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***Research Article***

# Effects of Meniscus Longitudinal Tear on Knee Biomechanics Based on Cross-Ligament Conditions

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**Abstract**

Knee meniscuses are fibrous cartilages that are present to disperse friction in the knee joint between the tibia and femur bones. They work to disperse body weight and reduce friction while moving. Because the condyles of the femur and the tibia converge at one point (which changes as they bend and stretch), the meniscus expand the weight of the body.

It is important to describe the mechanical behavior of the meniscus because of its significant role in bearing the load on the knee joint. Research shows Compressive stresses on the menisci have been shown to be a major factor in destructive joint injuries, including osteoarthritis. Anterior cruciate ligament tearcan also have a profound effect on the meniscus. Clinically, meniscus injury is common in patients with a tear cruciate ligament. The main purpose of this study is to determine the stress distribution diagram of internal and external menisci and to evaluate the comparison of healthy meniscus stress and meniscus tearwith the stability of the cruciate ligament and the instability of this ligament.

The bone structure of a healthy joint was designed and analyzed in ANSYS program package, and the forces applied to the meniscus under the presence or absence of ACL ligament were evaluated.

The results of biomechanical studies showed that tearof the meniscus and the anterior cruciate ligament play an important role in the stability of the meniscus. With the tearof the meniscus and ligament diagram, the distribution of stress and the amount of stress in the meniscus increases, which can be obtained by the interdependence of the meniscus and the surrounding ligaments for normal joint function.

**Keywords:** Meniscus, Cross-Ligament, Knee Biomechanics, FEM.

# Çapraz Bağ Koşullarına Dayalı Menisküsün Boyuna Yırtılmasının Diz Biyomekaniğine Etkileri

**Öz**

Diz menisküsleri, diz ekleminde tibia ve femur kemikleri arasındaki sürtünmeyi dağıtmak için mevcut olan lifli kıkırdaklardır. Hareket halindeyken vücut ağırlığını dağıtmak ve sürtünmeyi azaltmak için çalışırlar. Femur ve tibia kondilleri bir noktada birleştiğinden (ki bu büküldükçe ve esnedikçe değişir), menisküs vücudun ağırlığını dağıtır.

Diz eklemi üzerindeki yükü taşımadaki önemli rolü nedeniyle menisküsün mekanik davranışını tanımlamak önemlidir. Araştırmalar, menisküs üzerindeki baskı streslerinin osteoartrit dahil olmak üzere yıkıcı eklem yaralanmalarında önemli bir faktör olduğunu gösteriyor. Ön çapraz bağ yırtılması da menisküs üzerinde derin bir etkiye sahip olabilir. Klinik olarak menisküs yaralanması çapraz bağ yırtıklı hastalarda sık görülür. Bu çalışmanın temel amacı, iç ve dış menisküsün stres dağılım diyagramını belirlemek ve sağlıklı menisküs stresi ve menisküs rüptürünün çapraz bağın stabilitesi ve bu bağın instabilitesi ile karşılaştırmasını değerlendirmektir.

Sağlıklı bir eklemin kemik yapısı ANSYS program paketinde tasarlanarak analiz edilmiş ve ACL bağı varlığında veya yokluğunda menisküse uygulanan kuvvetler değerlendirilmiştir.

Biyomekanik çalışmaların sonuçları, menisküs ve ön çapraz bağın yırtılmasının menisküsün stabilitesinde önemli bir rol oynadığını göstermiştir. Menisküs ve bağ diyagramının yırtılması ile menisküs ve çevresindeki bağların normal eklem fonksiyonu için birbirine bağımlılığı ile elde edilebilecek olan menisküsteki stres dağılımı ve stres miktarı artar.
**Anahtar Kelimeler:** Çapraz Bağ, Menisküs, Diz Biyomekaniği, SEY

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# 1. Introduction

The meniscus of the knee consists of two semicircular wedge-shaped pieces fixed by a network of ligaments. The human knee consists of an external meniscus and an internal meniscus. That between the condyle of the femur and the tibia are located. The menisci are cartilage-like tissues but much stronger than that and have a high elasticity. Their main task is to absorb the shocks that enter the knee. When running, each time the sole of our foot hits the ground, the calf and thigh bones hit each other hard at the knee joint, and the meniscus reduces the severity of the impact by being located between the two bones. Meniscus function includes joint fluid distribution, articular cartilage nutrition, shock absorption, joint deepening, and compensation for incompatibility between the femoral and tibial condyles, and load bearing. Since the main function of the knee meniscus is load transfer and stability, this tissue must withstand many different forces, including compression, tensile and shear. The structure and composition of each semicircular meniscus are well suited for this purpose. This performance is created by the unique mechanical properties of the meniscus (Carter, Taylor, Spritzer, & Utturkar, 2015).

During normal activities such as walking or climbing stairs, the knee joint experiences loads of 2.7 - 4.9 times the body weight. Overall, the meniscus of the knee is estimated to withstand 45% to 75% of this load. The posterior horn of the meniscus bears more load than the anterior horn. When the knee is bent, it is more prone to injury, and the level of contact between the bones in the joint decreases by 30% for every 40 degrees, indicating variability in the meniscus load-bearing capacity. Various deviations from this morphology can occur through abnormal growth, disease, degeneration, or traumatic injury that results in degeneration and trauma to the meniscus. A meniscus tear may be long, usually starting at the back of the meniscus and may extend to the anterior meniscus. This meniscus, which is now divided into two parts inside and outside due to rupture, can be pressed against the condyle of the femur and its two inner and outer parts can be opened. This open position of the meniscus is called a ruptured bucket handl. Meniscus health toIntensity depends on the ligament joints of the knee. A cruciate ligament tearcan have a profound effect on the meniscus. Clinically, meniscus injury is common in patients with ruptured cruciate ligament, indicating interdependence of the meniscus and surrounding ligaments for normal joint function (Athanasiou & Adams, 2009).

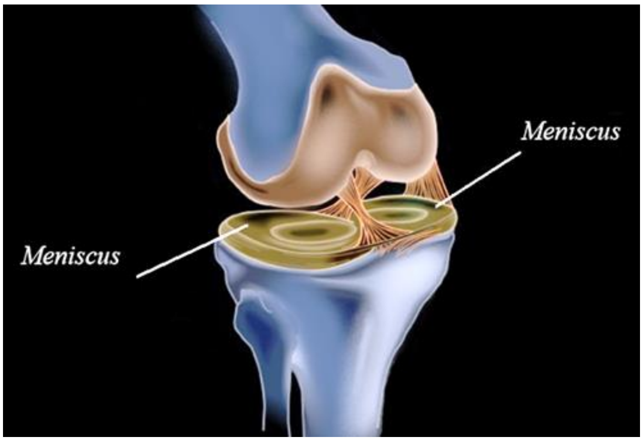

*Figure 1. Knee bone structure*

Due to the function of the meniscus in creating stability and shock absorption, this organ is at risk and the prevalence of meniscus tearin a lot of people, especially athletes. According to previous studies and clinical observations, the highest percentage of meniscus tear is longitudinal tear. In this study, longitudinal meniscus tear was investigated. Research has shown that compressive stresses on the menisci are a major factor in destructive joint injuries, including osteoarthritis. Anterior cruciate ligament (ACL) tear can also have a profound effect on the meniscus. In this study, the distribution of stress on the knee during longitudinal rupture of the internal meniscus along with the stability of the anterior cruciate ligament and the instability of this ligament were investigated (Pena, Calvo, & Martinez, 2005).

The main purpose of this study is to investigate the diagram of compressive stress distribution on the meniscus plates and to evaluate the comparison of healthy Minsk stress and Minsk rupture when the cruciate ligament is intact or torn.

# 2. Material and Method

In the first step, a model of the finite elements of the knee including the femur, tibia and meniscus was developed. Then loading was applied in three different modes including healthy meniscus, longitudinal tear of the meniscus when the ligament was healthy and longitudinal torn of the meniscus with rupture of the ligament on the knee and the results of different loadings were compared. Joint bone structure was meshed in ANSYS software, figure 2. The menisci were assumed to be homogeneous and linear elastic and isotropic transverses with a radial and longitudinal elastic modulus of 20 MPa and a circumferential 140 MPa. The poinson coefficient of the menisci was considered 0.2 in the isotropic plane and 0.3 in the non-isotropic plane and the shear modulus of the modulus Shear 57.7 in MPa from previous finite element studies. The anterior and posterior cruciate ligaments are assumed to be homogeneous, linear, and isotropic with an elastic modulus of 0.8 GPa and a Poisson ratio of 0.3. The meniscus density is 1450 kg/m3 and the density of the anterior and posterior cruciate ligaments is 1240 Kg/m3, respectively, according to previous research. Contact surfaces between femur and meniscus, meniscus and tibia, femur and tibia were modeled for both internal and external articular halves. Anterior and posterior cruciate ligaments, internal and external meniscus are attached to femur and tibia. The menisci transmit about 81% of the total vertical force of weight, of which 49% of the total force of weight is transmitted by the internal meniscus. A vertical pressure of 800 N, equivalent to a person's weight, is applied to the midline of the femur. compressive stress Shear has been compared. Only Static analysis is performed at full extrusion or zero degree of flexion. The results are in good agreement with the results of previous studies evaluated in this field.

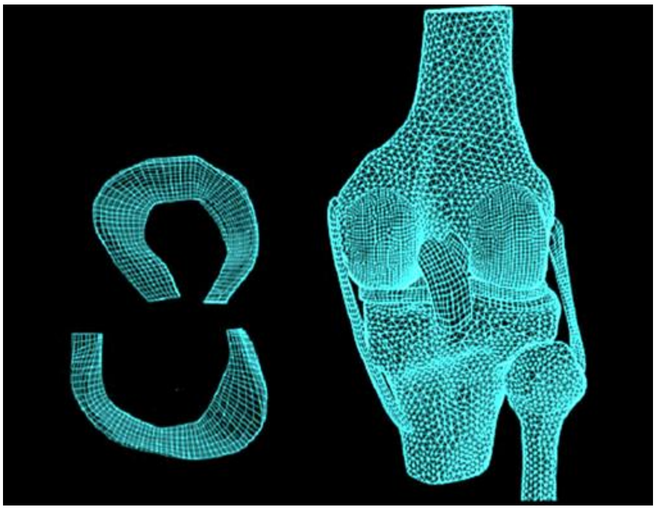

*Figure 2. FEM of Joints and menisci*

*Table 1. Mechanical properties of meniscus, Anterior and posterior cruciate ligament*

| *Model componeants* | *Density Kg/m3* | *Poiss on ratio* |
|---|---|---|
| *Meniscus* | *1450* | *0.26* |
| *Anterior cruciate ligament* | *1240* | *0.3* |
| *Posterior cruciate ligament* | *1240* | *0.3* |

## 3. Results and Discussion

Longitudinal meniscus tear occurs when the anterior cruciate ligament is intact. Maximum contact pressure in the inner meniscus is 33.73 MPa and in the external meniscus is 3.23 MPa. The main stresses are minimum in the inner meniscus with a value of 2.95 MPa and compression, and in the external meniscus with a value of 6.21 MPa and compression. The maximum shear stress on the inner meniscus plate is 8.7 MPa and on the external meniscus plate 4.67 MPa. As a result, the maximum contact pressure in the rupture of the internal meniscus has increased by about 63%. In longitudinal rupture of the internal meniscus with anterior cruciate ligament, the maximum contact pressure occurs in the internal meniscus with a value of 5.99 MPa and in the external meniscus with a value of 2.86 MPa. The main stresses are minimum in the inner meniscus with a value of 6.38 MPa and compressive, and in the external meniscus with a value of 9.33 MPa and compressive. The maximum shear stress on the inner meniscus plate is 6.38 MPa and on the external meniscus plate is 9.33 MPa. Contact pressure is 6.82 MPa in ligament rupture and 3.25 MPa in healthy ligament. As a result, the maximum contact pressure in the ligament rupture has increased by about 54%.

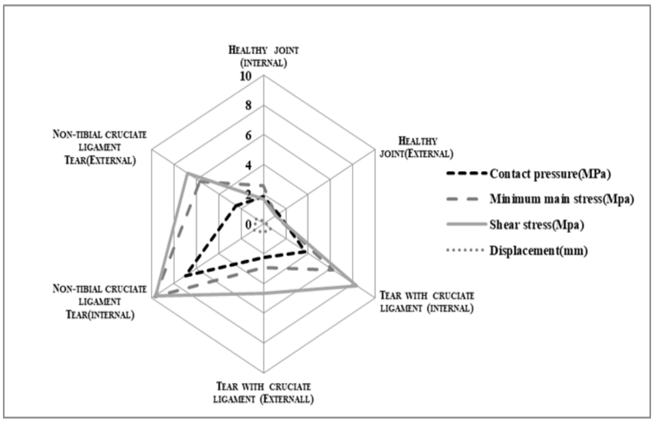


*Figure 3. Comparison of analysis values in different modes*

The model was compared with the logical results of previous papers, and although most of the results were qualitatively expressed, this study was able to provide a better understanding of the biomechanical behavior of the knee joint and different treatment methods. Previous studies have compared the types of meniscus tears, the effect of meniscectomy on the biomechanics of the knee to determine the critical areas of the meniscus to be considered in surgery, and compared the types of meniscectomy, but at the same time, longitudinal meniscus rupture when healthy or Anterior cruciate ligament rupture has not been investigated. The results of this study showed that ligaments play an important role in the stability of the menisci and the results show that the interdependence of the meniscus and surrounding ligaments for normal joint function can be obtained. In many previous 3D models, the femur and tibia were assumed to be homogeneous and orthotropic elastic, which in this modeling was considered first with orthotropic properties and then as rigid; However, due to the close results, in order to reduce the volume of calculations, in this study, the behavior of the dense femur and tibia bones was considered as rigid. Numerical results showed that each meniscus tear leads to an increase in compressive and shear stress in the meniscus on the inside of the knee, especially for the meniscus with anterior cruciate ligament rupture. According to the results obtained in ligament rupture, the amount of stress and stress distribution diagram increased. The prevalence of longitudinal rupture is higher in the internal meniscus. In a healthy knee, the maximum amount of tension in the internal meniscus is higher than in the external meniscus, so the internal meniscus will be more damaged. The areas receiving the maximum stresses are also different in these two, the maximum stresses are located in the inner meniscus in the posterior part and in the external meniscus in the anterior part of its edges. The amount of shear stress, displacement and strain is higher in the areas of the meniscus where more stress is applied. And weight gain strongly affects the amount of meniscus deformation and shear stress, but weight gain does not change the distribution and displacement diagrams.

## 4. Conclusions and Recommendations

The meniscus is known as the part of the knee joint that has limited regenerative capacity. The finite element method can be used to evaluate the load, to investigate the distribution of stress components and strain components, and finally to predict the mechanical behavior and stability of the knee meniscus and surrounding ligaments. This model provides a better understanding of the role of the meniscus in transmitting the force of weight on the knee.

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In fact, the precise three-dimensional finite element model of the knee joint can be used in many medical fields such as accident simulation, sports equipment design, orthopedic implant design and construction simulation, and surgical equipment improvement. Therefore, the results of stress distribution on the menisci at the clinical level are used in meniscectomy surgeries and artificial meniscus construction (Grassi, Dal Fabbro, & Di Paolo, 2021).

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