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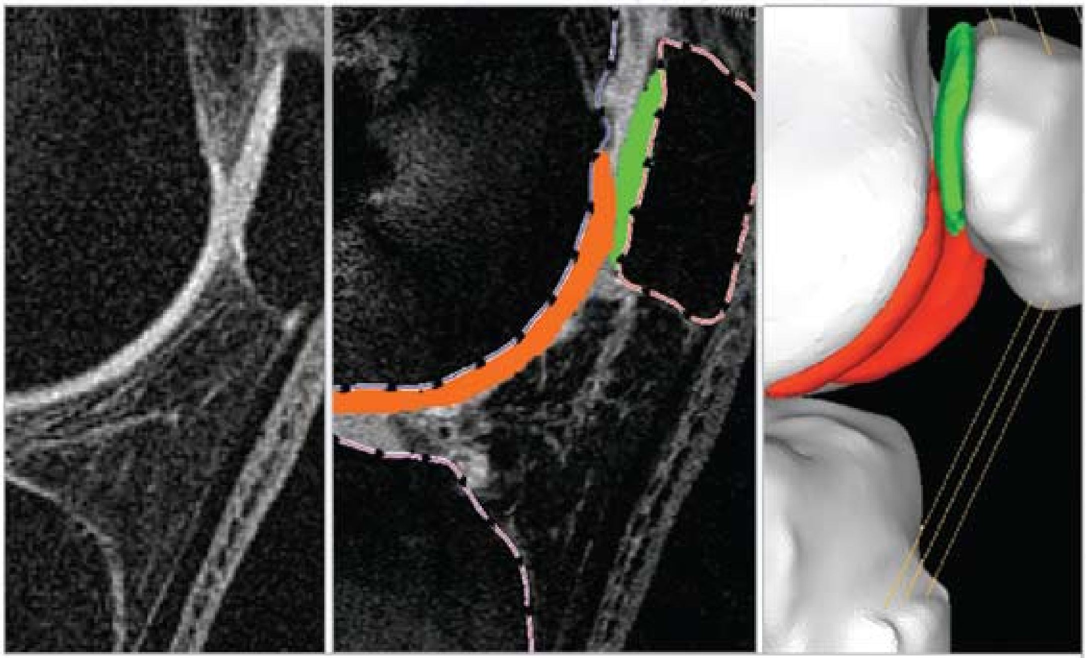

Fighting Knee Pain with Finite Element Modeling

HyperMesh® in a Pioneering Study at the Musculoskeletal Biomechanics Research Laboratory of USC

An Altair® HyperWorks® Success Story

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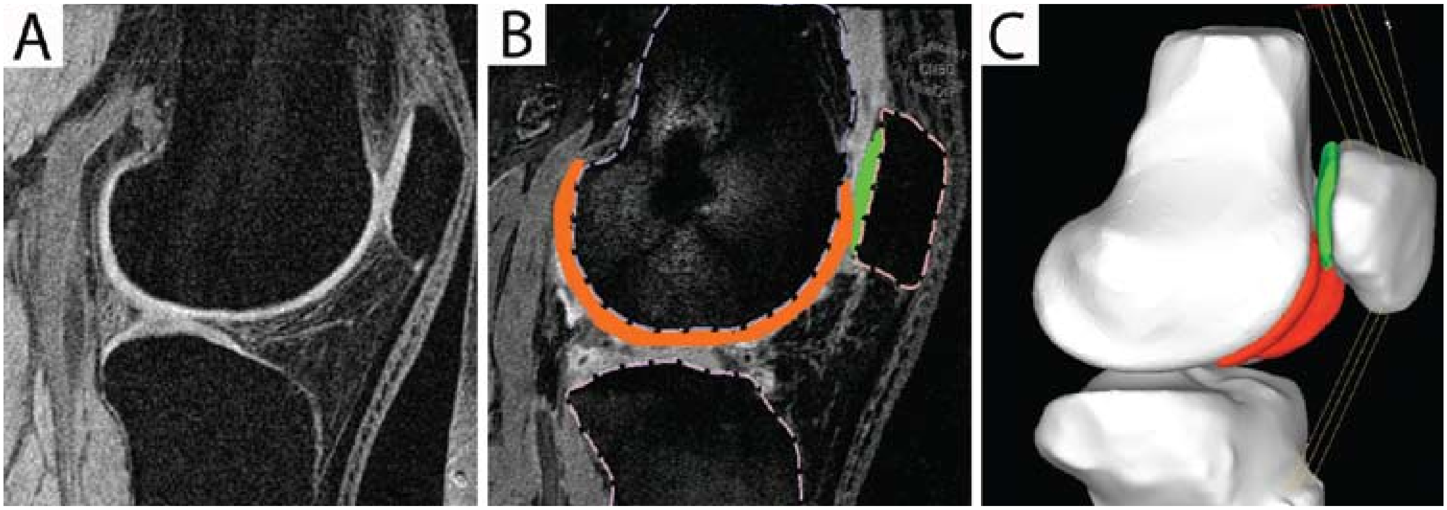
HyperMesh in A Pioneering Study at USC



In the Musculoskeletal Biomechanics Research Laboratory at USC, Dr. Shawn Farrokhi is working out answers to an important question: why many people are incapacitated by knee pain when others are not. This is a tough, intractable issue for people with arthritic knees since there is no cure for arthritis today. The ultimate solution is replacement of the joint with a prosthesis. However, the majority can not afford the procedure so most people make do with pain relievers or others simply bear the pain. Early detection can help, and that is the focus of Farrokhi's work.

He processes MRI images and uses HyperMesh, part of the HyperWorks CAE toolset, to create finite element models to analyze stress on the cartilage of the patellofemoral joint. This work, which is part of the basis for Farrokhi's PhD dissertation, aims ultimately at finding the best ways to head off the chronic pain of arthritic knees – a costly worldwide problem.

Modeling Knees in HyperMesh

MRI scans of subjects' knees under specific weight-bearing conditions are sent by the USC Imaging Center to Farrokhi as digital files utilizing a medical imaging standard. Each file is a two-dimensional digital image slice of the subject's knee. Farrokhi uses Tomovision's Sliceomatic software tools to outline the structures of interest on 120 of these slices and then segments them into a single 3D image. He then saves the image as a .STL file and imports it into HyperMesh.

"We're concerned with five components of the MRI image," says Farrokhi. "Three bones – the femur, the tibia, and the patella; then the cartilage that covers the femur, and the cartilage that covers the patella. The overall output of the model is the stress created between those two cartilaginous surfaces."

Farrokhi generates a surface for the model in HyperMesh and then creates the bone geometry as a rigid-body shell mesh. He also creates tetrahedral elements to represent the thickness of the cartilage. When the model is complete, he sends it to finite element solver to simulate the stresses within the two cartilages during squatting maneuvers at 15, 30, and 45 degrees of knee flexion.

The Results: Stress Patterns in Cartilage

The premise that Farrokhi is working on is that higher stresses cause wear and tear within the cartilage. Cartilage does not have nerve endings, so these stresses can't cause knee pain themselves. But the transfer of these stresses to the underlying bone can and do cause pain. In addition, the higher the stress that is transferred to the bone the greater the pain that is experienced.

"The flexibility of the HyperWorks applications as well as the high quality training I received from Altair Engineering helped me utilize their software effectively in a biomechanical research environment".

Dr. Shawn Farrokhi,
Musculoskeletal Biomechanics Research Laboratory

"One of the hypotheses is that the cartilage is thinner in people that have pain," says Farrokhi. "We have seen that. The forces that the quadriceps exerts, and the direction of those forces, are different in individuals that suffer pain. Those are the differences that we're trying to quantify.

"There's no way to quantify pain; it's too subjective. So we try not to make correlations between anything and pain. But from my MRI images I know the thickness and the volume of the cartilage, and its water content. We want to see if there's a relationship between those parameters and the levels of stress created in the cartilage."

One of the novel aspects of Farrokhi's work is that he creates an FEA model for each individual – for control subjects with healthy knees and for patients who have reported knee pain, some of which are his physical therapy patients. His goal is to capture the structural differences between painful and pain-free knees.

The Payoff: A Sound Approach to Avoiding Chronic Knee Pain

The group of subjects that Farrokhi is working on for his doctoral thesis consists of people 18 to 40 years of age, most of which are females. This is because women are almost twice as likely to have knee pain as men, due to a combination of factors. “It’s partly anatomical, partly a tendency to have weaker hip muscles, and partly a difference in activity levels,” says Farrokhi. Nevertheless, men tend to suffer knee pain because they are often more active, and this higher activity level is a predisposing factor. Military recruits provide an example: about a third of them develop knee pain during basic training - a hot topic among some health professionals.

By the time this knee pain results in arthritis that can be seen in X-rays and MRIs, it’s irreversible. So Farrokhi’s focus is on finding a way to screen people who are at a high risk of developing arthritis in their knees.

“Early detection is the key here,” he says. “If early knee pain leads to arthritis later in life, and we treat individuals with knee pain while they’re young, we’re going to slow down this process or prevent it from progressing to arthritis. We can intervene with therapy or pharmaceutical treatment. Then worldwide we can reduce treatment costs and avoid stress on the many who can’t afford knee replacement surgery.”

A Health Professional Masters Finite Element Modeling

Farrokhi had no engineering background when he conceived his approach to stress analysis in the knee joint. But after a colleague in the civil engineering department recommended HyperMesh as user-friendly, he contacted Altair Engineering.

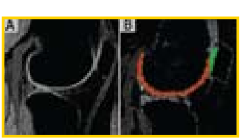
“I came into finite element modeling as a rookie,” says Farrokhi. “No one else in USC is applying FEA to the human body. So my three-day training on HyperMesh was my introduction to creating a model. Altair has been more than helpful in making this transition easy for me. One of the things I was most impressed with was that Altair engineers are willing to take that extra step, explain the process, provide background information, and put it all in a way that a non-engineer can understand.

Dr. Shawn Farrokhi

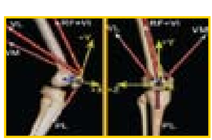
“Another thing that I like about HyperWorks: the impression that it’s a sort of family-operated setting where you feel very comfortable going from person to person, because everyone is on the same page and working for the same common purpose. I really appreciate that.”

Currently, Farrokhi is totally focused on his PhD thesis, which requires modeling 30 knees for stress analysis. After that, who knows?

“Now that I know how to apply FEA modeling to the knee joint, I can apply it to other body regions and do stress analysis. Back pain would be high on the list. Looking at stress in vivo is one of the biggest problems in biomechanics. That’s what we’re hoping to solve with this approach.”



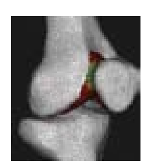
Subject Specific Geometry



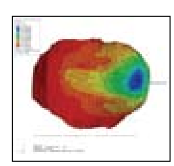
Subject Specific Muscle Forces

Subject Specific Kinematics

Model Input



Finite Element Model



Model Output

Model Simulation

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