back, lumbar spine, MRI spine, pain,*

physical activity, radiology, synovitis, trauma, and *zygopophyseal joints.* These pertinent terms were used to maximize the number of responses. The inclusionary criteria were opinion (commentary or editorial), case reports, investigational and explanatory research articles in English and French. The search strategy was then modified to include Boolean operators and by combining key indexing terms.

I researched textbooks relating to the disciplines of advanced imaging and the clinical treatment of low back pain. Gaseous clefts or fluid within the lumbar facet joints are discussed, however only in association with advanced facet disease and instability. Intracanicular synovial cysts were featured in the presence of fluid within the involved facet articulations on T2-weighted MR images, without mention of the facet component (Cox, 1999; Parizel et al., 1999). Multiple T2-weighted MR illustrations of normal, degenerative and pathological lumbar spines were located within the figures of reference books without mention of the bright facet response in the text or accompanying captions (Cox, 1999; Kaplan, 2001; Marchiori, 2005, pg. 570). Older references were used for original theories of degenerative joint disease and terms of art associated with radiographic practice. Their applicability and relevance remain essentially unaltered over time.

Radiographic Signs

Shorthand descriptions are commonly used by radiologists, pathologists and interventional surgeons to identify a diversity of imaging findings. Called *radiographic signs*, they are didactic in nature and create a mental picture, which emphasizes the significant characteristics of a two-dimensional black and white image and lead the

physician to a diagnosis. They are often descriptively characteristic, and for this reason considered diagnostic of a particular disease. Routinely used in chest, brain, gastrointestinal, and genitourinary imaging, there are signs specific to computerized tomography (CT), MRI, radionucleide imaging, diagnostic ultrasonography, and plain film x-ray. Examples include the Applesauce Sign (Tucker & Izant, 1971) of meconium ileus seen occasionally on abdominal x-rays of the newborn; the Snowcap Sign (van Gelderen, 2004) of avascular necrosis on plain film examination of the hip; and the Mickey Mouse Sign associated with biliary obstruction on diagnostic ultrasound of the portal vein (Bartrum & Crow, 1980).

Eisenberg, in his 1984 textbook, accounted for 455 known and named radiographic signs (1984). Because of technological developments in the field of imaging and due to the recent addition of modalities such as MRI, positron emission tomography (PET), diffusion weighted imaging (DWI), digital thermography, elastography, and tactile imaging that number has increased. The visualization of a known eponymously named radiographic sign makes the diagnosis for the practitioner.

This straight line association between sign and named disease is often referred to by members of the radiological community as an *Aunt Minnie* diagnosis (Felson, 1973). Today the Aunt Minnie diagnosis is used to refer to a correct radiographic finding with no differential diagnostic possibilities. The Radiographic Society of North America (2015) website commemorates this term of art in the form of a continuing education website for the radiographic community. Radiographic signs can be used to confirm

entities other than a specific pathology. There exists a family of radiographic signs that describes entire families of disease processes, rather than a specific diagnosis.

Patterns of disease can be described by their interaction with the various resistant systems of the body. Inflammation, for example, within a diarthrodial joint is characterized by the presence of intra-articular gas and can be identified by the Crescent Sign (Han & Witten, 1974). A Butterfly (Bat's Wing) shadow identifies extensive alveolar filling within both lungfields (Rendich, Levy, & Cove, 1941). The Padlock sign of the brain appears on CT as the result of non-specific cavitation and may be associated with volume averaging or a variety of space-occupying or multicystic lesions (De Villiers, 1981). Thumbprinting of the small bowel walls is associated with thrombosis of the mesenteric artery (Eisenberg, 1983). In each case specific pathologies are not identified; however processes such as inflammation, pulmonary edema, cavitation, or thrombosis are a step in the correct diagnostic direction. Process signs such as these are useful in the discussion of the BFS.

There are also examples of process radiographic signs that can be used to identify the independent variables of trauma, race/ethnicity, and BMI. A positive Metacarpal Sign, for example, can confirm congenital hypothyroidism (Archibald, Finby, & DeVito, 1959), but is also positive in patients with previous trauma to the hand (Poznanski, Werder, Giedion, Martin, & Shaw, 1977). Disruption of the posterior ligamentous structures following flexion injury to the spine can be associated with kyphotic angulation localized to one intervertebral level. The Acute Kyphosis Sign indicates tissue

damage and potential vertebral instability caused by traumatic hyperflexion of the spinal column (Scher, 1979).

The Heel Pad Sign is identified on x-ray or diagnostic ultrasound when the soft tissues at the plantar aspect of the calcaneus exceed 23 mm in thickness (Bohner & Ude, 1978). For consistency, and to eliminate the effects of image magnification and distortion, this measurement is only performed on images obtained using a film-focal distance of 42 inches. The sign is commonly seen in acromegaly, but is also positive in obese individuals or among subjects of Nigerian decent (Egwu, Anibeze, Ukoha, Esomonu, & Besong, 2013). Further, other researchers have found that a positive Heel Pad sign can be used to identify various occupations based on their physical activity (Burnfield, Few, Mohammed, & Perry, 2004; Egwu, Anibeze, & Akpuaka, 2012).

The frequent and objective appearance of increased T2-weighted MR signal in a lumbar facet joint (Czervionke & Fenton, 2008; Marcondes César et al., 2011; Yang & Yang, 2005) has validated the use of the radiographic term Bright Facet sign (Longmuir & Conley, 2008). There is a meaningful relationship between the BFS and degenerative articular changes and body habitus (Longmuir & Conley, 2008). The nature of this relationship and the existence of other such relationships are poorly understood. It is not clear whether the BFS is describing a disease, a process, or a variation of normal physiology.

Conceptual Framework

The conceptual framework of this study was based on empirical literature demonstrating a potential mechanism of action for a relationship between BFS and low

back pain. Yang and Yang (2005) were the first to evaluate the clinical significance of linear bright signal in lumbar facets on T2-weighted MR images. The number of intra-articular bright signals with lengths equal to that of the articular cartilage was gathered by a single reader and analyzed using Student's *t*-test and Fisher's exact.

The bright facet appearance was observed in 5 (6%) of the 84 facets examined among members of the control group and 31 (18%) of the 170 facet joints in the study group. Differences in frequency between the two groups were statistically significant, Student's t-test 3.111 $p < 0.005$; Fisher's exact test: 2.328, $p < 0.001$ (Yang & Yang, 2005). Longmuir and Conley (2008) imaged 630 lumbar facets ($n = 105$) and found the prevalence of bright facets averaged 66.5% at L4/L5, 56.5% at L3/L4 and 40.5% at L5/S1. Czervionke and Fenton (2007) examined 209 ($n = 209$) consecutive MR lumbar spine studies and determined bright facet involvement in 81 (41%) of the studies reviewed. The authors did not record the spinal levels of bright signal involvement, instead preferring to place significance on the involvement of the periarticular soft tissues.

Yang and Yang (2005) determined the bright facet appearance occurred not only at the same level as degenerative disc disease, but at levels superior to it. Of members of the study group, 23% of the joints with a bright facet appearance had disc disease at the same level. Fourteen of 31 (45%) of articulations with bright facets were located one level superior to the disc disease; six of 31 (19%) of joints with bright facets were located two levels superior to the disc disease; and bright facet sign was found in four facet joints at levels inferior to the discogenic disease in a patient with old healed compression

fractures of the L2 and L3 vertebral bodies associated with disease at the L1-L2 and L2-L3 discs.

Longmuir and Conley (2008) determined sufficient inter-examiner agreement in their study to advance a single descriptive term to unite the BFS and to introduce a grading system (Grades 0, 1, 2, 3, and 4). An association with degenerative facet changes at the next level superior and two levels superior to degenerative facet disease and 2 levels inferior to the presence of degenerative disc disease was reported. The BFS was found to be independent of degenerative changes at the disc and facet at the same level. Subjects in Longmuir and Conley with a BFS were found to have a mean Body Mass Index (BMI) of 28.97, 25% less than the 36.25 mean BMI of those without a BFS.

A retrospective study of 41 participants performed by Marcondes César et al. (2011) engaging four independent observers (three spinal surgeons and one radiologist) found good inter-examiner and intra-examiner agreement when evaluating the grading system employed by Longmuir and Conley (2008). The number of participants in the Longmuir and Conley (n = 105; 2008) investigation was low and since all individuals were referred for advanced imaging as part of a low back pain work-up, there is no comparison to a true asymptomatic control group. It should also be noted there was no mechanism in place for the investigators to exclude malingering subjects.

Marcondes César et al. (2011) found no statistical relationship between the bright facet appearance and degenerative disc and facet changes, at the same lumbar spinal level. Marcondes César et al. did not address their small sample size (n = 41) or include

the history, nature, or severity of their subjects' low back pain. Important independent variables relating to patient symptomology and BMI were not investigated. A grading system for determining degenerative joint disease was absent from their research protocol. Exclusionary criteria were not employed to define the cohort of participants. Finally, Marcondes César et al. did not provide much technical detail in the uniform acquisition of their MR images.

Czervionke and Fenton (2007) determined the frequency of bright facets among the members of their research cohort, correlated the side of the patients pain to the side of the lesion and classified the BFS in terms of involvement of the supporting soft tissues. It should be noted Czervionke and Fenton considered the bright facet appearance to be a synovitis, a non-infectious inflammatory osteoarthropathy.

Yang and Yang (2007) used a cohort of hospital-based low back patients (n = 43), all between the ages of 11 and 25 years. Patients were assigned to a study group if discogenic disease was present (n = 29), or to a control group if degenerative disease was not present (n = 14). A scale of uniformity or a definition of what constitutes degenerative disc disease was not employed by Yang and Yang. Yang and Yang did not evaluate degenerative changes at the facet articulation, which have been reported relate to degenerative disc disease (Bogduk, 1990; Urban & Roberts, 2003). Neither a working definition of the bright facet appearance, nor inter-examiner reliability was evaluated as part of the Yang and Yang methodology. Exclusionary criteria were not employed and all participants were less than 25 years of age. Yang and Yang concluded that the lumbar

bright facet appearance resulted in low back pain. Although Yang and Yang were able to establish a 59% frequency of bright facets among a cohort of low back pain patients with degenerative disc disease, this is an association and does not represent causation. Causal inference involves judgments that are made using the accumulated knowledge of multiple disciplines (Aschengrau & Seage III, 2008, p. 385). The attributes of cause include time order, association and directionality (Susser, 1991). Although efforts were made by Yang and Yang to follow appropriate research guidelines, there were methodological flaws and some faulty assumptions made, as noted.

Czervionke and Fenton (2007) reviewed 209 symptomatic lumbar MRI studies retrospectively, ensuring that each examination included a fat-saturation acquisition technique in addition to T2-weighted sequences as part of the imaging protocol. Fat-saturation is a category of multiple selective methods, including short inversion-time inversion recovery, composite radio frequency, spectrally-selective radio frequency, slice-selective gradient reversal to name a few, used to nullify the appearance of marrow and somatic fat signal on the final image which may obscure a tissue of interest. Fat saturation has been shown to be useful in the diagnosis of inflammatory diseases, particularly synovitis (Barakat et al. 2005), osteoarthritis (Link et al. 2003), bursitis (Skaf et al. 1999), and osteomyelitis (Georgy & Hesselink, 1994; Longo, Granata, Ricciardi, Gaeta & Blandino, 2003). Czervionke and Fenton considered the bright facet appearance to be a synovitis, a non-infectious inflammatory osteoarthropathy. This determination was made without examining the association of facet degeneration and the bright facet appearance. Such an association is significant when considering patient symptomatology

as any correlation to the bright facet may be confounded by osteoarthritis. Unfortunately, Czervionke and Fenton used only one observer, nullifying the possibility of inter-examiner agreement.

My study has extended the research protocol used by Longmuir and Conley (2008), using the same retrospective case series approach, the same number of professional observers, and involving a larger pool of participants. It was my aim to identify associations between the BFS and the independent variables of age, race/ethnicity, physical activity, BMI, trauma, low back pain and degenerative joint disease at the facet and intervertebral disc level. Established scales for the grading of intervertebral disc degeneration (Pfirrmann, Metzdorf, Zanetti, Hodler & Boos, 2001), facet degeneration (Fujiwara et al., 2000), and the BFS (Longmuir & Conley, 2008) were employed.

Bright Facet Sign

The descriptor bright facets was first used in email communications between professional colleagues in Cincinnati, Ohio (S. Pomeranz, personal communication, 2003). Bright facets was then an uncited spontaneous abbreviation used regarding lumbar facet effusion in the absence of patient symptoms and supportive findings. In the literature, the term BFS was first introduced by Yang and Yang (2005) in the English translation of their Mid Taiwan Journal of Medicine article, Significance of the Bright Facet Sign on T2W MRI of the Lumbar Facet Joint.

Magnetic resonance imaging is the standard of lumbar imaging modalities (Fryer, Quon & Smith, 2010) and is usually the initial study obtained for the evaluation of low back pain (Chaput, Padon, Rush, Lenehan, & Rahm, 2007). Although MRI has been in ever-increasing use since its introduction in 1977, it can still on occasion present a novel finding that is both interesting and yet of questionable significance. The sporadic appearance of high signal within the facet joints of the lumbar spine on fluid-specific magnetic resonance sequences is such a finding, and is not commonly encountered in the professional literature (Longmuir & Conley, 2008). The appearance of intra-articular bright or high signal is variable in size, linear, and always homogeneous in intensity (Czervionke & Fenton, 2008; Longmuir & Conley, 2008; Marcondes César et al., 2011). The outer margins are smooth, and without the irregular changes associated with subjacent bony erosion. The capsular margins are not distended and a periarticular mass lesion is not featured.

Grading the Bright Facet Sign

Longmuir and Conley (2008) put forth a grading system for the bright facet response. For academic purposes, the bright facet appearance was divided into 5 separate categories and appears in Figure 1. A verbal description of the Longmuir and Conley system is as follows:

Grade 0 = a normal facet without a bright facet response.
Grade 1 = bright facet response < 50% the length of the hyaline cartilage seen axially.
Grade 2 = bright facet response > 50% the length of the hyaline cartilage seen axially.
Grade 3 = bright facet response along the entire axial length of the hyaline cartilage.

Grade 4 = a Grade 3 response with facet gapping.

The *kappa* statistic (*k*) was applied to evaluate the interexaminer agreement for the 5 grades of bright facet response at each of the left and right L3/L4, L4/L5 and L5/S1 facets. They agreed on 89.52% of their responses, or 85% of the way between random agreement and perfect agreement. The *kappa* scores fall within the range of k=0.8037 to 0.9104 which according to Landis and Koch (1977) suggests an almost perfect association. Marcondes César et al. (2011) repeated the Longmuir and Conley grading system using the MRI scans of 41low back patients between the ages of 26 and 84 years (mean age, 48 ± 3 years) and determined good intra-examiner and inter-examiner agreement with respect to graded bright facet identification. Repeated and accurate identification of the BFS by multiple examiners illustrates consistency of recognition. It also suggests the working description of the BFS is accurate and helps to facilitate easy recognition. The repeatability of the Longmuir and Conley grading system by Marcondes César et al. grading suggests consistency, and by implication, utility. Using a supported grading system in the study imparts scientific rigor.

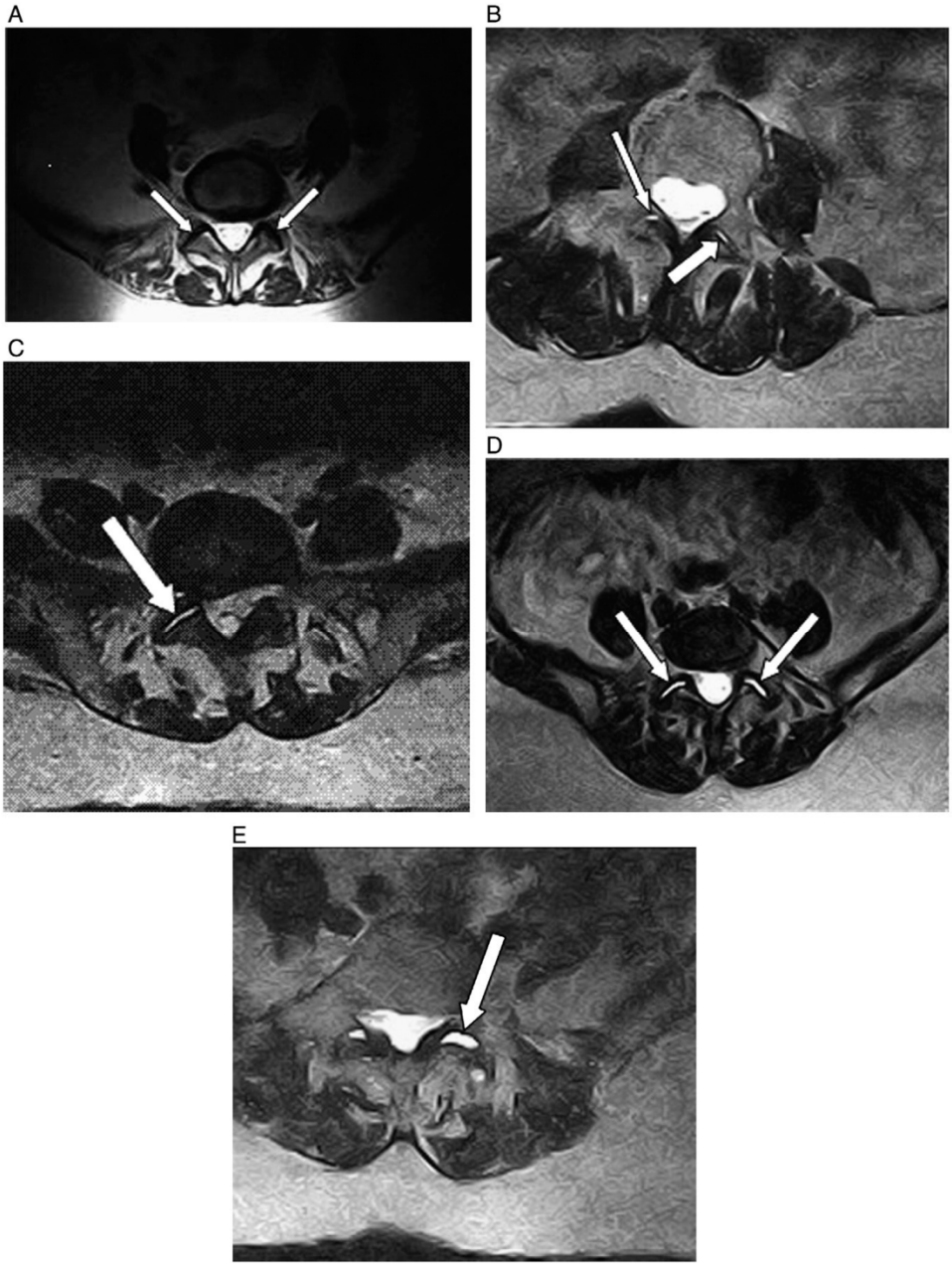

Figure 1. Bright Facet Sign grading system of Longmuir and Conley (2008). Grade 0, A; Grade 1, B; Grade 2,C; Grade 3, D; Grade 4, E.

Bright Facet Distribution and Symptomatology

Longmuir and Conley (2008) determined the total number of bright responses from a possible 630 facets (105 subjects, 6 facets per subject). Individually, they found that 290 (53.9%) and 284 (54.9%) facets respectively, did not demonstrate a bright facet response. Grades 1, 2 and 3, were closely represented in the final totals but varied when separated by spinal level. Bright facet responses averaged from 40.5% at L5/S1, 56.5% at L3/L4 and 66.5% at the L4/L5 level. The Grade 4 bright facet response involving facet gapping was uncommon, accounting for 1% of all bright facet responses, according to both examiners.

Czervionke and Fenton (2008) found bright facet responses in 41% of the 209 lumbar scans in their investigation. Equal numbers of articulations were involved at single levels or at multiple levels. Grade 2 involvement was the most common, with fewer facet joints showing grade 3 or grade 1 involvement. Only one grade 4 facet involvement was reported. Yang and Yang (2005) observed a bright facet sign in 5 of the 84 facet joints in the control group (6%) and in 31 or the 170 facet joints in the study group (18%). The difference in the frequency of BFS between these two groups was statistically significant (Student's t test: 3.111, $p < 0.0005$; Fisher's exact test: 2.328, $p < 0.0001$). The BFS was encountered at the same level as disc disease, but also at the levels superior to it. Their overall frequency of the BFS was 17 out of 29 subjects (58.6%). This frequency is similar to that of Longmuir & Conley (2008) and much lower than that reported by Yang and Yang. Observational studies with larger numbers of participants, both performed in the United States, show relative consistency in the number frequency

of the BFS. However the Yang and Yang study performed in Taiwan, presumably with almost exclusively Asian participants showed a much greater frequency of BFS.

One hundred percent of the 30 subjects in the Czervionke and Fenton (2008) study with unilateral, high grade (defined as grade 3 or grade 4) bright facet responses reported low back and/or lower extremity pain as their reason for undergoing advanced imaging. Further, the bright facet response was always on the same side as the reported symptoms. Yang and Yang (2005) reported bright facets among 6% of articulations in the control group, and 18% of facet joints in the study group. They maintained the 12% difference was significant and accounted for low back pain as the result of distention of the joint capsule, leading to stimulation of the sensitive capsular nerve endings, thereby inducing pain. Longmuir and Conley (2008) in their bright facet investigation did not use an asymptomatic control group. The independent variables of low back, unilateral and bilateral leg pain, sacroiliac joint pain, gluteal and anterior thigh pain were independent of the presence of, grade and distribution of the BFS. Not all potential causes of the BFS have been excluded. Technical factors, physiologic variables, and anatomical variants are possible causes for the BFS.

Possible Causes of the Bright Facet Appearance

Possible causes for bright facet changes were discussed in detail by Longmuir and Conley (2008). Several phenomenon and anatomical etiologies were considered. The magic angle phenomenon, for example, has been exploited for many years in chemical nuclear magnetic resonance (NMR) spectroscopy, where spinning a solid chemical

sample at an orientation of 54.74º to the main magnetic field (B_o) has been found to produce a significant increase in NMR signal (Hayes & Parellada, 1996). Magic angle effects are seen most frequently in tendons and ligaments. Rubenstein et al. (1993) showed that the magic angle effect may also be seen in hyaline cartilage. Goodwin, Zhu, and Dunn (2000) demonstrated a layered appearance within hyaline cartilage on T2 weighted images. At 54.74° to B_o changes in the dipolar interactions between loosely bound water hydrogen protons along the collagen fibrils in tendons, ligaments and hyaline articular cartilage account for a significant increase in T2 relaxation times. (Goodwin, Zhu & Dunn; Hayes & Parellada) This results in increased signal visibility in collagen structures with ordinary pulse sequences. A bright signal from this phenomenon is commonly seen in the ankle, rotator cuff, occasionally in the patellar tendon and elsewhere (Gatehouse & Bydder, 2003; Hayes & Parellada;). There are several reasons why it would be incorrect to assume that the bright facet response is the result of magic angle effect. First, the sign can be demonstrated simultaneously on both transaxial and sagittal images. Second, lumbar facet angles differ from side to side, (Fujiwara et al., 2001) as would their angulation to the main magnetic field; yet bright facets can be demonstrated bilaterally at the same level. Third, bright facets can be demonstrated on both horizontal and vertical field magnetic resonance imaging (MRI) scanners. The lumbar facets of recumbent patients cannot be positioned 54.74° to both magnetic fields at the same time. Since this disqualified the magic angle phenomenon as a cause of the bright facet appearance, perhaps there is a pragmatic structural etiology. It is possible that the variable appearance of a structural entity is responsible for bright facets.

The synovial tabs of the lumbar apophyseal joints have been a source of both anatomical and biomechanical speculation for many years (Bogduk & Engel, 1984). True synovial tabs are rudimentary fibrous invaginations of the dorsal and ventral joint capsule (Bogduk & Engel; Tondury, 1940; Zaccheo & Reale, 1956). These synovial reflections are normal constituents of the neonatal spine (Lewin, Moffett, & Viidik, 1962). So-called false menisci can be found at the superior and inferior joint margins and are considered to be fat-filled synovial reflections. Some contain fibrous tissue and likely arise as the result of mechanical stress. In either case, a fibrous and fatty morphology would not produce high signal on T2 weighted MR images and can also be excluded as causes of bright facet response. A meaningful association between osteoarthritis and the BFS has been described in the literature (Czervionke & Fenton, 2008; Longmuir & Conley, 2008; Yang & Yang, 2005). Changes in joint anatomy and physiology occur as the result of degenerative processes and may help account for the bright facet appearance.

Degenerative Joint Disease

DJD is an underlying disease related to the dependent outcome. It has a great influence on what independent variables I have chosen to examine. DJD (osteoarthrosis, osteoarthritis) accounts for 55% of all arthritis-related hospitalizations (Sacks, Helmick & Langmaid, 2004) and is the most common of the skeletal arthropathies. In the United States, approximately 36% of individuals have radiographically demonstrable osteoarthritic changes (Threlkeld & Currier, 1988).

Degenerative processes that involve the disc, known collectively as degenerative disc disease (DDD), are slow and largely biochemical in nature. Increased proteoglycan synthesis and the proliferation of chondrocytes are part of an initial response to joint disease and contrary to the natural enzymatic catalysis of articular material. Of the enzymes that influence disc metabolism, it is aggrecanase, metalloproteinase (MMP), and cathepsin that show an aptitude for breaking down high molecular weight glycoproteins such as fibronectin, proteoglycan, and collagen (Urban & Roberts, 2003). The loss of proteoglycans, such as the cartilage-specific aggrecan, slows the net movement of large uncharged cytokines and serum proteins through the vertebral endplate (Modic & Ross, 2007). This in turn, contributes to the loss of aggrecan fragments, accounting for desiccation of the disc and the degenerative cascade described by Kirkaldy-Willis (1983). This in turn facilitates penetration of the disc by growth factor complexes and cytokines which serve to accelerate the degenerative process. Aggrecan has been shown to inhibit the propagation of neural tissue. Its increased presence, associated with a loss of proteoglycan, may account for the increased neural ingrowth and vascular proliferation associated with degenerative discs in chronic low back pain patients.

Degenerative changes which occur at the facet level, known as degenerative facet disease (DFD) are similar to those changes which occur in other diarthrodial articulations of the body. Thinning and degradation of the articular cartilage leads to the creation of focal erosions with subchondral sclerosis of the underlying bone. The facet joint surfaces become denuded and hypertrophic with apophyseal misalignment and marginal osteophyte formation (Lalichman & Hunter, 2007).

Age

Age is a risk factor for DJD. The prevalence of radiographically demonstrable osteoarthritic changes increases to 86% between the ages of 75 and 79 years (Medsger & Masi, 1985). Lawrence et al. (1966) demonstrated some form of DJD of the spine, hips, knees, feet or hands in 100% of all individuals over 65 years of age. In the United States, between 63% and 85% of individuals past the age of 65 have demonstrable osseous degenerative changes, 35% to 50% of which are pain-productive (Cicuttini & Spector, 1995; Sack, 1995). Age is generally recognized as a major risk factor for DJD, however it is not necessarily a consequence of the aging process (Mankin, Brandt & Shulman, 1986; Tsang, 1990).

Degenerative joint changes are common among asymptomatic individuals (Jarvik, Hollingworth, Heagerty, Haynor, & Deyo; 2001). The anatomical and biochemical differences between the normal articular cartilage of the elderly and degenerative cartilage supports this position (Swedberg & Steinbauer, 1992). Hamerman (1983) summarizes these differences by stating that degenerative joint disease is age-related, however not age-dependent. Age is also known to influence the independent variables of physical activity and BMI (Consonni, Bertazzi, & Zocchetti, 1997). It may also influence the relationship that recent physical trauma has on the ability of the low back to recover by influencing the balance between bone absorption and bone formation (Lu, Hansen, Sapozhnikova, Hu, Miclau, & Marcucio, 2008). For these reasons, age will be managed in the data analysis portion of this investigation as a confounder.

Activity

Both a deficiency and an excess of joint motion have been shown to significantly impact the health of articular cartilage (Bader, Salter & Chowdhury, 2011; Rosenfeld, Seferiadis, Carlsson, & Gunnersson, 2003; Salter, 1989). The Framingham study illustrated the risk of developing DJD was greatest among individuals who performed job-related heavy labor, independent of obesity (Felson, 1990). Longmuir and Conley (2008) subdivided the occupations of their subjects into four basic categories, 1 through 4, based upon general job related activity where 1=very active, 2=active, 3=mostly sedentary and 4=sedentary. Additionally, supplementary categories 5=unemployed, 6=retired, 7=unknown/no response and 8=disabled were assigned to account for all the remaining responses. The occupational activities of the subjects in Longmuir and Conley were independent of the presence of a bright facet response.

Globally, back pain is often defined by work history and compartmentalized in terms of a previous or recent work-related injury (Videman & Battié, 1999). Such an event model implies that back pain is commonly the result of a series of work-related mechanical components that cause harm to the spine either as the result of a single episode or through repeated action. Work-related components may include prolonged sitting, assuming a sustained posture, twisting, bending, vibration, axial loading and industrial trauma. There is evidence that work exposure has a negative impact on the intervertebral disc (Brinckmann, Frobin, Biggermann, Tillotson, & Burton, 1998; Frank et al., 1996; Lings & Leboeuf-Yde, 2000). However, these factors cannot account for the

differences in lumbar degeneration found among members of the adult population (Videman & Battié). Additionally, a visible dose-response association between time consumed by work-related spinal abuse and osteoarthritis helps to reinforce scientific doubt about a causal connection (Frank et al., 1996). Occupational risk factors appear less significant in the cause of lumbar spine degeneration when compared with the combined influences of early childhood environment and genetic predisposition (Battié et al., 2009). Findings such as these case doubt upon the dominant role spinal loading was thought to play in degeneration of the lumbar spine and back pain and suggests a more complicated pathway.

Obesity

Multiple studies have shown obesity to be strongly predictive of degenerative joint disease (Karnik & Kanekar, 2012; Onyike, Crum, Lee, Lyketson, & Eaton, 2003; Sabharwal & Christelis, 2010). A study performed by Arokoski et al. (1993) showed that the knee and shoulder cartilage of young beagle dogs became thicker and more kinetically viable when forced to run four kilometers per day when compared with rested canines. Further, running similar canines in excess of 20 kilometers per day caused articular cartilage to wear prematurely and imparted a stiffness to its physical makeup not seem among rested beagles.

Body Mass Index (BMI) uses a mathematical formula that takes into account both a subject's height and weight and is calculated as BMI = mass kg/height m^2. The

World Health Organization (2013a) has adopted the following definitions for obesity based on the BMI figures given in Table 2.

Table 2

World Health Organization (2013a), Classification of Obesity

BMI	Classification
<18.5	underweight
18.5-24.9	normal weight
25.0-29.9	overweight
30.0-34.9	class I obesity
35.0-39.9	class II obesity
≥ 40.0	class III obesity

Note. Adapted from World Health Organization World Health Organization (2013a). Obesity and overweight. Retrieved from: http//www.who.int/mediacentre/factsheets/fs311/en/

Obesity as a cause of low back pain has been paradoxical. A dose-response relationship between BMI and low back pain does not exist (Mirtz & Greene, 2005). Obesity is a known risk factor for degenerative remodeling of the weight-bearing articulations of the human body (Felson, 1996). The increased load-bearing generated by a high BMI would, in turn, elevate intra-articular pressure and challenge the redistribution of forces across the joint surfaces. This would serve to accelerate the degenerative process throughout the lower lumbar spine (Kalichman, Guermazi, Li, & Hunter, 2009). Although it has been historically reported that overweight individuals are at increased risk for DJD in the weight-bearing articulations (Felson, 1996); and that a

variety of diseases, including obesity, prematurely influence the aging of joints leading to pain (Buckwalter, 1993), a direct relationship between BMI and low back pain has yet to be recognized in the literature (Visma et al., 2010).

Takatalo et al. (2013) used waist circumference and sagittal abdominal mensuration on a cohort of lumbar MRI scans as a proxy for abdominal obesity to determine if a relationship with BMI and disc degeneration existed. Despite a study cohort of $n = 302$, and stratified demographics, measures of obesity were associated with disc disease only among 21 year-old males. The authors speculated that female fat distribution, distributed about the hips, did not load the lumbar spine as it would in male subjects, who carry their excess body fat higher (Stevens, Katz & Huxley, 2010). The increased axial loading of the lumbar spine, they reasoned, would lead to disc degeneration by increasing the number of proinflammatory adipocytokines, native to adipose tissue. This in turn, may cause hepatocytes to increase serum C-reactive protein, leading to an inflammatory state which may create endothelial dysfunction and atherosclerosis, (Das, 2001; Warnberg et al. 2006) thus compromising the nutrition of the disc by reducing arterial blood flow. It does not seem likely that sufficient atherosclerotic change is present in the 21 year-old prevertebral anastomoses and intercostal arteries of their obese male cohort to account for any discogenic changes that were present.

In Longmuir and Conley, (2008), two-sample t-tests with equal variances were constructed. Subjects with a bright facet response have a mean BMI of 28.97 while subjects without a bright facet response have a mean BMI of 36.25. This represents a

25% difference. Patients without a bright facet response are, according to Longmuir and Conley, significantly heavier than those with a bright facet response. It is counter-intuitive that subjects in the Longmuir and Conley (2008) study with a BFS were found to have a mean BMI of 28.97, 25% less than the 36.25 mean BMI of those without a BFS. Obesity is also a moderate risk factor for low back pain (Benner, Alwash, Gaber, & Lovasz, 2003; Kalichman, Guermazi, Li, & Hunter). Considering that Czervionke and Fenton, (2008) and Yang and Yang, (2005) have argued that a strong relationship between the BFS and low back symptomatology exists, an unrecognized pathway between the causative physiological mechanism of the BFS and low back pain is likely.

Race/Ethnicity

Race and ethnicity are inexplicably intertwined and complicated. Often used as a synonym for race, ethnicity creates confusion through genetic polymorphism, differences in disease prevalence, and an absence of genetic signature that establishes a subject as a member of a particular race (Morris, 2001). The biological and anthropological communities are becoming increasingly satisfied to define race as a social construct and not so much as a dichotomy based in science (Goodman, 2000; Marks, 1995). Race/ethnicity is understudied in medical pain management, yet considered strongly predictive of health outcomes (Bates, Edwards, & Anderson, 1993; Morris).

Very few generalizations about pain and race/ethnicity exist in the literature (Morris, 2001). This is because both race/ethnicity and pain are flexible, culturally dependent and multifaceted in nature. Allison et al. (2002) reported in his British study

that musculoskeletal pain reported in three or more individual joints was less prevalent among white subjects than among ethnic minorities. Similar levels of osteoarthritic changes were described by Gibson et al. (1996) between subjects in white European populations and Pakistan. Carey at al. (1996) found a slightly lower prevalence of arthritic low back pain among non-white subjects in a telephone study performed in North Carolina. In the United States, the MMWR has asserted that self-reported pain associated with DJD varies little by race/ethnicity (Anonymous, 1996).

Pain itself can be subdivided into experimental, clinical, chronic and acute categories. Further, differences in pain response, perception, reporting, and severity varies widely between individuals and various study populations. Bates, Edwards, and Anderson (1993) determined that race/ethnicity was the most accurate predictor of low back pain intensity among a cross-section of individuals who self-identified as members of one of six separate ethnic affiliations. However, these authors found the intensity of pain to be independent of previous medical treatment, present medication, chief complaint and treating diagnosis. The authors did not define differences between national and ethnic identity.

Edwards and Fillingham (1999) compared the presence of lower thermal pain tolerance among a cohort of African-Americans when compared with Caucasians. The authors attributed their findings to differences in learned cultural changes influenced largely by expectancy and personal bias. Edwards and Fillingham recognized that minority status by itself can account for a lower thermal pain tolerance and

acknowledged an assumption assumed that their Caucasian study population was homogeneous in makeup. Sheffield, Biles, Orom, Maixner, and Sheps (2000) explored differences in perceived cutaneous pain between African-Americans and Whites. Although pain perception may vary between groups in terms of gender, opioid activity and , these variables were not controlled for as part of the investigation.

Relationships between the BFS and the independent variables of race/ethnicity, gender, occupation, BMI and date of birth are poorly represented in the literature. This may be due directly to the paucity of BFS studies in the peer-reviewed literature (Longmuir & Conley, 2008), or a concentration of effort directed at disease processes and societal problems with more tangible outcomes. Longmuir and Conley determined the ethic affiliation of their subjects by allowing each participant to self-select their race/ethnicity from the United States Postal Service (USPS) Employment Guidelines. Ordinal numbers were assigned to each affiliation to accommodate each response. An additional numerical category was assigned to represent an unknown/no response. Although Federal guidelines provide a mechanism by which an ethnic category can be assigned to a non-compliant subject, that option was not exercised in the Longmuir and Conley study. Ethnic distribution of the subjects in the Longmuir and Conley investigation was heavily skewed toward the White subjects, leaving little room for meaningful comparison. Ethnic comparisons were not explored in the BFS investigations of Yang and Yang, (2005) and Marcondes César et al. (2011), however since both studies recruited participants solely from their countries of origin (Taiwan and Brazil), it is presumed their respective cohorts are predominantly Asian and Hispanic, respectively.

Trauma

Trauma is the most important risk factor predisposing an articulation to degeneration (Childs Cymet & Sinkov, 2006; McCarty, Manzi, Medsger, Ramsey-Goldman, Laporte, & Kwoh, 2005). The wear-and-tear process helps to explain many of the manifestations of DJD, but does not account for all of the changes that occur in degenerative intra-articular cartilage. Erlich (1985) and Hamerman (1989) both maintain it is the microenvironment of the articular cartilage that instigates and drives the degenerative process. Extracellular proteolytic enzymes produces by chondrocytes are responsible for the degradation of the superficial layers of articular cartilage. Reparative processes begin, unfortunately they are unable to match the magnitude and duration of the chondrolytic changes. Owing to their close structural interdependence, degenerative changes within the articular cartilage lead to similar changes in surrounding synovial tissue and subchondral bone.

Longmuir and Conley (2008) did not find a significant association between the presence of a BFS and low back trauma within the past 12 months. There was also no association with the severity of low back pain as self-described on a Visual Analog Pain scale of 1-10. The traumatic events accounted for by Longmuir and Conley included axial loading, motor vehicle trauma, blunt force trauma, slip and fall injury, lifting injury, running injury, bending, gymnasium or athletically acquired trauma, and forceful sneezing. No other studies were found in the literature, which examined trauma as a risk factor for BFS.

Gender

Gender was not found to be a significant predisposing factor in the appearance of a BFS (Longmuir & Conley, 2008; Yang &Yang, 2005). Typically, radiographic signs do not discriminate between males and females. There are exceptions when the sign in question is observed in an organ or anatomical structure not common to both sexes. Examples include the John Thomas sign (Thomas, Lyons, & Walker, 1998) among men and the Indefinite Uterus sign (Bowie, 1977) in women. Gender differences do, however, appear to affect the rate and extent of lumbar osteoarthritic changes.

Fujiwara et al. (2000) imaged and tested 110 lumbar motion segments from 44 gender-balanced human spines. Disc and facet degeneration were graded using high field MRI and intersegmental motion was measured using a three-dimensional motion analysis system. In their study, females were found to exhibit significantly greater intersegmental motion (flexion: $p < 0.01$, extension: $p < 0.05$ and lateral bending $p < 0.05$) when compared with males. Intersegmental motion showed the effects of disc degeneration on lumbar spinal motion to be similar between men and women. However, the same study showed facet joint degeneration to influence motion changes between men and women. Where articular cartilage degeneration was noted, axial rotational motion increased among males, where lateral bending and flexion motion decreased in female segments. Subchondral sclerosis significantly decreased the motion (female: axial rotation, $p < 0.05$; extension, $p < 0.05$ versus male: flexion, $p < 0.05$). The number and severity of

osteophyte formation had not significant association with intersegmental motion. Degenerative changes between the genders may themselves differ.

Degenerative joint disease is more common among males than females of the same age (Harada, Okuizumi, Miyagi, & Genda, 1998). Degenerative changes are more prevalent among men below the age of 45 years where they are more prevalent among women over 55 years of age (Nachemson, Schultz, & Berkson, 1979). The degenerative process may be affected after middle age by perimenopausal osteopenia. Gender differences, as they related to spinal osteoarthritis, have not been well investigated (Fugiwara et al., 2000).

Methodology

I used an observational epidemiologic nested case-control design that consisted of the analysis of lumbar MRI scans performed at advanced imaging facilities in Hurst, Texas; Overland Park, Kansas; and Phoenix, Arizona. The subjects were patients referred from local primary care health care providers (MD, DC and DO) for imaging of the lumbar spine for diagnostic purposes. A case-control study is a method by which the investigator identifies and enrolls cases of a disease, in this instance low back buttock and leg pain, and a sample of the source population that gave rise to the cases (van der Mei et al, 2003). Since MRI examination is a costly imaging modality; and that third party reimbursement is non-existent for such cases; and it is unethical to expose asymptomatic patients to the hazards of advanced imaging, the source population that gave rise to these cases will be omitted. This also negates the use of a cohort investigatory strategy.

Inclusionary and exclusionary criteria were used for the purpose of limiting medical liability, and excluding specified co-morbidities which may contribute conflicting medical diagnoses and false positives.

The grading of radiographically observed anatomic variations and pathological changes is common in the medical literature and a familiar practice within the subspecialty of diagnostic imaging (Dieppe et al., 2005). The Meyerding System of classification for spondylolisthesis (Wright, 2003); the grouping of brain tumors (National Cancer Institute, 2013); the assessment of lumbar disc disease (Pfirrmann, Metzdorf, Zanetti, Hodler, & Boos, 2001); the Goutallier grading system of fatty degenerative changes within the tendons of the rotator cuff (Goutallier, Postel, Bernageau, Lavau, & Voisin, 1995); and the Gustilo system of open fracture classification (Kurup, 2013) all quantify differences on a progressively graded numerical scale. This is done to assess risk, describe the severity or benignancy of a disease process, to document the advancement of disease, and to create a common basis for comparison between similarly affected individuals (World Health Organization, 2013b). For these reasons, the grading of the BFS using the system proposed by Longmuir and Conley (2008) is consistent with the available medical literature.

Each patient referred to the imaging facility was asked to complete an introductory patient questionnaire to provide information about their present condition to assist the radiological staff in the interpretation of their scan and the formulation of a diagnosis; to provide historical health information to help exclude contraindication to MR examination; and assist the investigators in their characterization of the BFS. Information

collected included the subjects' gender, occupation, BMI, date of birth, race/ethnicity, current symptomatology and some historical and socioeconomic information. This is basic demographic information, commonly shared as part of the electronic medical records system at any medium-sized hospital or imaging center. Individuals who choose to participate in this investigation were required to complete a Bright Facets Patient Questionnaire, which can be found in the Appendix.

The development of Picture Archiving and Communications Systems (PACS) has allowed medical providers the ability to exchange useful patient demographic information across entire organizations. Shared records systems have reduced costs to third party payers, improved access by physicians and improved the quality of health research and care (Aidyan, Berbaum, & Smith, 1995; White, Berbaum, & Smith, 1994). The clinical information provided by Hospital Information Systems (HIS) and PACS imaging information has resulted in the cross-connection of all imaging studies for a given patient; provided the necessary pathway to enable the automatic retrieval of relevant prior studies; update patient demographics when patient information is changed; and permit an imaging department or center to store and maintain patient radiology data and images (Loux, Coleman, Ralston & Coburn, 2008). The utility of demographic data when combined with the patient's historical record of diagnostic imaging are powerful tools in the hands of patient care providers and researchers (seventh annual survey, 2005).

Summary

Low back pain is a common and costly problem, both domestically and globally (Maniakis & Gray, 2000). An association between low back pain and lumbar degenerative joint change is supported in the literature (Borenstein; Fujiwara et al., 2000; Jarvik & Deyo, 2002). A statistical relationship also exists between the bright facet appearance and degenerative joint disease of the lumbar disc and facet joints (Czervionke & Fenton, 2008; Longmuir & Conley, 2008; Yang & Yang, 2005; Young Cho, Murovic, & Park, 2009). An unrecognized or previously unreported pathway between the causative physiological mechanism of the BFS and low back pain may exist. There exists a gap in the current literature related to such a pathway. A satisfactory explanation of this pathway could be significant to the early identification and treatment of low back pain.

Radiographic signs are shorthand descriptors intended to condense a diversity of imaging findings to a practical and useable form. They are considered a standard of medical care and frequently employed in the specialties of radiology and neuroradiology. Radiographic signs are often pathognomonic of a particular disease (Tucker & Izant, 1971; von Gelderen, 2004), and can also be used to identify a disease process to help formulate a differential diagnosis (Han & Izant, 1971; Devilliers, 1981). Physiological processes such as inflammation and joint effusion are commonly encountered in clinical practice and two processes thought to be associated with the intra-articular changes that denote a BFS (Czervionke & Fenton, 2008; Yang & Yang, 2005). Some radiographic signs also serve a dual purpose by identifying an ailment and revealing demographic information regarding the patient's history, activity level, race/ethnicity, or body habitus

(Burnfield, Few, Mohammed, & Perry, 2004; Egwu, Anibeze, Ukoha, Esomonu, & Besong, 2013; Poznanski, Werder, Giedion, Martin, & Shaw, 1977). Each of these independent variables can significantly influence lumbar facet joint function and the volume of joint fluid therein.

MRI is a significant diagnostic modality for the evaluation of the lumbar spine. The bright facet response is a commonly occurring finding on T2-weighted MR images of the lumbar spine. It has been referred to alternately in the literature as facet effusion, bright facet appearance and BFS. There exists sufficient repeatability and reliability that a descriptive shorthand phrase can be applied to the bright facet response to convey a complete mental picture to the radiologist that will serve to refine a differential diagnosis, the BFS. Only recently has the BFS been identified in the literature and investigations exploring the relationships between the independent variables of low back pain, osteoarthritis and age are rare. Only one investigation has considered the independent variables of BMI, race/ethnicity, physical activity and recent trauma.

If the echo time (TE) of the MR images exceeds 45 msec., then is it clear that joint fluid is being imaged. Since most normal diarthrodial joints have fluid, it is a matter of how much is normal for that particular joint in that aged individual. In the case of the lumbar spine there exists significant variation in fluid volume to account for a BFS. Synovitis, marked by hyperemia and inflammatory infiltrate within the synovium could account for the BFS. Since early lumbar facet degeneration is marked by such intra-articular changes then a causative relationship between degenerative facet disease and a

bright facet response would be logical. Were this true, significant relationships between the presence of the BFS and osteoarthritic changes at the facet and intervertebral disc would occur at the same level and be plainly evident in the literature. This is not the case because the BFS is independent of degenerative changes at the disc and facet at the same level, and conflicts with the degenerative model featuring synovitis and hyperemia as the first step in the osteoarthritic process. This is particularly true at L4-L5 where fluid within the lumbar facets is considered to be the result of degeneration of the synovial facet articulation and directly associated with lumbar spinal instability, common among perimenopausal women. This corresponds to the same spinal level in the Longmuir and Conley (2008) study at which the majority of bright facets were found (66.5%).

Multiple studies have shown obesity to be strongly predictive of degenerative joint disease (Karnik & Kanekar, 2012; Onyike, Crum, Lee, Lyketson & Eaton, 2003; Sabharwal & Christelis, 2010). If the BFS represents the inflammatory exudate of a degenerative facet joint as suggested, (Chaput et al., 2007; Czervionke & Fenton, 2008; Yang & Yang, 2005) then affected subjects should have a relatively high BMI. This was contradicted by subjects in the Longmuir and Conley (2008) study where individuals with a BFS were found to have a mean BMI of 28.97, 25% less than the 36.25 mean BMI of those without a BFS. Kirkaldy-Willis and Farfan (1982) were the first to unify a host of pathophysiologic observations regarding the progression of degenerative lumbar changes into what is now known as the "degenerative cascade." Vernon-Roberts and Pirie (1977) determined that degenerative disc changes were always accompanied by degenerative

facet changes and concluded that disc degeneration was a determining factor leading to facet arthrosis.

Age is a major risk factor for DJD, however it is not necessarily a consequence of the aging process (Mankin, Brandt & Shulman, 1986; Tsang, 1990). Degenerative changes are common among asymptomatic individuals (Jarvik, Hollingworth, Heagerty, Haynor & Deyo; 2001). The anatomical and biochemical differences between the normal articular cartilage of the elderly and degenerative cartilage supports this position (Swedberg & Steinbauer, 1992). Hamerman (1983) summarizes these differences by stating that DJD is age-related, however not age-dependent. Age modifies the effects of physical activity and BMI. For these reasons age was managed in the data analysis portion of this investigation as a confounder.

For these reasons, the BFS may not represent a diagnostic imaging finding indicative of the joint effusion associated with DJD, prone to the risk factors of age, wear-and-tear and obesity. The BFS may instead represent a separate physiological phenomenon (Longmuir & Conley, 2008), asymptomatic in etiology, and related to the natural history of synovial fluid, its diffusivity in articular cartilage or its electrical conductivity. The body of literature relating to this field would benefit significantly from the clarification of such a causative physiological mechanism. A larger cross-sectional study, such as I have performed, could help explain the association between common low back pain and the BFS and satisfy the gap in the current literature. Further, there is a paradoxical association between increased BMI and the BFS, as it involves the presence of DJD. The mechanisms responsible for the production of the BFS might lead to a better

understanding of diarthrodial joint function. This could also contribute significantly to the current body of knowledge related to low back pain. In turn, this could lead to modification of treatment protocols and also provide a mechanism for earlier detection of DJD which in turn could contribute to positive social change by reducing pain and suffering related to low back pain.

In chapter 3, I discuss the methodology of this study. I have performed a quantitative observational investigation, nested case-control type, evaluating MRI studies for the presence, or absence, of the BFS and its associations with the covariates of race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration, after adjusting for age. I have invited a cohort of adult men and women to participate from a stream of symptomatic patients referred to an MRI facility for non-contrasted lumbar spine imaging. Exclusionary criteria limited study participation. These were individuals referred for advanced lumbar spine imaging by primary health care providers as part of their usual clinical work-up for low back pain.

Chapter 3: Research Method

Introduction

The BFS has a statistical association with DJD and low back pain (Czervionke & Fenton, 2008; Yang & Yang, 2005). Paradoxically, the BFS also has a statistically significant association with patients with low BMI (Longmuir & Conley, 2008). This is unexpected as obesity is considered a strong predictor of DJD (Karnik & Kanekar, 2012; Sabharwal & Christelis, 2010). The low back pain associated with the BFS may adhere to a different physiological pathway than the pain associated with DJD and by extension, its risk contributing factors. A previously unreported pathway between the causative physiological mechanism of the BFS and low back pain may exist to facilitate this association. An exploration of the relationships that exist between the BFS and its associations with the covariates race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration, after adjusting for age may lead to a better understanding of such a pathway.

This investigation could contribute to the current body of knowledge related to low back pain. There is the possibility that a previously unspecified pathway could lead to the modification of treatment protocols and provide a mechanism for the earlier detection of degenerative joint disease, which could contribute to positive social change by reducing the pain and suffering related to low back pain. The physiology of bright facets may help account for disparities in low back pain. Considering the global prevalence of low back pain, the direct and indirect health costs, and loss of productivity, an improved understanding of the pathophysiology may lead to positive social change.

This investigation was quantitative and observational (nested case-control) in nature and entailed independent evaluations of MRI studies for the presence or absence of the BFS. In my analysis, I focused on identifying significant associations of the BFS with the covariates of race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration, after adjusting for age. Participant treatment was not part of this investigation.

Three-hundred and fifty scans were independently reviewed by residency-trained and board certified radiologists, sufficient to provide academic rigor. I invited a cohort of adult men and women to participate from a stream of symptomatic patients referred to an MRI facility for noncontrasted lumbar spine imaging. Open-designed 0.7 tesla (midfield) PHONAR MR units in use at the participating imaging facilities were used for this project. I determined the interexaminer agreement, between the two examiners, of the absolute presence or absence of a BFS using Cronbach's alpha. Bivariate statistics, including the *t* test, correlation, and chi square were employed to determine nonrandom associations between the dependent variable of BFS and covariates of race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration. There is minor risk involved in this study owing to the potential compromise of patient confidentiality. The MRI studies and health information records in this investigation were not examined anonymously; however, every effort was made to keep them confidential.

In this chapter, I detail the study design for this investigation, the sampling strategy, data collection and management, and the rationale for the methods of statistical analysis. I review the variables and confounders used in this study and present the threats

to validity. Finally, I discuss the steps I have taken to protect of the rights of the participants in this investigation.

Research Design and Rationale

For this research, I useda quantitative, observational research design with secondary cross-sectional data collected during radiologist-patient interactions. The dependent variable was BFS. The research questions and associated null and alternate hypotheses guiding this study were:

Research Question 1

Is there an association between the dependent variable BFS and the independent variable degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and degenerative joint disease.

Research Question 2

Is there an association between the dependent variable Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the BFS and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Although patient volume can be seasonal and vary according to a variety of economic factors, I determined the number of participants (n = 350) in this investigation based on a power analysis computation performed using G*Power. A 24-hour turn-around time for diagnostic interpretation is important and customary. For this reason, images were interpreted for pathology by the appropriate reading radiologist before they were forwarded to the study observers for BFS review.

Observational cross-sectional studies have been the research standard in the investigations of the BFS conducted by Yang and Yang, (2005); Friedrich et al., (2007); Czervionke and Fenton, (2008); Longmuir and Conley, (2008), and Marcondes César et al., (2011). Because all participants in this study were symptomatic, a comparison to enrolled asymptomatic participants was not possible. Since medical ethics allow only symptomatic patients to be eligible for advanced imaging, prescreening of the images was used to admit equal numbers of patients both with, and without, BFS to the investigation. This created a nested case-control investigation, which increased the statistical power of the study by providing a comparison group.

Methodology

Setting and Sample

I invited a cohort of adult men and women to participate from a stream of symptomatic patients referred to an MRI facility for noncontrasted lumbar spine imaging.

These were individuals referred for advanced lumbar spine imaging by primary health care providers as part of their usual clinical work-up for low back pain. Three MRI facilities agreed to participate in the study; they are located in Hurst, Texas; Overland Park, Kansas; and Phoenix, Arizona. Although scan volume at these imaging facilities vary by day, season, and in accordance with the insurance reimbursement climate, each office receives approximately 95 to 120 low back patients for noncontrasted MR imaging each month.

For convenience and consistency, low back pain patients were invited to participate as they signed in at the reception desk of each MRI facility, and not at the offices of the individual referring providers. Each patient referred to the imaging facility completed an introductory patient questionnaire to:

- Provide information about their present condition to assist the radiological staff in the interpretation of their imaging study;
- Provide information to help exclude contraindications to the MRI examination;
- Assist the investigators in their characterization of the BFS. Information collected includes the subjects' gender, occupation, BMI, date of birth, race/ethnicity, current lumbar symptomatology and some historical information.

All participants provided all data to be used in this study during the normal course of the MRI process. No additional questions were asked of them directly by study personnel. The inclusion criteria were as follows:

- The subject must be referred for MRI examination of the lumbar spine by a primary care physician (MD, DO, DC) or nurse practitioner (FNP, FNP-C) for

diagnostic purposes. No examinations will be made for educational or research reasons.

- The subject is at least 18 years of age and able to give written informed consent in English.
- The subject will be available to complete all acquisitions of the lumbar MR examination.

All lumbar MRI studies were completed, of good technical quality, and performed without contrast enhancement using the established imaging protocol of T1 and T2 FSE sagittal and axial images.

The exclusion criteria were as follows:

- Currently receiving intravenous or intramuscular narcotics or spinal epidural injections.
- Cancer, systemic or visceral disease (e.g. auto-immune diseases such as systemic lupus erythematosus, rheumatoid arthritis, ankylosing spondylitis, etc.).
- Fracture, or status post thoracolumbar surgery.
- Transitional lumbosacral segment, congenital absence of one or congenital fusion of two or more vertebral bodies.
- Substance abuse.
- Prolonged use of corticosteroids or osteopenia/osteoporosis.
- Hemorrhagic disease of current use of anti-coagulant therapy.
- Persons suffering from dementia or cognitive impairments.

- Contraindications to MR examination as determined by the Medical Director at each imaging facility to include, however not limited to: pregnancy, seizure disorder, ferromagnetic surgical appliances, aneurysm clips, eye or ear implants, shrapnel, metal fragments, claustrophobia and pregnancy.

The minimal sample size for this investigation was determined using G*Power v. 3.0.10, a downloadable software made available by the American Psychological Association. This program runs on widely used computer platforms and provides improved effect size calculators and graphic options (Faul, Erdfelder, Lang, & Buchner, 2007). I selected the output parameters based on a medium effect size of h = .50 using a power level of 80% and an allocation ratio of 1:1 for a two-tailed test. This produced a minimal total sample size of 128 participants (Figure 2).

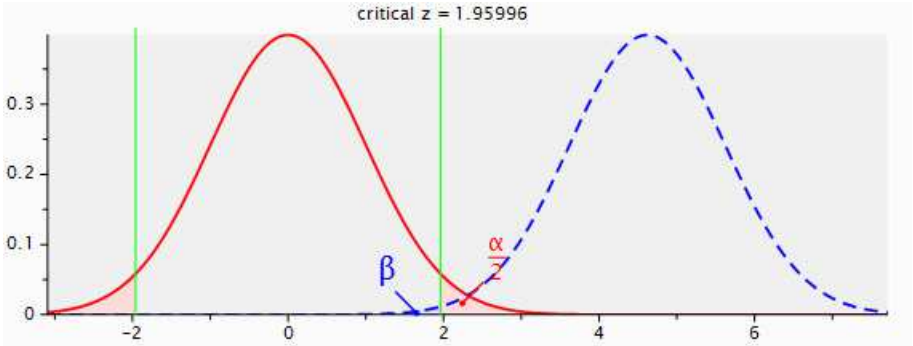

Figure 2. Medium effect size of h = .50 and a minimal total sample size of 128 participants.

As I was not confident of a 1:1 allocation ratio break point, I chose to inflate the minimum sample size to 350 participants, the approximate total monthly lumbar MRI scan volume for the three imaging sites. This increased the statistical power level, the

probability of correctly rejecting the null hypothesis when it is false in a given population, to .99. This imparted rigor to the investigation by substantially reducing the chance of rejecting a false null hypothesis (Figure 3).

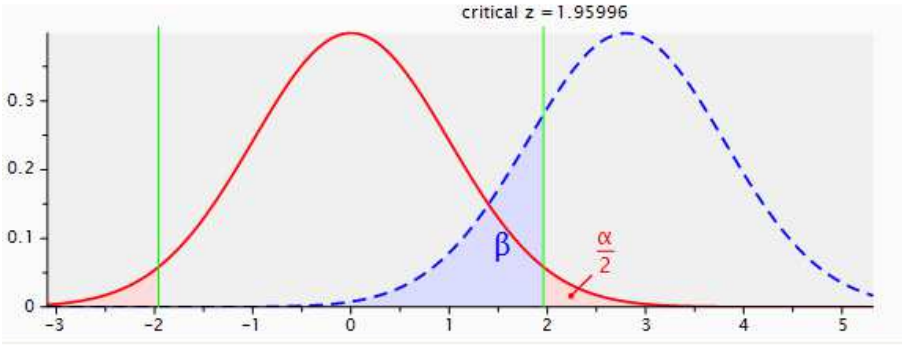

Figure 3. Medium effect size of h = .50 and a minimal total sample size of 350 participants.

Procedures for Recruitment, Participation, and Data Collection

I invited all patients referred for lumbar imaging to participate in the study upon presentation to the facility, providing they satisfied the inclusion criteria of the study, and MRI examination was not medically contraindicated. The invitation was in the form of a plain language statement, which described who was conducting the study, why the study was being performed, the academic institution involved, and explained the purpose of the consent forms participants were required to sign. The plain language statement is included in the Appendix. Also included in the Appendix is a statement regarding the privacy of personal medical information, and the patients' ability to decline participation in the study. Should the participant have had questions or complaints about involvement in the study, contact information was provided so that a concerned individual could contact a Walden University representative or myself.

Patients that chose to participate were required to sign two consent forms. The first was a consent for procedure/commercial insurance consent to undergo the advanced imaging procedure and understand the limited risks involved, that the patient is financially responsible for any balance not covered by insurance benefits, and that the imaging facility and its delegates may use their diagnostic images anonymously, for teaching and research purposes. The second consent pertains to the privacy and disclosure of medical records. All participants were advised in writing that information obtained during this research project is confidential. Any information obtained in this investigation would not be released without their written consent.

Each patient referred to the imaging facility was required to complete an introductory patient questionnaire to provide information about their present condition to assist the radiological staff in the interpretation of their scan and the formulation of a diagnosis. This questionnaire was used to provide historical health information to help exclude contraindication to MR examination and assist the investigators in their characterization of the BFS. Information collected included the subject's gender, occupation, BMI, date of birth, race/ethnicity, current lumbar symptomatology and some historical information. All patients were providing all data to be used by this study during the normal course of the MRI process. No additional questions were asked of them directly by study personnel.

Two experienced musculoskeletal radiologists received training in the BFS by reviewing the Training Program for Bright Facet Sign Data Collection. The Training Program consisted of T2-weighted MR images showing what a Bright Facet Sign looks

like in both the axial and sagittal planes. The Training Program for Bright Facet Sign Data Collection is included in the Appendix. Additionally, they received a written definition of the BFS and were required to familiarize themselves with the data collection instrument (Bright Facet Worksheet). The grading of lumbar degenerative joint disease was addressed on the collection instrument and covered in the training program. It was discussed at both the intervertebral and facet articulations. Descriptive grading systems for degenerative changes at the intervertebral disc and facet joint locations have been developed by Pfirrmann et al. (2001) and Grogan et al. (1997), respectively, and the defining published work of each were required reading for each of the examiners.

The senior technologist at the imaging facility was responsible for ensuring image quality, and making qualified MR lumbar cases available to the data collectors, after each set of images was dictated by in-house radiological personnel and prescreened for the presence or absence of the BFS. Randomization to exposure was not an issue in this protocol, since there was no experimental intervention. For participation, only those patients and their MR images that met the inclusion criteria, both for imaging by the facility and inclusion in this study, were shared with the data collectors. Likewise, there were exclusionary criteria to disqualify a patient from MR imaging and participation in this study. A third party payer assumed the cost of performing the imaging as an insurance benefit, to which each participant was entitled.

Instrumentation and Materials

MR imaging is a common, safe, and medically accepted imaging modality when a routine imaging protocol is performed under the supervision of qualified and licensed personnel. Contraindications to MR scans include the presence of ferromagnetic surgical instrumentation and implants, metal fragments, claustrophobia and seizure disorders. MRI has not been FDA approved for pregnant women. Only those participants among whom MRI examination was not contraindicated were included in the study population.

Open-designed 0.7 tesla (midfield) Fonar MR units in use at the Hurst, TX; Kansas City, KS; and Phoenix AZ facilities were used for this research and were under contract to receive factory preventative maintenance by Fonar Corporation. The most recent monthly site history report at the time of the study subject's examination showed no down time attributable to mechanical malfunction. The established lumbar imaging protocol was sagittal T1-weighted and fast spin echo (FSE) T2-weighted images obtained at the mid body of T12 through sacrum and axial angled T1-weighted and FSE T2-weighted images obtained through the L3 through S1 intervertebral discs. Matrix 256 x 256; NEX: 4. Contrast enhancement was not employed for this study. All participants for this study were imaged using the same protocol.

The images were electronically transmitted to the data collectors in their private offices via the internet utilizing the imaging software Digital Jacket 5.0 Pro. Every precaution to protect the privacy of each participant was followed. A discussion on patient confidentiality appears later in this chapter. The examiners interpreted each lumbar study, utilizing their own search pattern without an established time limit. One

Bright Facet Worksheet was completed by each data collector for each lumbar study. The same MRI studies were seen by each of the examiners on the same day. The data collectors did not communicate their findings with each other. I received the Bright Facet Worksheets and applied frequency and intra-examiner and inter-examiner agreement statistics.

This was an observational study using primary data from a single cohort that included those with, and those without the BFS. Observational cross-sectional studies have been the research standard in the investigation of the BFS conducted by Yang and Yang, (2005); Friedrich et al., (2007); Czervionke and Fenton, (2008); Longmuir and Conley, (2008), and Marcondes César et al., (2011). Of these, Marcondes César et al. verified the BFS grading system of Longmuir and Conley with good interobserver and intraobserver reliability. The data collection instrument, included in the Appendix as Bright Facet Worksheet, accommodated the measurement of the BFS as an ordinal variable by specifying a spinal level, a side (L/R), and a bright facet grade (0-4) according to the system of Longmuir and Conley.

An MRI grading system for intervertebral disc degeneration was put forward by Pfirrmann, Metzdorf, Zanetti, Hodler and Boos (2001). This system, in constant use since its inception is frequently encountered in the literature (Adams & Roughley, 2006; Boos et al., 2002). It is simple, noninvasive, and convenient (Griffith et al. 2001;Yu, Qian, Yin, Ren & Hu, 2012;). The Pfirrmann et al. grading system correlates with the Modic changes of the subjacent vertebral marrow (Yu, Qian, Yin, Ren & Hu) and the T2 relaxation times for varying levels of lumbar disc degeneration (Marinelli, Haughton, &

Anderson, 2010). Kettler and Wilks, (2004) in their evaluation of 42 grading systems for cervical and lumbar disc degeneration endorse the use of the Pfirrmann system for investigational purposes because of its high intraobserver reliability and ease of use. Griffith et al. suggest the Pfirrmann grading system is suitable for the in vivo quantitative evaluation of disc changes, however it may be inadequate in cases involving severe disc degeneration.

Twelve classification systems for the classification of lumbar facet joint degeneration appear in the literature (Kettler & Wilks, 2004). Of these, almost all rely on the combined use of MRI and CT (Pathria, Sartoris, & Resnick, 1987; Weishaupt, Zanetti, Boos & Hodler, 1999). The classification of lumbar facet degeneration utilizing only MRI has been accomplished by Grogan, Nowicki, Schmidt and Haughton (1997). This system assesses the degree of articular cartilage degeneration and subchondral bone sclerosis. Four grades are used in what is considered to be a non-invasive and simple system (Fujiwara et al., 2000). Both axial MR images and a verbal description are part of the definition. Fujiwara and coworkers reference it multiple times in the literature as the lumbar facet grading system of choice.

I used the Bright Facets Patient Questionnaire to collect information relating to data provided directly by each participant. Race/ethnicity was self-assigned by each participant based on the six categories provided by the U.S. Office of Management and Budget. These are White, Black or African American, Hispanic, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander (OMB, 2010). Gender, a nominal covariate, was also identified by each participant on the questionnaire.

I treated low back pain as two separate covariates, those of duration and intensity. Duration was self-recorded by each participant into one of five categories. These were: < 1 year, 1 year, 1-2 years, 2-5 years, and >5 years. A psychometric response scale, the visual analog scale (VAS), was used to grade the subjective intensity of their low back pain on the day of the MR examination. Long used to determine preferences for health outcomes, the VAS is easy and inexpensive to administer and lends itself readily to self-completion (Torrance, Feeny, & Furlong, 2014). Reliability of the VAS for acute pain measurement as determined by the use of intraclass coefficients is considered high (Bijur, Silver, & Gallagher, 2001).

Physical activity was occupation-based, psychometrically measured, and self-reported by each participant on the Bright Facets Patient Questionnaire. A five-point Likert scale was used for this purpose with the following categories: very active, active, mostly sedentary, sedentary, unemployed/retired or disabled. The values between each successive item are equivalent, and although arbitrary in nature, there is symmetry of categories presented about a midpoint. If the patient was involved in a physically traumatic event in the past 12 months, they would self-report the nature of the trauma. The available selections were: axial loading, motor vehicle collision, blunt force, slip and fall, lifting, running, miss-stepped, squatting, bending, athletic, sneeze, no response/uncategorized. Age in this investigation was managed as a confounder, and was determined from the patients' date of birth and verified by the technologist from the participant's photographic identification.

Data Collection and Management

As a matter of standard practice, patients presenting to the reception desk of an MR imaging facility are asked to arrive thirty minutes before their scheduled appointment time. This provided sufficient time for each patient to complete an introductory questionnaire, which elicited necessary demographic and historical information. The questions varied slightly by facility, but were designed to obtain previous surgical information, and to exclude candidates for whom an MRI examination is contraindicated. There was an informed consent form which sought consent to perform the patient examination, a commercial/Medicare Insurance form which requested authorization to provide health and billing information to a third party payer, and a review of systems questionnaire. After completion of these introductory forms, the patient met privately with an MRI technician in an enclosed room. Each handwritten response was reviewed line-by-line and read aloud by the technician before the patient executed the form with a confirmatory signature. It was at this time those patients, qualified by the inclusionary and exclusionary criteria, were invited to become study participants and given a copy of the research plain language statement. The participants also completed a Bright Facets Patient Questionnaire form, and were assigned a study code number (001 through 350). The study code was separate from the patient identification number that each imaging facility used to track medical records. The table with assigned patient study code numbers and assigned codes has been stored separately from all other study information. Once the patients were dressed in the patient gown, and prior to the actual scan, the MRI technician measured the height and weight and entered the information at the top of the

Bright Facets Patient Questionnaire form. After the MR scan was completed and the on-sight Medical Director had approved the quality of the scan, the participant was dismissed and allowed to change. The Bright Facets Worksheet and completed Bright Facets Questionnaire were faxed to me at the same time as the lumbar MR images were exported via a Digital Imaging and Communications in Medicine (DICOM) send operation. These forms and digital images were sent to my office where the study code number was placed on the Bright Facets Worksheet, the lumbar images were blinded, and the assigned patient ID number was electronically affixed to the DICOM images. A musculoskeletal radiologist other than me, prescreened the lumbar MR examinations at my office, to ensure a nested case-control protocol using equal numbers of participants both with, and without the BFS. The lumbar MR examination and Bright Facet Worksheet were then forwarded to the readers for purposes of grading the presence or absence of DJD and the BFS. Readers had already reviewed and completed the Training Program for Bright Data Collection introduced in Chapter 1 and discussed in the Procedures for Recruitment, Participation, and Data Collection section of Chapter 3.

Once completed by the reader, the completed Bright Facet Worksheet was returned to me and I add the gender, occupation, BMI, DOB, and symptoms. Transcription of data was performed at my office by a senior member of my billing department using a Microsoft Excel 2007 ^{TM} spreadsheet. A flowchart summarizes the methodology of this investigation (Figure 4).

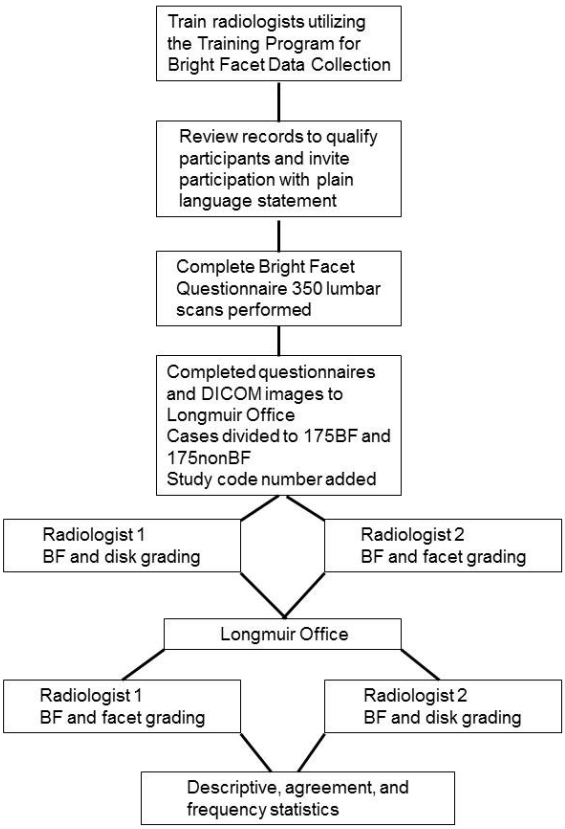

Figure 4. Methodology flowchart of investigation.

Study Variables

Dependent Variable

The dependent variable is the presence or absence of a BFS, its spinal location and grade (Table 3). The BFS is defined by Longmuir and Conley (2008) as the presence of increased intra-articular signal with a lumbar facet articulation on a T2-weighted image in the absence of discernible pathology (Longmuir & Conley, 2008). Spinal levels are the anatomical designations of L1/L2, L2/L3, L3/L4, L4/L5, and L5/S1. Since the ten

lumbar facet articulations are paired structures, a BFS may be left-sided, right-sided, or bilateral, involving both the left and right sides. The radiologists functioning as data collectors utilized the grading system introduced by Longmuir and Conley and sustained by Marcondes César et al., (2011) establishing grades 0 through 4. By definition, different grades of BFS may be established at different sides of the same spinal level. The measurement level is ordinal with the specification of a spinal level, a side (L/R), and a grade. The BFS can also be binomial with yes or no presence of the BFS at each spinal level. To conserve power, I combined the results of the two readers based on a Cronbach's alpha greater than 90%. To reduce the likelihood of a type 1 error, I assigned the more conservative of the two ratings where discrepancies existed.

Independent Variables

For purposes of statistical analysis, the independent variables of gender, ethnic identity, physical activity, BMI, trauma, low back pain, DDD, and DFD were treated as covariates. The type of each variable, its source, potential responses, and level of measurement are presented in Table 3.

Table 3

Study Variables

Variable Type	Variable name	Source	Potential responses	Level of measurement
Dependent	Bright Facet Sign (BFS)	MRI Scan	Graded 0 - 4 Longmuir & Conley	Ordinal
Covariate	BMI	Computed from height and weight measurements	18.5 - 40 kg/m^2	Ratio
Covariate	Degenerative Joint Disease at the Disc (DDD)	MRI Scan	Graded I - V Pfirrmann et al.	Ordinal
Covariate	Degenerative Joint Disease of the Facet (DFD)	MRI Scan	Graded 1 - 4 Grogan et al.	Ordinal
Covariate	Gender	Self-reported by participant on the Bright Facet Patient Questionnaire	Male or Female	Nominal
Covariate	Duration of Low Back Pain	Self-reported by participant on the Bright Facet Patient Questionnaire	< 1 year 1 year 1-2 years 2-5 years > 5 years	Ordinal
Covariate	Intensity of Low Back Pain	Self-reported by participant on the Bright Facet Patient Questionnaire	VAS 1-10	Ordinal
Covariate	Physical Activity	Self-reported by participant on the Bright Facet Patient Questionnaire	According to occupation: very active, active, mostly sedentary, sedentary, unemployed,retired, disabled	Nominal

table continues

Variable Type	Variable name	Source	Potential responses	Level of measurement
Covariate	Race/Ethnicity	Self-assigned by participant on the Bright Facet Patient Questionnaire	White, Hispanic, Black, American Indian or Alaska Native, Asian Native, Hawaiian or other Pacific Islander,unknown or no response	Nominal
Covariate	Trauma	Self-assigned by participant on the Bright Facet Patient Questionnaire	Yes or No	Nominal
Covariate	Type of Trauma	Self-reported by participant on the Bright Facet Patient Questionnaire	Axial loading, MVC, blunt force, slip and fall, lifting, running, misstepped, squatting, bending, athletic, sneeze, no response or uncategorized	Nominal
Confounder	Age	Date of Birth	Years	Interval

Height and weight are continuous variables. They were used to compute the BMI in kg/m^2, recorded at the ratio level of measurement. The grading of DJD into DDD and DFD are ordinal in nature, following the grading systems of Pfirrmann et al. (2001) and Grogan et al. (1977), respectively. Race/ethnicity, gender, the presence of low back pain, and history of trauma are, by definition, nominal levels of measurement. Physical activity, self-reported by the participant by occupation, was ordinal. The duration of low back pain and type of participant trauma were recorded as ordinal and nominal measurements, respectively.

Ratio and interval level variables were converted to categorical ones as needed to conserve power. This was necessary, as the sample size could not support a logistic model with multiple continuous variables. Variables were categorized based on convention, as with BMI, and consistent with physiological processes, as with age. In a few cases, ordinal and categorical variables were converted to binomials. VAS, a highly subjective measure of the intensity of pain was categorized as low (five or less) or high (greater than five).

Confounders

Degenerative joint disease is age-related, however not age-dependent (Hamerman, 1983). Age is generally recognized as a major risk factor for DJD; however DJD is not necessarily a consequence of the aging process (Mankin, Brandt & Shulman, 1986; Tsang, 1990). Longmuir and Conley (2008) suggest the relationship BFS shares with DJD may be magnified by the age of the participant. Age also influences the covariates of BMI and physical activity (Consonni, Bertazzi & Zocchetti, 1997). It may also influence the relationship that recent physical trauma has on the ability of the lumbar spine to recover by influencing the balance between bone absorption and bone formation (Lu, Hansen, Sapozhnikova, Hu, Miclau & Marcucio, 2008). For these reasons, I treated age as a confounder and controled for it during the statistical analysis of the relationship between the BFS and the covariates of gender, race/ethnicity, physical activity, BMI, trauma, low back pain, DDD, and DFD.

Confounding is not caused by the investigator or the study design, but is common to a free-living population of study subjects with unevenly distributed attributes

(Aschengrau & Seage III, 2008). In this study, each of the individual covariates I discussed was associated with the BFS, or has contributory influence over the presence or absence of low back pain, DJD or BMI. The covariates may have related to the dependent variable differently in the presence of each other. Because of the significance of a combined effect, individual covariates cannot be excluded and are therefore dealt with during the analysis phase. Ordinal or Multinomial Logistic Regression analysis will help to illuminate their individual contributions to the outcome and relationships to the BFS. The effect physical exercise had on the BFS cannot be included owing to an absence of collected data for this covariate. Physical activity, however, was measured using the self-reported occupational activity for each participant.

Data Analysis

After the data was collected and recorded in a spreadsheet, it was transferred to SPSS® statistical software (IBM Corp., 2013). I then used SPSS to compute descriptive statistics to identify the characteristics of my study sample, bivariate statistics to evaluate confounding, and bivariate and multivariate statistics to test my hypotheses. The aim of this research project was to identify and account for the presence of the BFS in a cohort of low back pain patients. Since I was attempting to answer two research questions, with different numbers and categories of covariates, I dealt with their data analysis separately, and in two different ways.

Research Question 1

Is there an association between the dependent variable Bright Facet Sign and the independent variable degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and degenerative joint disease.

To determine the association between BFS and covariates of DDD and DFD, initial analysis assessed the frequencies with which these variables were found in both the cases and the controls. Each was then subjected to bivariate analysis to assess the potential pairs of BFS grade, spinal level, DDD grade and DFD grade as shown in Table 4.

Table 4

Bivariate Analysis Pairs Performed in Question 1

	BFS grade	Spine level	Grade DFD	Grade DDD
BFS Grade		BFS Grade vs Spine Level	BFS Grade vs Grade DFD	BFS Grade vs Grade DDD
Spine Level	Spine Level vs BFS Grade		Spine Level vs Grade DFD	Spine Level vs Grade DDD
Grade DFD	Grade DFD vs BFS Grade	Grade DFD vs Spine Level		Grade DFD vs Grade DDD
Grade DDD	Grade DDD vs BFS grade	Grade DDD vs Spine level	Grade DDD vs Grade DFD	

I chose bivariate analysis as it represents the simultaneous analysis of two categorical variables. Bivariate analysis simplified the concept of relationships between two variables, determined whether there exists an association, and defined the strength of

that association. If differences existed between the variables, the significance of the difference was expressed mathematically.

I tested the assumption of normality of the ordinal variables, BFS, DJD, and DDD and based my decision to use parametric or non-parametric tests on the results. The parametric test to assess correlation is Pearson's *r*, while its nonparametric analogue is Spearman's Rho. Both provide a measure of agreement and are their results are interpreted based on the strength of the association. Both Pearson's *r* and Spearman's Rho can range from -1 to 1, with an *r* of -1 indicating a perfect negative linear relationship, an *r* of 0 indicating no linear relationship, and an *r* of + 1 indicating a perfect positive linear relationship between variables. I have used the test statistic and the associated *p* -value in my interpretations. The test result was considered statistically significant based on a *p-value* of <.05.

Research Question 2

Is there an association between the dependent variable Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

I performed logistic regression analysis to evaluate the relationship between BFS and the covariates of DJD, gender, BMI, race/ethnicity, physical activity, previous trauma, and low back pain, presented in Table 3. The covariates may have related to the dependent variable differently in the presence of each other. To evaluate the relationships between the dependent variable BFS and the covariates of race/ethnicity, physical activity, BMI, trauma, and low back pain, Ordinal Logistic Regression (OLR) was planned. OLR is a helpful non-parametric approach in circumstances where the dependent variable is represented by values in a set of ordered categories (Brant, 1990). More powerful than the other form of Logistic Regression, Multinomial Logistic Regression (MLR), the successful use of OLR is dependent upon the ability of the data to meet the assumptions of ordinality. The ordinal model assumes that all data in the calculation are case specific; that each covariate has a single value for each participant. The OLR model assumes the distance between each category of the outcome to be proportional. Further, the collinearity of the covariates is assumed to be low, however it is not absolute that the covariates be statistically independent of each other. Finally, the ordinal model also assumes that the covariates themselves cannot predict perfectly the value of the dependent variable. Without testing my data, I could not know whether the assumptions would be met. Typically, if the assumptions for OLR are not met, the alternative MLR is used. Unfortunately, MLR requires large sample sizes and is likely not suited to this study. I therefore determined that binomial logistic regression was the preferred alternative to OLR if assumptions were not met. While binomial logistic regression cannot measure a dose response or how associations vary based on the

intensity of the BFS, it can produce odds ratios to suggest the likelihood of the presence of the BFS given a set of covariates. Thus, it can be used to examine statistically and clinically significant relationships between exposures and outcomes. As with OLR and MLR, the results of the binomial logistic regression cannot confer causality.

If OLR is used to help model the selection of independent variables, it relies on the assumption of irrelevant alternatives. That is, the statistical odds of preferring one independent variable to another will not depend on the presence or absence of additional irrelevant alternatives (Brant test). The selection of a correct reference value for each variable cannot be understated. For the BFS, a "0" in the BFS grading system of Longmuir & Conley (2008) was used as a reference so that any increased risks observed would translate to an increased risk of encountering a BFS, and not an increased risk of not encountering a BFS.

GENLIN and PLUM are the two alternate procedures SPSS provides to perform OLR. Of these, GENLIN is faster and easier to perform. The presence of empty or extremely small cell numbers creates difficulty when running an OLR model. This can be verified one of two ways in SPSS by making simple cross-tabulations, or using the Cellinfo option on the print subcommand. The latter method should be used only with independent variables that are categorical, otherwise the table be will be lengthy and interpretation will be rendered difficult. After running the model, a Case Processing Summary table will be presented giving the number and percentage of cases in each level of the dependent variable. Concern is created if one level contains very few cases. Even

if all 350 observations in the data set were used in the analysis, fewer observations could be used if any of the variables had missing values. SPSS does a list-wise deletion of cases with missing values.

A proportional odds test, the Brant test of parallel regression assumption, provides results of a series of underlying binary logistic regression models across different category comparisons. The assumptions of OLR are violated when a non-interval dependent variable is used. If the proportionality assumption of OLR is violated, an MLR model can be used. Unfortunately, MLR is less parsimonious and can be considered dubious on substantive grounds (Brown, 2013).

A large sample size is a prerequisite to the use of MLR. MLR also uses multiple equations, requiring a larger sample size than OLR. As with OLR, cross-tabulation between categorical predictors and dependent variables can be used with MLR to detect small cell numbers. Model diagnostics are not as straightforward as they are with OLR. The detection of outliers or influential data points required separate logistic regression modeling.

As stated, binomial logistic regression is my best option if my data cannot meet the assumptions of OLR. For the binomial logistic regression, the dependent variable has to be binomial. The dependent variable, BFS, if converted to a binomial is coded as 0 if not present and 1 if present. The interpretation of the results of this regression is based on the odds ratio and the associated confidence intervals or p-values. Confidence intervals that contain the number 1 and p-values >.05 indicate that the association tested is not

statistically significant. I will use three models, one for each spinal level, created using the binomial form of the BFS and the covariates I found significant based on bivariate tests to determine the significance of associations and test my hypothesis.

Threats to Study Validity

I anticipated several threats to validity in this research project. Typically, case-control studies are inexpensive, fewer subjects are needed, particularly for unusual or uncommon diseases, and the studies are generally not lengthy. Unfortunately, the selection of an appropriate control group can be challenging. Case-control studies are prone to selection bias (Aschengrau & Seage III, 2008). This is generally present when control participants are not drawn from a source population with similar exposures, or are chosen using different selection criteria than those for the case participants. The nested case-control protocol in this investigation used equal numbers of individuals with, and without the BFS, drawn from source populations of symptomatic low back pain patients from MRI centers in three states. The exclusionary criteria were established and applied equally to all prospective participants.

Since the completion of a patient questionnaire and the use of medical records were included in this investigation, there exists a potential for recall bias. Having the patient complete the questionnaire and then affirming their responses verbally in consultation with an MR technologist serves to support the accuracy of the information provided. By limiting the participants' history of traumatic events to the previous twelve

months, recollections of long-past events are eliminated and the potential for recall bias is reduced.

There was the potential for information bias, resulting from non-uniform criteria on the part of the referring healthcare provider for referral to an MRI facility for lumbar imaging. Different medical offices have different levels of medical record specificity and accuracy. Although the State Board of Medical Examiners enforces a minimum level of care in each jurisdiction, individual effort and competency play a role in the completeness of each patients' individual medical records. For this reason, new information was solicited on the Bright Facets Patient Questionnaire regarding the level and duration of the patients' symptoms, occupation, height and weight. This new information, solicited at the time the participant presented for the scan, was not subject to the transcription inaccuracies of previously existing records from unfamiliar medical office sources.

The Bright Facet Patient Questionnaire appears in the Appendix section. The participant provided their date of birth and gender, and made selections to self-report their ethnic affiliation, the duration and level of their low back pain, physical activity, and the history and nature of trauma within the past 12 months. The height and weight of each participant was taken by the technologist and also provided on the Bright Facet Patient Questionnaire. A patient identification number was generated by each imaging facility and appears in the upper right corner of the questionnaire. The study code, assigned by me, also appeared in the upper right corner.

Protection of Participant Rights

Ethical considerations included the need for verbal and written informed consent from the participants; protecting the subjects from harm and discomfort; and the confidentiality of experimental data. There was risk, Level 2, involved in this study owing to the potential compromise of patient confidentiality. The MRI studies and health information records in this investigation were not to be examined anonymously, however, every effort was made to keep them confidential. Initially, the images and data were stored on the secure hard drives of the PC's belonging to the principal investigators and data collectors. The interpretation of images was done in the data collectors' private offices. The software used to access the images was password protected. Students, interns and residents were not in attendance to observe while these images were interpreted.

The PCs of the data collectors are single user units and resided in the locked private offices of the data collectors involved. As a matter of office policy, there was restricted entry, and access to the computer systems was password protected. There existed the internal security provided by Windows 7, firewalls, a system of routers, blocks of static IP addresses and Norton Antivirus™ 2014, AVG 2013 and McAfee virus scan 2014. All data is encrypted. The restricted dissemination of the data obtained in this study is discussed in the Consent for Procedure section of the Bright Facets Patient Questionnaire. The information obtained in this study however, may be used for statistical analysis or scientific purposes with the patient's right to privacy retained. The results of this study will appear in a thesis to be written by myself, in journal publications, and in presentations at conferences, and there will be no reference or

inference made to any individual or group that may identify the study participants. Written assurance that all information will be held in confidence, away from insurance carriers and adverse counsel, and will be released only with their written consent will help to mitigate a participant's tendency towards exaggeration.

Anonymous study code numbers (001 through 350) were assigned to each participant linking the Bright Facet Patient Questionnaire to their respective lumbar MR scan. The study code numbers were separate from the patient identification number assigned by each imaging facility. The table with assigned patient study code numbers and assigned codes was stored separately from all other study information in my office. I am the HIPAA compliance officer for my office, and have provided all study record information with the same level of confidentially and security as all other non-study related patient health information in my possession.

I have completed and submit an Institutional Review Board (IRB) application to an independent ethics committee approved by Walden University prior to beginning the data collection process. The purpose of the IRB is to monitor and review biomedical and behavioral research involving human research subjects to assure the rights and welfare of the participants have been protected and that sound and scientific standards have been maintained.

Summary

The purpose of this study was to explore the frequency of the BFS, a dependent variable, and its relationship to the covariates of BMI, DJD, race/ethnicity, gender, low

back pain, physical activity, and trauma, after adjusting for age. I invited a cohort of adult men and women to participate from a stream of symptomatic patients referred to one of three geographically separate MRI facilities for non-contrasted lumbar spine imaging. Successful participants have satisfied the inclusionary and exclusionary criteria, and provided anthropomorphic and historical data before undergoing non-contrasted magnetic resonance imaging of the lumbar spine. The minimal sample size for this investigation was determined using G*Power v. 3.0.10. A medium effect size of $h = .50$ using 350 participants produced a statistical power level of 99% for a two-tailed test. Prescreening of the finished images divided 350 completed lumbar examinations into 175 case and 175 control participant groups to comply with the nested case-control protocol. Two experienced musculoskeletal radiologists, acting as data collectors, reviewed the Training Program for Bright Facets Data Collection to insure uniformity in the recognition and grading of the BFS and DJD. Data collection instruments were completed by each data collector following the examination of each blinded lumbar MRI study and returned to myself for statistical analysis. OLR was the appropriate statistical test for this study because the dependent variable was ordinal and the aim of this study was to evaluate the relationship between the covariates and the dependent variable. If my assumptions are not met, binomial logistic regression will be used instead.

This investigation could contribute to the current body of knowledge related to low back pain. A previously unreported pathway between the causative physiological mechanism of the BFS and low back pain may exist to facilitate this association. An exploration of the relationships that exist between the BFS and its associations with the

covariates of race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration may lead to a better understanding of such a pathway.

Chapter 4: Results and Discussion

Introduction

The BFS has shown a statistically significant association with DJD and low back pain (Czervionke & Fenton, 2008; Yang & Yang, 2005;). Paradoxically, the BFS has also displayed a statistically significant association with patients with low BMI (Longmuir & Conley, 2008). This is unexpected, because increased age (Medsger & Masi, 1985; Sack, 1995) and obesity have both been considered strong predictors of DJD (Karnik & Kanekar, 2012; Sabharwal & Christelis, 2010). The low back pain associated with the BFS may belong to a different physiological pathway than the pain associated with DJD and by extension, its risk factors of advancing age and obesity. A previously unreported pathway between the causative physiological mechanism of the BFS and low back pain may exist that would clarify this association. I conducted an exploration of the relationships that exist between the BFS and its associations with the independent variables of age, race/ethnicity, physical activity, BMI, trauma, low back pain, and disc and facet degeneration, which may lead to a better understanding of such a pathway.

If such an alternate pathway did exist, it would contribute significantly to the body of knowledge of low back pain. The discovery of such a pathway could lead to the earlier detection of degenerative lumbar findings, resulting in the modification of treatment protocols for low back pain. The early detection of degenerative spinal disease could contribute to positive social change by reducing the pain and suffering related to low back pain. The physiology of bright facets may help account for gender, anthropometric and race disparities in low back pain. Considering the global prevalence

of low back pain, the direct and indirect health costs, and loss of productivity, an improved understanding of the pathophysiology of low back pain may lead to positive social change through a reduction in health care costs, decreased morbidity and improved quality of life.

Research Questions and Hypotheses

There are two research questions guiding this research. The questions including null and alternative hypothesis are:

Research Question 1

Is there an association between the dependent variable Bright Facet Sign and the independent variable degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and degenerative joint disease.

Research Question 2

Is there an association between the dependent variable Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age, and degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the BFS and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age, and degenerative joint disease.

I completed my data analysis and will discuss my results with a review of subject recruitment, data acquisition, and grading of the BFS, degenerative disc, and degenerative facet disease. I will discuss interexaminer agreement between data collectors and my use of Chronbach's alpha to determine final coefficients at each spinal level. I assembled the demographic characteristics of my subject cohort, and have listed them in table format. I have also produced descriptive statistics for all categorical and continuous variables. I have employed bivariate statistics to measure differences in means for the continuous variable, BFS, with the dichotomous variables of gender, history of recent trauma, and VAS at each of the spinal levels examined. I have performed three linear regressions by using the BFS as a scale variable to evaluate the relationships between BFS and the covariates established as significant based on the bivariate tests at each spinal level. I used Backwards Conditional Linear Regression to detect significant associations between the independent variables included in each model and the BFS at that spinal level. Finally, I used Logistic Regression to compute odds ratios, allowing me to estimate the likelihood of a BFS at each spinal level based on exposure.

Data Collection

I invited all patients who were referred for lumbar imaging to any of three magnetic resonance imaging facilities to participate in the study upon presentation to the facility, providing they satisfied the inclusion criteria, and MRI examination was not

medically contraindicated. In total, I reviewed 489 lumbar MRI studies to admit 350 examinations for interexaminer grading and statistical analysis. Twenty-two subjects were disqualified based on the presence of congenital block vertebrae (n = 4), diskitis (n = 2), osteolytic metastatic disease from an unknown primary (n = 5), surgical residuals from previous lumbar foraminotomy, interbody fusion, microdiskectomy, and vertebroplasty (n = 11). The remaining 117 MR examinations were all BFS-positive cases, and disregarded in an attempt to satisfy the nested case control protocol of 175 non-BFS cases. The relative paucity of non-BFS participants extended the time necessary for data collection from the original estimate of four weeks to a total of eight weeks. Patient participation was excellent, as relayed to me by the MR technologists, as only fourteen presenting individuals declined to participate in the study.

Discrepancies in body weight were commonplace when a copy of the patients' driver's license and their response on the introductory patient questionnaire were compared with the measured results obtained by the technologist in the dressing area of the MRI suite. Driver's License and questionnaire weights were frequently lower, owing to the extended time over which a state driver's license remains valid, and perhaps personal vanity. For purposes of computing BMI, the weight obtained using a calibrated Healthometer® Physician Beam Scale the day of the examination was used. Reported and actual height measurements were consistently similar. None of the participants refused to self-identify themselves by gender or race/ethnicity.

I provided blinded MRI cases were provided electronically to two experienced musculoskeletal radiologists functioning as data collectors. After completing the Training

Program for Bright Facet Sign Data Collection, they began the process of reporting and grading the presence or absence of the BFS, degenerative disc, and degenerative facet disease. Subject-specific information and the data collectors' findings relating to the presence and grading of the dependent variable, and grading of the independent variables of disc and facet degeneration were placed in ordinal structure from data gathered from the Bright Facets Worksheet. All numerical values were formalized in Microsoft Excel® and imported into SPSS®, an integrated statistical software package that provides data analysis and management.

Results

Categorical Variables

Descriptive statistics were assembled using SPSS® to summarize the characteristics of the categorical variables, and organize them in a manageable form. For the independent variables of DDD and DFD, individual responses were summarized at each of the three lumbar spinal levels to correspond with the established grading systems of Pfirrmann, (2001) and Grogan et al. (1997), respectively. Similarly, response categories for gender, occupational-based activity, race/ethnicity, pain duration, and nature of trauma were provided in accordance with the possible choices on the Bright Facets Worksheet provided to the data collectors. I calculated frequencies and their associated percentages and provide them in Table 5.

Table 5

Descriptive Statistics (Categorical Variables)

Variable name	Response	Frequency	Percent
BFS L3/L4	Yes	191	54.6
BFS L4/L5	Yes	198	56.6
BFS L5/S1	Yes	165	47.1
Disc Disease (DDD)	1	33	9.4
L3/L4	2	72	20.6
	3	99	28.3
	4	107	30.6
	5	39	11.2
DDD L4/L5	1	30	8.6
	2	38	10.9
	3	9	19.7
	4	153	43.8
	5	60	17.2
DDD L5/S1	1	32	9.1
	2	36	10.3
	3	48	13.8
	4	110	31.5
	5	124	35.4
Facet Joint Disease	1	130	37.1
(DFD) L3/L4	2	169	48.3
	3	45	12.9
	4	6	1.7
Facet Joint Disease	1	86	24.6
(DFD) L4/L5	2	165	47.1

table continues

Variable name	Response	Frequency	Percent
	3	84	24
	4	15	4.3
DFD L5/S1	1	72	20.6
	2	201	57.4
	3	62	17.7
	4	14	4.0
Gender	Male	192	54.9
Occupation-based	Very active	85	24.3
Activity Level	Active	83	23.7
	Mostly sedentary	54	15.4
	Sedentary	21	6
	Unemployed	30	8.6
	Retired	46	13.1
	Disabled	8	2.3
Race/Ethnicity	White	299	85.4
	Black	14	4
	Hispanic	18	5.4
Pain Duration	< 1 year	200	57.1
	1 year	38	10.9
	1-2 years	27	7.7
	2-5 years	44	12.6
	>5 years	41	11.7
Trauma (<12 mo)	Yes	90	25.7
Nature	Unknown	242	69.2
	Lifting	29	8.3
	MVC	19	5.4
	Slip and Fall	19	5.4
	Other	41	11.7

For ease of reporting, the frequency of a BFS was expressed as a function of the number of affected individuals in the study and was calculated as a percentage of the total number of study participants (n = 350). For example, 198 individuals (56.6%) were determined to have a BFS at the L4/L5 level, making this the most common level for a BFS to occur. The BFS was slightly less common at the L3/L4 (54.5%) level and least common at the L5/S1 (47.1%) level.

Degenerative disc disease was present at all three spinal levels, and identified in all 350 participants, at various grades, at the L3/L4 and L5/S1 levels. Two hundred and ninety individuals were diagnosed with DDD at the L4/L5 level. Grade IV DDD was most common at the L3/L4 (30.6% of individuals) and L4/L5 (43.8%) levels, while the most advanced stage, grade V, was most commonly observed at L5/S1(35.49%). Degenerative facet disease was common at each lumbar level, and recorded in 350 subjects at the L3/L4 and L4/L5 levels, and at the L5/S1 level in 349 individuals. Grade2 facet degeneration was by far the most common of DFD grades at each spinal level, representing 48.3%, 47.1% and 57.4% of all cases at the L3/L4, L4/L5 and L5/S1 levels, respectively.

In terms of job-related activity, most subjects (58.0%) considered themselves as *very active*, or *active*, while 21.4% self-identified at *sedentary* or *mostly sedentary*. In terms of race/ethnicity, an overwhelming majority (85.4%) of participants were white. Fifty-five percent of individuals participating in the study were male, and 57.1%

experienced low back pain for less than a year immediately prior to their MRI examination. Most could not identify the nature of their low back injury.

Continuous Variables

Mean values and standard deviations were calculated for each of the three continuous variables, age, BMI, and pain VAS, and are presented in Table 6.

Table 6

Descriptive Statistics (Continuous Variables)

Variable name	Mean	Standard deviation
Age (Years)	49.36	15.64
BMI	29.65	6.83
Pain VAS	5.59	1.83

The mean age of study subjects (n = 350) was 49.36 ± 15.64 years, placing the average participant in the middle-years of life. This is reasonably congruent with the reported occupation-based activity levels of very active and active. The mean BMI (n = 350) was 29.65 ± 6.83 placing the average subject high in the overweight (25.0 - 29.9) category according to the WHO (2013a) classification of obesity. Pain, rated on a Visual Analogue Scale of 1-10 for subjects (n = 350) gave a mean value of 5.59 ± 1.83, very close to midline of the index.

Interexaminer Agreement

Cronbach's alpha is a measure of internal consistency. Values were computed for both examiners using each of the six pairs of facets joints for the BFS and DFD, while the three spinal levels were used to grade for the presence of DDD. These values are reported in Table 7.

Table 7

Inter-examiner Agreement Between the Two Data Collectors (n = 350)

Observation	Location	Cronbach's alpha
BFS	Left L3/L4	.996
	Right L3/L4	.988
	Left L4/L5	.988
	Right L4/L5	.978
	Left L5/S1	.994
	Right L5/S1	.986
Disc Disease (DDD)	L3/L4	.997
	L4/L5	.991
	L5/S1	.988
Facet Joint Disease	Left L3/L4	.972
(DFD)	Right L3/L4	.942
	Left L4/L5	.984
	Right L4/L5	.918
	Left L5/S1	.958
	Right L5/S1	.939

Interexaminer agreement at all spinal levels, for each of the three categorical variables of BFS, DDD, and DFD $\geq .9$. Kline (2000) reports $\alpha \geq 0.9$ as excellent (High-stakes testing). Due to the high level of agreement between the two raters, the values

assigned for each observation were combined for statistical analysis. Where there was discordance, the more conservative observation was retained. The high amount of agreement indicates that we can reject the possibility that the examiners are making their determinations on the presence or absence, and grade of BFS, DDD and DFD by random chance.

Continuous to Categorized Variables

To increase the power for Research Question 2, I combined the continuous independent and confounder variables into categories. This reduced the number of cells needed for the logistic regression and increased the power to detect associations if they exist. I divided age into four categories based on the physiological processes involved with low back pain. I also divided BMI using established WHO (2013a) categories. Pain is a very subjective measure and as such, I subdivided VAS into only two categories representing low and high intensity. These are shown below in Table 8.

Table 8

Continuous Variables Converted to Categorized Variables for Logistic Regressio.

Variable name	New name	Category number	Range	Frequency (percent)
Age (Months)	Age_Cat	1	< 30	50 (4.3)
		2	31-50	121 (34.6)
		3	51-65	133 (38)
		4	> 65	46 (13.1)
BMI	BMI_Cat	1	< 18.5	24 (6.9)
		2	18.5-24.9	73 (20.9)

table continues

Variable name	New name	Category number	Range	Frequency (percent)
		3	25.0-29.9	118 (33.7)
		4	30.0-34.9	69 (9.7)
		5	>35.0	66 (18.9)
Pain VAS	VAS_Cat	1	≤ 5	153 (43.7)
		2	>5	197 (56.3)

Bivariate Statistics

I used the Chi Square test statistic to determine statistically significant relationships between the dependent variable, BFS, coded as a binomial, and each of the independent variables I collected. The Chi Square test statistics and their confidence intervals for each spinal level are presented in tables 9, 10, and 11.

Table 9

Chi Square Test Results at Spinal Level L3/L4

Independent variable	Chi-square statistic	df	Statistical significance
Gender	9.058	1	.003
OCC	10.063	7	.185
Race	2.721	2	.257
Pain Duration	4.405	4	.354
Trauma	1.44	1	.230
Nature of Injury	7.941	4	.094
Age_Cat	8.248	3	.041
BMI_Cat	19.414	4	.001

table continues

Independent variable	Chi-square statistic	df	Statistical significance
VAS_Cat	.572	1	.449
DDD	6.068	8	.640
DFD	17.854	11	.085

At the L3/L4 spinal level Chi Square suggests statistical significance between the variables of Gender (p = .003), BMI_Cat (p = .001), Nature of injury (p = .094), DFD (p = .085), and Age_Cat (p = .041); and the BFS. A small p-value provides evidence against the null hypothesis and decreases the probability of a type 1 error. The Chi Square test statistic and associated p-value indicates the existence, but not the magnitude, of an association. The OR produced by the logistic regression will suggest the magnitude of any significant associations.

Table 10

Chi Square Test Results at Spinal Level L4/L5

Independent Variable	Chi Square statistic	df	Statistical Significance
Gender	.202	1	.653
OCC	8.441	7	.295
Race	1.930	2	.381
Pain Duration	11.711	4	.02
Trauma	2.255	1	.133
Nature of Injury	4.975	4	.290
Age_Cat	1.149	3	.765

table continues

Independent Variable	Chi Square statistic	df	Statistical Significance
BMI_Cat	23.212	4	<.001
VAS_Cat	.114	1	.735
DDD	3.650	7	.819
DFD	49.201	13	<.001

At the L4/L5 spinal level, I found statistically significant associations between BFS and the variables of BMI_Cat ($p < .001$), DFD ($p < .001$), Duration of Pain ($p = .02$).

Table 11

Chi Square Test Results at Spinal Level L5/S1

Independent Variable	Chi Square statistic	df	Statistical Significance
Gender	.002	1	.961
OCC	7.631	7	.366
Race	1.299	2	.522
Pain Duration	3.656	4	.455
Trauma	1.863	1	.172
Nature of Injury	8.962	4	.062
Age_Cat	1.909	3	.591
BMI_Cat	19.423	4	.001
VAS_Cat	1.750	1	.186
DDD	7.313	7	.397
DFD	21.719	14	.085

At the L5/S1 spinal level statistical significance between the variables of BMI_Cat (p = .001), Nature of Injury (p = .062), and DFD (p = .085) and BFS are suggested.

Research Question 1

Is there an association between the dependent variable Bright Facet Sign and the independent variable degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and degenerative joint disease.

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and degenerative joint disease.

To answer Research Question 1, I used Spearman's Rho, a nonparametric measure of statistical dependence, to measure correlations between ratings of BFS and DDD and DFD at each spinal level. Spearman's Rho was used because the assigned ranks are not normally distributed and therefore Pearson's r was not appropriate. As a non-parametric test, Spearman's Rho does not require the assumption of normality. My results appear in Table 12.

Table 12

Spearman's Rho BFS, DDD, and DFD at each Spinal Level

Spine Level	BFSL and DDD (*p* Value)	BFSR and DDD (*p* Value)	BFSL and DFDL (*p* Value)	BFSR and DFDR (*p* Value)	DDD and DFDL (*p* Value)	DDD and DFDR (*p* Value)
L3-L4	.092	.012	-.099	-.102	.286	.411
	(.085)	(.828)	(.064)	(.056)	(<.001)	(<.001)
L4-L5	-.036	-.048	-.277	-.213	.215	.196
	(.498)	(.368)	(<.001)	(<.001)	(<.001)	(<.001)
L5-S1	-.030	.022	-.092	-.145	.334	.298
	(.572)	(.684)	(.084)	(.006)	(<.001)	(<.001)

Negative values indicate inverse relationships exist between the BFS and DFD at the left and right facet joints for all three spinal levels. Inverse relationships also occur between the BFS on both the left and right sides and DDD at the L4/L5 level; and the BFS on the left side at L5/S1 and DDD. In practical terms, this means that as the grading of the observed degenerative change increases, the grading of the observed BFS decreases. Computed p-values indicate these inverse relationships are significant at the L4/L5 facets, bilaterally, and at the right L5/S1 facet joint. I was able to reject the null hypothesis of no relationship between BFS and DDD. Significant relationships occur at all three spinal levels between the association of DDD and DFD. This indicates that as the grade of DDD increases, so does the grade of DFD at the same spinal level. With DDD and DFD I was able to reject the null hypothesis. No association was identified

between the BFS and DDD at any spinal level. Therefore, I was unable to reject the null hypothesis of a correlation between BFS and DDD.

Research Question 2

Is there an association between the dependent variable Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease?

Null hypothesis (H_{01}): There is no association between the Bright Facet Sign and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease?

Alternate hypothesis (H_{A1}): There is an association between the Bright Facet Sign and the independent variables ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

The statistical test that I proposed to use to answer this research question was Ordinal Logistic Regression. One of the assumptions required by Ordinal Logistic Regression is that the difference between ranks must be equal. To test this assumption, I used the Test of Parallel Lines. The results of this test were a Chi Square test statistic of 119.614, with 25 Degrees of Freedom (Df) and a significance less than .001. The null hypothesis for this test states that the location parameters (slope coefficients) are the same across response categories. The significance of my test results caused me to reject this null hypothesis and recognize that the assumptions required by Ordinal Logistic Regression were not met.

The large number of independent variables and the relatively small study populations resulted in too many empty cells. Therefore, I decided that the best approach to answer this research question was Binary Logistic Regression.

I compressed the BFS data into a bivariate variable, using yes or no to indicate the presence of BFS, and used logistic regression to model associations at each spinal level. While this eliminated my ability to consider a dose effect related to the ranking of BFS, it did allow me to compute the OR for each of the variables I found significant ($p < .10$) at the bivariate level, which I could not have done using Ordinal Logistic Regression or Nominal Logistic Regression. The independent variables included in the model for each spinal level are summarized in Table 13.

Table 13

Significant Variables Based on Bivariate Statistics

L3/L4	L4/L5	L5/S1
Gender	Pain Duration	Nature of Injury
Nature of Injury	BMI_Cat	BMI_Cat
Age_Cat	Facet Joint Disease	Facet Joint Disease
BMI_Cat		
Facet Joint Disease		

I used Backwards Conditional Logistic Regression to detect significant associations, if they existed between the independent variables included in each model and the presence of BFS at that spinal level. The significant associations ($p < 0.5$) at each level based on inclusion in the final model are presented in Tables 14, 15, and 16.

Table 14

Binary Logistic Regression Results L3/L4

Variable	Response	B	Exp(B)	Significance
Gender	Female	.932	2.541	<.001
BMI_Cat	Indicator 18.5-24.9			
	< 18.5	-1.319	.267	.012
	25.0-29.9	-.980	.375	.003
	30.0-34.9	.162	1.176	.672
	> 35.0	-.726	.484	.058
Age_Cat	Indicator < 30			
	31-50	.007	.993	.989
	51-65	-.115	.892	.767
	> 65	.786	2.195	.038
DFD	1			
	2	-.782	.458	.004
	3	-.666	.514	.106
	4	-.322	.725	.741

Female participants were 2.5-times more likely to have a BFS at the L3/L4 level than males. With respect to BMI_Cat, Age_Cat, and DFD "1", negative B values indicated a decreased likelihood of having a BFS at the L3/L4 level. Conversely, positive B values indicated an increased likelihood of having a BFS.

Participants with BMIs less than 18.5, and 25.0-29.9 were significantly less likely to have a BFS than those between 18.5 and 24.9. There was no difference in the likelihood of BFS for those in the 18.5-24.9 and 30-34.9 categories. I found no significant difference between 18.5-24.9 and > 35, perhaps due to a small sample size for the >35

group. Participants below the age of 30 were less likely to have a BFS than those over 65 years of age. Finally, subjects with a DFD of grade 2 were just under half as likely to have a BFS, when compared with grade 1. This supports the inverse relationship at L3/L4 between DFD and BFS that was determined using Spearman's Rho..

Table 15

Binary Logistic Regression Results L4/L5

Variable	Response	B	Exp(B)	Significance
Pain Duration	< 1year			
	1 year	-.185	.831	.662
	1 to 2 years	-.435	.647	.336
	2 to 5 years	-.106	.899	.779
	Other	-1.146	.317	.005
BMI_Cat	Indicator 18.5-24.9			
	< 18.5	-2.405	.090	<.001
	25.0-29.9	-.911	.402	.011
	30.0-34.9	-.748	.474	.064
	> 35.0	-.934	.393	.024
DFD	"1"			
	2	.226	1.254	.455
	3	-.480	.228	<.001
	4	.859	2.361	.219

At the L4/L5 level, those subjects who reported a Pain Duration, response of "other" were less likely to have a BFS than those whose pain duration was less than 1 year. Participants with BMIs less than 18.5, and between 25.0-29.9 are significantly less

likely to have a BFS than those between 18.5 and 24.9. The difference in the BMI_Cat between L3/L4 and L4/L5 is that at L4/L5, greater than 35 was less likely to have a BFS when compared to those in the 18.5-24.9 category. Those participants with grade 3 degeneration at this spinal level were one-fourth as likely to have a BFS than those with grade 1 degeneration.

Table 16

Binary Logistic Regression Results L5/S1

Variable	Response	B	Exp(B)	Significance
BMI_Cat	Indicator 18.5-24.9			
	< 18.5	1.969	.140	.001
	25.0-29.9	-.737	.478	.015
	30.0-34.9	.021	1.022	.950
	> 35.0	-.604	.547	.079

The only significant independent variable at the L5/S1 level is BMI_Cat. The interpretation of these results is the same as that for L3/L4, that is, individuals with BMIs less than 18.5 and 25-29.9 were significantly less likely to have a BFS than those between 18.5 and 24.9.

At each of the spinal levels, the final logistic regression model predicted between 60- 65% of the dependent variable correctly. The Chi Square statistic was less than .05, which indicates to reject the null hypothesis that the observed values are not different from the predicted values. While the results can be used to determine the odds ratios and significance of each of the independent variables in the presence of the others, the models

cannot be used to predict the presence of BFS based on the independent variables included in this study.

My second research question asked if there is an association between the dependent variable BFS and the independent variables of physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease. With respect to the associated null hypothesis, I rejected it, as there were significant relationships, though they differed at each spinal level. These were expressed by the Appendixs in tables 14, 15 and 16.

Summary

I invited all patients who were referred to any of three imaging facilities for magnetic resonance imaging of the lumbar spine to participate in my study. Individuals that satisfied the inclusion criteria, did not meet my exclusionary criteria, and among whom MRI examination was not medically contraindicated became research subjects. Twenty-two individuals were disqualified based on the presence of various systemic diseases, or congenital anomalies. Data collection lasted for eight weeks. Patient participation was excellent, as only fourteen individuals declined to become study subjects. Three hundred and fifty compliant subjects participated in the research project, 175 with, and 175 without a BFS. The 350 MRI cases were blinded and provided electronically to two musculoskeletal radiologists acting as data collectors. I organized and analyzed all numerical values.

Descriptive statistics for categorical and continuous variables were calculated and organized into Tables 5 and 6. The former were organized by frequency and presented

the percentage of the total number of participants (n=350); the latter were expressed by mean and standard deviation. Cronbach's alpha was used to determine inter-examiner agreement between the two data collectors. Values were computed for both examiners using each of the six pairs of facets joints for the BFS and DFD, while the three spinal levels were used to grade for the presence of DDD. These values are reported in Table 7. An inter-examiner agreement of $\alpha \geq 0.9$ was categorized as excellent (Kline, 2000). The high level of agreement justified the combining of observations between examiners. To increase the power of the logistic regression to answer Research Question 2, I converted the continuous independent to categorized variables. The Chi Square test statistic was used to determine statistically significant relationships between the dependent variable BFS, and each of the independent variables I collected. Significance varied by spinal level. Relationships between gender, Age_Cat, BMI_Cat, DFD, and BFS were found at L3/L4; relationships between Pain Duration, BMI_Cat, DFD and BFS were found at L4/L5; and relationships between Nature of Injury, BMI_Cat, DFD and BFS at L5/S1.

There were two research questions guiding this research. The null hypothesis for the first research question poses that there are no associations between the dependent variable Bright Facet Sign and the independent variables representing degenerative joint disease. I was able to reject that null hypothesis, as I found significant associations between the Bright Facet Sign and degenerative joint disease. Spearman's Rho found inverse relationships between the grade of DFD and the grade of BFS at all three lumbar levels. Further inverse relationships were found between the BFS at L4/L5 and DDD, and the BFS at the left L5/S1 facets and DDD. Of these, significance was associated

bilaterally with the BFS and DFD at L4/L5, and on the right side with BFS and DFD at L5/S1.

The null hypothesis for the second research question poses that there are no associations between the Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease. The statistical test that I used to answer this research question was Ordinal Linear Regression. One of the assumptions required by Ordinal Linear Regression is that the difference between ranks must be equal. To test this assumption, I used the Test of Parallel Lines. The results of this test were a Chi Square test statistic of 119.614, with 25 Degrees of Freedom and a significance of less than .001. The null hypothesis for this test states that the location parameters (slope coefficients) are the same across response categories. The significance of my test results caused me to reject this null hypothesis and recognize that the assumptions required by Ordinal Linear Regression were not met. The large number of independent variables and the relatively small study populations resulted in too many empty cells. Therefore, I determined that the best approach to answer this research question was Binary Logistic Regression.

Logistic regression was performed at all three lumbar spinal levels. I was able to reject the null hypothesis at each of these levels, though the final models were different. There was an association between the dependent variable Bright Facet Sign and the independent variables of gender, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease. The relationships are different at each spinal level and are presented as the Appendixs in Tables 14, 15, and 16.

At L3/L4 females were determined more likely than males to have a BFS. Individuals over 65 years of age were also more likely to have a BFS than those under 30. Also, individuals with BMIs less than 18.5 and 25-29.9 were significantly less likely to have a FMS than those between 18.5 and 24.9. Individuals with grade 2 DFD were less likely to have a BFS than those with grade 1 DFD. This is supported by Spearman's Rho as an example of the inverse relationship that exists between BFS and DFD at all three spinal levels. At L4/L5 individuals with a Pain Duration response of "other" were less likely to have a BFS than those whose pain duration was less than 1 year. Again, BMIs less than 18.5 and 25-29.9 are significantly less likely to have a BFS than those between 18.5 and 24.9. Participants with a DFD of grade 3 were one-fourth as likely to have a BFS as those with grade 1 facet degeneration. The only significant independent variable at the L5/S1 is BMI. There was no association between the BFS and race/ethnicity, or DDD.

At each of the spinal levels, the final logistic regression model predicted between 60- 65% of the dependent variable correctly. The Chi Square statistic was less than .05, which indicates to reject the null hypothesis that the observed values are not different from the predicted values. This indicates that while the results can be used to determine the odds ratios and significance of each of the independent variables in the presence of the others, the models cannot be used to predict the presence of BFS based on the independent variables included in this study.

In Chapter 5, I discuss the significance of my results and reconcile them with the existing literature. Confounding is expanded upon, and suggestions for improvement are

made. I present recommendations for further study. Finally, I discuss the significance of my findings in terms of its potential to initiate positive social change.

Chapter 5: Discussion, Conclusions, and Recommendations

Introduction

The bright facet appearance is not well understood by the radiological community and has been poorly represented in the literature (Longmuir & Conley, 2008). Anecdotal discussions among colleagues attributed the bright facet appearance to synovitis, the inflammatory first step in a degenerative process known as osteoarthritis. The extant literature includes a description, definition, and grading convention for the BFS (Czervionke & Fenton, 2008; Longmuir & Conley; Yang & Yang, 2005).

While it was established in 2008 as a diagnostic imaging finding, the etiology of the BFS remains unclear (Longmuir & Conley, 2008). The intent of this research was to determine the magnitude and significance, if any, between independent variables and the existence of the BFS. Previous findings suggested shared associations with low back pain and DJD (Czervionke & Fenton, 2008; Yang & Yang, 2005). The BFS has previously displayed a statistically significant association with low BMI (Longmuir & Conley). This is unexpected, as increased age (Medsger & Masi, 1985; Sack, 1995) and obesity have both been considered strong predictors of DJD (Karnik & Kanekar, 2012; Sabharwal & Christelis, 2010). It is possible that the low back pain associated with the BFS may be part of a different physiological pathway than the pain associated with DJD.

In this study, I explored the relationships that exist between the BFS and the independent variables of age, race/ethnicity, physical activity, BMI, trauma, low back

pain, and disc and facet degeneration. These relationships may lead to an improved understanding of the physiological pain pathway associated with the BFS. If such an alternate pathway does exist, it would contribute significantly to the body of knowledge of low back pain. The discovery of such a pathway could lead to the earlier detection of degenerative lumbar findings, resulting in the modification of treatment protocols for low back pain. The early detection of degenerative spinal disease could contribute to positive social change by reducing the pain and suffering associated with low back pain.

My discussion begins with a brief overview of my research methodology and most notable findings. This is followed by an in-depth review of study demographics and independent variables as they pertain to the study population and the existing literature. I then discuss interexaminer agreement and the significant associations between the BFS and independent variable of degenerative joint disease that respond to my first research question. Thereafter is my review of the BFS and its varied associations with the independent variables that comprise my second research question. This is followed by a summary of bias and the limitations of my study. Finally, I consider the implications for social change and close with my research conclusions.

Interpretation of the Findings

I used a nested case-control study with 350 lumbar MRI studies from low back pain patients to help determine if there was an association between the dependent variable BFS and the independent variable, degenerative joint disease. These same cases and controls were then used to determine the magnitude and significance of associations between the binomial dependent variable BFS and the independent variables of

race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease. Inverse relationships were found between the magnitude of the BFS and the magnitude of DFD at all three lumbar levels. Further, individuals with BMIs in the underweight and overweight ranges were found significantly less likely to have a BFS than those participants of normal weight. Gender and age were found to have an association with the BFS, however confined to only one spinal level. There was no association between the BFS and race/ethnicity, or a BFS and the presence of DDD at the same spinal level.

Demographics

Race/ethnicity and age. I computed and organized descriptive statistics for all categorical and continuous variables. I found my study was heavily skewed towards White subjects (85.4%) with much smaller numbers of African American (5.4%) and Hispanic (4%) participants. Similarly, the study of Longmuir and Conley (2008) was heavily weighted towards White participants (75%). The predominant number of White subjects in the present study may reflect the demographics of the communities in which the imaging centers are located, the availability of insurance coverage, regional economic factors, referral patterns among local healthcare practitioners, or varied patient compliance. My use of three imaging facilities in non-contiguous geographic locations was intended to help incorporate more ethnic and racial diversity among study participants.

The mean age of study subjects (n = 350) in my investigation was 49.4 ± 15.64 years, placing the average participant in the middle-years of life. This is reasonably

congruent with the reported occupation-based activity levels of very active and active. This is also consistent with the Longmuir and Conley (2008) study cohort (n = 105) with an age range of 18-84 years, and a mean age of 46.51 years ± 16.01. This coincides with the findings of Loney and Stratford (1999) in their review of 18 low back pain studies which estimate an increased prevalence of low back pain among individuals between 40-60 years of age. Large variations in community prevalence rates of low back pain are common, and may be attributed to a lack of standardization in the definitions of both pain duration and severity. Yang and Yang (2005) excluded study participants 25 years of age and older to help decrease the influence age-related degeneration may have on their findings. Participant ages were not reported in the 209 patient study of Czervionke and Fenton (2008). In my analysis of the factors associated with BFS, I have included age as a potential confounder.

Trauma and pain. Only 25.7% of subjects reported an incident of lumbar spinal trauma within the past 12 months, while 57.1% reported their low back pain to be of less than 12 months in duration. This would indicate most participants in this study seeking care for low back pain had a recent onset of low back pain, which was non-traumatic in origin. This is consistent with the Longmuir and Conley (2008) study in which 29.5% of participants reported low back trauma within the previous 12 months, and 53.3% reported their low back pain to be of less than 12 months in duration.

For most patients, low back pain symptoms are nonspecific, and generally self-limiting. Many individuals treat themselves without seeking medical advice (Atlas & Deyo, 2001). Patients who seek medical care for low back pain are often dissatisfied with

their care and recommended treatment (Cherkin, Deyo, & Berg, 1991). Many patients feel there is little they can do to prevent an episode of acute low back pain from becoming chronic in nature (Cherkin, Deyo, Berg, Bergman, & Lishner, 1991). Additionally, there is a sense of frustration among primary care physicians with their inability to meet the needs of patients with low back pain (Cherkin, Deyo, Berg, Bergman, & Lishner, 1991).This may help account for the small number of participants in this study that sought care following a traumatic episode of low back trauma, and why only approximately half sought care for symptoms that had lasted for greater than 12 months.

Almost half the participants in this investigation had low back pain that can be considered chronic in nature. The number of previous exacerbations of low back pain, the number and specialty of healthcare practitioners consulted, the number and type of diagnostic imaging studies ordered, diagnoses rendered, successful patient outcomes, and patient satisfaction are all beyond the scope of this investigation. McPhillips-Tangum, Cherkin, Rhodes, and Markham (1998) asserted that patients with low back pain repeatedly seek care from a variety of healthcare practitioners. This is not, they suggest, because a previous therapy was particularly successful, but because previous care was unable to determine the cause of their pain, or answer fundamental questions about the value of their diagnostic tests and need for interprofessional referral.

The severity of low back pain, rated in my study on a Visual Analogue Scale of 1-10 for subjects gave a mean value of 5.59 ± 1.83, very close to midline of the index. The perception of pain, its intensity, and persistence are all subjective in nature and open to

individual interpretation (Koyama, McHaffie, Laurienti, & Coghill, 2004). A graded classification system of pain, common in medical practice and useful as a measure of severity, may not discriminate among the highest levels of pain severity as well as measures of disability, affective distress and loss of life control (Von Korff, Ormel, Keefe, & Dworkin, 1992). In this case, the midline mean value of VAS Pain was equivocal. Omitting Pain VAS as an independent variable from my bivariate analysis could have caused me to commit a type II error, by failing to detect an effect that is present. For this reason, it was included in my analysis as a binomial variable.

BMI. The mean BMI (n = 350) of my study subjects was 29.65 ± 6.83, placing the average subject high in the overweight (25.0 - 29.9) category according to the WHO (2013a) classification of obesity. In the Longmuir and Conley (2008) study, the mean BMI (n = 105) was 29.67±3.42, also placing participants high in the overweight (25.0-29.9) category. According to the CDC (2014), 34.9% of. adults in the United States are obese (> 30.0). Non-Hispanic blacks have the highest age-adjusted rates of obesity (47.8%), followed by Hispanics (42.5%), non-Hispanic whites (32.6%), and non-Hispanic Asians (10.8%). In the year 2014, the average United States male and female were was found to have BMIs of 29.0, and 28.7, respectively (CDC).

Although BMI is a commonly-employed and useful ratio variable, its use is limited. Individuals with a muscular build are likely to score a higher BMI than the less-muscular participants, placing them in the overweight category despite a healthy body mass. It is unclear what percentage of participants in the current study were sufficiently muscular to artificially increase their BMI, however my study mean of 29.65 closely

approximates the national average. This suggests that from a BMI perspective, my study cohort is representative of a national mean.

BFS. The frequency distribution of the BFS for the entire study cohort was determined to be 47.1% at L5/S1, 54.6% at L3/L4, and 56.6% at L4/L5. This maintains the increasing order of frequency established by Longmuir and Conley (2008) of 40.5% at L5/S1, 56.5% at L3/L4 and 66.5% at L4/L5. In both studies, the smallest and largest numbers of the BFS were found at the L5/S1 and L4/L5 levels, respectively. In the current study, 198 individuals (56.6%) were determined to have a BFS. This compares with 54.4% of symptomatic individuals in the Longmuir and Conley study, 41% in the Czervionke and Fenton (2008) investigation, and 18% in the research of Yang and Yang (2005).

Czervionke and Fenton (2008) used the addition of a fat saturation MRI sequence (n = 209) to evaluate the BFS, and used a working definition of the BFS that included extracapsular findings. Yang and Yang (2005) limited their study to individuals (n = 43) below 25 years of age. Perhaps the BFS demographics of the present study would have changed with the addition of some form of fat suppression imaging. Both the Czervionke and Fenton and Yang and Yang studies referred to the BFS as synovitis, and associated its appearance with low back pain.

Inter-examiner Agreement

I computed t agreement of the MRI evaluators on the grading of the BFS, DDD and DFD utilizing Cronbach's alpha, and determined it to be $\alpha \geq 0.918$, which is excellent, according to Kline (2000). The high agreement between radiologists and their

collective abilities to evaluate for the presence of degenerative disc and degenerative facet disease adds rigor to the respective grading systems of Pfirrmann et al. (2001) and Grogan, et al. (1997) used in the evaluation of these independent variables. High inter-examiner agreement for the grading of the BFS was significant in this study ($\alpha \geq .978$) and in the investigation performed by Longmuir and Conley (2008; $\kappa \geq .80$). This adds support to both the MRI appearance of the BFS, and the grading system proposed by Longmuir and Conley and reviewed by Marcondes César et al. (2011).

This high interexaminer agreement also supports the conceptual framework for this study, which was based on the physiologic mechanisms associated with the BFS and their meaning as it relates to low back pain. Diagnostic imaging modalities are used to identify abnormal findings, which may be attributed to normal variation or disease. Alterations in structure and function help to explain subjective low back pain. The recognition and high interexaminer agreement on the location, appearance, and grading of such alterations as the BFS underscores the ability of providers to reliably and objectively identify this novel MRI finding and by extension, its associated symptomatology and unique pathway.

Research Question 1

My first research question was about the association between the dependent variable, the Bright Facet Sign, and the independent variable of degenerative joint disease. Kirkaldy-Willis and Farfan (1983) asserted that degenerative facet disease can be divided into five consecutive stages of development and is a significant cause of the local and radiating pain known as the facet syndrome. Early in the degenerative facet

process, synovitis occurs and is marked by hyperemia and an inflammatory cell infiltrate within the apophyseal joint capsule. Synovitis, marked by hyperemia and inflammatory infiltrate within the synovium could account for the BFS seen on T2-weighted MR images.

Czervionke and Fenton (2008) and Yang and Yang (2005) believed so and refer to the BFS as synovitis. Because early lumbar facet degeneration is marked by such intra-articular changes, then a causal relationship between degenerative face disease and a bright facet response would be logical. In my study, Spearman's Rho, a non-parametric analogue of Pearson's correlation, demonstrated that as the magnitude of a BFS increased, the magnitude of facet diseased, at all lumbar facet joints on the left and right side, at each of the three spinal levels studied, decreased. This inverse relationship was significant at the left and right facets at L4/L5, and at L5/S1, on the right side only. This finding from my study is notably contrary to the conclusions of Kirkaldy-Willis and Farfan (1983) that as part of the degenerative cascade, the proliferation of degenerative synovitis is required as an early precursor to the BFS. My findings are also contrary to the conclusions of Czervionke and Fenton (2008), and Yang and Yang (2005) that an increased T2-weighted intra-articular signal represents facet arthropathy. Facet arthropathy, by the classic definition of Kirkaldy-Willis and Farfan (1983) cannot occur in the absence of synovitis; my findings suggest that the BFS does not require synovitis.

In the inter-examiner reliability study of Longmuir and Conley (2008), Fisher's exact test was employed to determine nonrandom associations between the categorical variables of bright facet response and degenerative disc and facet changes. In that study

the presence of DFD was recorded by the data collectors, but not graded. Degenerative disc disease was, however graded using the same scale advanced by Pfirrmann et al. (2001). Fisher's exact test was used by Longmuir and Conley instead of more traditional measures of association such as Chi Square due to the presence of empty cells in the matrices. Separate matrices were constructed for the two examiners. A Fisher's exact < .05 was considered statistically significant. Degenerative facet changes were reported by Longmuir and Conley at L5/S1 in 40% of subjects by Examiner 2 with BFSs noted in 58% of the subjects and by Examiner 1 at the right L3/L4 facets (Fisher's exact = 0.036) and in 64% of the subjects at the right L4/L5 facets (Fisher's exact = 0.004). Examiner 1 reported degenerative facets at 48% of subjects with at least some bright facet responses noted by Examiner 1 at the left L4/L5 facets in 68% of the subjects (Fisher's exact = 0.001) Additionally, Examiner 1 reported at least some degree of degenerative disc disease in 41% of subjects at L3/L4 with at least some degree of bright facet response noted by Examiner 2 at the right L5/S1 facet articulations in 41% of the subjects (Fisher's exact = 0.013). Just as with my present investigation, statistically significant inverse relationships were found by Longmuir and Conley between the BFS and degenerative disc or facet joint disease at the same level.

In this investigation, I found a significant and direct association between the presence of degenerative disc disease and degenerative facet disease at all three lumbar levels. As the magnitude of DDD increased, so did the magnitude of DFD. Since the intervertebral disc and facets are closely related, both physiologically and anatomically, degeneration affecting one will eventually affect the other (Bogduk, 1990). The temporal

direction of the relationship is not well documented. There is however, limited evidence to suggest that in general, the changes may first appear at the disc, and later progress to the facets. The working hypothesis suggests that increased loss of disc height leads to increased loading and subsequent degeneration of the facet joints. (Fujiwara et al. 1999; Fujiwara et al. 2000). Since an inverse relationship between the magnitude of the BFS and the magnitude of DFD at the same articulation was seen, it would follow that there is no positive association between the presence of a BFS and DDD at the same lumbar spinal level.

The framework for Research Question 1 was based on the literature demonstrating a potential mechanism of action for a relationship between BFS and low back pain. Longmuir and Conley (2008) showed the bright facet phenomenon to be a reliably recognizable MRI finding, sufficiently so, that it became known in the literature as the Bright Facet Sign. Further, Longmuir and Conley advanced a grading system for the BFS. Yang and Yang (2005) and Czervionke and Fenton (2008) have shown an association between low back pain and the BFS. In this study, I have demonstrated that the magnitude of the BFS is inversely proportional to DFD at the same level. This is a strong inverse relationship. I have also shown there is not a positive association between the presence of a BFS and DDD at the same lumbar spinal level. H_{01} was: There is no association between the BFS and degenerative joint disease. Therefore, there was sufficient statistical rigor to assert the strength of the inverse relationship between the BFS and DFD at the same level was not the result of chance alone. There was also sufficient statistical power to maintain the negative association between the presence of

the BFS and DDD was not the result of chance. Thus, the null hypothesis of independence between DJD and the presence of the BFS was rejected. This suggests the physiological pathway associated with low back pain, secondary to osteoarthritic change at the facet level, is different than the pathway responsible for the production of a BFS.

Research Question 2

My second research question focused on the association between the dependent variable Bright Facet Sign and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease. For this investigation, I considered BFS a binomial representing the presence or absence of the sign and not the magnitude as graded for Research Question 1. The approach I used, binary logistic regression, for modeling the relationships between my binomial dependent variable, BFS, and included independent variables ($p < .10$ at the bivariate level) allowed me to compute odds ratios allowing me to evaluate the individual associations in terms of direction, magnitude, and significance. The independent variables included in my linear regression model for each spinal level were summarized in Table 13 in chapter 4. Binary Logistic Regression suggested some similar, and some different associations between the BFS and my selection of independent variables at each of the spinal levels under investigation. There was no association between the BFS and race/ethnicity at any of the lumbar levels. Similarly, Longmuir and Conley (2008) also reported that the presence of the BFS was independent of ethnicity. This finding may have been obscured by the paucity of nonwhite subjects (25% of the total) in their cohort as well as my current subject cohort.

Spinal level L3/L4.

Age and gender. Participants were more likely to have a BFS at the L3/L4 level if their age was 65 years or greater (OR = .038). This is the only level at which age was found to have a significant relationship to the BFS. The relationship between DJD and age is complex. Age is a risk factor for DJD (Medsger & Masi, 1985), yet DJD is not necessarily a consequence of the aging process (Mankin, Brandt, & Shulman, 1986). It should be noted that Loney and Stratford (1999) in their review of 18 low back pain studies estimated an increased prevalence of low back pain among individuals between 40-60 years of age. This suggests low back pain is less common among patients in the 60 years and older group, the same demographic that are at a greater risk for DJD, yet have an increased likelihood of a BFS at the L3/L4 level. Age is known to influence the independent variables of physical activity and BMI (Consonni, Bertazzi, & Zocchetti, 2997). For these reasons, it is possible that the association between the BFS and age greater than 60 years at the L3/L4 level may be confounded by the combined effects of the independent variables of physical activity and BMI. Yang and Yang (2005) limited the age of their study subjects to below 25 years of age to limit the effect age had on the presence of the BFS.

Female patients were 2.54 times more likely than male participants (OR<.001) to have a BFS at the L3/L4 level. Gender was not determined to be associated with the BFS by Longmuir and Conley (2008) or Yang and Yang (2005). Radiographic signs do not discriminate between males and females. Exceptions occur when the sign is observed in an organ or anatomical structure not shared by both genders. Differences in gender do,

however, appear to affect the rate and extent of lumbar osteoarthritic changes (Fujiwara et al., 2000). The fact that spinal degenerative joint disease is more common among males than females of the same age (Harada, Okuizumi, Miyagi, & Genda, 1998) supports my conclusion that the BFS is independent of DFD at the L3/L4 level.

Body Mass Index. Participants with BMIs less than 18.5 and 25.0-29.9 are significantly less likely to have a BFS than those between 18.5 and 24.9. There is no difference in the likelihood of BFS for those in the 18.5-30-34.9 categories. The WHO (2013a) describes the 18.5-24.9 category, the BMI most predictive of a BFS at the L3/L4 spinal level as “normal" weight. This is especially significant in this investigation where the average participant has a BMI of 25.0-29.9, described as “overweight.”

The increased load-bearing on the lumbar facets generated by a high BMI would elevate intra-articular pressure and challenge the redistribution of forces across the joint surfaces. This, according to Kalichman, Guermazi, Li, and Hunter, (2009) would serve to accelerate the degenerative process throughout the lower lumbar spine. Yet it is the normal BMI participants in my study that appear predisposed to a BFS. Not only have I shown that the BFS has an inverse relationship with degenerative facet disease at all three levels, but the expected high BMI that would accompany the formation of degenerative synovitis had no association with the formation of a BFS. In their 2008 investigation, Longmuir and Conley constructed two-sample *t*-tests with equal variances. Subjects with a BFS were found to have a BMI of 28.97, whereas subjects without a BFS were found to have a mean BMI of 36.25. This represents a 25% difference. Patients without a BFS are significantly heavier than those with a BFS.

DFD. At the L3/L4 level I found a significant inverse association (OR = .004), between the binomial variable, BFS, and the categorical variable, DFD. This finding indicates that those with a DFD of Grade I were less likely to have the BFS than those with a DFD Grade of 2. The inverse direction of the association of BFS and DFD at this spinal level supports the inverse, though not significant, relationship between the magnitude of a BFS response and the magnitude of DFD suggested by Spearman's Rho, used to address Research Question 1 at spinal level L3/L4.

The traditional medical standard was to ground health and disease in the relationships that exist between host, agent, and environment. Known as the triangle of epidemiology, this model was fundamental to each of the health sciences. Although an appropriate foundation for communicable disease, this model neglected to acknowledge the dynamic interactions between social, behavioral, and biological factors (Pellmar, Brant, & Baird, 2002). Because lifestyle diseases have replaced infectious processes as the leading causes of morbidity and mortality in industrialized nations, a new model was developed to include pre-existing diseases, physical factors, ecological elements, and environmental causes (Kaplan, 2004). This new model, known as the advanced triangle of epidemiology, takes into consideration the classic components of the communicable disease model while embracing a broader field of contributory factors (Krieger, 2001). The concept of an infectious agent has been replaced by causative factors, and the host is instead represented by a group or population of individuals taking into account their individual and shared characteristics (Pellmar, Brant, & Baird). Each question in this

investigation is supported by the theoretical framework of the advanced epidemiologic triangle.

Spinal Level L4/L5.

Body Mass Index. The association of BMI and BFS at spinal level L4/L5 suggests that participants with a BMI within the normal range (18.5-24.9) were at a higher risk of having the BFS than those with lower BMI (<18.5) and higher BMI (< 30.0). The magnitude of the increased risk, based on the OR, varied from 2 (BMI 30 - 34.9) to 11 (BMI < 18.5) times the risk of the BFS for those with a normal BMI (18.5 - 24.9).

The intra-articular pressure of the facet joints, increased by the axial loading associated with an increased BMI would redistribute the increased load-bearing across the facet surfaces. Kalichman, Guermazi, Li, and Hunter, (2009) determined this would accelerate lower lumbar degenerative changes. However, in the current study, it was the subjects with normal BMIs that developed a BFS. These findings showed that the BFS had an inverse relationship with degenerative facet disease at L3/L4 andL4/L5. The high BMI that would be expected to associate with the formation of degenerative synovitis had no association with the formation of a BFS at L4/L5. This underscores the Longmuir and Conley (2008) conclusion where BFS subjects were found to have a BMI of 28.97, and subjects without a BFS were found to have a mean BMI of 36.25, representing a 25% difference. Participants in the Longmuir and Conley study without a bright facet response were significantly heavier than those with a BFS.

DFD. As with spinal level L3/L4, at spinal level L4/L5, I found a significant, though inverse, association (OR = .004), between the binomial variable, BFS, and the categorical variable, DFD. This finding suggests that those with a DFD of Grade 1 are less likely to have the BFS than those with a DFD Grade of 3. The inverse direction of the association of BFS and DFD at this spinal level supports the statistically significant inverse relationship between the magnitude of the BFS and the magnitude of the DFD suggested by Spearman's Rho in response to Research Question 1.

Both Yang and Yang (2005) and Czervionke and Fenton (2008) determined that the BFS of the lumbar spine indicates increased joint effusion, which usually results in low back pain. Czervionke and Fenton assert that there is a correlation between the location of the BFS and the site of the patient's pain. From their subject cohort of $n = 209$, a sample of 30 of the most recent patients was created who displayed a BFS that was both unilateral and limited to a single spinal level among whom, alternate chronic sources of pain such as disc displacement/derangement and central canal stenosis were eliminated. The side of symptoms was tested for correlation with the side on which the BFS was evident. All 30 subjects (100%) showed a unilateral BFS and reported back pain and/or extremity pain, and the pain was always on the same side as the MR signal abnormality.

Pain duration. Subjects were more three-times more likely (OR = .005) to have a BFS at the L4/L5 level if the duration of their low back pain was below one year. In the current study, 57.1% of subjects reported their low back pain to be of less than 12 months in duration. This would indicate most participants in this study seeking care for low back pain had a recent onset of low back pain. Duration of pain in association with the BFS is

not represented in the literature. Neither Yang and Yang (2005), nor Czervionke and Fenton (2008), both of whom associate low back pain with the BFS, addressed the duration of their subjects' symptoms.

The National Institute of Neurological Disorders and Stroke (2014) maintained that most low back pain is acute or short term in nature and persists a few days to a few weeks. Further, subacute low back pain has an average duration of 4 to 12 weeks, and is generally self-limiting. Approximately 20% of individuals with acute low back pain progress to chronic low back pain with symptoms at one year after initial onset. Pain of a short duration does not favor the chronic wear-and-tear process often used to help explain many of the manifestations of DJD. It does not, however, account for all the changes present in the intra-articular facet cartilage. It is the microenvironment of the articular cartilage that both instigates and drives the degenerative process (Hamerman, 1989). Low back pain of a short duration may subvert the time necessary for facet degeneration to occur. This may lend support to my assertion that the magnitude of the BFS and DFD are mutually exclusive.

Spinal level L5/S1.

Body Mass Index. The association of BMI and BFS at spinal level L5/S1 suggests that participants with a BMI within the normal range (18.5-24.9) are at a higher risk of having the BFS than those with lower BMI (< 18.5) and higher BMI (> 24.9). The WHO (2013a) describes the 18.5-24.9 category, the BMI most predictive of a BFS at all three lumbar spinal levels as “normal" weight. This is especially significant at L5/S1 where gravitational load bearing is at its greatest (Kalichman, Guermazi, Li, & Hunter,

2009). The average subject in the current study has a BMI of 25.0-29.9, described as "overweight." As described at the previous two spinal levels, I have shown that the BFS has an inverse relationship with degenerative facet disease at L5/S1. Once again, the expected high BMI that would likely associate with the formation of degenerative synovitis had no association with the formation of a BFS at L5/S1. This is consistent with the conclusions of Longmuir and Conley (2008) at L5/S1, as they were at L3/L4 and L5/S1.

The framework for Research Question 2 was based on the existing literature demonstrating a potential mechanism of action for a relationship between BFS and low back pain. Longmuir and Conley (2008) showed the bright facet phenomenon to be a reliably recognizable MRI finding, sufficiently so that it became known in the literature as the Bright Facet Sign. Further, Longmuir and Conley advanced a grading system for the BFS. Yang and Yang (2005) and Czervionke and Fenton (2008) have shown an association between low back pain and the BFS. I have demonstrated in this study that the magnitude of the BFS was strongly inversely proportional to DFD at the same level. I have also shown there was not a positive association between the presence of a BFS and DDD at the same lumbar spinal level. I found no association between the BFS and the independent variables of race/ethnicity or physical activity. There was an association between the BFS and the duration of low back pain; however this was at the L3/L4 spinal level only, and occurred only when the duration of low back pain was less than 12 months in duration. Finally, an association occurred at all three spinal levels with BMI, such that the magnitude of the BFS was inverse to the magnitude of DFD, at the same

spinal level. H_{01} was there is no association between the BFS and the independent variables race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease.

Based on my findings, I rejected the null hypothesis that there is no association between the BFS and the independent variables of race/ethnicity, physical activity, BMI, trauma, and low back pain, after adjusting for age and degenerative joint disease. This suggests the physiological pathway associated with low back pain, secondary to osteoarthritic change at the facet level, is different than the pathway responsible for the production of a BFS.

The conceptual framework of this study was based on the empirical literature demonstrating a potential mechanism of action for a relationship between BFS and low back pain. Longmuir and Conley (2008) defined and graded the BFS. Yang and Yang (2005) and Czervionke and Fenton (2008) demonstrated that low back pain was associated with the BFS. My present study has demonstrated that the magnitude of the BFS is inversely proportional to DFD at the same level. The association I found between female gender at L3-L4, and pain of less than 12 months duration at L4-L5, support my conclusion of the formation of a BFS when DFD is less likely. Further, I have shown that the formation of a BFS is more likely to occur among individuals with a normal BMI, thereby removing them from the higher BMI categories of overweight and obesity which are regarded as risk factors for DJD. It appears that the physiological pathway associated with low back pain, secondary to osteoarthritic change at the facet, is different than the pathway responsible for the production of a BFS.

Limitations of the Study

The limitations of any investigation are those design characteristics which influence the interpretation of the findings and place constraints on the generalizability and practical application of the results. This was not an experimental study and I was unable to collect data on asymptomatic individuals in a control group. This study was observational in nature. Participants were recruited from among patients with a referral order for MR imaging of the lumbar spine to evaluate the cause of their low back symptoms. Therefore all of the subjects in this investigation were low back pain sufferers. The use of the case-control design did allow comparisons between those with and without a BFS.

There was an underlying assumption on my part that clinical indications adequately justified lumbar MRI examination. Although primary healthcare practitioners adhere to a common set of physical findings and patient symptoms before ordering such a costly form of advanced imaging, individual preferences, prejudices, personal experiences, and availability (referral bias) may all influence the pattern of interprofessional referral. I was also unable to exclude malingering subjects. Patients may exaggerate symptoms, particularly when third-party reimbursement is involved (Mittenberg, Patton, Canyock, & Condit, 2002). This is a form of information bias. Recall and response bias are introduced by the study questionnaire when subjects are asked to categorize the duration of their low back pain, and approximate their level of pain. The latter may vary significantly over the duration of pain.

The tissue source of low back pain cannot be specified in a majority of patient circumstances. That is, clinical practice guidelines do not readily allow for discrimination between pain caused by the intervertebral disc, and that of the lumbar facet articulation. There has been no systemic review of the accuracy of diagnostic tests used to identify the source of low back pain (Hancock, et al., 2007). Further, none of the clinical tests to identify the lumbar facet joint as a primary source of pain are known to be either informative or predictive (Hancock et al., 2007). For these reasons, I concerned myself with subjects complaining of generalized low back pain, and not pain that is facet-generated or discogenic in etiology. Broad generalizations from a research study to symptomatic and asymptomatic patient populations should be reserved for high-quality, controlled clinical trials involving large numbers of participants.

In this study, inter-examiner agreement was measured, and using Cronbach's alpha as a measure of internal consistency, found to be high. Intra-examiner agreement was not measured as part of this study. This was done, in part, to conserve resources. More importantly, the high inter-examiner agreement in the Longmuir and Conley (2008) study cast doubt on the possibility that intra-examiner agreement could have surpassed its already high level of agreement. A third data collector, although not necessary to satisfy the general aims of this study, could have altered the inter-examiner reliability.

Although the list of exclusionary criteria was robust, it was not possible to control for the presence of non-steroidal anti-inflammatory agents (NSAIDs). NSAIDs fall primarily into three main categories: ibuprofen, (e.g. brand names such as Advil, Motrin, and Nuprin), naproxen (e.g. brand names such as Aleve and Naprosyn) and COX-2

inhibitors (e.g. brand names such as Bextra and Celebrex). The sustained concentration of NSAIDs in synovial fluid is recognized in the literature, and known to exceed that of plasma (Day, McLachian, Graham, & Williams, 1999). NSAIDs decrease the synthesis of prostaglandins in synovial fluid, although there are few data on the kinetics of NSAIDS in the synovial medium. This could in turn influence the accumulation of intra-articular fluid which accounts for the BFS. The self-report of NSAIDs by participants could have introduced recall bias, based on poor recollection, misunderstanding, or recall associated with the intensity of the participants' pain.

Computed tomography (CT) is a highly accurate and expedient imaging modality for the detection of subtle lumbar pathology (Brown, Antevil, Sise, & Sack, 2005). The addition of CT, obviously suited to examining cortical detail, could have improved the grading of degenerative changes at the facet articulations. Potential reviewer bias may be inferred by the former inter-professional relationship shared by the data collectors. In this case, both musculoskeletal radiologists were trained in the same post-doctoral radiology residency program by the same Radiology Department Chairman, and imaging staff. Radiology residents are encouraged to think logically and emulate the problem-solving thought processes of their department heads (R. Conley, personal communication, February 21, 2014). This may result in a lack of diagnostic diversity, should multiple former residents participate as MRI readers. Similarly, colleagues at the same MR imaging center, or who have shared a previous work place, may develop diagnostic film-reading traits that result in a tendency toward group-think (B. Hosler, personal communication, February 16, 2014). Bias was reduced in this investigation through the

use of the Bright Facets Training Program, and by having different data collectors evaluate for the presence of a BFS and DJD.

Sample bias can arise when the intended sample does not adequately reflect the spectrum of characteristics in the target population. Although I used three separate MRI facilities in three different states, the subject cohort was heavily skewed towards White participants. This will detract from the generalizability of the study. Average participants, when evaluated in terms of their BMI, fell within the mildly "overweight" category. Whether this represents a lack of diversity in the study sample, or an accurate assessment of the average age group in these geographic locations is unclear. Stratification, based on the variables of gender, occupation, height, weight, age, and race/ethnicity, though not possible in this study, may have refined the profile of a BFS participant. This in turn could have improved the predictability of a BFS response in a given individual.

Participation bias does not appear to be a significant factor in this study. The number of individuals that refused participation was very small. However, individuals in this study were selected on the basis of availability for MR imaging. This represents image-based selection bias, and is a common bias in the medical literature (Sica, 2006). It is possible the total study population of low back pain sufferers may differ from those with the same disease or exposure who could not, for reasons of insurance availability, geography, or transportation, undergo an MR imaging study. I attempted to decrease image-based selection bias by using non-hospital affiliated MR imaging centers that accept a variety of payment schemes, to include private pay, Medicare, Medicaid, group

health insurance, workman's compensation, statutory lien, and automobile personal injury protection.

Recommendations for Future Research

The paucity of published information relating to the BFS, as is usually the case with new radiographic descriptors, indicates that considerable work remains to be accomplished. More comprehensive and stratified longitudinal studies are indicated to help explain the etiology of the lumbar BFS. The onset, longevity, and transitory nature of bright facets also need to be explored. Whether the bright facet response represents synovial inflammation or a normal variant remains to be seen. Its relationship to articular symptoms and disease bears careful investigation.

Aside from this nested case-control analysis, other research strategies may include the use of asymptomatic control groups. Additional independent variables to include more invasive methods to discriminate between pain that is facet or disc-generated may be implemented. This could also include the premortum MR imaging of patients to help facilitate the harvesting of synovial tissue and fluid from bright facets for detailed analysis. The histological evaluation of synovium taken from involved, and non-involved facet joints, may yield significant morphological differences. Chemical differences between the thixotropic lubricant of normal lumbar facet joint surfaces and those with a BFS may also prove fruitful, particularly if testing is sensitive for the intra-cellular products of soft tissue inflammation.

It might also be useful to see if a BFS can be reproduced by the intra-articular irrigation of the synovium with hypertonic saline solutions. Mechanical irritation may

also produce a BFS. The use of diagnostic nerve blocks is the most reliable way to diagnose lumbar facet joint pain (Saravanakumar & Harvey, 2008). An association between the presence of a BFS and pain at a particular facet joint could be established by temporarily denervating a symptomatic facet articulation, providing the iatrogenic creation of a hemarthrosis is avoided. Although these investigatory suggestions may have academic merit, they are all labor intensive and require significant monetary resources.

Implications for Social Change

In this study I have shown the magnitude of the BFS to be inversely proportional to the presence of degenerative change when at the same facet; not just at one lumbar spinal level, but at all three lumbar levels examined in this investigation. I have also demonstrated the increased likelihood of presence of a BFS among those with a BMI in the "normal" 18.5 - 24.9 range, and not in the study mean of "overweight" 25.0-29.9, would be expected if the BFS accompanied the degenerative facet changes associated with increased axial loading. My findings refute the belief that the MR imaging entity known at the BFS represents a step in the formation of degenerative facet disease.

Facet joints are pain sensitive structures, and- are known to contain tissue types considered significant in their ability to generate painful stimuli (Saravanakumar & Harvey, 2008). I have discussed how pain generated by facet articulations is commonly associated with the presence of osteoarthritis, particularly in cases of people of advancing age and those suffering from obesity. The condition associated with a finding of the BFS is painful in nature (Czervionke & Fenton, 2008; Yang &Yang, 2005). The findings of my study suggests pain generated at a facet articulation which has a BFS, is statistically

disassociated with the presence of degenerative facet disease, and may use a pathway other than that commonly associated with osteoarthritis to generate pain.

The understanding of mechanisms responsible for the production of the BFS might lead to a better understanding of diarthrodial joint function and contribute to the current body of knowledge related to low back pain. This could lead to the modification of treatment protocols and also provide a mechanism for earlier detection of degenerative joint disease which in turn could contribute to positive social change by reducing the pain and suffering associated with low back pain. Considering the global prevalence of low back pain, the direct and indirect health costs, and loss of manpower, an improved understanding of the pathophysiology may contribute to positive social change.

Conclusion and Social Change

Non-specific low back pain is a common problem (Borenstein, 2000). With a 65% lifetime prevalence among the adult population (Papageorgiou, Croft, Ferry, Jayson & Silman, 1995), low back pain has a significant impact upon world public health (Maniakis & Gray, 2000). In the United States alone, low back pain is responsible for up to 148 million lost work days annually, with an estimated loss of $28 billion in productivity (Maetzel and Li; Pai & Sundaram, 2004). It is known that pain can emanate from a variety of lumbar spinal structures, and can be acute or chronic in nature (Manchikanti, et al., 2004). Lumbar facets act as the primary generators of pain in 15-45% of individuals with axial low back pain (Kykowski & Wong, 2012) and at least 10-15% of individuals with chronic low back pain (Saravanakumar & Harvey, 2008).The association between back pain and degenerative facet disease is supported in the literature

(Borenstein, 2000, Fujiwara, et al., 2000); the incidence of DFD is increased among the overweight in our society (Onyike, Crum, Lee, Lykestson, & Eaton, 2003; Sabharwal & Christelis, 2010).

The BFS is a common finding on T2-weighted images of the lumbar spine, and working descriptions of the BFS have been presented in the literature (Czervionke & Fenton, 2008; Longmuir & Conley, 2008; Yang & Yang, 2005). A grading system for the BFS has been advanced by Longmuir and Conley, and verified by Marcondes César et al. (2011). An undefined, however, statistically significant relationship exists between the presence of the BFS and degenerative joint disease of the lumbar disc and facets (Longmuir & Conley, 2008). Considering that Czervionke and Fenton, and Yang and Yang have argued that a strong relationship between the BFS and low back symptomatology exists, an unrecognized or previously unreported pathway between the causative physiological mechanism of the BFS and low back pain may exist. This study helps to fill a gap in the current literature related to a pathway which could be significant to the early identification and treatment of low back pain.

In my investigation, I found a significant and direct association between the presence of degenerative disc disease and degenerative facet disease at all three lumbar levels. As the magnitude of DDD increased, so did the magnitude of DFD. This supports Bogduk (1990), suggesting that the intervertebral disc and facets are related both anatomically and physiologically, and degeneration affecting one will eventually affect the other. In this study, there was no positive association between the presence of a BFS and DDD at the same lumbar spinal level. This investigation determined an inverse

relationship existed between the magnitude of the BFS and the magnitude of the DFD at the same spinal level. This refutes a commonly held belief of radiologists, neuroradiologists, orthopedists, and selected published references that maintain the BFS represents synovitis, an inflammatory first step in the degenerative process of the facet articulation.

The inverse relationship between DFD and the BFS is underscored by my discovery of the association the BFS shares with low back pain patients with a "normal" BMI, removing them from the at-risk "overweight" demographic where DJD is more prevalent. This is counter-intuitive as the prevailing literature not only states that obesity is strongly predictive of DJD, (Karnik & Kanekar, 2012; Onyike, Crum, Lee, Lykestson, & Eaton, 2003; Sabharwal & Christelis, 2010), but the increased load-bearing of the spinal articulations brought about by increased BMI accelerates the degenerative process throughout the lower lumbar spine (Kalichman, Guermazi, Li, & Hunter (2009).

This casts new importance on the BFS as a diagnostic entity in MR imaging. Historically the subject of spirited debate among colleagues, the appearance of intra-articular high signal on a T2-weighted spinal image is often ignored by reading radiologists (Longmuir & Conley, 2008). Sometimes, the BFS appearance is attributed incorrectly to magic angle phenomenon, synovitis, facet arthropathy, or normal variation (Longmuir & Conley, 2008). Now established as a graded entity, distinct from DJD, and with a significant association with body morphology, this investigation has elevated the BFS to a diagnostic entity that needs to be recognized as a part of the doctor/patient narrative and a formal radiographic report.

Like all diarthrodial synovium lined joints throughout the body, the facet articulations of the lumbar spine are predisposed to arthropathy (Modic & Ross, 2007). Increased craniocaudal stress on the facet surfaces results in joint space narrowing, subchondral sclerosis and osteophyte formation, the very definition of degenerative joint disease. Facet degeneration alone may account for the symptoms of low back pain (Modic & Ross, 2007). A lumbar facet with a BFS, described in the literature as an early manifestation of degenerative joint disease, is believed to have a positive association with low back pain (Cervionke & Fenton, 2008; Yang & Yang, 2005). The findings of this study suggested that pain generated at a lumbar facet articulation, which has a BFS, was disassociated with the presence of degenerative facet disease. The perception of pain from a facet with a BFS may use a pathway other than that which is commonly associated with osteoarthritis. This will add to the diagnostic repertoire of healthcare practitioners who treat low back patients, by presenting a heretofore-unknown organic cause of low back pain which is independent of osteoarthritis, bringing with it with new opportunities for research into the etiology and early treatment of low back pain. Much work remains to be done to help explain the physiology of the BFS, its duration, and the specific nature of its ability to, in the absence of degenerative arthropathy, generate low back pain.

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Appendix A: Bright Facet Sign Training Program for Data Collection 5D's (Directions,Definition, Diagrams, Description and Degeneration) Directions

You will be provided multiple lumbar MRI cases for detailed examination. To avoid eye strain and fatigue, these cases can be spread out over several reading sessions.

Please make sure to view all the images. There is an accompanying questionnaire, completed by the patient, that co-ordinates with each case. It provides important information regarding the patient, identified only by a case number, demographics, history and presenting symptoms. While viewing the lumbar MR images, complete 1 copy of the BFS Worksheet per patient while evaluating for the presence or absence, and grade, of the Bright Facet Sign (BFS), degenerative disc, and degenerative joint disease (DJD).

The definition, diagram, description and degeneration sections of this document will serve as guidelines throughout your decision making process. Please complete the entire worksheet. There is no time limit. At the end of each reading session, turn in the completed BFS worksheets to the senior investigator whose contact information has already been provided to you. Thank you for lending your expertise to this project.

Definition

The BFS is a linear, homogenous high signal appearance occasionally seen occupying the apophyseal joint space on a T2-weighted MR image and is shown in Figures 1 and 2. The grading process for the BFS is shown in Figure 3A-D.

Description

The BFS is high signal, homogenous in density, and although variable in size, appears contained within the lumbar facet joint margins. It is rectilinear without the irregular contour one might associate with subjacent bony erosion. The capsular margins do not appear appreciably distended and there is no evidence of periarticular mass or extra-articular fluid accumulation. For the purposes of this investigation, assume the BFS to be variable in location, frequency and grade. It can occur unilaterally or bilaterally, at none, or any of the lumbar apophyseal locations imaged.

Longmuir and Conley (2008) put forth a grading system for the bright facet response. For academic purposes, the bright facet appearance was divided into 5 separate categories, Grades 0 through 4 (Figure 3A-D).

Diagrams

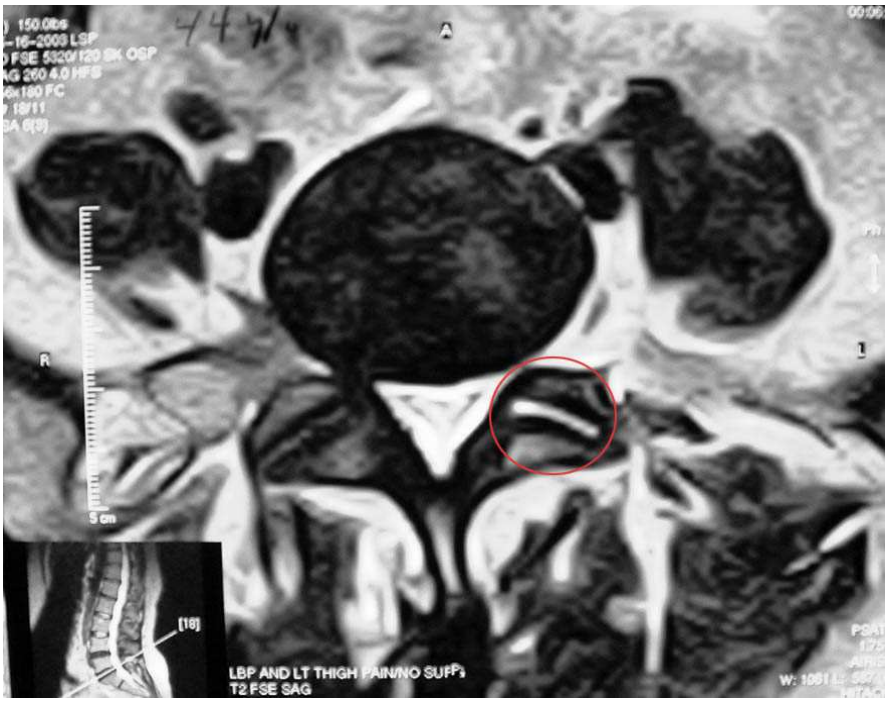

Figure A1. A BFS observed at the left L5/S1 facet joint (red circle) on a T2-weighted FSE axial image of the lumbar spine.

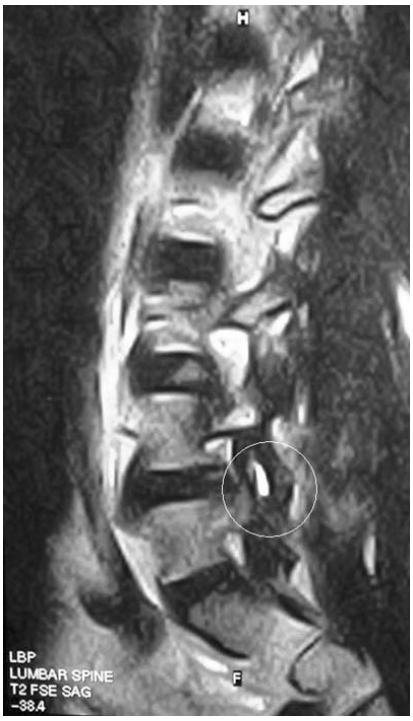

Figure A2. A BFS observed at the right L4/L5 facet joint (white circle) on a T2-weighted FSE axial image of the lumbar spine.

Figure 3A-D. The grading system for the BFS on axial T2-weighted lumbar MR images. A. Grade 0 = a normal facet without a bright facet response. B. Grade 1 = bright facet response < 50% the length of the hyaline cartilage. C. Grade 2 = bright facet response > 50% the length of the hyaline cartilage. D. bright facet response along the entire axial length of the hyaline cartilage. E. Grade 4 = a Grade 3 response with facet gapping (Longmuir and Conley, 2008).

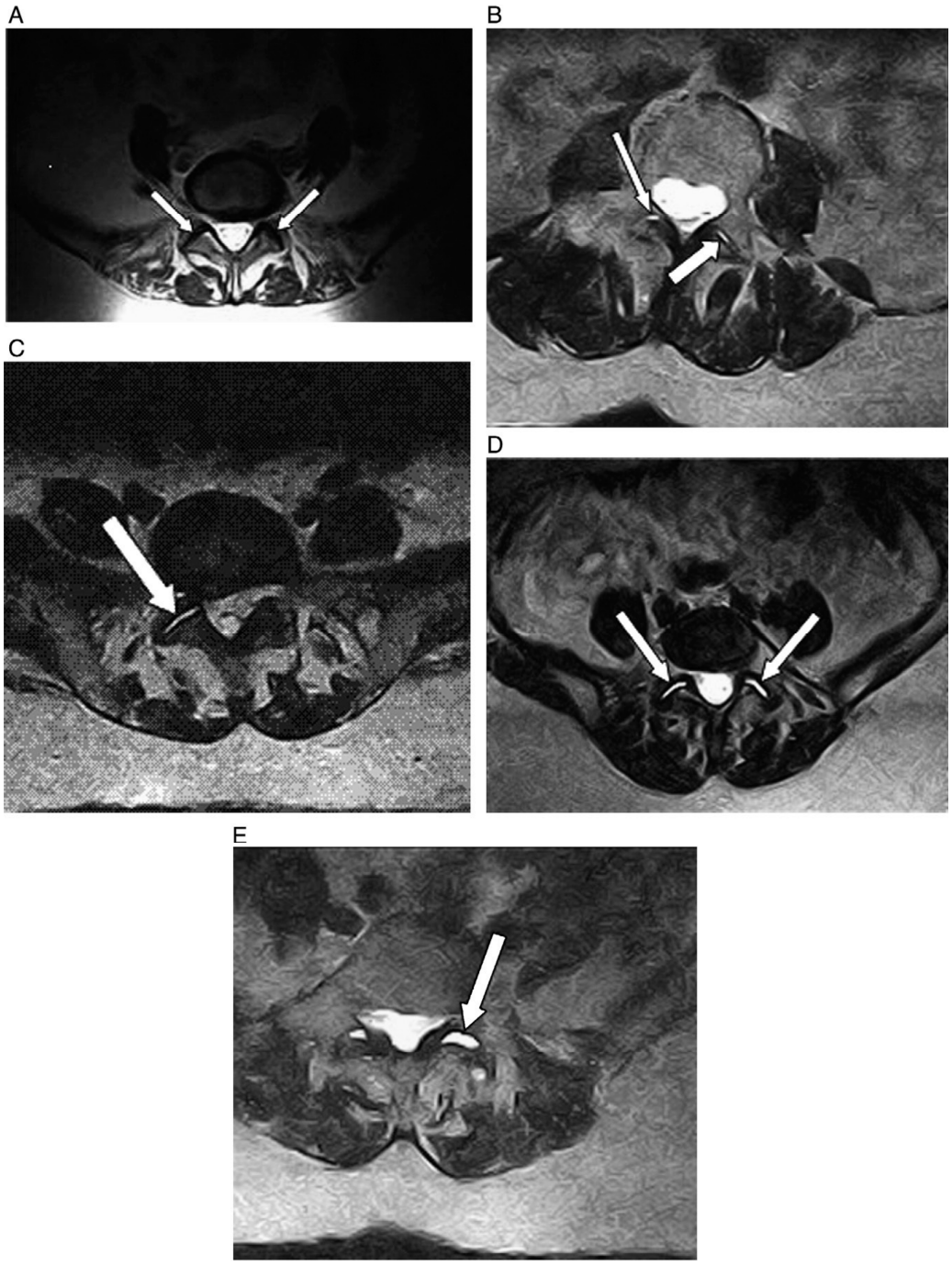

Figure 1. Bright Facet Sign grading system of Longmuir and Conley (2008). Grade 0, A; Grade 1, B; Grade 2,C; Grade 3, D; Grade 4, E.

Degeneration

As you are aware, degenerative changes may be observed at the intervertebral disc and/or the facet articulations throughout the lumbar spine. These changes can be graded, in the case of disc disease according to the morphological scheme of Pfirrmann et al. (2001). The written (Table 1) and diagrammatic renditions (Figure 4) of both the gross morphological and MRI assessments appear below. Grades I through V are employed to describe the increasing presence of nuclear, annular, end plate and vertebral body changes, seen sagittally.

Table A1

The Descriptive Grading Assessment of the Intervertebral Disc by T2-weighted MRI Appearance

Grade	Structure	Nucleus and annulus	Signal intensity	Disc height
I	Homogeneous, bright white	Clear	Hyperintense, isointense to CSF	Normal
II	Inhomogeneous with or without horizontal bands	Clear	Hyperintense, isointense to CSF	Normal
III	Inhomogeneous, gray	Unclear	Intermediate	Normal to ↓
IV	Inhomogeneous gray to black	Lost	Intermediate to hypointense	Normal to ↓↓
V	Inhomogeneous, black	Lost	Hypointense	Collapsed

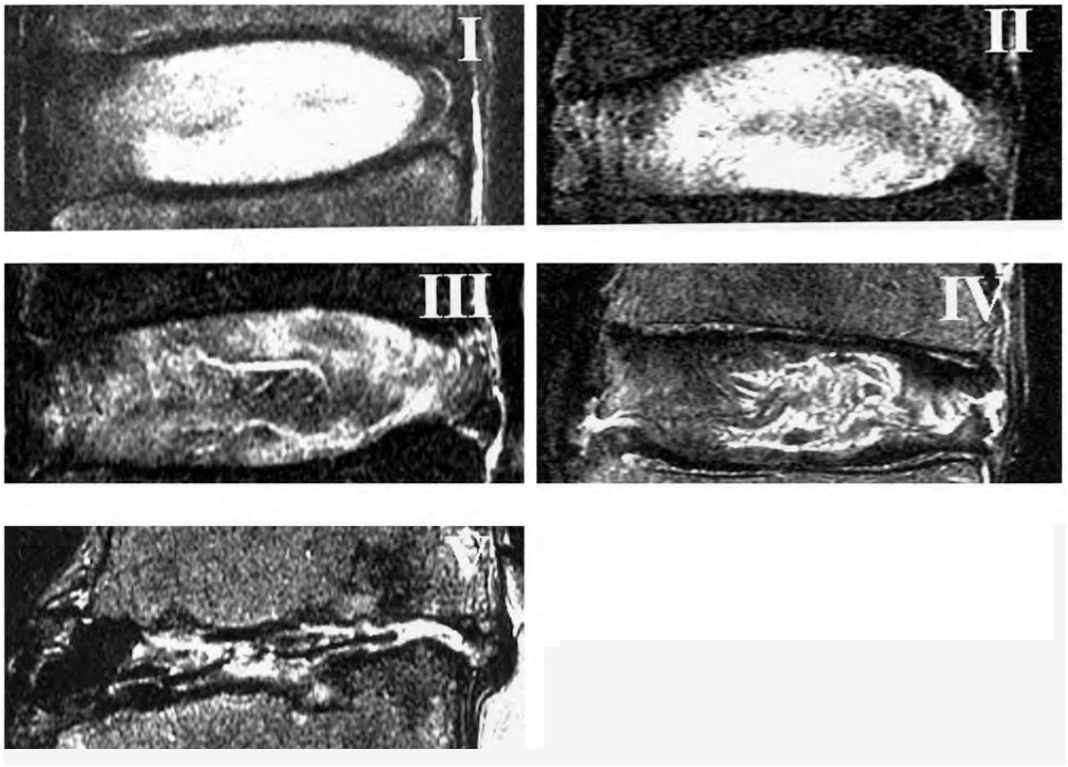

Figure A4. *Note.* Adapted from Pfirrmann, C. W. A., Metzdorf, A., Zanetti, M., Hodler, J., & Boos, N. (2001). Magnetic resonance classification of lumbar intervertebral disc degeneration. *Spine*. 26(17), 1875.

In the case of degenerative changes at the facet articulations, Grogan et al. (1997) categorized the presence of apophyseal articular changes according to their appearance on MRI. Grades 1 through 4 were used to describe the increasing presence of joint space narrowing, reactive sclerosis and osteophyte formation. This system is outlined below descriptively (Table A2) and diagrammatically (Figure 5A-D).

Table A2

Four Grades of Facet Joint Degenerative Changes

Grade 1 - Normal

Grade 2 - Mild (joint space narrowing or mild osteophyte formation)

Grade 3 - Moderate (sclerosis or moderate osteophyte formation)

Grade 4 - Severe (marked osteophyte formation).

Note: Adapted from Grogan, J., Nowicki, B. H., Schmidt, T. A., & Haughton, V. M. (1997). Lumbar facet joint tropism does not accelerate degeneration of the facet joints. *American Journal of Neuroradiology*. 18(7), 1327.

Figure 5A-D. Four grades of facet joint degeneration on MRI. A. Grade 1: normal. B. Grade 2. Joint space narrowing or mild osteophyte. C. Grade 3: Sclerosis or moderate osteophyte. D. Grade 4: Market osteophyte. (Grogan et al. 1997).

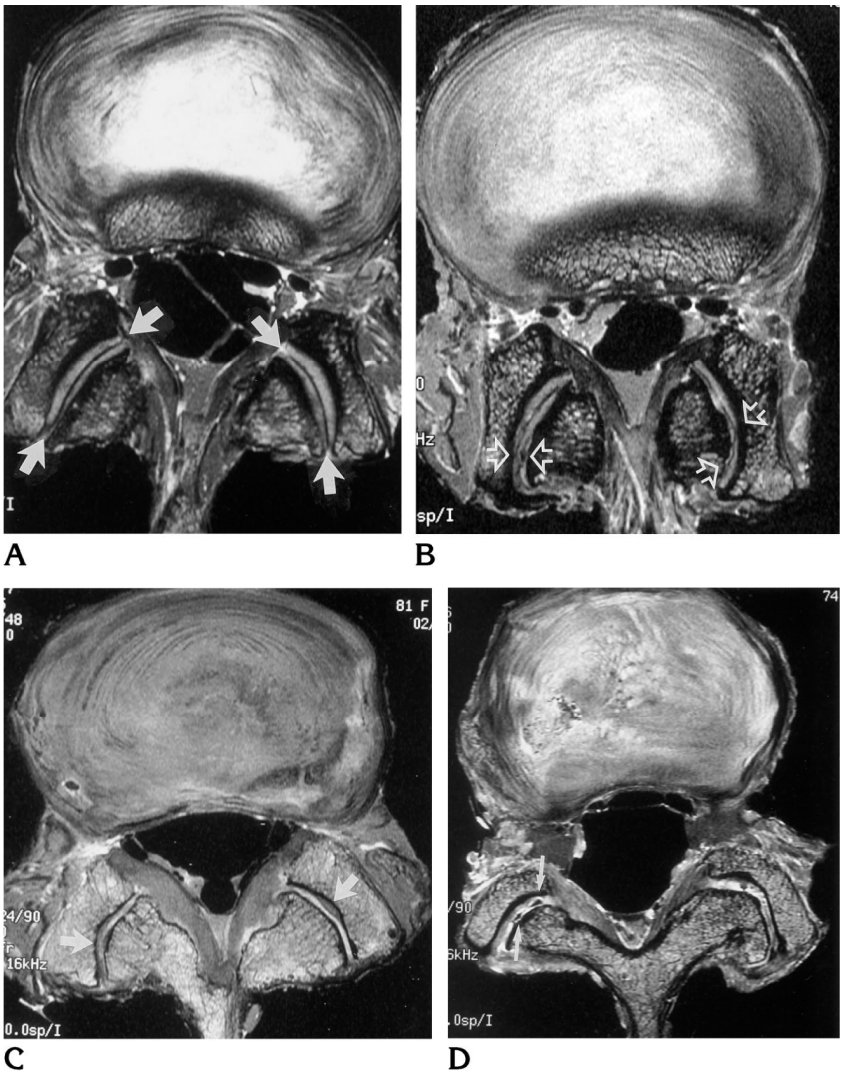

Figure A5. Four grades of facet joint degeneration on MRI. A. Grade 1: normal. B. Grade 2. Joint space narrowing or mild osteophyte. C. Grade 3: Sclerosis or moderate osteophyte. D. Grade 4: Market osteophyte. Note: Adapted from Grogan, J., Nowicki, B. H., Schmidt, T. A., & Haughton, V. M. (1997). Lumbar facet joint tropism does not accelerate degeneration of the facet joints. *American Journal of Neuroradiology*. 18(7), 1325-1329.

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Appendix B: Bright Facets Worksheet Coding Key

Study Code #: Patient Number. A unique identifier assigned by me, 001 through 350

Gender: Patient's Sex. 1=male, 2=female.

DOB: Date Of Birth. Provided by the patient, verified by technician.

Occupat: Occupation. Based upon general job related activity levels 1 through 4.
1=very active, 2=active, 3=mostly sedentary, 4=sedentary.
5=unemployed, 6=retired,7=unknown/no response, 8=disabled.

Height: Height in inches as provided by the technician

Weight: Weight in pounds as provided by the technician

Race/ethnicity: Ethnic affiliation selected by the patient from the USPS employment guidelines. 1=Caucasian (white), 2=African American (black), 3= Hispanic, 4=American/Alaskan, 5=Asian, 6=Hawaii/Pacific 7=other, 8=unknown/no response.

LBP Duration: Duration of Symptoms reported by the patient.
1=<1year, 2=1year, 3=1-2 year, 4=2-5yr, 5=>1year

VAS: Visual Analogue Scale. Patient rates the severity of symptoms on a scale of 1 to 10 as reported by the patient. 0=the complete absence of symptoms, 10=the greatest possible intensity of the primary symptom immaginable.11= unrated/no response.

BF ex 1: Examiner 1, are any bright facets seen anywhere on this MRI study? 2=yes, 1=no
BF ex 2: Examiner 2, are any bright facets seen anywhere on this MRI study? 2=yes, 1=no
L1/L2 L1: Examiner 1, grade the bright facet response on the left side at L3/L4 0 through 4.
L1/L2 R1: Examiner 1, grade the bright facet response on the right side at L3/L4 0 through 4.
L1/L2 L1: Examiner 2, grade the bright facet response on the left side at L3/L4 0 through 4.
L1/L2 R1: Examiner 2, grade the bright facet response on the right side at L3/L4 0 through 4.
L2/L3L2: Examiner 1, grade the bright facet response on the left side at L3/L4 0 through 4.
L2/L3 R2: Examiner 1, grade the bright facet response on the right side at L3/L4 0 through 4.

L2/L3L2: Examiner 2, grade the bright facet response on the left side at L3/L4 0 through 4.
L2/L3 R2: Examiner 2, grade the bright facet response on the right side at L3/L4 0 through 4.
L3/L4 L1: Examiner 1, grade the bright facet response on the left side at L3/L4 0 through 4.
L3/L4 R1: Examiner 1, grade the bright facet response on the right side at L3/L4 0 through 4.
L3/L4 L2: Examiner 2, grade the bright facet response on the left side at L3/L4 0 through 4.
L3/L4 R2: Examiner 2, grade the bright facet response on the right side at L3/L4 0 through 4.
L4/L5 L1: Examiner 1, grade the bright facet response on the left side at L4/L5 0 through 4.
L4/L5 R1: Examiner 1, grade the bright facet response on the right side at L4/L5 0 through 4.
L4/L5 L2: Examiner 2, grade the bright facet response on the left side at L4/L5 0 through 4.
L4/L5 R2: Examiner 2, grade the bright facet response on the right side at L4/L5 0 through 4.
L5/S1 L1: Examiner 1, grade the bright facet response on the left side at L4/L5 0 through 4.
L5/S1 R1: Examiner 1, grade the bright facet response on the right side at L4/L5 0 through 4.
L5/S1 L2: Examiner 2, grade the bright facet response on the left side at L4/L5 0 through 4.
L5/S1 R2: Examiner 2, grade the bright facet response on the right side at L4/L5 0 through 4.

0=no bright facet response, 1=<25% bright facet response on axial image, 2=<50% bright facet response on axial image, 3=100% bright facet response on axial image, 4=100% bright facet response on axial image with gapped facet.

Trauma: Has there been any low back trauma within the past 12 months? 2=yes, 1=no.

N.O.I.: If yes, give the nature of that injury. 1=axial loading, 2=motor vehicle injury, 3=blunt force 4=slip and fall injury, 5=lifting injury, 6=running injury, 7=miss-stepped, 8=squatting injury 9=bending injury, 10=gym/athletic injury, 11=sneeze, 12=uncategorized/no response.

L1/L2dsc1: Examiner 1, grade disc degeneration at L1/L2, on scale of 0 through 5
L1/L2dsc2: Examiner 2, grade disc degeneration at L1/L2, on scale of 0 through 5
L2/L3dsc1: Examiner 1, grade disc degeneration at L2/L3, on scale of 0 through 5
L2/L3dsc2: Examiner 2, grade disc degeneration at L2/L3, on scale of 0 through 5

L3/L4dsc1: Examiner 1, grade disc degeneration at L3/L4, on scale of 0 through 5
L3/L4dsc2: Examiner 2, grade disc degeneration at L3/L4, on scale of 0 through 5
L4/L5dsc1: Examiner 1, grade disc degeneration at L4/L5, on scale of 0 through 5
L4/L5dsc2: Examiner 2, grade disc degeneration at L4/L5, on scale of 0 through 5
L5/S1dsc1: Examiner 1, grade disc degeneration at L5/S1, on scale of 0 through 5
L5/S1dsc2: Examiner 2, grade disc degeneration at L5/S1, on scale of 0 through 5

L1/L2fac1: Examiner 1, presence of facet degeneration at L1/L2. 2=yes, 1=no
L1/L2fac2: Examiner 2, presence of facet degeneration at L1/L2. 2=yes, 1=no
L2/L3fac1: Examiner 1, presence of facet degeneration at L2/L3. 2=yes, 1=no
L2/L3fac2: Examiner 2, presence of facet degeneration at L2/L3. 2=yes, 1=no
L3/L4fac1: Examiner 1, presence of facet degeneration at L3/L4. 2=yes, 1=no
L3/L4fac2: Examiner 2, presence of facet degeneration at L3/L4. 2=yes, 1=no
L4/L5fac1: Examiner 1, presence of facet degeneration at L4/L5. 2=yes, 1=no
L4/L5fac2: Examiner 2, presence of facet degeneration at L4/L5. 2=yes, 1=no
L5/S1fac1: Examiner 1, presence of facet degeneration at L5/S1. 2=yes, 1=no
L5/S1fac2: Examiner 2, presence of facet degeneration at L5/S1. 2=yes, 1=no

Appendix C: Bright Facet Worksheet

STUDY CODE # _____ GENDER: M F DOB _____ AGE _____

OCCUPATION: vactive active msed sed unemp retired unk/nresp disable

HEIGHT: _____ WEIGHT: _____ LBS: _____

RACE/ETHNICITY: W AA AI/AN ASN H H/PI unknown/no response

LOW BACK PAIN DURATION <1yr 1yr 1-2yr 2-5yr >5yr

LOW BACK PAIN VAS 1 2 3 4 5 6 7 8 9 10

EXAMINER 1 2

BRIGHT FACETS: Y N

L1/L2 L R Bilateral

L2/L3 L R Bilateral

L3/L4 L R Bilateral

L4/L5 L R Bilateral

L5/S1 L R Bilateral

HISTORY:

Lumbar trauma within last 12 months Y N

Nature of injury: axial loading
blunt force
lifting injury
MVC
slip & fall
other: _____

DISC DISEASE

Level:

Grade I _____

Grade II _____

Grade III _____

FACET JOINT DISEASE

Level:

Grade 1 _____

Grade 2 _____

Grade 3 _____

Grade IV _____ Grade 4 _____

Grade V _____

Appendix D: Bright Facets Patient Questionnaire

Bright Facets Patient Questionnaire

Please answer the following questions to the best of your ability.

Answer all questions.

1. Name: _____
2. Mailing address: _____
   _____
3. Sex (circle one): M F Date of Birth _____

To be completed by MRI staff
Patient ID # _____
Study Code # _____
Height: _____ ft/in
Weight: _____ lbs.

4. What is your occupation? _____

5. What is your race (circle one)?

   A. White B. African American C. Hispanic D. American Indian or Alaska Native

   E. Asian Native F. Hawaiian/Pacific Islander G. Unknown H. Prefer not to answer

6. How would you rate your physical activity at work (circle one)?

   A. very active B. active C. mostly sedentary D. unemployed E. retired F. disabled

7. Do you have low back pain (circle one): Yes No

8. On a scale of 1 to 10, where 1 is the complete absence of pain and 10 is the greatest possible intensity of the pain imaginable, rate the low back pain you feel today (circle one).

   1 2 3 4 5 6 7 8 9 10

9. How long has your low back been hurting (circle one)?

   A. less than 1year B. 1year C. 1-2years D. 2-5years E. more than 5years

10. Have you been injured in the last 12 months (circle one)? Yes No

11. If you have been injured in the last 12 months, what type of injury was it (circle one)?

axial loading car accident blunt force trauma slip and fall lifting running, misstepped squatting bending athletic injury, sneeze, no category

Do you or have you ever had any of the following conditions or medical devices:

Eye or ear implant	☐	Cardiac pacemaker	☐	Kidney disease	☐	
Aneurysm clips	☐	Any surgical clips	☐	Liver disease	☐	
Aortic clips	☐	Heart valve replacement	☐	Seizures	☐	
I.U.D.	☐	Spinal Or Ventricular Shunt	☐	Blood Thinners	☐	
Joint replacements	☐	Metal mesh implants	☐	Asthma	☐	Contrast:_____
Wire Sutures	☐	Shrapnel	☐	Sickle Cell Anemia	☐	
Dentures	☐	Metal fragments	☐	Multiple Sclerosis	☐	Amount:_____
Cancer_____	☐	Claustrophobia	☐	Are you pregnant?	☐	

List all Surgeries:_____

Consent for procedure:

I understand that failure to provide adequate medical history can be hazardous to my safety. I have provided a comprehensive medical history and have been informed of the contraindications of this procedure. I give consent for the injection of a contrast if deemed necessary by my physician or the interpreting physician. I understand that MRI has not been FDA approved for pregnant women.

Commercial/Medicare Insurance Lifetime consent form:

I request that payment of authorized medicare/insurance benefits be made on my behalf to MRI/Medical Imaging for any services furnished me. I authorize any holder of medical information about me to release to the health care financing administration or my insurance company and its agents any information needed to determine benefits or the benefits payable for related services. A copy of this signature is as valid as the original. I understand that I am financially responsible for any balance not covered by my insurance carrier and my insurance carrier does not guarantee benefits.

MRI and its delegates may use my images (anonymously) for teaching research and publication.

Signature:_____ Date:_____

Appendix E: Plain Language Statement Regarding Research Project

Dear Patients and Friends,

A research project is being conducted, and you are invited to participate. We are studying the frequency of a common finding that may or may not be present in your low back. These findings are called Bright Facet signs. While we are looking at your MRI scan, we would like to look for these signs. Are you agreeable? No additional MRI scans are needed to conduct the research other than what has been prescribed by your doctor.

This research project is required for a PhD program undertaken by the principal investigator through Walden University, School of Public Health. Your participation is voluntary and does not affect the outcome or the results of your low back MRI examination. If you choose to participate please complete the intake forms when the technician instructs you to do so. Your completion of these surveys will imply your consent to participate in this study. This imaging facility will ask you to sign two consent forms. The first is a consent to undergo the MRI examination and the second is a privacy policy regarding the disclosure of medical records.

We want you to know that we respect the privacy of your personal medical records and will do all we can to secure and protect that privacy. We strive to always take reasonable precautions to protect that privacy. When it is appropriate and necessary, we provide the minimum necessary information about treatment, payment or health care operations, in order to provide health care that is in your best interest. We also want you to know that we support your full access to your personal medical records. You may refuse to consent to the use or disclosure of your personal health information, but this must be in writing.

Your completion and return of the survey indicates your consent to participate in the study. Please keep this letter for your personal records. If you have questions about the study, please contact me at xxx.xxxx@xxx.xxx or xxx-xxx-xxxx. If you want to talk privately about your rights as a participant, you can call Dr. Leilani Endicott (Walden University representative) at 1-800-xxx-xxxx, extension 1210. Walden University's approval number for the study is _____ and it expires on _____. While there is no monetary or other compensation for participating in this study, you will be providing information that may help improve health care for this vulnerable population. Thank you for your consideration.

Thank you,
Dr. Gary A. Longmuir, Principal Investigator