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The Effect of Proximal Fibula Osteotomy on Meniscus and Articular Cartilage Using the Finite Element Method

The graduate school of University of Ulsan

Department of Mechanical Engineering

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By

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LI TIANSHU의 공학석사학위 논문을 인준함

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The Effect of Proximal Fibula Osteotomy on Meniscus and Articular Cartilage Using the Finite Element Method

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Abstract

Arthritis generally refers to the occurrence of the body's joints and surrounding tissues, by inflammation, infection, degradation, trauma or other factors caused by the inflammatory disease, can be divided into dozens of. The number of people is increasing all over the world. The clinical manifestations are joint redness, swelling, heat, pain, dysfunction and joint deformity, which can lead to joint disability and affect patients' quality of life. Joint space too small can cause arthritis. Joint space means the space between the joints of the body. In the case of the knee joint, the medial part of the knee joint is the cruciate ligament and the meniscus, and above the meniscus is the femur and below the meniscus is the tibia; There are ligaments, bursa, synovium, muscle, tendon, fat and many other structures around the joint. These structures are not closely connected when the knee joint is relaxed. There will be Spaces in these tissues, and there will be joint fluid or tissue fluid in the gap. Patient’s joint space and after fibula osteotomy joint space are shown in Figure 1. Traditional arthritis surgery (High Tibia Osteotomy) is expensive, complex and difficult for older patients to recover from. Proxima Fibula Osteotomy which has emerged in recent years, has the advantages of being less invasive and cheaper. However, without theoretical

support from the perspective of mechanical mechanics, this experiment mainly carried out CAE simulation on the leg models of varus angle 0°, 3° and 5° patients, so as to provide theoretical support for the new type of surgery.

To study the effect of the-upper and middle fibula osteotomy on the-knee stress in patients with osteoarthritis of the knee. Methods CT scans of the affected knee and full-length weighted X-rays of both lower limbs were performed on a normal male subject. CT data were obtained and a three-dimensional finite element model of the knee was constructed. 3-Matic software to rotate the femur 3 ° and 5 ° to simulate knee stress immediately after proximal fibula osteotomy (PFO) surgery and one month after. Preoperative immediately post-operative, and six months post-operative results indicate that; stress on the medial meniscus had a decreasing trend, while stress on the lateral meniscus increased significantly.

Three-dimensional finite element calculations and analysis, theoretically confirmed that upper and middle fibula osteotomy can reduce medial knee stress as a treatment for medial compartment osteoarthritis of the knee.

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Chapter 1 Introduction

Osteoarthritis is the most common cause of disability pain and immobility in elderly people. According to Yingze ’s theory of Uneven Knee Settlement [1,2], the lateral tibial plateau does not collapse due to complete fibula support; rather, the medial tibial plateau has greater settlement than the lateral platform due to this lack of support, which in turn leads to a gradual increase in the knee varus. Proximal fibula osteotomy removes part of the proximal fibula bone, making fibula support incomplete, thus, weakening the support of the fibula to the lateral tibial platform. Osteoarthritis is a degenerative disease. It is caused by degeneration of articular cartilage, reactive hyperplasia of joint margins and subchondral bone caused by aging, obesity, strain, trauma, congenital abnormalities of joints, and joint deformities. Osteoarthropathy, degenerative arthritis, senile arthritis, hypertrophic arthritis, etc. The clinical manifestations are slowly developing joint pain, tenderness, stiffness, joint swelling, restricted mobility, and joint deformities. The main treatment for arthritis is to reduce the weight of the joints and excessive large-scale activities to delay the progress of the disease.

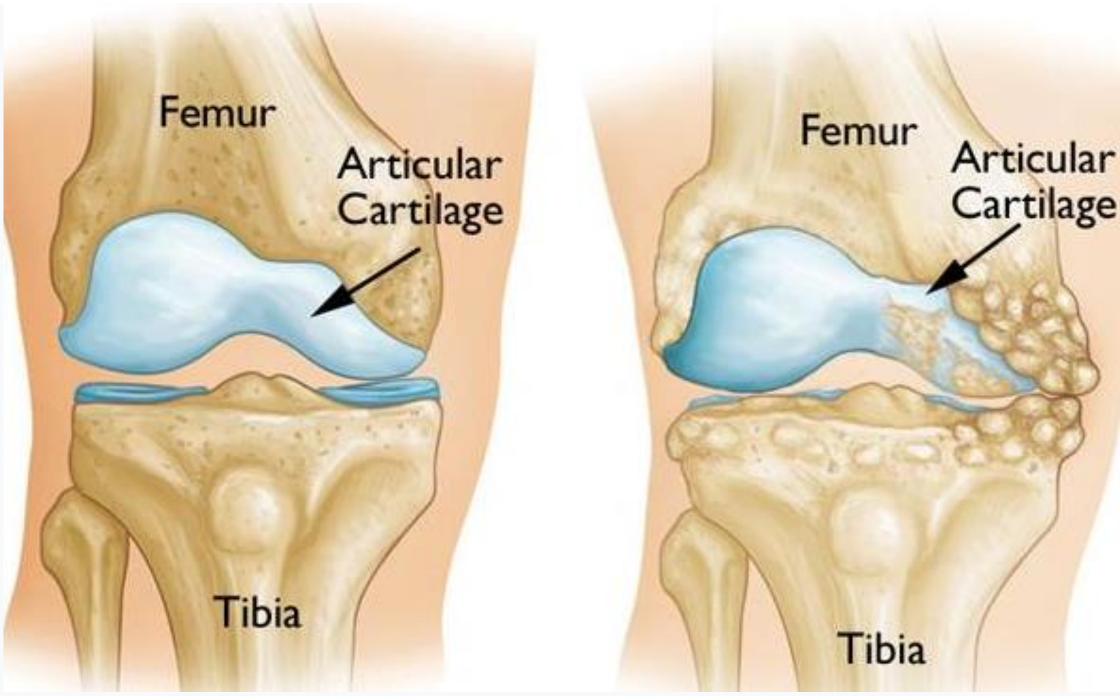


Figure 1-1. Humans knee joint

Obese patients should lose weight and reduce joint load. Crutches or walking sticks can be used when the joints of the lower extremities are damaged in order to reduce the burden on the joints. Physiotherapy and appropriate exercise can maintain the range of motion of the joints, and if necessary, use splint braces and canes, etc., to help control acute symptoms. Anti-inflammatory analgesic drugs can reduce or control symptoms, but should be used with caution after evaluating the patient's risk factors and should not be taken for a long time. Cartilage protective agents such as glucosamine sulfate have the effect of relieving symptoms and improving functions, while long-term use can delay the structural progress of the disease. For advanced cases, under the condition that the whole body can tolerate surgery, artificial joint replacement is currently recognized as an effective method to eliminate pain, correct deformities, and improve function, which can greatly improve the quality of life of patients.

At the same time as the knee joint moves outward, the lower limbs bear the weight. The force line can be recovered to a certain extent, eventually preventing the symptoms from worsening and relieving knee pain. [3,4,5,6] Although high tibial osteotomy (HTO) is the preferred treatment for young patients with medial compartment osteoarthritis of the knee, HTO has several potential postoperative drawbacks. A 2015 study reported that proximal fibula osteotomy (PFO) can relieve pain and improve joint function for knee osteoarthritis patients.

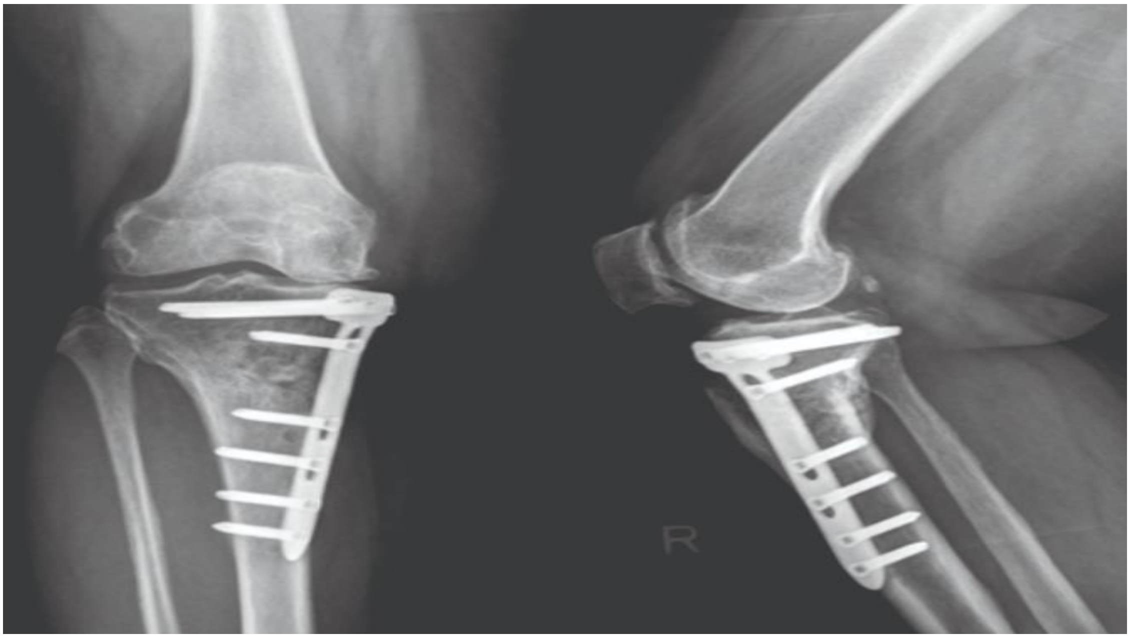


Figure 1-2. CT files of patients with arthritis after high tibial osteotomy (HTO)

PFO has the relative advantages of being a simple operation that is less invasive and less prone to infection, involves an easy recovery after surgery, and is inexpensive. Almost all patients'pain was relieved after surgery. In the subgroup of patients with osteoarthritis of the knee joint, PFO either delayed or replaced HTO. All osteotomies were performed with a proximal posterolateral approach to the fibula. The surgical incision for PFO should be approximately 4 cm which is slightly behind. After finding the gap between the long and short fibula and the soleus muscle, the soleus bluntly separated from the fibula, revealing the fibula after subperiosteal dissection. At 6 cm below the fibular head, the approximately 2 cm fibula segment was excised, and the broken end was sealed with bone wax to prevent the broken end of the fibula from healing. From the 4th to 14th days post-surgery, patients continued to strengthen the knee joint through active and passive flexion and extension exercises, gradually extending their walking distance with support from a walker and then with crutches. Three weeks post-surgery, patients walked with full weight on the knees. CT and MRI scans of patient knees were conducted six months after osteotomy.

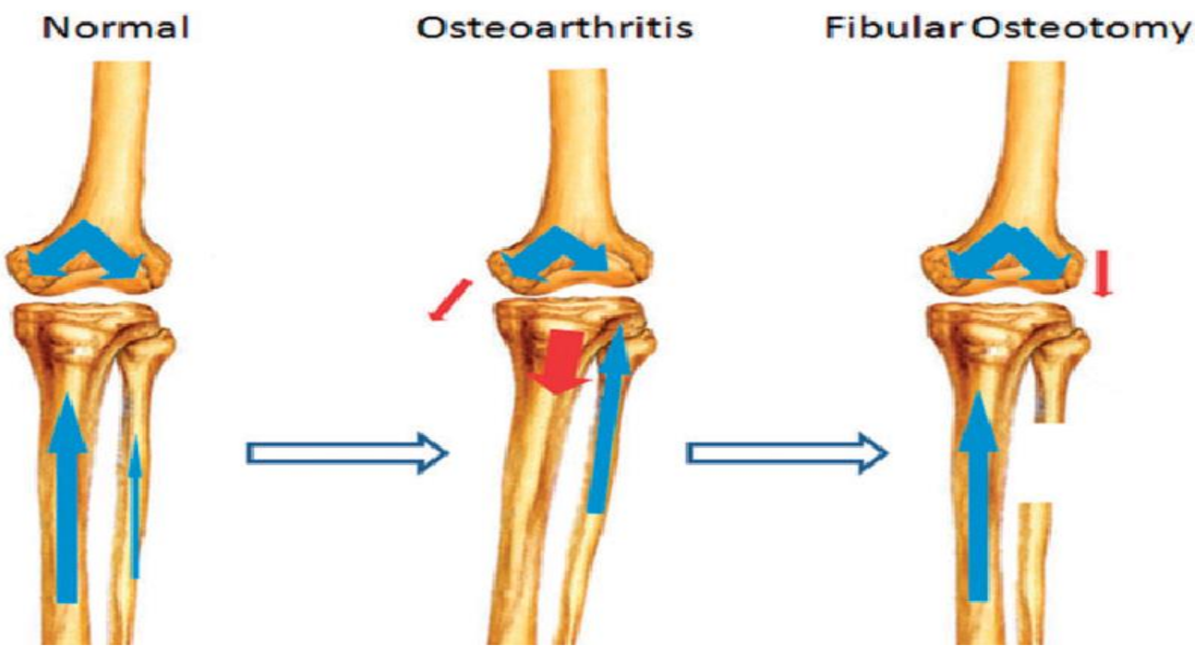


Figure 1-3. Force distribution on the leg. (Normal person、Patient and Patient after fibular osteotomy)

With the development of FEM (Finite Element Method) technology. Many mechanical engineering problems can be solved by finite element method. FEM is a mathematical approximation method for simulating the real physical system (geometry and load conditions). A real system with a finite number of unknowns can be approximated with an infinite number of unknowns by using simple and interacting elements (that is, units). Finite element analysis is to replace complex problems with simpler ones and then solve them. It regards the solution domain as composed of a number of small interconnected subdomains called finite elements, assumes a suitable (relatively simple) approximate solution for each element, and then deduces that the solution of this domain satisfies the overall conditions (such as the structural equilibrium conditions), thus obtaining the solution of the problem. Since the actual problem is replaced by a simpler one, the solution is not an exact one, but an approximate one. Because most practical problems are difficult to get an accurate solution, the finite element method has become an effective engineering analysis method because of its high computational accuracy and adaptability to various complex shapes. Finite elements are discrete elements that collectively represent the actual continuous domain. The concept of the finite element has been around for centuries, such as approximating a circle with a polygon (a finite number of linear elements) to find its circumference, but it has only recently been proposed as a method. Initially known as matrix approximation, finite element method (FEM) has been used to calculate the structural strength of aircraft and is of great interest to mechanics scientists because of its convenience, practicability and effectiveness. After decades of efforts, with the rapid development and popularization of computer technology, finite element method has rapidly expanded from structural engineering strength analysis and calculation to almost all fields of science and technology, and become a colorful, widely used and practical and efficient numerical analysis method. In this study, we used ABAQUS to conduct CAE simulations of a fibula model to evaluate the short-term efficacy of fibula osteotomy for alleviating pain and improving joint space function.

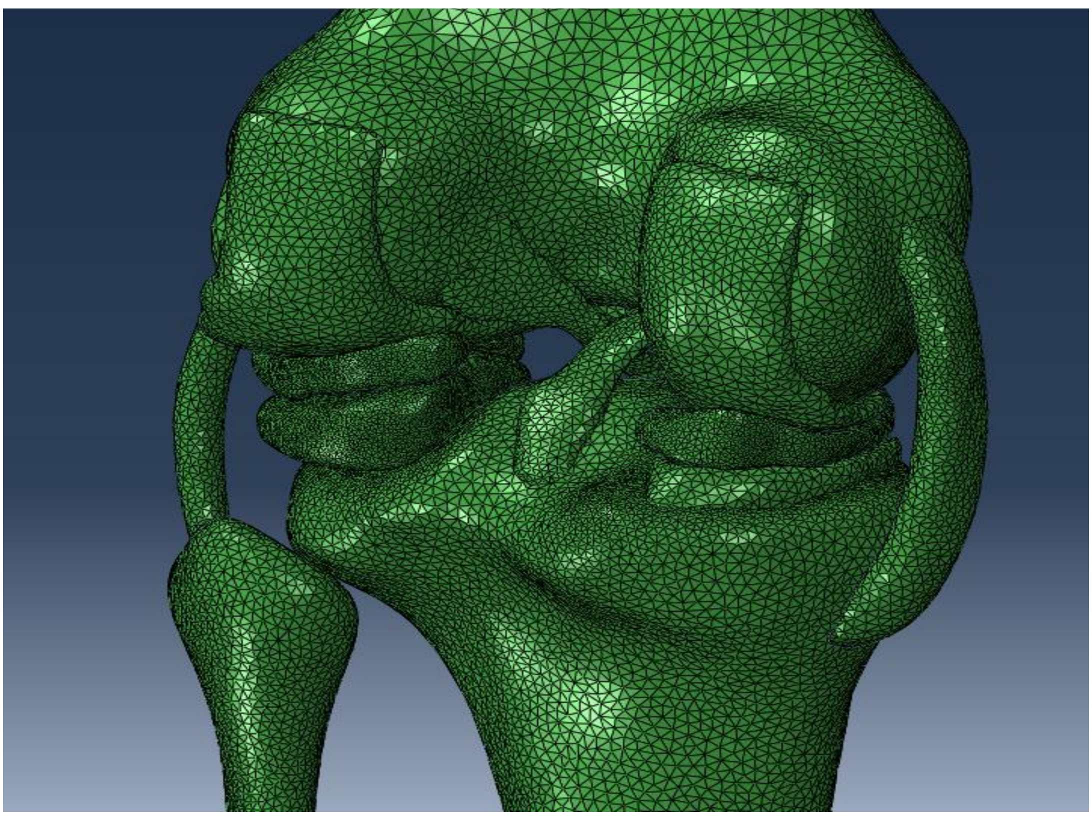


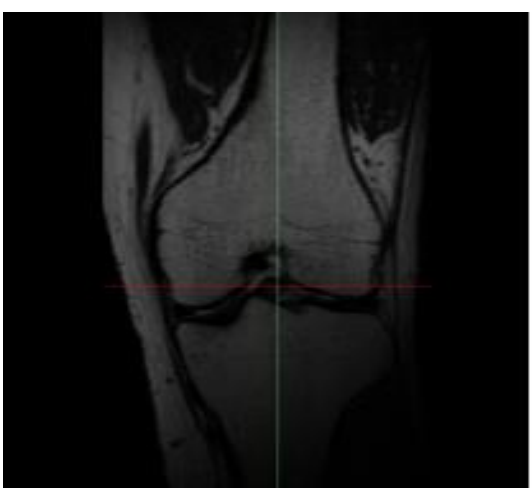
Figure 1-4. Knee joint model in ABAQUS

The varus angle is a term used to describe how the kinetic chain works. The healthy varus angle enables us to move our body efficiently by properly supporting all the elements in the dynamic chain. Abnormal varus angle cause the body to "overcompensate" the "weak links" in the kinetic chain, leading to increasing energy consumption, muscle fatigue and pain. In this simulation experiment, we will perform the simulation work of the knee joint of patients with varus angle of 10 °, 5 ° and 3 °.

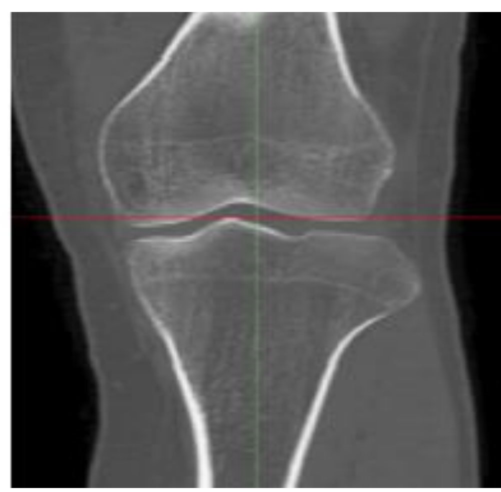
Chapter 2 Material and Method

2.1 Modeling

A normal person's knee joint (healthy, no history of arthritis, weight 80kg) underwent CT and MRI scanning and Mimics software was used to extract the data, reconstruct the knee joint geometric model, export the data in STL format file. In this research, we tried a surgical method different from the traditional one. About 2cm of fibula was excised at the middle end of the fibula, and the broken end was sealed with bone wax to prevent the broken end of the fibula from healing. To find out which method is better than the traditional one.



MRI FILE



CT FILE

Figure. 2-1. CT and MRI images of the knee joint Data Analysis

Repair the model in 3-Matic software and a mesh file was established after smooth processing. A 3-Matic INP file was then imported into ABAQUS for finite element analysis. Based on the previously validated knee-joint FE model, the following features were included in this study. An FE model of the knee joint with accurate anatomy was developed using data obtained from medical imaging of a healthy, skeletally mature, young male with no history of knee injury. The model included of the lower extremity in addition to soft tissue details of patellofemoral and tibiofemoral aspects of the knee joint. It also included the major ligaments, articular cartilage, and menisci. Scans were obtained using a supine imaging apparatus in which the legs were in an unloaded neutral position. The CT and MRI scans were developed with slice thicknesses of 1 mm and 1 mm, respectively. The CT data were imported into the Mimics software (version 14.1; Materialise, Leuven, Belgium), which was used to developed the three-dimensional (3D) geometrical surface of the femur, tibia, and, fibula at full extension. The medial and lateral menisci, femoral cartilage, and major ligaments were developed manually in 3D reconstruction models based on MRI. MRI was also used to reconstruct a femur with a distal thickness of 10.2 cm and a tibia with a proximal thickness of seven centimeters. To match the positional coordinates of each model, we defined anatomic reference points as the central point of the diaphysis of the femur in the reconstructed CT and MRI models.

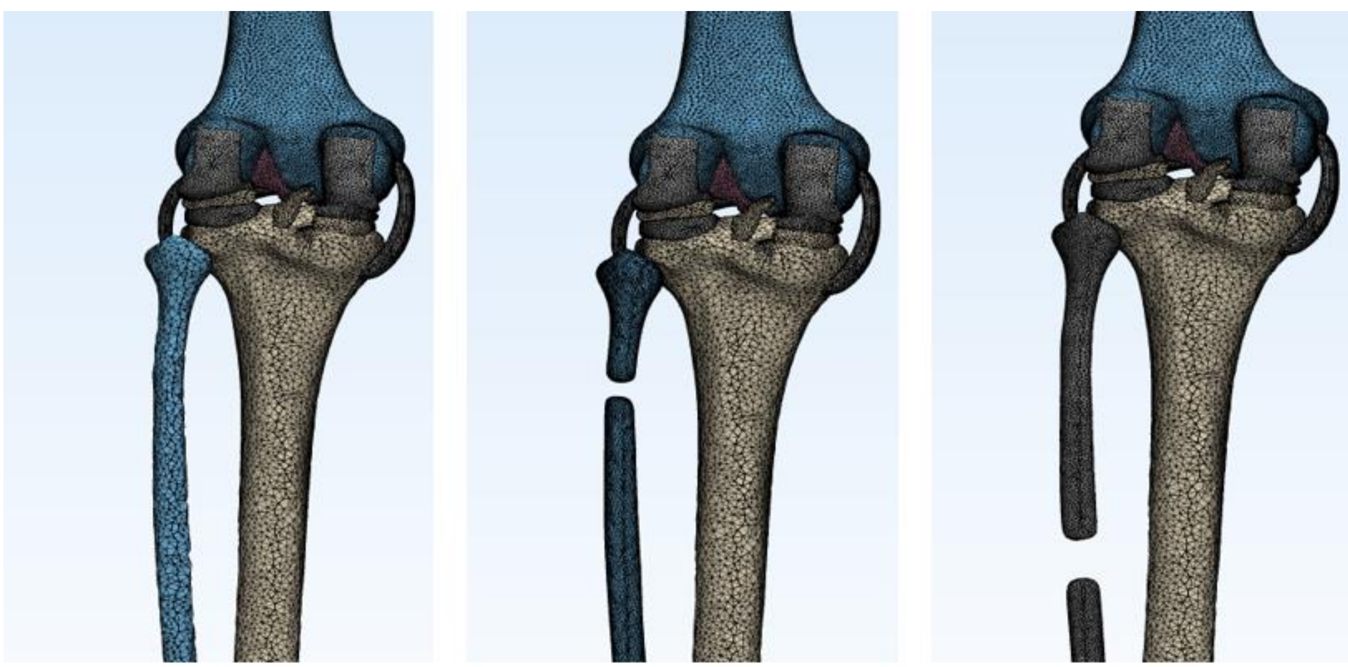


Figure. 2-2. 3-Matic models of new before PFO、 after PFO and new method model

2.2 Model Validation

In order to ensure the accuracy of the results, the accuracy of the model is the most important. Therefore, we must compare the shear stress of each soft tissue of the knee joint with the same load, boundary conditions, and material properties as compared with other papers to ensure that our model can be used. To compared with Lan Li's paper.The model in this paper was verified by using an adult male with a height of 178cm, weight of 65kg, healthy legs and no history of arthritis as the basic model. Comparison of the simulation results of healthy human joints in SCI papers If we apply the same load, the same boundary conditions, the same material properties, we can get roughly the same results. The load we applied in the model validation was 1150N, and the boundary condition was that the femur was fixed in the X and Y directions, and the femur was rotated and fixed in the X1,Y1 and Z1 directions. Only degrees of freedom are left in the Y direction. So we can prove that the structure of our model is all right. So we can see the results, the shear stress on the soft tissue of knee joint almost the same Figure (3,4,5).

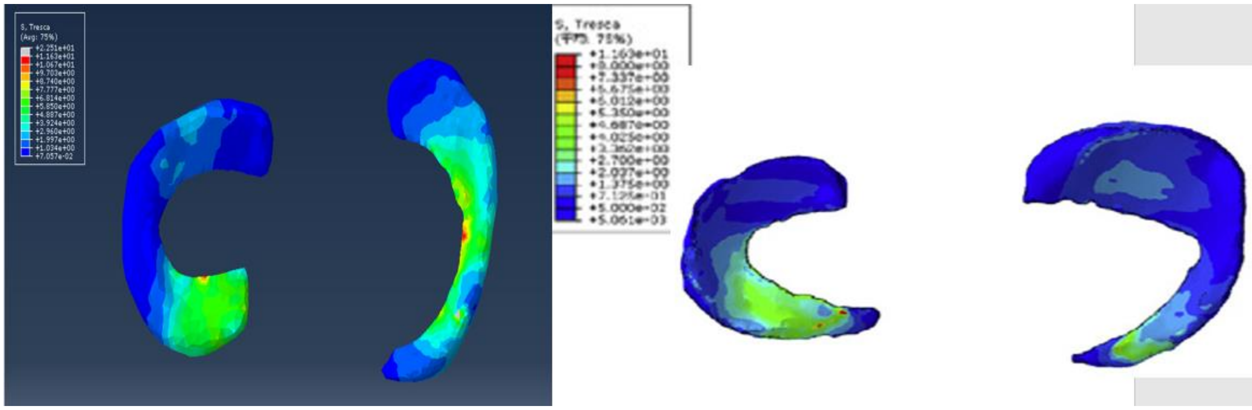


Figure.2-3 The shear stress on the meniscus. (Left is my result. Right one is from SCI paper)

In Figure.2-3, we can see shear stress distribution, maximum shear stress almost the same as SCI paper. The maximum shear stress all concentrate on the lateral meniscus, the maximum shear stress is 11.63MPa.

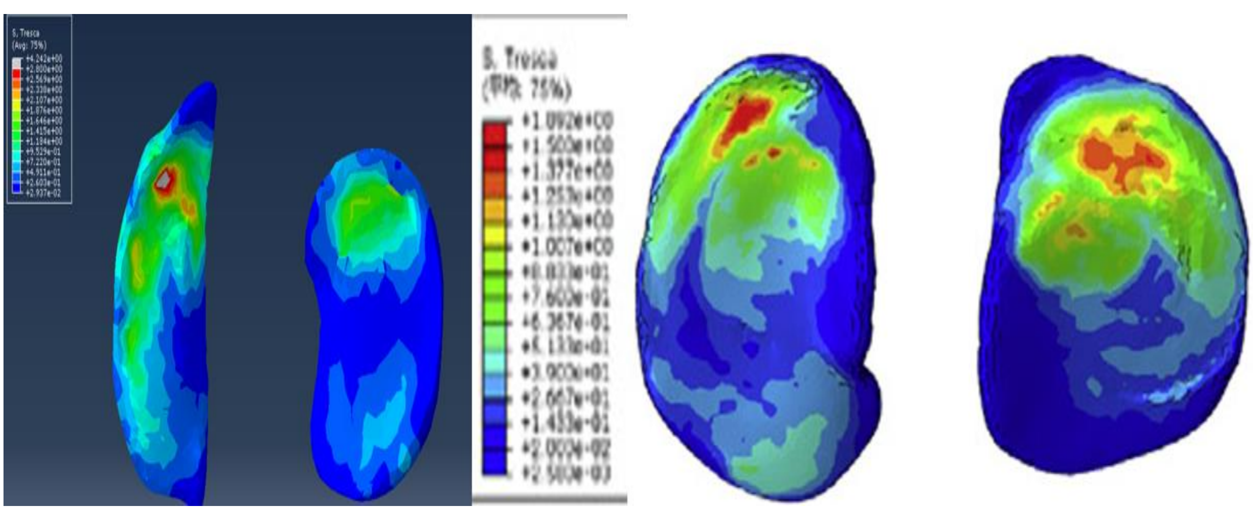


Figure.2-4 The shear stress on the tibia cartilage. (Left is my result. Right one is from SCI paper)

In Figure.2-4, we can see shear stress distribution, maximum shear stress almost the same as SCI paper. The maximum shear stress all concentrate on the medial tibia cartilage, the maximum shear stress is 11.63MPa.

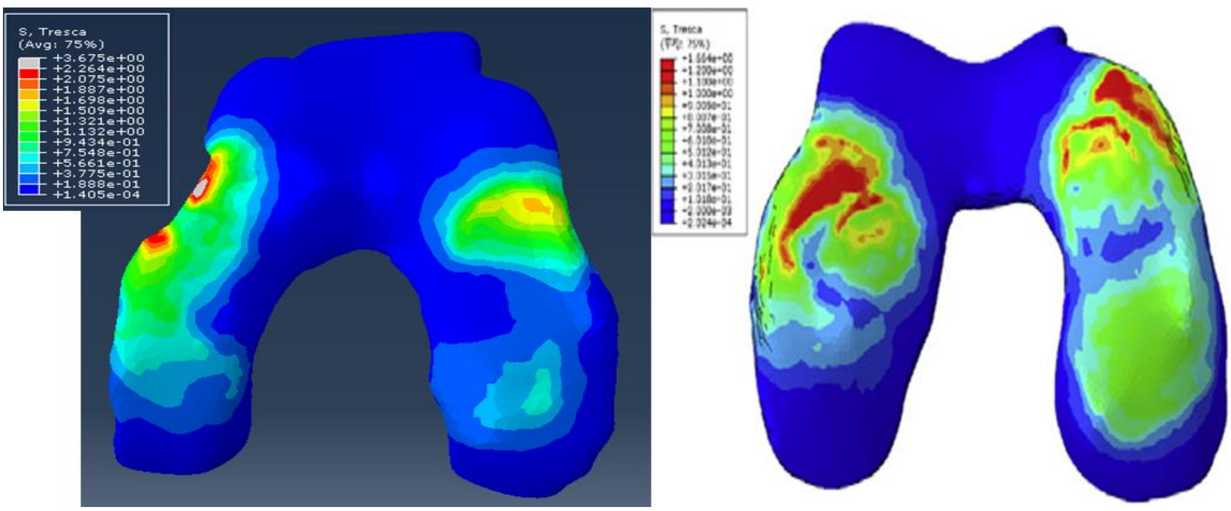


Figure.2-5 The shear stress on the femur cartilage. (Left is my result. Right one is from SCI paper)

In Figure.2-5, we can see shear stress distribution, maximum shear stress almost the same as SCI paper. The maximum shear stress all concentrate on the medial femur cartilage, the maximum shear stress is 11.63MPa. Above all, it can be concluded that the shear stress of our model on the meniscus and knee cartilage is approximately the same under the same loading, material properties and boundary conditions. Our model can be used for simulation and get accurate results

2.3 Material properties

Part	Young' s modulus (MPa)	Poisson' s ratio
Bone	5000	0.3
cartilage	50	0.46
meniscus	59	0.49
ligament	45	0.48

Figure.2-6 Tissue properties of the human knee.

Tissues material properties are shown in Figure 1. Part ‘Bone’ including femur、fibula and tibia.

Part ‘cartilage’ including tibia cartilage and femur cartilage. Part ‘meniscus’ including lateral meniscus

and medial meniscus. Part ‘ligament’ including cruciate ligaments、lateral ligament and medial ligament.

2.4 Load and Boundary Condition

The subject of our simulation is an 80-kg male thus, the reference point was set 50 mm above the femur which defined the upper part of the femur by coupling. In order to perform the simulation work that pressure of human body weight on the femur. We select a reference point in ABAQUS and use the coupling command to attach the reference point to the femoral upper surface. The concentration force of 400 newtons is applied to the reference point. So that the force of 400 newtons is evenly applied to the top of the femur. Force (400 Newtons) was applied to the reference point to simulate body weight pressure against the femur. We fixed the midsection of the femur in the X and Y directions and fixed the bottom of the tibia and fibula.

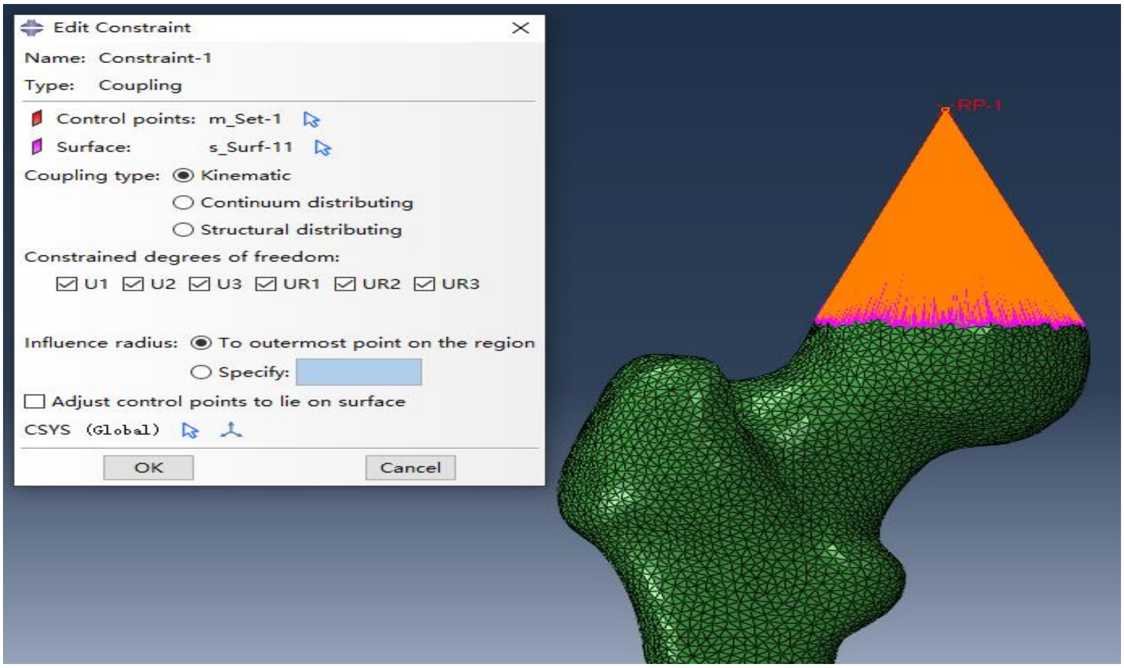


Figure. 2-7 Boundary Condition in simulation work.

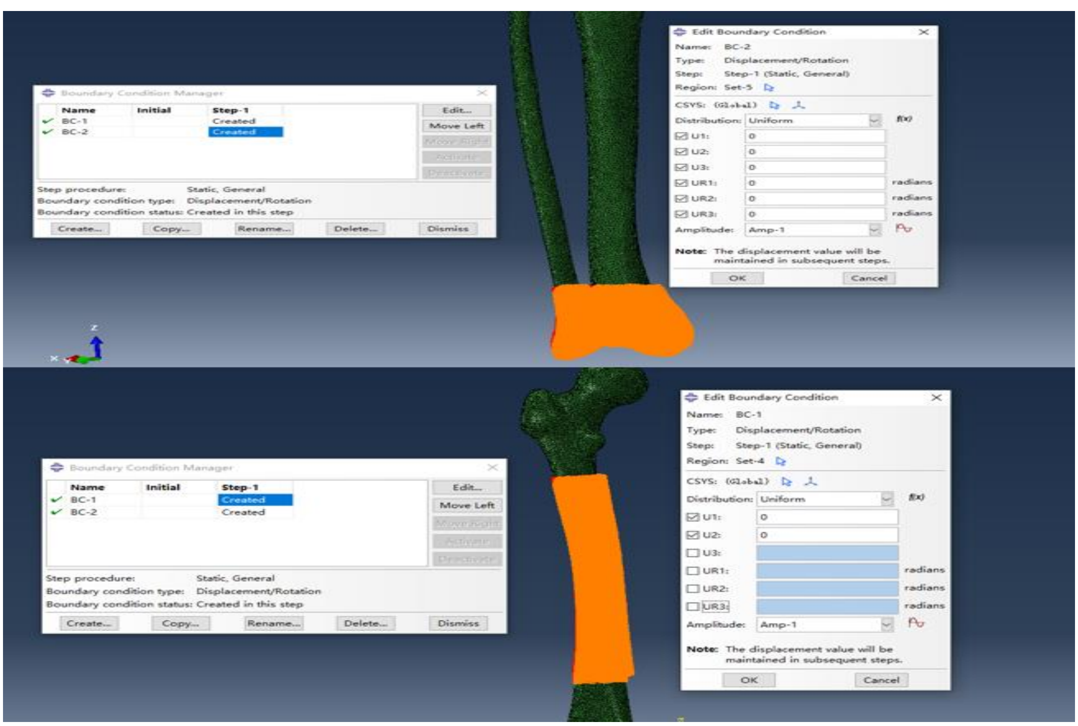


Figure. 2-8 Boundary Condition in simulation work.

Based on the structure of the human body, there is no slide between bone (femur and tibia) and cartilage. So, in this research we used constraint is Tie. Between meniscus and cartilages, I used interaction is surface to surface, and defined the coefficient of friction is 0.05. [7]

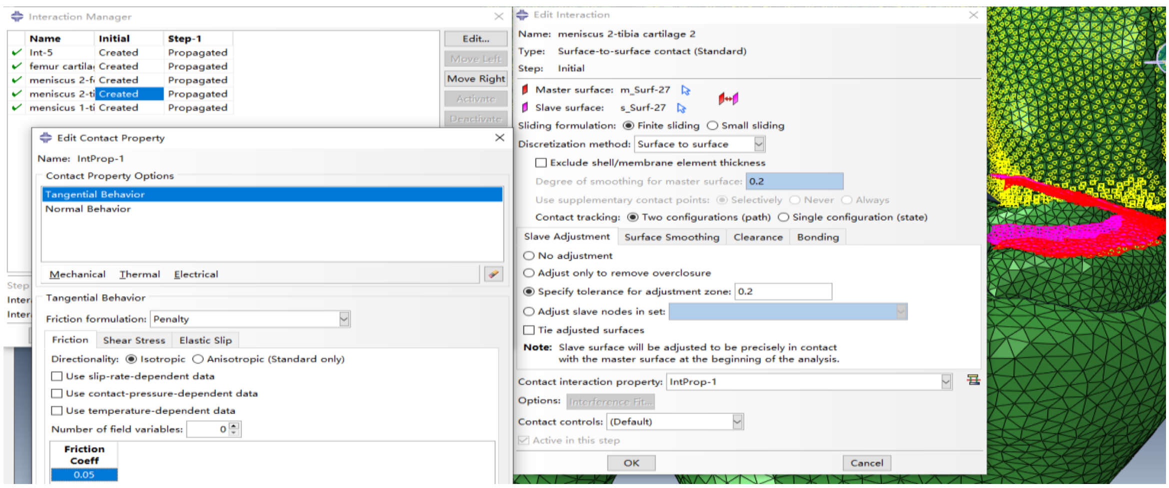


Figure. 2-9 Interaction between meniscus and cartilage.

Chapter 3 Result

3.1 Stress on the meniscus

Prior to surgery, stress is mainly concentrated on the medial meniscus. After surgery, stress is evenly distributed across the two meniscuses, which reduces stress on the internal meniscus and, thus, reducing the concentration force on the patient's knee joint. Figure 4 shows a patient's Varus Angle at 5°in a patient before undergoing PFO operation, and then after PFO, when the patient's Varus Angle returned to 3°, at which point, the meniscus was fully recovered.

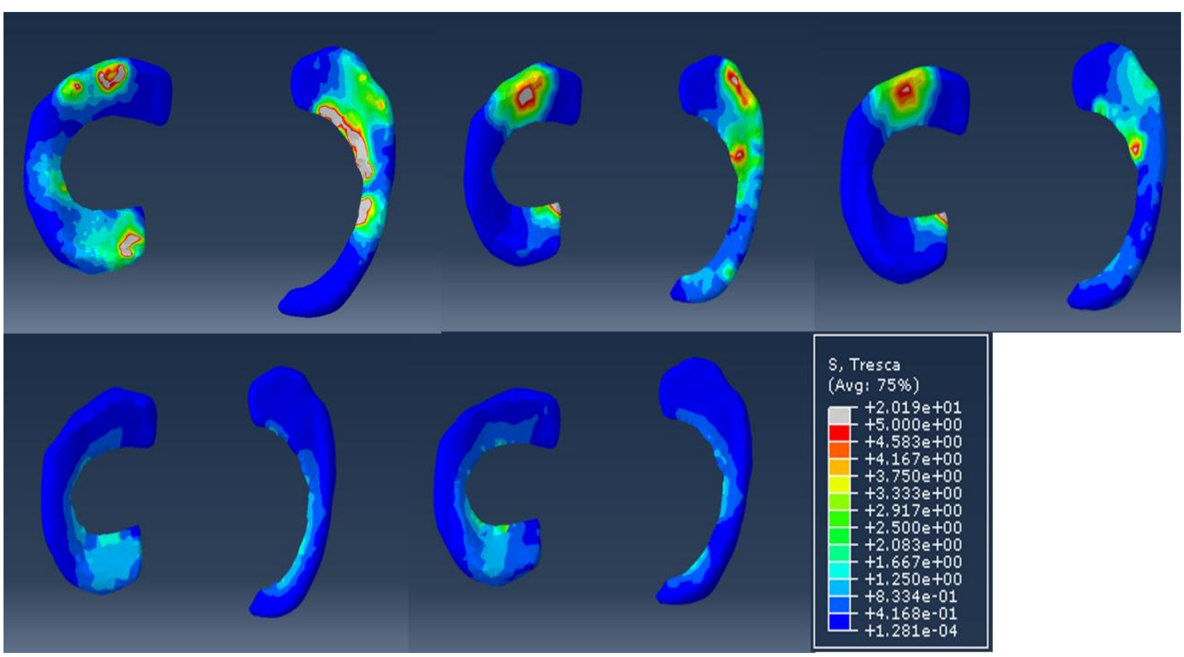


Fig. 3-1. Stress on the meniscus before and after osteotomy(10° before PFO, 10° After PFO，5° ，3° ，0°).

Through CAE simulations, we can show that when the patient's varus angle is 10°, the maximum shear stress on the meniscus is 20.19Mpa. For a short period, the Varus Angle remained unchanged, and the meniscus shear stress reduced to 15.58Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 5°, and the maximum shear stress on the meniscus further reduced to 10.63Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 3°, and the maximum shear stress on the meniscus further reduced to 3.18Mpa. After the patient fully recovered, the shear stress on the meniscus was 3.14 MPa.

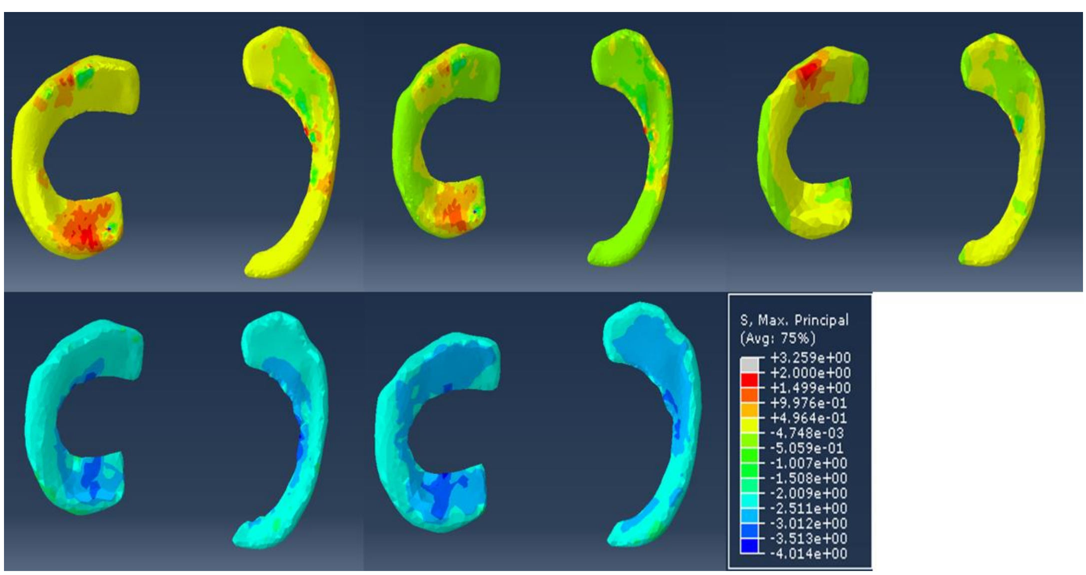


Fig. 3-2. Compressive stress on the meniscus before and after osteotomy(10° before PFO, 10° After PFO，5°，3°，0°).

Through CAE simulations, we can show that when the patient's varus angle is 10°, the maximum compressive stress on the meniscus is 3.26Mpa. For a short period, the Varus Angle remained unchanged, and the meniscus compressive stress reduced to 2.73Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 5°, and the maximum compressive stress on the meniscus further reduced to 1.55Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 3°, and the maximum compressive stress on the meniscus further reduced to 1.15Mpa. After the patient fully recovered, the compressive stress on the meniscus was 1.13 MPa.

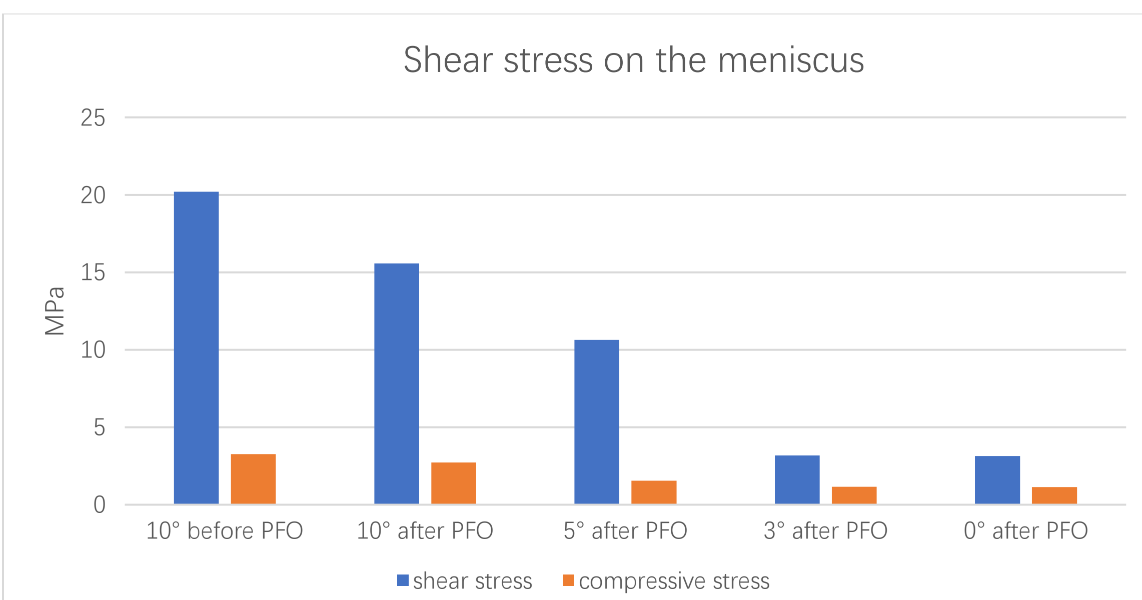


Fig. 3-3. Compressive stress and shear stress on the meniscus (MPa)

3.2 stress on the femur cartilage

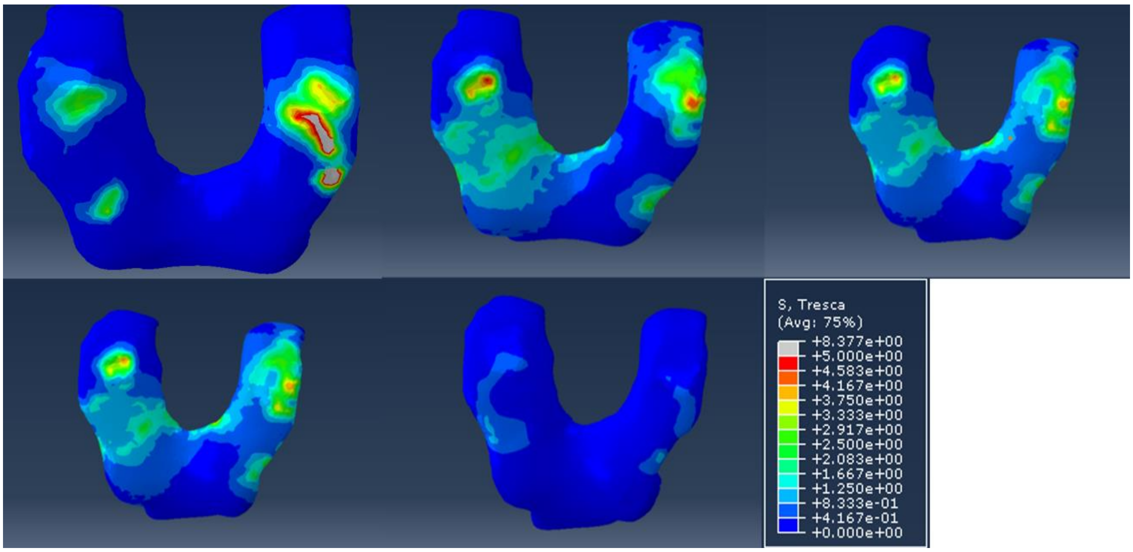


Fig. 3-4. Shear stress on the femur cartilage Before and after osteotomy(10°, 5°, 3°, 0°).

The same as meniscus, we can show that when the patient's varus angle is 10°, the maximum shear stress on the femur cartilage is 8.33Mpa. For a short period, the Varus Angle remained unchanged, and the femur cartilage shear stress reduced to 5.0Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 5°, and the maximum shear stress on the femur cartilage further reduced to 4.17Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 3°, and the maximum shear stress on the femur cartilage further reduced to3.75Mpa. After the patient fully recovered, the shear stress on the femur cartilage was 1.01 MPa.

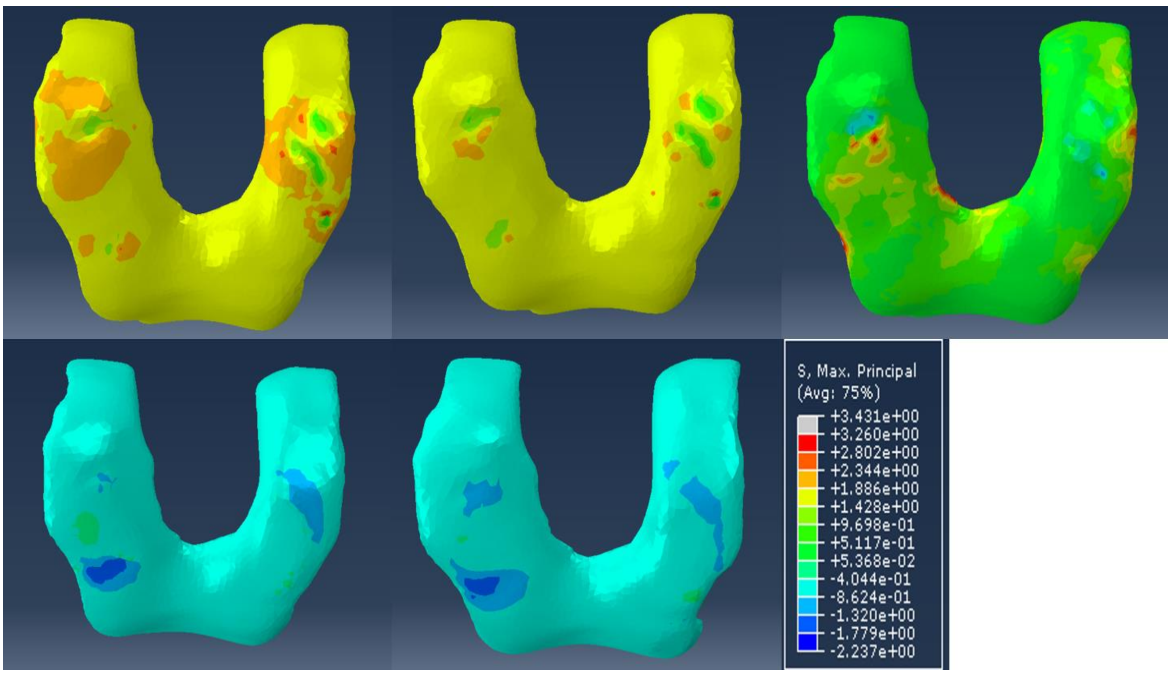


Fig. 3-5. Compressive stress on the meniscus before and after osteotomy(10° before PFO, 10° After PFO，5°，3°，0°).

Through CAE simulations, we can show that when the patient's varus angle is 10°, the maximum compressive stress on the femur cartilage is 3.26Mpa. For a short period, the Varus Angle remained unchanged, and the femur cartilage compressive stress reduced to 2.73Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 5°, and the maximum compressive stress on the femur cartilage further reduced to 1.55Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 3°, and the maximum compressive stress on the femur cartilage further reduced to 1.15Mpa. After the patient fully recovered, the compressive stress on the femur cartilage was 1.13 MPa.

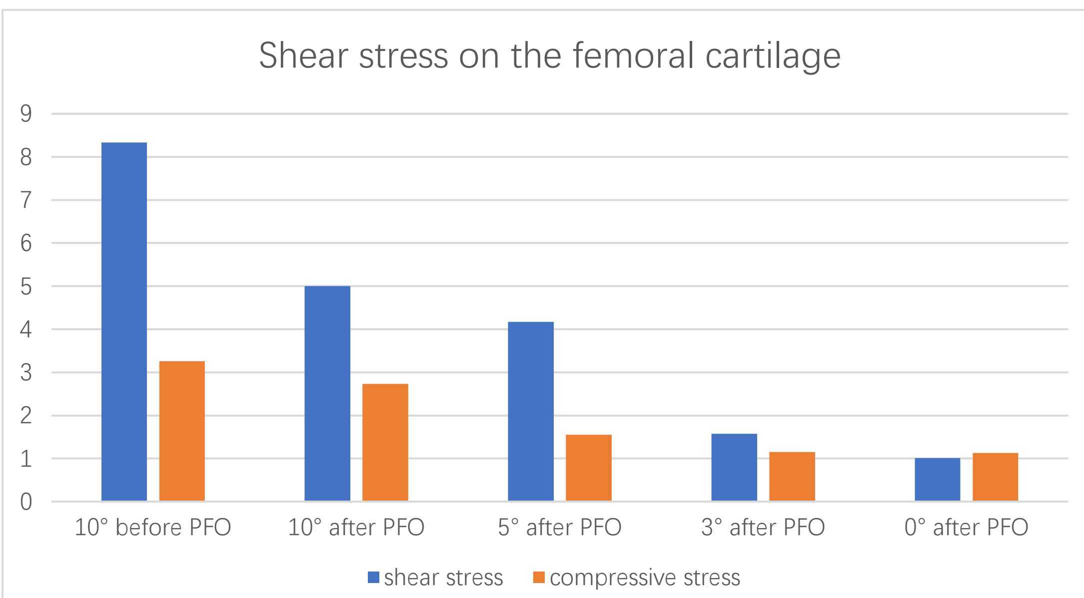


Fig. 3-6. Compressive stress and shear stress on the femur cartilage (MPa)

3.3 Stress on tibia cartilage

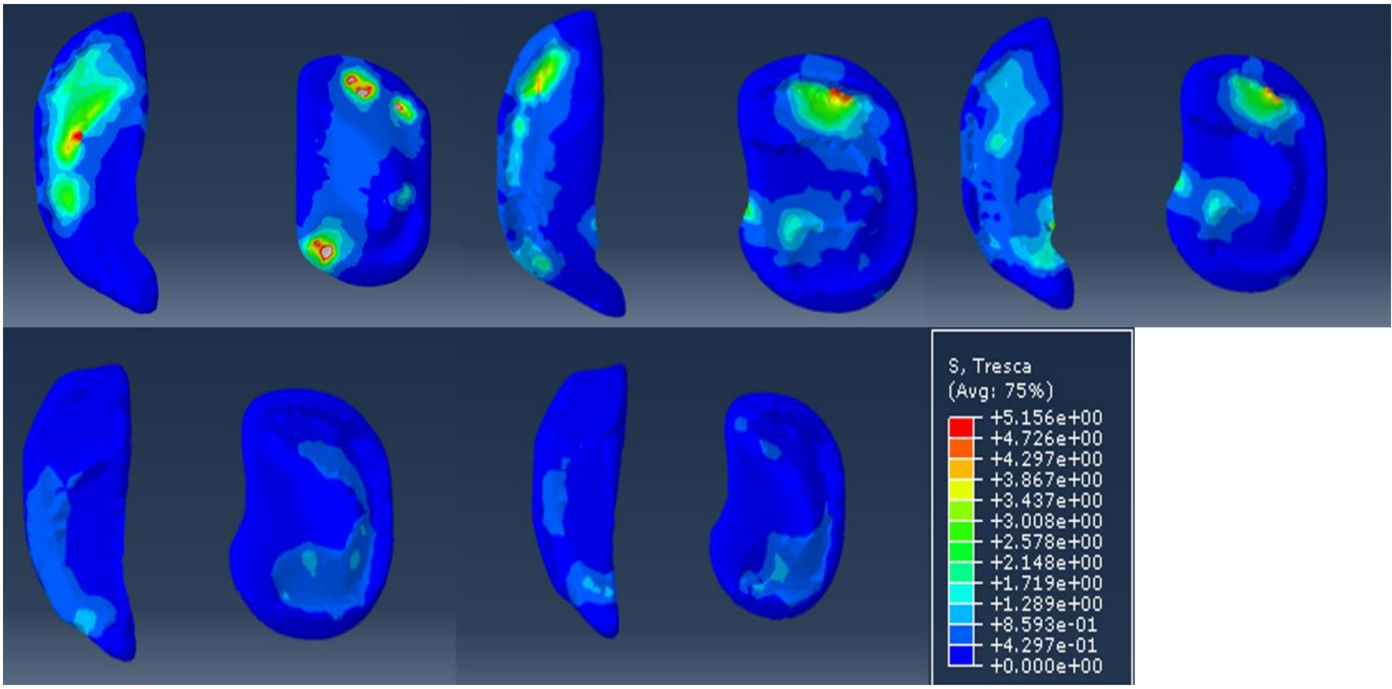


Fig. 3-7. Shear Stress on the tibia cartilage Before and after osteotomy(5°, 3°, 0°)

The same as meniscus and femur cartilage, we can show that when the patient's varus angle is 10°, the maximum shear stress on the tibia cartilage is 5.16Mpa. For a short period, the Varus Angle remained unchanged, and the tibia cartilage shear stress reduced to 4.72Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 5°, and the maximum shear stress on the tibia cartilage further reduced to 4.53Mpa.

Then, after a subsequent period of self-recovery, the varus angle reduced to 3°, and the maximum shear stress on the tibia cartilage further reduced to 2.55Mpa. After the patient fully recovered, the shear stress on the tibia cartilage was 1.77 MPa.

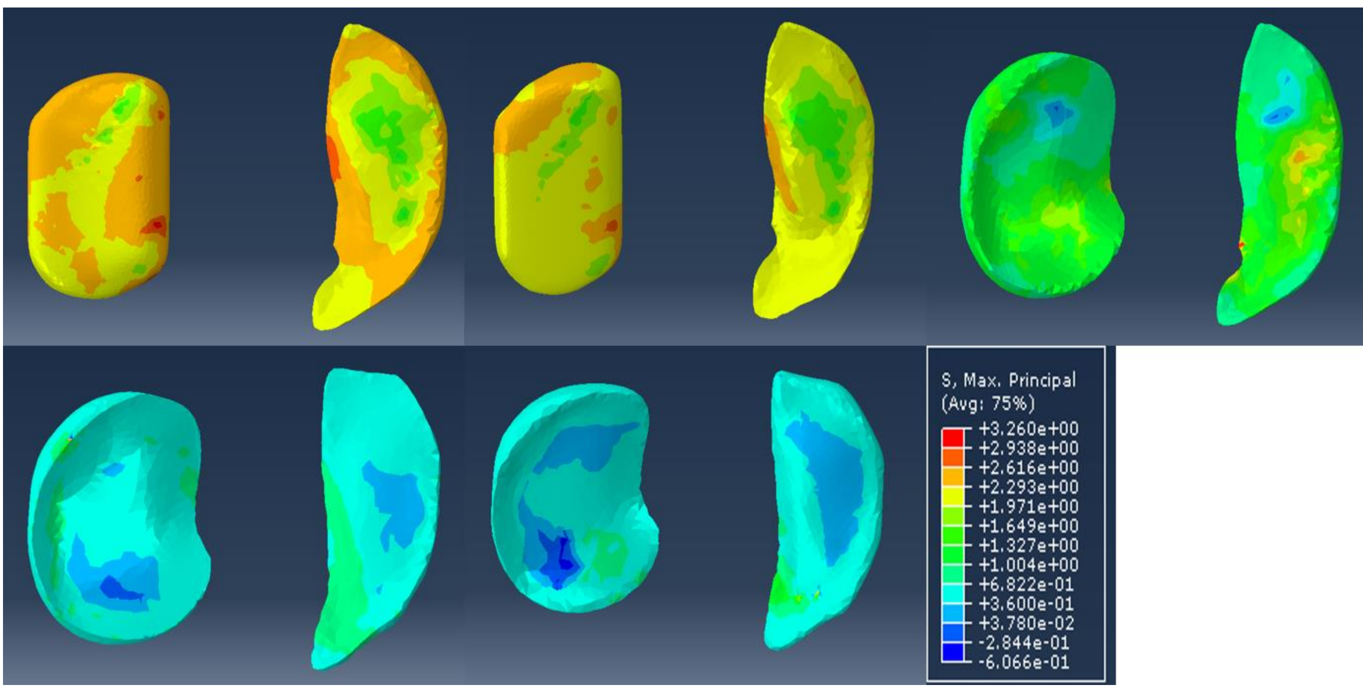


Fig. 3-8. Compressive stress on the tibia cartilage before and after osteotomy(10° before PFO, 10° After PFO，5°，3°，0°).

Through CAE simulations, we can show that when the patient's varus angle is 10°, the maximum compressive stress on the tibia cartilage is 3.26Mpa. For a short period, the Varus Angle remained unchanged, and the tibia cartilage compressive stress reduced to 2.73Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 5°, and the maximum compressive stress on the tibia cartilage further reduced to 1.55Mpa. Then, after a subsequent period of self-recovery, the varus angle reduced to 3°, and the maximum compressive stress on the tibia cartilage further reduced to 1.15Mpa. After the patient fully recovered, the compressive stress on the tibia was 1.13 MPa.

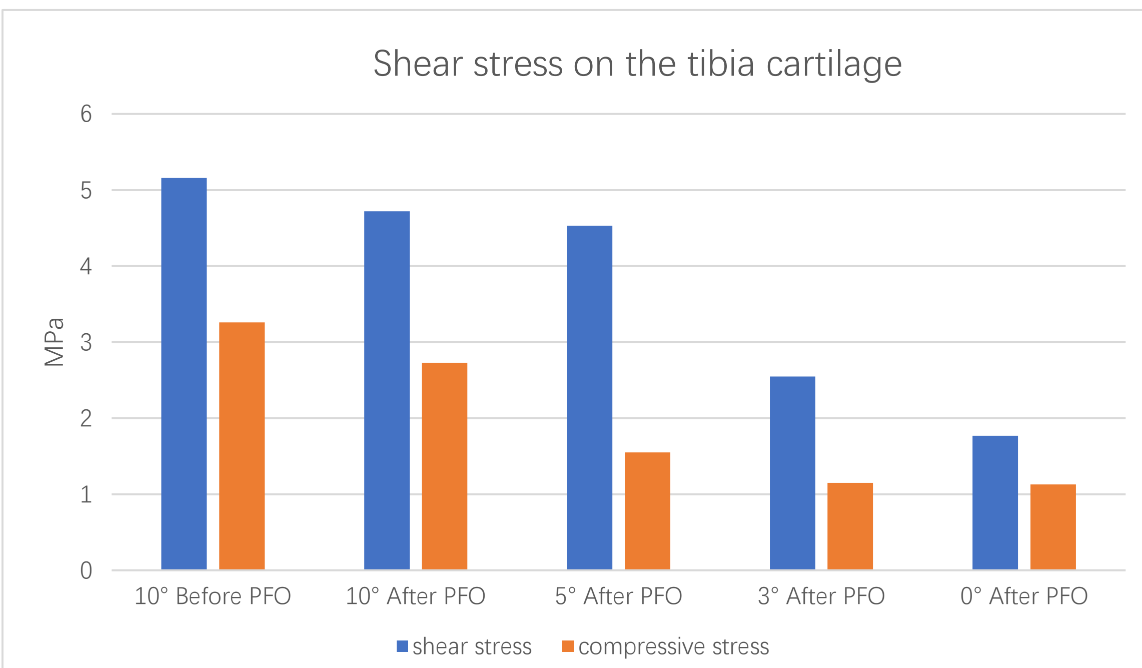


Fig. 3-9. Compressive stress and shear stress on the tibia cartilage (MPa)

3.4 Varus angle 10 degrees Mises

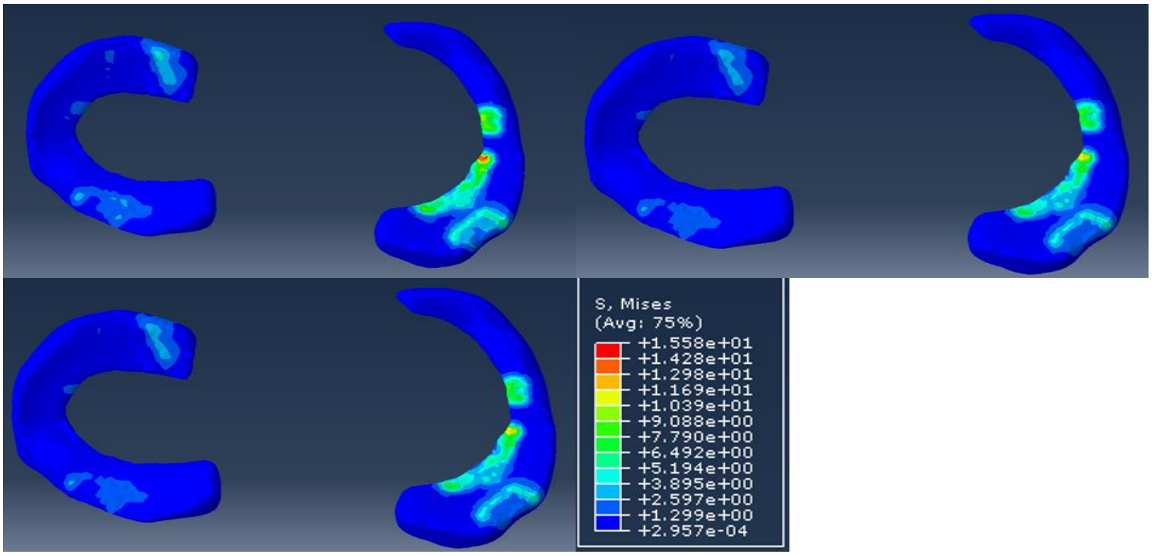


Fig. 3-10 10° Mises on the meniscus (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

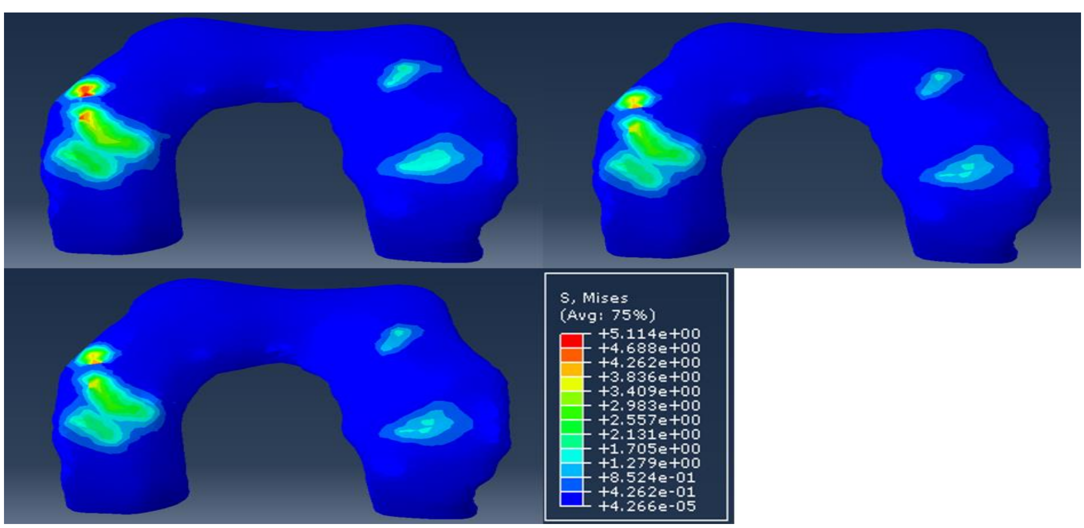


Fig. 3-11 10° Mises on the femur cartilage (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

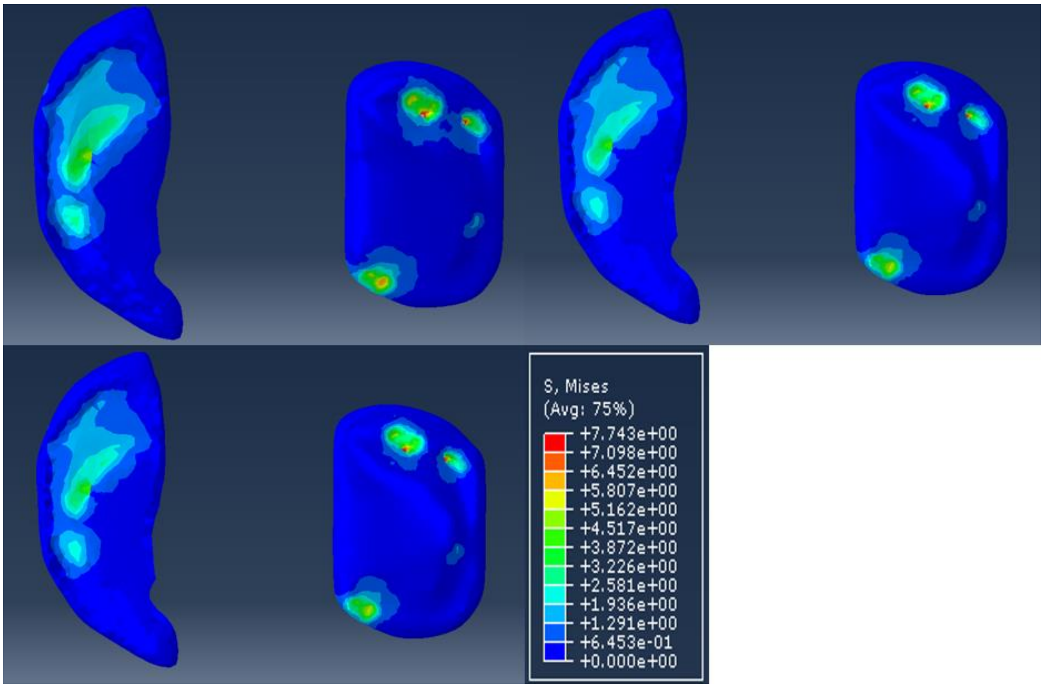


Fig. 3-12 10° Mises on the tibia cartilage (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

As shown in figure 14,15,16, when varus Angle is 10°. The maximum Mises stress on meniscus decreased from 15.58MPa to 12.98MPa after PFO. The maximum Mises stress on the femur cartilage decreased from 5.11MPa to 3.84MPa. The maximum Mises stress on the tibia cartilage decreased from 7.74MPa to 7.10MPa. So we can easily calculate that at a varus Angle of 10 degrees, the Mises stress on the meniscus decreased by 2.6MPa immediately after surgery, the Mises stress on the femoral cartilage decreased by 1.27MPa, and the Mises stress on the tibial cartilage decreased by 0.64MPa. In addition, in this experiment, we also adopted a surgical method not used in clinical trials, that is, to cut the middle part of the fibula and observe the difference in mechanical Angle between the upper end of the fibula and the middle part of the fibula. As the results show, the results obtained by the two methods are exactly the same in terms of mechanics.

3.5 Varus angle 5 degrees Mises

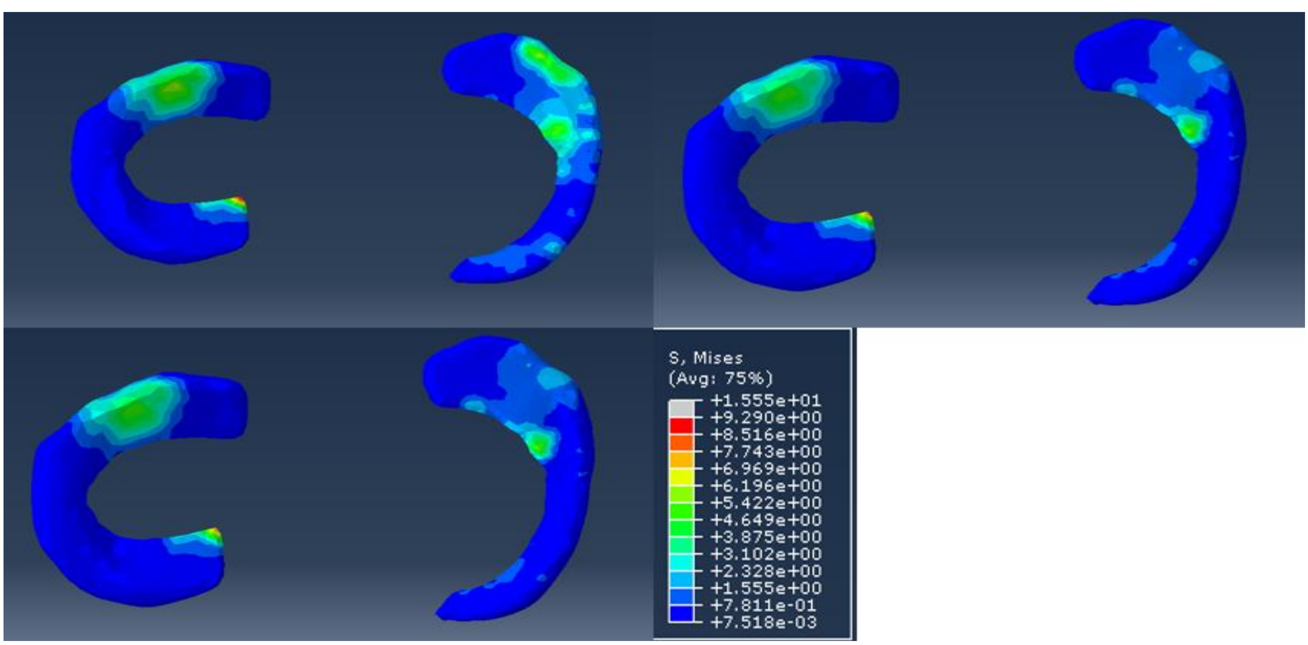


Fig. 3-13 5° Mises on the meniscus (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

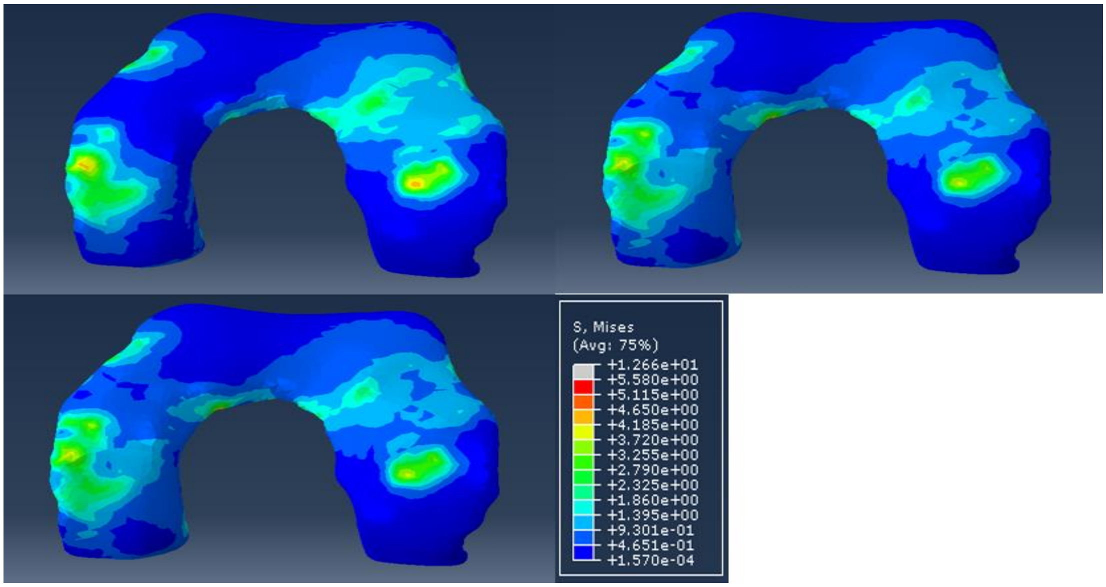


Fig. 3-14　5° Mises on the femur cartilage (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

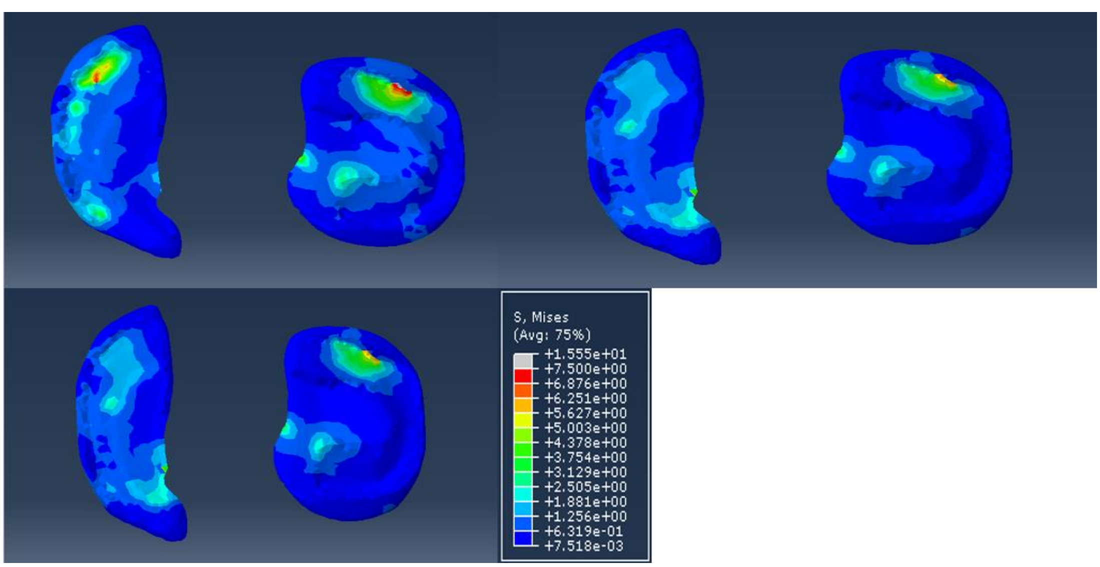


Fig. 3-15　5°　Mises on the tibia cartilage (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

As shown in figure 17,18,19, when varus Angle is 5°. The maximum Mises stress on meniscus decreased from 9.29MPa to 7.47MPa after PFO. The maximum Mises stress on the femur cartilage decreased from 4.65MPa to 4.185MPa. The maximum Mises stress on the tibia cartilage decreased from 7.50MPa to 6.88MPa. So we can easily calculate that at a varus Angle of 5 degrees, the Mises stress on the meniscus decreased by 1.82MPa immediately after surgery, the Mises stress on the femoral cartilage decreased by 0.48MPa, and the Mises stress on the tibial cartilage decreased by 0.62MPa. In addition, in this experiment, we also adopted a surgical method not used in clinical trials, that is, to cut the middle part of the fibula and observe the difference in mechanical Angle between the upper end of the fibula and the middle part of the fibula. As the results show, the results obtained by the two methods are exactly the same in terms of mechanics.

3.6 Varus angle 3 degrees Mises

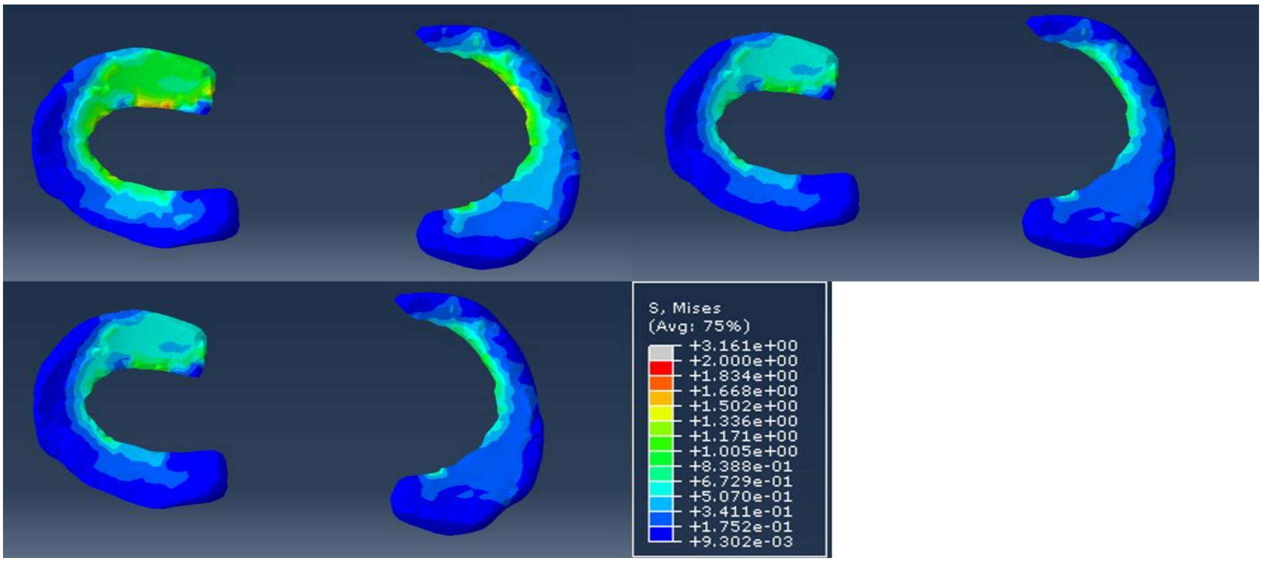


Fig. 3-16 3° Mises on the meniscus (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

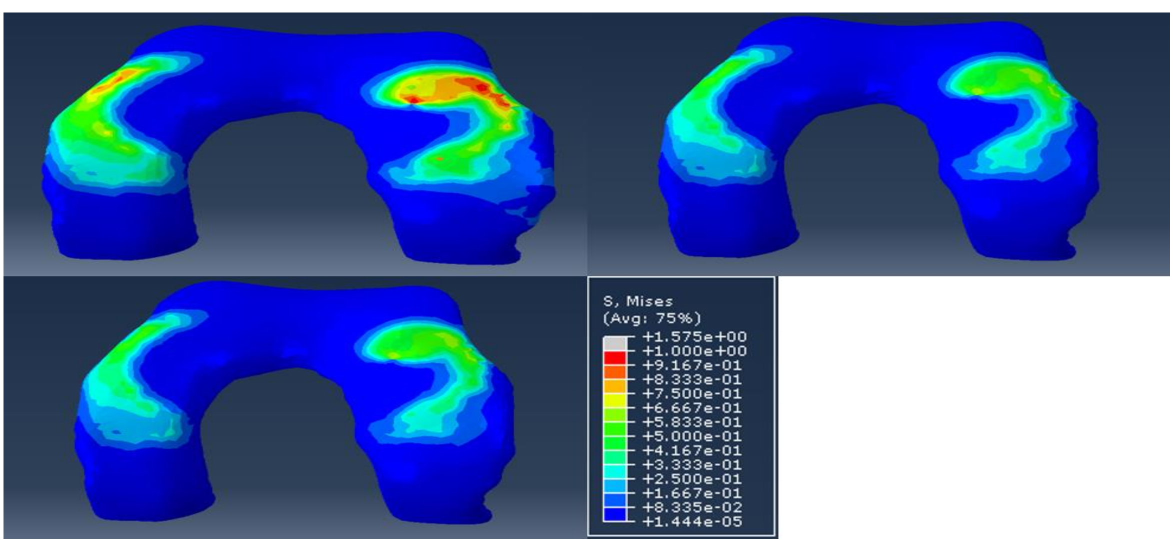


Fig. 3-17 3° Mises on the femur cartilage (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

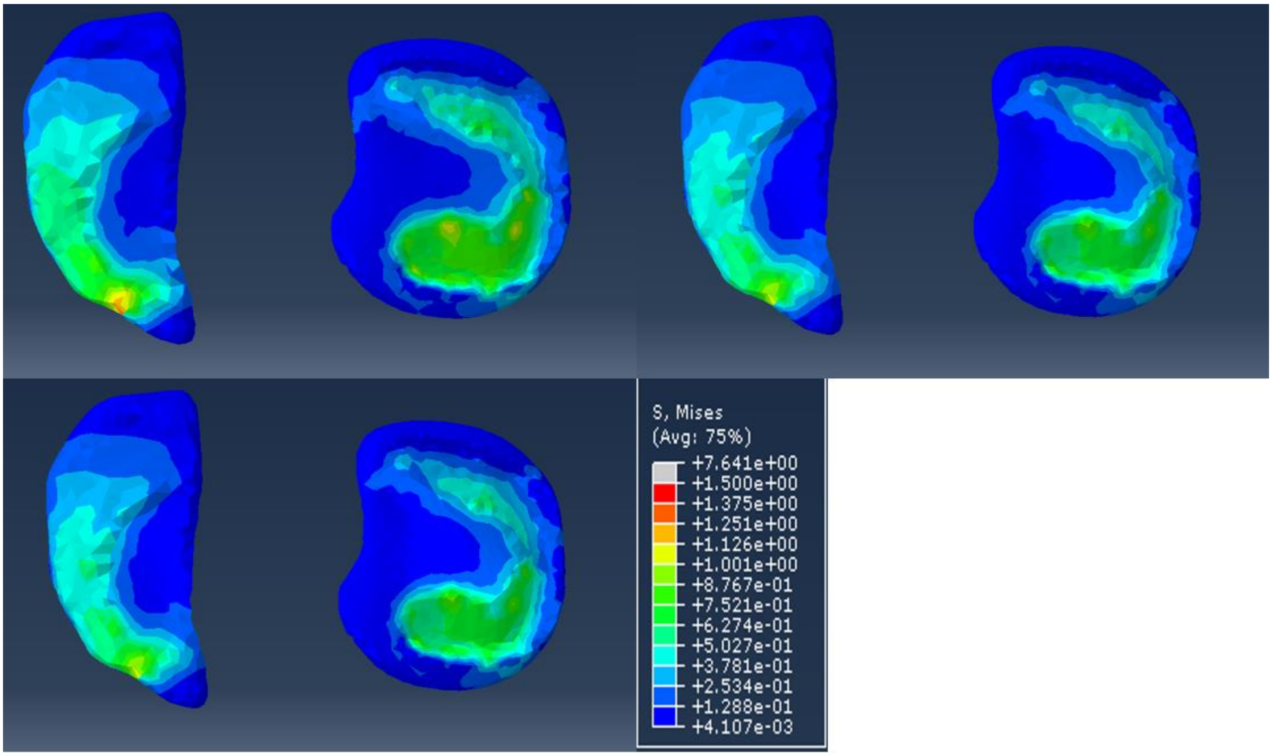


Fig. 3-18 3° Mises on the tibia cartilage (Before Osteotomy, After Proximal Fibula Osteotomy, After cut center fibula)

As shown in figure 20,21,22, when varus Angle is 3°. The maximum Mises stress on meniscus decreased from 2.0MPa to 1.17MPa after PFO. The maximum Mises stress on the femur cartilage decreased from 1.0MPa to 0.67MPa. The maximum Mises stress on the tibia cartilage decreased from 1.375MPa to 1.126MPa. So we can easily calculate that at a varus Angle of 3 degrees, the Mises stress on the meniscus decreased by

0.83MPa immediately after surgery, the Mises stress on the femoral cartilage decreased by 0.33MPa, and the Mises stress on the tibial cartilage decreased by 0.25MPa. In addition, in this experiment, we also adopted a surgical method not used in clinical trials, that is, to cut the middle part of the fibula and observe the difference in mechanical Angle between the upper end of the fibula and the middle part of the fibula. As the results show, the results obtained by the two methods are exactly the same in terms of mechanics.

Chapter 4 Conclusion and Future work

4.1 Discussion and Conclusion

Through this simulation, we can know that when varus Angle is 10 degrees in patients with arthritis, fibula proximal osteotomy can effectively reduce the stress concentration on the soft tissue such as meniscus, improve the joint space and reduce the patient's pain. However, this operation is different from the traditional high tibial osteotomy, although it has the advantages of small trauma and low cost. However, from the results of 3.4-3.6, we can know that the effect of proximal fibula osteotomy is slow and more dependent on the patient's self-recovery. When the patient's varus angle was small, the effect was not obvious. It can be easily seen from the results of 3.1-3.3 that varus angle continued to decrease and shear stress and compressive stress decrease follow the varus angle after the patient recovered by herself. But, the biomechanical theory of uneven knee settlement argues that the lateral tibial plateau does not collapse with complete fibula support; rather, when the medial tibial plateau has a greater settlement than the lateral platform due to lack of support, the varus angle gradually begins to increase [8,9]. Proximal fibula osteotomy removes part of the proximal fibula bone, making fibula support incomplete, so that support of the fibula to the lateral tibial platform can weaken; and, as the knee joint moves outward, the lower limbs can bear the weight. The force line can also be recovered to a certain extent, eventually preventing the symptoms from worsening and relieving knee pain. As Figure 6 shows, compared with high tibia osteotomy (HTO) [10], proximal fibula osteotomy avoids complications such as prosthesis loosening, infection, and fracturing around the prosthesis after joint replacement and can effectively relieve knee pain and improve knee function.

Above all, proximal fibular osteotomy is a simple and inexpensive osteotomy surgery alternative for arthritis patients. It can effectively reduce damage to the patient and the stress on the cartilage and meniscus of the knee joint. APFO can also effectively change the joint space, reducing pain.

4.2 Future work

In this simulation experiment, our model mainly adopts tetrahedral mesh. However, the accuracy of hexahedral mesh is higher when calculated by finite element method. Because the model is too complex to study time, we do not use hexahedral mesh. After this study, I will re-divide the hexahedral grid and compare it with the existing results. See which method is better

References

(1) Zhang Yingze, Li Cunxiang, Li Jidong, etc. Study on the mechanism of uneven settlement in the process of knee degeneration and varus [J]. Journal of Hebei Medical University, 2014, 35 (2): 218-219. DOI: 10.3969 / j.issn.1007-3205.2014.02.037.

(2) Yang ZY, Chen W, Li CX, et al. Medial compartment decompression by fibular osteotomy to treat medial compartment knee osteoarthritis: a pilot study[J]. Orthopedics, 2015, 38(12):e1110-e1114. DOI:10.3928/01477447-20151120-08.

(3) Johnson DR, Dennis DA, Kindsfater KA, et al. Evaluation of total knee arthroplasty performed with and without computer navigation: a bilateral total knee arthroplasty study[J]. J Arthroplasty, 2013, 28(3):455-458. DOI:10.1016/j.arth.2012.06.026.

(4) Morris MJ, Lombardi AV Jr, Berend KR, et al. Clinical results of patellofemoral arthroplasty[J]. Arthroplasty, 2013, 28(9Suppl):199-201. DOI:10.1016/j.arth.2013.05.012.

(5) Mont MA, Johnson AJ, Naziri Q, et al. Patellofemoral arthroplasty: 7-year mean follow-up[J].J Arthroplasty, 2012, 27(3):358-361. DOI:10.1016/j.arth.2011.07.010.

(6) Siparsky P, Ryzewicz M, Peterson B, et al. Arthroscopic treatment of osteoarthritis of the knee: are there any evidence-based indications ? [J]. Clin Orthop Relat Res, 2007, 455:107-112.

(7) Wagner M, Frenk A, Frigg R. New concepts for bone fracture treatment and the Locking Compression Plate[J]. Surg Technol Int, 2004, 12:271-277.

(8) BROUWER RW, RAAIJ TMV, JAKMA TTSC, et al. Braces and orthoses for treating osteoarthritis of the knee[J]. Cochrane Database Syst Rev,2005,25(1):CD004020.

(9) ZHAO Liang, ZHENG Ming, CHEN Lei, ZHONG Jian-yuan, SONG Wei, LIN Jian-hui. Study on the Changes of Knee Joint Stress in Patients with Osteoarthritis of Knee Joint by Middle and Upper Fibula Osteotomy. DOI：10.16662/j.cnki.1674-0742.2019.33.100.

(10) Fact sheet: two-midnight rule. https://wwwcmsgov/newsroom/fact-sheets/ fact-sheet-two-midnight-rule-0; 2015. [accessed 18.09.2019].