

# Biomechanical Research Progress on Degenerative Changes and Injuries of Lumbar Intervertebral Discs

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## Abstract:

This paper comprehensively analyzes the biomechanical research progress on degenerative changes and injuries of lumbar intervertebral discs. Firstly, the anatomical structure and physiological functions of lumbar intervertebral discs, including the annulus fibrosus, nucleus pulposus, and cartilaginous endplates, are introduced. Then, the biomechanical mechanisms leading to degenerative changes of lumbar intervertebral discs, such as the effects of load, pressure, and poor posture, are discussed. Subsequently, the biomechanical characteristics of lumbar intervertebral disc injuries, including protrusion, extrusion, and fissures, are analyzed. Regarding biomechanical models and their applications, the paper discusses the principles, applications, and limitations of finite element models and multibody dynamics models. Finally, the significance of this research for clinical practice and future studies is summarized, and further directions for exploration are proposed.

## Keywords:

Lumbar Intervertebral Disc, Degenerative Changes, Injuries, Biomechanics

## 1. Introduction

The lumbar intervertebral disc is an essential component of the human spine, and its health status is crucial for maintaining the normal function and stability of the spine. However, with aging and changes in lifestyle, lumbar intervertebral discs often undergo degenerative changes and injuries, leading to pain and functional impairments that significantly affect patients' quality of life. Therefore, biomechanical research on degenerative changes and injuries of lumbar intervertebral discs has become essential. In this paper, we will comprehensively review the recent progress in biomechanical research on degenerative changes and injuries of lumbar intervertebral discs to enhance understanding in this field. Firstly, we will introduce the anatomical structure and physiological functions of lumbar intervertebral discs, exploring their vital roles in spinal stability and motion. Then, we will discuss the biomechanical mechanisms leading to degenerative changes of lumbar intervertebral discs and the biomechanical characteristics of lumbar intervertebral disc injuries. Next,

we will introduce biomechanical models and their applications, along with their significance for clinical practice and future research. Through this comprehensive discussion, we aim to provide a deeper theoretical foundation and insights for the prevention, diagnosis, and treatment of degenerative changes and injuries of lumbar intervertebral discs. By delving into the biomechanical properties of lumbar intervertebral discs, we hope to provide more effective methods for the treatment and rehabilitation of related diseases, thereby improving patients' quality of life and advancing the field of spinal health.

## **2. Lumbar Intervertebral Disc Anatomy and Physiological Functions**

### ***2.1. Overview of Anatomical Structure***

The lumbar intervertebral disc, located between adjacent lumbar vertebral bodies, is a soft tissue structure composed of the fibrous cartilaginous ring and the central nucleus pulposus. Anatomically, the lumbar intervertebral disc can be divided into three main parts: the annulus fibrosus, nucleus pulposus, and cartilaginous endplates. Firstly, the annulus fibrosus consists of concentric layers of fibrous tissue surrounding the nucleus pulposus. It provides structural support with its multi-layered cross-arranged fibers, offering elasticity and toughness to withstand pressures and tensions from various directions, thereby maintaining the shape and stability of the lumbar intervertebral disc. Secondly, the nucleus pulposus, located centrally within the annulus fibrosus, is a gel-like substance. It possesses excellent water absorption and cushioning properties, acting to dampen and buffer spinal movements, thus protecting the spine and neural tissues from external forces. Lastly, the cartilaginous endplates, situated on the upper and lower surfaces of the lumbar intervertebral disc, connect the annulus fibrosus to the vertebral bodies. With good conductivity, cartilaginous endplates aid in force transmission and maintain the connection and stability between the lumbar intervertebral disc and adjacent vertebrae. These three components work together to form the structural framework of the lumbar intervertebral disc, providing stability and flexibility to the spine while playing a crucial role in protecting neural tissues and relieving spinal pressure. A thorough understanding of the anatomical structure of the lumbar intervertebral disc contributes to a better comprehension of its physiological functions and significance in spinal health and mobility [1].

### ***2.2. Functions of the Annulus Fibrosus***

The annulus fibrosus plays a crucial role in the lumbar intervertebral disc. One of its primary functions is to provide structural support. With concentric layers of fibrous tissue, the annulus fibrosus can withstand pressures and tensions from various directions, maintaining the shape and stability of the lumbar intervertebral disc. Additionally, it acts as a barrier separating the nucleus pulposus, preventing its gel-like substance from protruding or shifting outward, thus helping to maintain the shape and position of the nucleus pulposus. Its elasticity and toughness also limit excessive spinal movements, preventing over-twisting or bending of the spine, thus protecting the spine and neural tissues from injury. Moreover, the annulus fibrosus effectively transmits forces from the upper and lower vertebrae, aiding in pressure dispersion and maintaining spinal stability. Therefore, the annulus fibrosus plays an indispensable role in maintaining the function and structural integrity of the lumbar intervertebral disc. A thorough understanding of its function contributes to a better understanding of

the physiological characteristics of the lumbar intervertebral disc, providing a theoretical basis for the prevention and treatment of related diseases[2].

### ***2.3. Functions of the Nucleus Pulposus***

The nucleus pulposus is a crucial component of the lumbar intervertebral disc, and its functions are essential. Primarily composed of a gel-like substance, the nucleus pulposus serves several key functions: Firstly, it possesses excellent water absorption properties. This allows the nucleus pulposus to absorb fluids under pressure, maintaining elasticity of the lumbar intervertebral disc during compression and reducing friction between intervertebral discs, thus assisting in alleviating pressure and friction during spinal movements. Secondly, the nucleus pulposus provides excellent cushioning effects. During spinal movement, it absorbs pressure from the upper and lower vertebrae and disperses it to surrounding structures, reducing stress on the spine and neural structures, thereby protecting the spine from injury. Additionally, the nucleus pulposus helps maintain the overall shape of the lumbar intervertebral disc by filling the central cavity of the annulus fibrosus, thus preserving the normal physiological curvature and posture of the spine, maintaining spinal stability. Overall, the nucleus pulposus plays a vital role in the lumbar intervertebral disc. Its water absorption, cushioning, and shape-maintaining functions provide excellent support and protection for the spine, contributing to spinal stability and normal function. A deeper understanding of the function of the nucleus pulposus helps to better understand the physiological characteristics of the lumbar intervertebral disc and provides a theoretical basis for the prevention and treatment of related diseases.

### ***2.4. Role of the Cartilaginous Endplates***

The cartilaginous endplates are essential components connecting the lumbar intervertebral disc and adjacent vertebrae, playing a crucial role. The cartilaginous endplates serve several key functions: Firstly, they act to transmit forces. Situated on the upper and lower surfaces of the lumbar intervertebral disc, connecting the annulus fibrosus and the vertebral bodies' cartilaginous endplates effectively transmit forces from the upper and lower vertebrae. This helps disperse pressure to surrounding structures, reducing stress on the lumbar intervertebral disc and vertebrae, protecting the spinal structure from injury. Secondly, cartilaginous endplates provide stability and connectivity. By connecting the lumbar intervertebral disc and adjacent vertebrae, they help maintain the connection and stability between the lumbar intervertebral disc and vertebrae. This contributes to maintaining the normal physiological curvature and posture of the spine, preserving spinal stability. Additionally, cartilaginous endplates have some elasticity and shock absorption function. During spinal movement, they absorb shock from the upper and lower vertebrae and disperse it to surrounding structures, reducing stress on the spinal structure, assisting in alleviating pressure and friction during spinal movement. Overall, cartilaginous endplates play an indispensable role in the lumbar intervertebral disc. Their functions in force transmission, stability, connectivity, and shock absorption provide important support and protection for the spine, contributing to maintaining spinal stability and normal function. A deeper understanding of the role of cartilaginous endplates helps to better understand the physiological characteristics of the lumbar intervertebral disc and provides a theoretical basis for the prevention and treatment of related diseases [3].

### **3. Biomechanical Mechanisms of Lumbar Intervertebral Disc Degeneration**

#### ***3.1. Effects of Load on Degeneration***

The biomechanical mechanisms of lumbar intervertebral disc degeneration involve various factors, among which the effects of load are significant. Load refers to the forces acting on the spine and lumbar intervertebral discs, including static and dynamic loads. Static load refers to stable forces continuously applied to the spine and lumbar intervertebral discs, such as body weight and gravity. Prolonged exposure to static loads may lead to uneven distribution of pressure on lumbar intervertebral disc tissues, accelerating annulus fibrosus degeneration. Particularly in sitting and standing positions, lumbar intervertebral discs are subjected to significant static loads, which may accelerate their degeneration. Dynamic loads refer to transient forces generated by movement and activity, such as walking, running, and weightlifting. These dynamic loads can subject the spine and lumbar intervertebral discs to cyclic pressure and tension. If they exceed the lumbar intervertebral disc's tolerance range, they may cause annulus fibrosus damage and nucleus pulposus deformation, thereby accelerating lumbar intervertebral disc degeneration. Additionally, poor posture and positions may adversely affect lumbar intervertebral disc loading. For example, prolonged maintenance of poor sitting or bending postures may increase lumbar intervertebral disc pressure, leading to degeneration of lumbar intervertebral disc tissues. In summary, load significantly affects lumbar intervertebral disc degeneration. Both static and dynamic loads may cause damage and degeneration of lumbar intervertebral disc tissues, while poor posture and positions exacerbate this process. Therefore, reducing adverse loads on lumbar intervertebral discs, maintaining good posture and positions, is crucial for preventing and delaying lumbar intervertebral disc degeneration.

#### ***3.2. Relationship between Pressure and Degeneration***

There is a close relationship between pressure and lumbar intervertebral disc degeneration, with improper pressure distribution and excessive pressure being significant factors leading to degeneration. Firstly, prolonged exposure to inappropriate pressure may lead to degeneration of lumbar intervertebral disc tissues. Under normal circumstances, lumbar intervertebral discs can withstand pressure from body weight and movement. However, excessive or uneven pressure distribution may lead to annulus fibrosus and nucleus pulposus damage and deformation. For example, excessive sitting, standing, or lifting may cause uneven pressure on lumbar intervertebral discs, accelerating their degeneration. Secondly, changes in pressure may lead to deformation and damage of lumbar intervertebral disc tissues[4]. Physiologically, lumbar intervertebral discs can adapt to different pressures and tensions, maintaining their structure and function. However, when pressure exceeds the lumbar intervertebral disc's tolerance range, the annulus fibrosus may develop cracks or injuries, and the nucleus pulposus may be compressed and deformed, leading to lumbar intervertebral disc degeneration. Additionally, lumbar intervertebral disc degeneration may lead to changes in pressure distribution, forming a vicious cycle. Degenerated lumbar intervertebral discs lose their original structure and function, reducing their ability to absorb and disperse pressure, thus causing surrounding tissues to bear greater pressure. This may accelerate the process of lumbar intervertebral disc degeneration, forming a vicious cycle. Therefore,

reasonable control and dispersion of pressure, avoiding excessive or uneven pressure distribution, are crucial for preventing and delaying lumbar intervertebral disc degeneration. Adopting correct posture and positions, avoiding prolonged maintenance of the same posture, and properly controlling body weight all contribute to maintaining lumbar intervertebral disc health and function.

### ***3.3. Influence of Poor Posture on Disc Degeneration***

The influence of poor posture on lumbar intervertebral disc degeneration is an important but often overlooked factor. Prolonged maintenance of poor posture may accelerate lumbar intervertebral disc degeneration, with the following impacts: Firstly, prolonged maintenance of the same poor posture increases lumbar intervertebral disc pressure. For example, prolonged bending or incorrect sitting postures may cause uneven pressure on lumbar intervertebral discs, accelerating their degeneration. Such postures may lead to annulus fibrosus damage and nucleus pulposus deformation, exacerbating lumbar intervertebral disc degeneration. Secondly, poor posture may lead to excessive stretching or twisting of lumbar intervertebral discs. In certain postures, lumbar intervertebral discs may be subjected to excessive stretching or twisting, leading to annulus fibrosus stretching and nucleus pulposus deformation. This excessive force may damage lumbar intervertebral disc tissues, accelerating their degeneration. Additionally, poor posture may lead to poor habitual loading of lumbar intervertebral discs. Some poor postures may cause abnormal loading of lumbar intervertebral discs, increasing their pressure and tension, accelerating the degenerative process. This poor habitual loading may cause wear and tear on lumbar intervertebral disc tissues, exacerbating the degree of degeneration. Therefore, correct posture and positions are crucial for maintaining lumbar intervertebral disc health and function. Adopting correct postures, avoiding prolonged maintenance of the same poor posture, is significant for preventing and delaying lumbar intervertebral disc degeneration. Timely correction of poor posture and adoption of appropriate posture and exercise habits help maintain lumbar intervertebral disc health and function, reducing the occurrence of degeneration.

## **4. Biomechanical Characteristics of Lumbar Intervertebral Disc Injury**

### ***4.1. Biomechanical Characteristics of Protrusion and Extrusion***

Protrusion and extrusion of the lumbar intervertebral disc are common forms of spinal injury, and their biomechanical characteristics influence the severity of the injury and treatment methods. Protrusion and extrusion refer to the partial or complete protrusion or compression of the lumbar intervertebral disc tissue into the spinal canal or the surrounding area of the nerve root. Firstly, protrusion and extrusion are typically caused by structural damage to the lumbar intervertebral disc. For example, cracks or damage to the annulus fibrosus of the lumbar intervertebral disc may cause the nucleus pulposus to protrude outward. This type of injury may deform the structure of the lumbar intervertebral disc, increasing the risk of protrusion and extrusion. Secondly, protrusion and extrusion may also be influenced by external forces. For instance, twisting or compression of the lumbar vertebrae may cause partial tissue of the lumbar intervertebral disc to protrude outward, leading to protrusion and extrusion. Additionally, external trauma or accidental injury may also result in protrusion and extrusion of the lumbar intervertebral disc. Furthermore, the

biomechanical characteristics of protrusion and extrusion are also related to the position and structure of the spinal canal and nerve roots. For example, lumbar intervertebral disc protrusion or extrusion may compress the nerve roots within the spinal canal, resulting in nerve root compression and damage, leading to pain and neurological dysfunction. In summary, protrusion and extrusion are common forms of lumbar intervertebral disc injury, and their biomechanical characteristics are influenced by various factors. Understanding the biomechanical characteristics of protrusion and extrusion helps us better understand their mechanisms and clinical manifestations, providing guidance for the diagnosis and treatment of related injuries [5].

#### **4.2. Biomechanical Changes Caused by Cracks**

Cracks in the lumbar intervertebral disc are a common form of injury that may lead to significant biomechanical changes. Cracks typically involve partial fractures or damage to the annulus fibrosus, and their biomechanical characteristics are as follows: Firstly, cracks may cause the lumbar intervertebral disc to lose its structural integrity. The annulus fibrosus is one of the main supporting structures of the lumbar intervertebral disc, and the appearance of cracks may result in partial or complete fractures of the annulus fibrosus, making the structure of the lumbar intervertebral disc unstable. This structural change may affect the function of the lumbar intervertebral disc, increasing the risk of disc damage. Secondly, cracks may cause changes in the pressure distribution of the lumbar intervertebral disc. Under normal circumstances, the lumbar intervertebral disc can evenly distribute the body's pressure, maintaining the stability and function of the spine. However, the appearance of cracks may lead to uneven pressure distribution in the lumbar intervertebral disc, increasing the pressure on certain areas, thereby increasing the risk of disc damage. Additionally, cracks may also lead to a decrease in the elasticity and toughness of the lumbar intervertebral disc. Cracks in the annulus fibrosus may weaken its resistance to stretching and compression, making the lumbar intervertebral disc more susceptible to external forces and increasing the risk of disc damage. In summary, cracks may cause significant biomechanical changes in the lumbar intervertebral disc, including loss of structural integrity, changes in pressure distribution, and a decrease in elasticity and toughness. Understanding the biomechanical changes caused by cracks helps us better understand the mechanisms of lumbar intervertebral disc damage and provides guidance for the diagnosis and treatment of related injuries.

### **5. Biomechanical Models and Their Applications**

#### **5.1. Finite Element Model**

The finite element model is a commonly used biomechanical modeling method used to simulate and analyze the mechanical behavior of biological tissues and organs. This model decomposes complex biological structures into multiple small finite elements and solves the interactions between these elements using numerical methods to simulate and predict the mechanical response of biological tissues under different loading conditions. The finite element model has a wide range of applications in lumbar intervertebral disc research. By constructing finite element models of lumbar intervertebral discs, the stress distribution, deformation, and stress-strain response of lumbar intervertebral discs under different loading conditions can be simulated, thus deepening our understanding of the biomechanical characteristics of lumbar

intervertebral discs. The finite element model can also be used to study the mechanisms of degenerative changes and injuries in lumbar intervertebral discs. By introducing different types of injury models and material parameters, the process of degenerative changes and injuries in lumbar intervertebral discs can be simulated and analyzed, thus exploring the biomechanical mechanisms and prevention strategies of related injuries. Additionally, the finite element model can be used to design and optimize treatment methods for lumbar intervertebral discs. By simulating different surgical procedures and treatment plans, the effects of these procedures on the mechanical performance of lumbar intervertebral discs can be evaluated, guiding the selection of surgical procedures and optimizing the design of treatment plans. In conclusion, the finite element model is a powerful biomechanical modeling tool that plays an important role in lumbar intervertebral disc research. It helps us to deepen our understanding of the biomechanical characteristics of lumbar intervertebral discs, reveal the mechanisms of degenerative changes and injuries, and guide the design and optimization of related treatment methods.

### ***5.2. Multibody Dynamics Model***

The multibody dynamics model is another commonly used biomechanical modeling method used to study the dynamic behavior of multiple interacting rigid bodies or soft tissues in biological systems. In lumbar intervertebral disc research, the multibody dynamics model can be used to simulate and analyze the dynamic response of the spine and lumbar intervertebral discs under different motion conditions. The multibody dynamics model typically treats the spine and lumbar intervertebral discs as multiple rigid bodies or elastic connectors, describing their interaction relationships using physical principles such as Newton's laws of motion and Hooke's law. By solving the model equations numerically, the displacement, velocity, and acceleration of the spine and lumbar intervertebral discs during different motion processes can be simulated and predicted. The multibody dynamics model has important applications in lumbar intervertebral disc research. Firstly, it can be used to simulate and analyze the dynamic behavior of lumbar intervertebral discs under normal physiological conditions. By simulating various daily activities and motion processes of the human body, the loading conditions of lumbar intervertebral discs under different motion states can be studied, revealing the mechanical characteristics and functions of lumbar intervertebral discs. Secondly, the multibody dynamics model can also be used to study the mechanisms of degenerative changes and injuries in lumbar intervertebral discs. By introducing different types of injury models and material parameters, the deformation and stress distribution of lumbar intervertebral discs during loading can be simulated and analyzed, thus revealing the biomechanical mechanisms of degenerative changes and injuries. Finally, the multibody dynamics model can be used to design and evaluate treatment methods for lumbar intervertebral discs. By simulating different surgical procedures and treatment plans, the effects of these procedures on the dynamic behavior of lumbar intervertebral discs can be evaluated, guiding the selection of surgical procedures and optimizing the design of treatment plans. In summary, the multibody dynamics model is an important biomechanical modeling method with broad application prospects in lumbar intervertebral disc research. It helps us to deepen our understanding of the dynamic behavior and mechanical characteristics of lumbar intervertebral discs, reveal the mechanisms of degenerative changes and injuries, and guide the design and evaluation of related treatment methods.

## 6. Clinical Significance and Future Research Directions

Lumbar intervertebral disc-related diseases have a serious impact on patients' quality of life and health, so it is of great significance to study their clinical significance and future research directions. Firstly, understanding the clinical significance of lumbar intervertebral disc-related diseases is crucial for developing personalized treatment plans and improving patients' quality of life. By studying the etiology, influencing factors, and clinical manifestations of diseases in depth, we can better understand the nature and clinical characteristics of diseases, providing scientific basis for clinical diagnosis and treatment. Secondly, future research should focus on the prevention and early intervention of lumbar intervertebral disc-related diseases. By exploring the mechanisms and risk factors of degenerative changes, protrusions, extrusions, and other diseases of lumbar intervertebral discs, effective prevention strategies can be formulated to detect and intervene potential risk factors in advance, reducing the incidence and severity of diseases. Additionally, future research should focus on personalized treatment research and application. The treatment effects of lumbar intervertebral disc-related diseases may vary among individuals, so personalized treatment is particularly important. By studying the individual differences in genetics, biomarkers, clinical characteristics, etc., more precise and effective treatment plans can be formulated to improve the success rate of treatment and patients' quality of life. Finally, future research should also focus on the promotion of clinical translational research. By rapidly translating the achievements of basic scientific research into clinical practice, better treatment plans and services can be provided to patients, improving treatment effectiveness and patients' quality of life. In summary, in-depth study of the clinical significance and future research directions of lumbar intervertebral disc-related diseases is of great significance for guiding clinical practice, improving treatment effectiveness, and patients' quality of life. By focusing on prevention and early intervention, personalized treatment research and application, and the promotion of clinical translational research, better theoretical support and clinical guidance can be provided for the diagnosis and treatment of lumbar intervertebral disc-related diseases.

## 7. Conclusions

Lumbar intervertebral disc-related diseases are one of the significant factors affecting human health, causing serious impacts on patients' quality of life and physical functions. Through in-depth research on the anatomical structure, physiological function, degenerative changes, and biomechanical characteristics of lumbar intervertebral discs, we can better understand the mechanisms and clinical manifestations of these diseases, providing a scientific basis for clinical diagnosis and treatment. Future research should focus on early prevention and intervention of lumbar intervertebral disc-related diseases, personalized treatment research and application, and the promotion of clinical translational research. Through these efforts, we can better prevent and treat lumbar intervertebral disc-related diseases, thereby improving patients' quality of life and health. In conclusion, lumbar intervertebral disc-related diseases are complex medical issues that require interdisciplinary collaboration and ongoing research efforts. With the collective efforts of scientists, we believe that we can better understand the nature of these diseases and provide better medical services and health management programs for patients.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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