FEA Analysis of Meniscal Tears and Partial Meniscectomies

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Abstract: The meniscus is a wedge-shaped structure of fibro cartilage located between the condyles of the femur and the tibial plateau. Often overlooked, the meniscus is a vital part of the knee joint that is used for enlarging the contact surface between the articular cartilages of the two bones. It is also used for weight bearing, joint stabilization, joint lubrication, articular cartilage nutrition, and proprioception. A meniscal tear is a common injury that occurs in the knee and can lead to swelling, effusion, stiffness, cracking, locking or catching, and pain along the joint line. Because the meniscus cannot repair itself, it is often necessary to surgically remove part of the damaged tissue, a procedure known as a meniscectomy. In this study, different kinds of meniscal tears and their associated meniscectomies were researched. This goal of this project is to gain a better understanding of the effects that meniscal tears and their meniscectomies have on the stresses experienced by the meniscus and cartilage layers. The long-term health of the femoral and tibial cartilages can be comprised when they are subjected to the exertion of abnormally high stresses, a scenario that can greatly increase the risk of osteoarthritis. The three papers that were focused on utilized finite element analysis, or FEA, to show the resulting stresses cause by tears and meniscectomies of various sizes and locations.

Methods: Two of our studies used CT scans and MRI images of an adult volunteer to create a 3D image of a healthy knee joint. These joints included the femur, tibia, menisci, major ligaments, and articular cartilage layers. Both used material properties and boundary conditions found in previous studies to closely resemble those of an actual human knee. They both performed the simulations under an axial load of 1150 N. One of the studies done by Dong et al. [1] used the softwares Mimics 10.0 and Hypermesh 10.0 to perform their analysis. The bones, ligaments, and cartilage were made up of 23,554 2mm x 2mm brick elements. The meniscus itself was made from 4,327 1mm x 1mm brick elements. This study then modeled four different meniscal tears and their corresponding meniscectomies, which can be seen below in Figure 1.

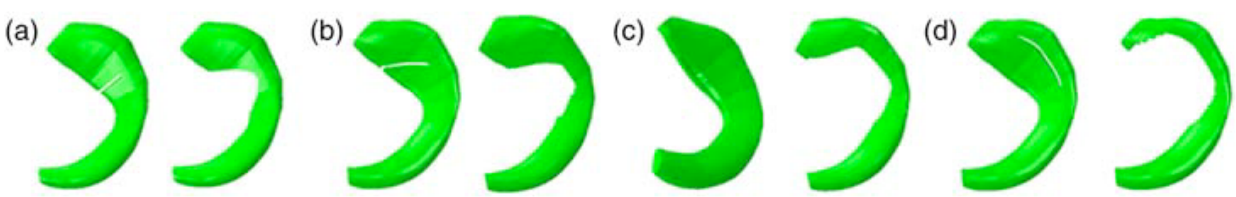


Figure 1: Tears a) radial b) oblique c) horizontal and d) longitudinal [1]

In the second study by Pena et al. [2], the knee joint was simulated using softwares I-deas 9.0 and Abaqus 6.3. The boney surfaces were made up of 4,783 four-node elements while the cartilage, ligaments, and menisci were made up of 5,195 eight-node elements. Again, the authors created four menisci, each with a different tear (seen in Figure 2).

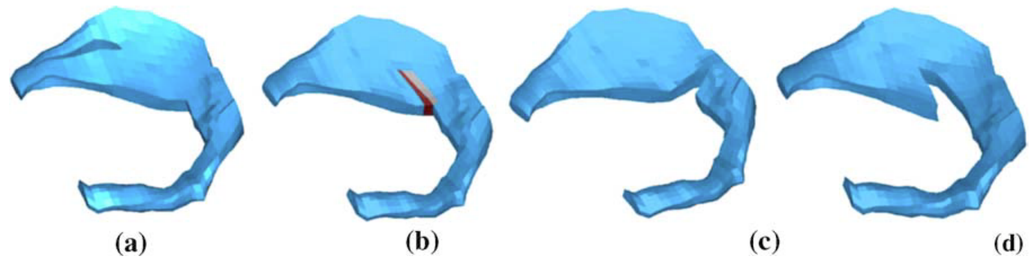


Figure 2: Tears a) longitudinal b) oblique c) transverse d) parrot beak [2]

The third study by Vadher et al. [3], an analysis of an axisymmetric model of the human knee, was developed and analyzed using Adina 8.2 on a UNIX platform. This model consisted of cartilage made up of three separate layers, an approach previously proven to be essential in getting accurate results when using an axisymmetric knee model. A pressure of .17 MPa was applied to the top surface of the femur, which corresponds to half of the body weight of a 60 kg person. Eight different cases were considered, including an intact meniscus and various amounts of meniscus removal (10%, 20%, 30%, 40%, 50%, 60%, and 65%).

Results: While examining the peak compressive stresses present in a healthy knee, Dong et al. [1] observed that the meniscus experienced a stress of 3.00 MPa while the femoral and tibial cartilages experienced stresses of 3.2 MPa and 2.75 MPa, respectively. Pena et al. [2], however, found the stress in the meniscus to be 2.75 MPa and the stresses in the femoral and tibial cartilages to be 2.32 MPa and 2.55 MPa, respectively. This study computed the stress concentrations on both the medial and lateral sides of these components. Furthermore, this study discovered that the maximum stresses in each of these components occurred on the medial side in a healthy knee joint. Although somewhat different, the stress values for both of these studies lie within similar ranges and are good representations of the knee. The percent increases in stresses are the most important things to note because these values take into account the initial differences. Vadher et al. [3] shows an FEA cut-away of a full meniscus, which can be seen in Figure 3. It is clear that the stress is concentrated on the outer part of the meniscus, which allows for minimal stresses on the femoral and tibial cartilages.

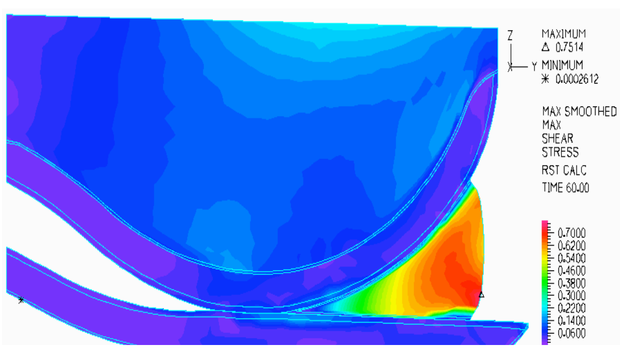
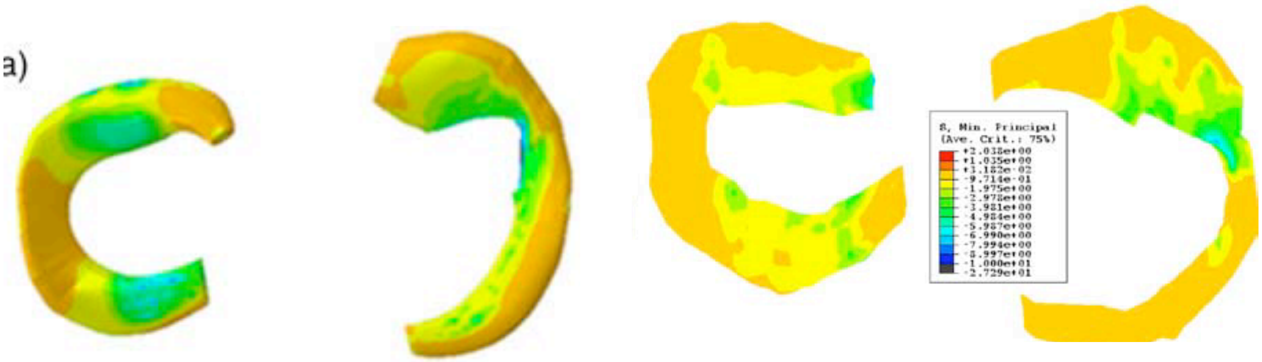


Figure 3: Max stress on axisymmetric knee with full meniscus [3]

Longitudinal tears require the most amount of cartilage to be removed. Accordingly, these meniscectomies lead to the biggest increase in stresses. Dong et al. [1] found that the maximum stress in the meniscus was 6.4 MPa, while the maximum stresses in the tibial and femoral cartilages were 3.92 MPa and 4.24 MPa, respectively. These values correspond to percent increases of 113%, 43%, and 33%, respectively. Similarly, Pena et al. [2] found the stress increases present in the medial meniscus, tibial cartilage, and femoral cartilage to be 107%, 31%, and 50%, respectively.

Another interesting scenario that was examined by both Pena and Dong was the radial meniscectomy. The results they each found for respective stress increases vary quite a bit from one study to the other. Dong et al. [1] found the stress increase in the meniscus to be 83%. The femoral cartilage stress increased by only 12% and the tibial cartilage, only by 15%. Pena et al. [2], found that the stresses increased by 154%, 63%, and 35%, a much more dramatic change. The discrepancies found between the two sets of results were likely a consequence of different interpretations of the partial radial meniscectomy, as seen in Figure 4 and Figure 5.



All of the results found in the study done by Dong et al. [1] can be viewed below in Table 1 with the following abbreviations: CSFC, concentration stress on femoral cartilages; CSTC, concentration stress on tibial cartilage; CSM, concentration stress on meniscus. All of these stresses are taken from the medial condyle.

	CSFC	CSTC	CSM
Healthy knee joint	3.20	2.75	3.00
Radial meniscal tear	3.86	3.42	4.67
Oblique meniscal tear	4.12	3.96	4.90
Horizontal meniscal tear	3.48	3.27	4.32
Longitudinal meniscal tear	3.65	3.44	4.60
Radial meniscectomy	3.58	3.16	5.50
Oblique meniscectomy	3.66	3.25	5.72
Horizontal meniscectomy	4.02	3.57	6.25
Longitudinal meniscectomy	4.24	3.92	6.40

Table 1: Resulting stresses (MPa) found by Dong [1]

All of the results found in the study done by Pena et al. [2] can be seen in Table 2, which has the following abbreviations: SLM, compression stress in the lateral meniscus; SMM, compression stress in medial meniscus; SMC, compression stress in medial condyle cartilage; SLC, compression stress in lateral condyle cartilage; SMT, compression stress in medial tibial cartilage and SLT: compression stress in lateral tibial cartilage.

	SLM	SMM	SMC	SLC	SMT	SLT
Healthy joint	1.62	2.75	2.32	1.42	2.55	1.20
Longitudinal meniscectomy	2.43	5.7	3.49	2.91	3.36	2.49
Radial meniscectomy	4.98	7	3.79	3.21	3.35	3.80
Oblique meniscectomy	5.3	8.12	3.75	3.17	4.52	3.18
Total medial meniscectomy	10		6.41	5.74	5.34	4.83

Table 2: Resulting stresses (MPa) found by Pena [2]

Discussion: Meniscal tears and meniscectomies are every day occurances. The information found through FEA studies can help doctors to make important medical descisions and also help to predict the long term effects that partial meniscectomies may cause. Important conclusions can be deduced by examining the results of these different studies. First, the study done by Vadher et al. [3] illustrates that the amount of meniscus removed during a meniscectomy should be minimized. Removing more tissue can lead to a large increase in stresses experienced in the knee joint, as seen in Figure 6. After the initial 10% removal, each additional 10% resulted in large stress increases and increasingly abnormal loading on the articular cartilages, conditions which can cause degeneration and ultimately osteoarthritis if no deterrent courses of action are taken.

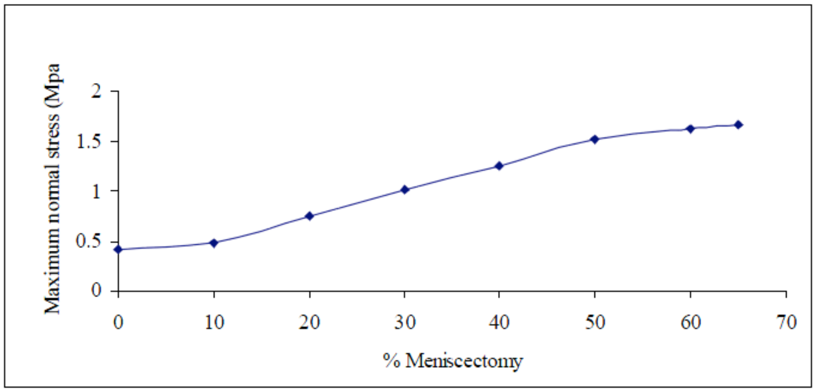


Figure 6: Maximum normal stress in the articular cartilage with respect to % medial meniscus removal

The results of the study done by Pena et al. [2] show that removing sections of the medial meniscus has a more drastic effect on the lateral menisci that it does on the medial menisci, an effect which can be seen in the results of Table 2. Removing sections of the medial meniscus causes the lateral meniscus to have a larger contact surface with both the femur and the tibia, consequently forcing the lateral side to encompass more of the load. Compression stresses can experience increases up to 207% in radial meniscectomies and up to 217% in oblique meniscectomies. Again, these large increases in stress concentrations can lead to cartilage degeneration and eventually osteoarthritis as well.

The results found by Dong et al. [1] show comparisons of the stresses caused by the meniscectomies and by the corresponding meniscal tears that prompted them. According to the results found in Table 1, it is apparent that the tear can often cause more stress than the resulting meniscectomy. In these cases It is clearly advantageous to perform the partial meniscectomy. In the cases of longitudinal and radial tears, partial meniscectomies can actually be the source of greater pressures than their respective tears. But, these meniscectomies are often performed anyways, regardless of potential stress changes, because longitudinal and horizontal tears have been shown to cause major problems in the functionality of the knee joint.

Lastly, the results of Pena et al. [2] allow for comparison between partial meniscectomies and full meniscectomies, the preferred form of treatment prior to partial meniscectomies. Full meniscectomies are much easier to perform and have been shown to cause less problems for the patient during the recovery process. However, by reffering to Table 2 and examining Figure 7, it is

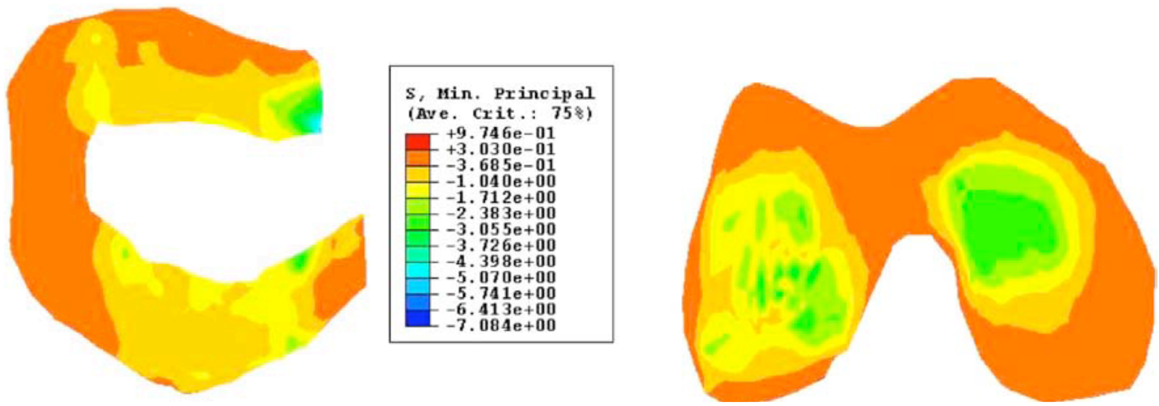


Figure 7: Stress concentrations in the lateral meniscus and tibial cartilage due to a full medial meniscectomy by Pena [2]

apparent that a full medial meniscectomy cause huge increases in stress in both the lateral meniscus and the articular cartilage layers, 517% and 300% respectively. This massive increase in stresses would undoubtedly lead to mass cartilage degeneration and osteoartritis in the not-so-distant future.

Conclusion: The three studies that were examined each used finite element analyses to investigate the compression stresses on the articular cartilages and on the fibrocartilaginous meniscus. They each showed the resulting stresses present in a healthy knee joint in addition to the results that occured after partial meniscectomies were performed on a torn meniscus. Comparisons of the three studies were made, and conclusion were drawn about the effects that meniscectomies can have on the future health of particular knee joints. FEA analyses provide an easy way to simulate the actual changes that can occur in a knee after surgery and give doctors a basis for making important deciscions on how to handle individual cases without having to make irreversible changes to the knee.

Work Cited

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