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On the Cover: Professor Damien Lacroix, Research Director of Insigneo
Cover photo by Keith Sharples Photography
THE REAL WONDERS OF ENGINEERING

When we think of the wonders of engineering, we might think of machines, bridges, deep sea-oil wells, or the myriad of devices that improve every facet of our lives. But in the 21st century, the real wonders of engineering will be far more personal; in fact, they will be exactly that...personal. We are entering an age of engineering where you and I will no longer be second thoughts in product engineering, but rather at the center of human experience-based design, particularly as we innovate for health.

For the past 10 years, as the lead of Dassault Systèmes’ Life Sciences Industry, I have seen the patient-centric vision starting to become a reality at an accelerated pace. Through medical and scientific progress, catalyzed by digitalization, incredible innovative healthcare solutions are surfacing to the benefit of patients. By connecting engineering with people, we significantly enhance the ability to truly address unmet medical needs.

At this year’s Science in the Age of Experience conference, we saw a glimpse of the convergence of science and engineering that offers us a new horizon of innovation. It is this pioneering spirit that inspired this special edition of SIMULIA Community News.

As you read through this magazine, you will discover some profound examples at the leading edge of biomechanical engineering. In the cover story, we see researchers at the Insigneo Institute highlighting their commitment to in silico medicine, demonstrating that we can not only model the human spine, but we can predict the ideal procedures to return function to normal. You will also see several examples of simulation of the human heart and cardiovascular system, some of the foundational work that inspired our own Living Heart Project, our contribution to fueling the transformation of engineering and connecting it to the patient experience.

In Georges Limbert’s work, he may not answer the question of whether beauty is skin deep, but he does demonstrate that we can understand the underlying physics that control the appearance of our skin and use this knowledge in new and exciting ways.

Maybe the best look into the future comes from Professor Ellen Kuhl at Stanford, who showcases her approach to engineering education by challenging her students to actually model themselves. Through this lens we can see how truly personal engineering can be and how we can improve our lives directly.

As exciting as all of this innovation is, we must remember that when we turn our focus to Life Sciences and human experiences, we must exercise the utmost caution to ensure the safe application of our technology. The leader in providing this safety net for our ideas is the FDA. So we also hear from Donna Lochner, who has been at the forefront of helping to guide the regulatory process for medical devices into science-based processes. Her vision is a breath of fresh air for all of us who dream of a future where medical device innovation is not bottlenecked by trial-and-error testing.

I hope you enjoy this edition as much as I do and draw your own inspiration for what is possible by connecting engineering to the human experience with SIMULIA technology.

JEAN COLOMBEL,
Vice President, Life Sciences, Dassault Systèmes
Virtual Human Modeling: Putting People at the Center of Engineering

By Steve Levine, Senior Director, SIMULIA Strategic Initiatives

If you think of engineering as the art of designing things that work, you’re only partly right. For more than 200 years, companies have focused on engineering great products: man-made devices and machines that do exactly what they are intended to do. But today we expect more. Engineering competitive products means considering the people who will use, wear or, in the case of medical devices, host those products as well. Design perfect harmony between product and user.

The relationship between man and machine is changing rapidly and as engineers we have to embrace that in our work. This imperative is already being expressed in the marketplace: Just look around you; cars are now engineered for optimal driver experience or even a shared driving experience with the car itself, full time wearable devices that monitor your health 24-7, smart clothing that responds to your level of activity—even patient-specific medical devices that are designed and manufactured to fit a single, unique human being.

In the marketplace, many of these innovations are still in their infancy, but there’s no denying they are the future and the winners will be those who prepare now. If you are a product engineer you need to start thinking about how to factor the “human element” into your simulation-driven design process. It’s not only temperature, pressure, acceleration or other measurable quantities of physical phenomena that can affect product behavior: the user’s own interaction with the product can affect performance and durability as well and must be considered in the design phase.

And the corollary remains true, that the product design greatly affects the user experience. Designing in the right experience is essential in today’s competitive market and critical to building brand loyalty. Waiting until physical prototype or production phase is not the time to learn you don’t have this right. Never has the age-old adage of form following function been truer but the bar has been raised.

Factoring in the Human Experience

The complex interactions of the body with, for example, something as ubiquitous as a car seat, are a challenge to simulate. Bone, muscle, tissue, even blood supply—all these may need to be factored into the model when you are trying to define what a user can easily recognize as “comfort.” If you think the comfort of a car seat is not all that important, think again. Many purchasing decisions distill down to something as seemingly minor as how good the seat feels during a test drive, the first measure of perceived quality which influences the rest of the buying experience.

Can you design a good product for human use without factoring in the human? Of course—but should you? At our Science in the Age of Experience event we heard about an athletic-shoe company who can readily engineer the desired physical response of their shoes entirely on the computer, yet they include an accurate human foot model to simulate comfort—the user experience which is the #1 priority for the runner thinking of buying.

At Dassault Systèmes’ SIMULIA, through our close relationships with customers we were able to see this transformation some time ago. In response we have been investing in new technology and collaborating with industry leaders to make Virtual Human Modeling a reality. This special issue of SIMULIA Community News gives testimony to this fact and demonstrates some of the tremendous progress that has already been made. At the Science conference, we described our bold technology strategy for delivering the comprehensive multiscale/multiphysics portfolio required to enable human-centric, simulation driven-design. The genesis of this strategy was the challenge to help our customers move beyond PLM—remove current limitations of virtual product development that is void of user experience—and embrace a product development strategy for a sustainable world where those products are harmonized with nature and life. Our most advanced activity, the widely acclaimed Living Heart Project was our first to see how far we could go if we united a worldwide community on this important mission. It has set a new standard for collaboration and defined a new direction for computer-aided engineering, but it’s no longer the only example. Inspired by this work, we are now setting our sights on a future software strategy with the entire human body in mind.
We believe that, across all industries, every customer that adopts this approach will produce better products and user experiences, delivered faster, more cost effectively and tuned to the precise demands of today’s diverse global markets. In this issue you’ll see examples of the kind of applications already possible today, including those from leaders in the research community, the industrial sector and even clinical applications in patients.

For example, in the retail clothing industry, MDAC is helping Toyobo create human simulation models to analyze the pressure of clothing on the body as it moves to design for maximum comfort. As you may recall from previous issues of SIMULIA Community News, Wolfel has made great strides in creating a full human model with which to measure the forces of a person’s body on the seat of a vehicle. At Stanford University they are truly getting personal by creating individual-specific anatomy models to study everything from bone regrowth in tennis and football players to the effects of high heel shoes on women’s feet, and even brain surgery—yielding invaluable insights into the behavior of the human body.

Of course one of the most exciting fields in which these tools have the potential to improve our lives is Life Sciences. We all like to think of ourselves as unique—and, as it turns out from the medical point of view, we are!

**CONVERGENCE HAS BEGUN**

The convergence of science and engineering has begun to alter the landscape in Life Sciences, and we will all live better lives as a result. No strangers to advanced simulation, the academic, industry and clinical worlds already recognize the critical need to understand and model the human body. Using virtual human modeling to engineer safer and more effective device designs and procedures is just the tip of the iceberg. In the very near future, the shape, size and properties of almost anything—from arterial stents and aortic valves to replacement knees and hips, from plates and screws for repairing broken bones to bio-compatible plastic skull patches—will be custom-created for an individual. Devices can be virtually “fitted” to identify which will perform best inside a patient’s body, or to determine if a custom device is needed. Patients will become better educated on their options, which will alter the relationship with their doctors and surgeons, and influence their choice of treatment and device. Such a change will disrupt the industry as we know it today, and the winners will be those who learn to flourish in such an environment.

The full power of personalized simulation can be realized through the use of SIMULIA’s simulation platform with complementary solutions from partners like Materialise and Synopsys, Inc. for translating 2D scan data into 3D meshes, or Intel and Hewlett-Packard Enterprise for high-performance computing. Adding our capabilities for optimization (Tosca, Isight) and fatigue-life evaluation (fe-safe) creates the ability to rapidly replicate the process used by nature for refining designs based on a “survival-of-the-fittest” methodology.

These are exciting times to be an engineer. Now that BIOVIA has joined the other DS brands, we are developing the digital continuity necessary to build models that go from atoms to parts, components to systems—or from cells to organs, or individuals to entire populations. This truly is unprecedented and I’m eager to see how you will use the tools to make the impossible, possible.

Imagine selecting, and even designing the performance qualities of, the specific materials that will deliver products with a precise user experience—right off the production line. Add in the benefits of collaboration with the 3D EXPERIENCE® platform and imagination moves toward reality even faster.

I hope you see why I believe we are on the threshold of a true transformation in product design and engineering. Think about the products you help to develop, use yourself, or the medical care you or your family receive. Ask yourself if such a human-centric transformation would change the game. Now is the time to be part of this profound shift and we’re here to help you master—and enjoy—the experience.

For More Information

www.3ds.com/products-services/simulia/solutions/life-sciences
Case Study

SIMULATING SMARTER STEMNTS
Admedes, a leading provider of self-expanding Nitinol medical components, employs Dassault Systèmes’ Living Heart to support simulation and optimization of implant function.
He immediately recognized its potential. Having a 3D model of the human heart would give him and the team far greater visibility to its inner workings, allowing them to virtually implant their Nitinol devices directly into the heart model and rapidly analyze various product designs. It would also mean far less need for in-vivo testing—a huge cost benefit to their customers, and something that would greatly speed the design cycle. The company applied for membership to the LHP and was accepted soon after.

The Living Heart Project is a collaborative effort between Dassault Systèmes and dozens of medical researchers, device manufacturers, clinicians, and regulatory agencies. These include the United States Food and Drug Administration, Stanford University, The Mayo Clinic, the universities of Texas, Southampton, Cape Town, and others, as well as leading pharmaceutical and device suppliers. Hempel looked forward to working as part of this prodigious group.

**PUSHING BOUNDARIES**

Hempel started by evaluating the 3D heart model on its own, but quickly moved to “implant” a generic heart valve frame made of Nitinol. He created a cylindrical surface in which to mount the frame, “crimped” it to 10 mm (0.394 in.), and actuated contact between the outer surface of the cylinder and the tissue of the 3D heart, “almost like a real implantation,” he says.

“Determining accurate boundary conditions and the amount of load acting on the frame body is very important to the development of these types of devices,” Hempel explains. “Without that information, there’s no way to identify the fatigue strains during the actual application in the body. However, it is very difficult to obtain this data from animal studies, which suffer from large uncertainties.”

This is where the LHP model comes into play. Hempel was able to visualize the strains produced during valve implantation, as well as the strains generated during the heartbeat. He then took the simulation a step further by optimizing the design using Tosca Structure. Rather than using the Living Heart model itself for optimization, he mimicked the loading seen in the model by extracting boundary conditions and applying them for optimization.

“We received the Extended Token for our Abaqus suite last year, so we had the option to try out additional tools,” he
Case Study

says. “Tosca was fairly new to me at the time, but after six iterations I was able to reduce the maximum strain by 35%, the alternating strain amplitude in a fatigue life evaluation by almost 50%, and better distribute strains overall. The design changes were quite small actually, so I was both surprised and quite pleased that they would have such an impact on product strength.”

“Prior to Tosca, we could analyze customer designs, offering advice based on our extensive experience with Nitinol products, but there was no chance to actually compute an optimized design,” says Hempel. “That’s all changed now.”

PUSHING AHEAD

There’s more work to be done. Hempel says he postponed simulation of the “leaflets”—sections of the valve body that actually contain the blood during the closure cycle—for future testing. “I didn’t have the requisite computational time needed to perform such an analysis during this initial study, so I could only extract the compression of the device that occurs with contraction of the heart,” he says. “I did, however, apply additional radial displacement—which we can gain from experiments or analytical approximations to simulate leaflet closure—in order to make the simulation as accurate as possible.”

Tosca topology optimization results. The cross-section to the right clearly shows stress reduction at the top and bottom portions of the strut joint.

Hempel looks forward to simulating the entire heart valve including the leaflets using fluid structure interaction, and to gain greater understanding of the impact of disease and age on valve design. He also anticipates using Isight (for parametric optimization), fe-safe (for fatigue analysis), and other modules within the Abaqus product suite.

His vision is that methodology such as this will be standard in the future. “Perhaps one day we will have commercially available patient-specific cardiovascular devices,” he says. “Until then, the Living Heart project provides many possibilities not only for design optimization, but also for playing a strong role in academic teaching and training of anyone involved in cardiology work.”

“Our goal was to reduce crimp and fatigue strains in a generic heart valve design,” he concludes. “We accomplished this goal and have used what we learned to assist our customers. We also provided feedback to Dassault Systèmes on ways to improve the Living Heart model—something they were very receptive to. It’s been a lot of fun to work with cutting-edge technology such as this. I’ve learned a lot from it.”

For More Information
www.admedes.com
The FDA’s Center for Devices and Radiological Health (CDRH) is responsible for assuring the safety, effectiveness, performance and quality of medical devices and radiation-emitting products used to treat, prevent, and diagnose disease. With a keen eye on the future, the CDRH has set new Regulatory Science Priorities for 2016 that include the development of computational modeling technologies to support regulatory decision making.

The FDA recently developed the Medical Device Development Tools (MDDT) program to allow for new methods for evaluating medical devices to be qualified for use in regulatory submissions to CDRH. The program aims to provide MDDT developers and medical device manufacturers with a mechanism for discussing early product concepts with FDA, fostering collaboration on tool development as well as increasing the use of the qualified tools.

How can the CDRH leverage realistic simulation technology to further their mission to protect and promote the public health?

Medical device FDA premarket submissions include computational modeling and simulation of the medical devices and their engineering analyses. Examples include finite element analyses of stents, orthopedic implants, anterior chamber intraocular lenses; and computational fluid dynamics of heart valves and ventricular-assist devices.

Although the use of computational modeling and simulation (cm&s) for regulatory purposes has lagged that in other industries, over the past decade we have begun to see a dramatic increase in the use of cm&s, particularly in the following areas:

- **Computer models of patients** are used to support the approval or clearance of new medical devices. These models of patients, such as the Virtual Family set of virtual anatomical models (VF), have been used in over 120 submissions to the FDA. Most of these submissions have used the VF to demonstrate that an implanted medical device will not cause the heating of tissue when a patient undergoes MRI.

- **Population modeling methods** enable a more comprehensive understanding of the differences and similarities for a wide range of data sets, which may also lead to improved medical device designs for more people. An example of this type of tool is The Musculoskeletal Atlas Project, a population model of the musculoskeletal system, which was supported in part through FDA extramural support.

- **Virtual clinical trials** create computational approaches to design virtual patients or simulate a clinical study itself.

Virtual patients may be incorporated in clinical study designs, allowing for smaller clinical studies or enrichment of the clinical study with virtual patients having conditions with low prevalence in the clinical study cohort. FDA researchers are developing methodologies for conducting in silico imaging clinical trials. In one such project, Virtual Imaging Clinical Trials for Regulatory Evaluation (VICTRE), an all-digital imaging pipeline will be made available open source for simulating three-dimensional breast imaging systems, now approved only through burdensome clinical trials.

The CDRH recognizes the great potential of computational modeling and simulation as an efficient and effective method for the evaluation of medical devices and believes the MDDT process can be used to support regulatory submissions. Examples of MDDTs currently being reviewed by FDA include Vextec’s computational durability software for predicting fatigue failure of medical devices and SIMULIA’s Abaqus Knee Simulator for predicting the performance of artificial implants.

1. www.fda.gov/medicaldevices/scienceandresearch/medicaldevicedevelopmenttoolsmddt/default.htm
2. www.fda.gov/aboutfda/centersoffices/officeofmedicalproductsandtobacco/cdrh/cdrhoffices/ucm302074.htm
3. www.fda.gov/MedicalDevices/ScienceandResearch/ResearchPrograms/ucm477379.htm
4. www.fda.gov/ScienceResearch/SpecialTopics/RegulatoryScience/ucm452322.htm
5. www.fda.gov/ScienceResearch/SpecialTopics/RegulatoryScience/ucm227223.htm
6. www.fda.gov/MedicalDevices/ScienceandResearch/ResearchPrograms/ucm477418.htm

For More Information
www.fda.gov
The Insigneo Institute for in silico Medicine at the University of Sheffield, UK, is transforming how engineering is being used in medicine, with support from Dassault Systèmes. “This transformation is perhaps the most far-reaching ever to benefit medical practice, as computational technologies begin to alter the ways in which clinical decisions are made,” says Prof. Damien Lacroix, Research Director of Insigneo. “These computer-driven processes are enabling clinicians for the first time to combine exquisitely detailed 3D mathematical models of their patients with finite element (FE) solution systems to see into their patients’ futures.”

Employing in silico medicine in this way allows doctors to consider different treatment options in the safety of computer models, Lacroix points out. “FE solutions present clinical teams with new ‘biomarkers’—previously unavailable computed measures of physiological status—that lend strong support to their decisions. Clinicians are learning to cope with complexity by introducing computational simulation.”

Various applications have been developed within Insigneo, though they are at different Technology Readiness Levels (TRL)—some being close to the clinics and others still at the stage of basic science. Below are three examples:

**CLINICAL DECISION-MAKING FOR TREATMENT OF LOWER BACK PAIN**
To improve upon the existing clinical approaches to the diagnosis and treatment of spinal conditions, in silico techniques were developed through an EC-funded project, MySpine, led by Lacroix, to help clinicians select the treatment that promises the greatest long-term success for each patient. Applying this approach on a patient-specific basis is a great example of how this transformative process will impact medicine (See Figure 1).

**TISSUE ENGINEERING SCAFFOLD FOR REGENERATIVE MEDICINE**
All soft tissues are made of interstitial fluid and a solid matrix usually composed of collagen. Thus many scaffolds that are developed for regenerative medicine are made of collagen gel that will interact with cells seeded within the scaffold. A poro-hyperelastic finite element model of such a gel was developed using Abaqus by Dr. Andre Castro from Insigneo. He calculated the solid and fluid mechanical stimuli acting on the cells when the scaffold is deformed in a bioreactor or in situ in the body. This will help experimentalists to better design their scaffolds and bioreactors for the optimization of tissue regeneration (See Figure 2).

**MECHANOTRANSDUCTION IN CELL REGULATION**
The glycocalyx layer in the membrane of many cells is believed to be essential for sensing mechanical stimuli that can activate functions such as migration, proliferation and differentiation. Lacroix developed a single-cell FE model using Abaqus which was later coupled by Insigneo’s Stefania Marcotti into a fluid-structure interaction simulation (See Figure 3). These models allow for quantitative measurement of properties affecting human cells in physiological and pathological environments. This quantitative data can provide insight into important cell properties, but is often challenging to acquire in experimental settings. The simulations produce useful information on cell mechanics and mechanotransduction that allows for further understanding of these complex biological questions.

**VIRTUAL REALITY IN THE CLASSROOM**
Insigneo’s efforts to integrate in silico medicine into real-world, clinical applications have continued alongside the development of one of the most advanced technologies of our

“With the introduction of these tools, clinicians will be able to work towards disease prevention—reducing the number of people who get sick—and better treatment, which in turn minimizes patient complications.”

— Prof. Damien Lacroix, Research Director, Insigneo
time: virtual reality (VR). With grant funding by La Fondation of Dassault Systèmes, the group plans to bring two brand new VR laboratories—including a virtual reality “cave”—to the M.Eng. and M.Sc. candidates at Sheffield. Students from different backgrounds (mechanical and bioengineering, science, or medicine) will be offered the opportunity to take courses that use VR technology in the lab to study, interact with, and create biomechanical models based on real human geometry.

"We are trying to develop a VR lab where students will be able to visualize computational simulations," says Lacroix. "The labs that are being proposed focus on the spine and the cardiovascular system. In each of these, we want to have the students interact with some imaging data from a patient and be able to build personalized models that represent the geometry and physiological properties of the individual. From there we will be able to predict stresses and strains on the body as well as investigate particular diseases—and find the best treatments for a specific person."

After dedicating the last four years of the development of in silico medicine to research, Insigneo has recognized the need for new types of researchers and engineers who can master the novel technologies related to simulation. Accordingly, they have created a new degree in Mechanical Engineering with Biomechanics, which includes course work in computational medicine as well as the two VR labs. "By training with all this new technology, students at Sheffield will be the ones who will bring it forward into the real world and find applications in which to use it," says Lacroix.

**CLINICIANS TO BENEFIT AS WELL AS STUDENTS**

Abaqus is one of Insigneo’s main simulation tools, but the institute plans on expanding to other SIMULIA software as well—including obtaining a licence for the 3DEXPERIENCE® platform this year. "We have received a lot of interest from clinicians who want to implement enhanced visualization into their practices," says Lacroix. "We would like to develop a portal where doctors of all backgrounds will be able to upload imaging data from their patients. We then would use that information in a workflow—integrated within the 3DEXPERIENCE platform—in which we would be able to preserve the images, develop patient-specific models, and eventually provide the clinicians with predictions about the outcome of any given treatment."

Lacroix and the rest of the team at Insigneo understand the power of simulation, as well as the savings that can result from adopting simulation tools like Abaqus. "It’s important to look at the total cost of care when deciding on whether or not to integrate simulation into medical practice," he explains. "It can save you money while also leading to better quality care for patients. With the introduction of these tools, clinicians will be able to work towards disease prevention—reducing the number of people who get sick—and better treatment, which in turn minimizes patient complications."

Lacroix also believes that the use of in silico technology within clinical trials has the potential to massively cut costs for clinicians. "There are three phases to clinical testing and Phase III is by far the most expensive," he says. "More often than not, it is during Phase III (testing on several thousand people) that new drugs or medical devices fail. A high number of patient tests are needed for statistical reliability, but if we used a mechanical model instead, we could account for the specificity of each person and reduce the number of tests needed."

Performing in silico trials in this way could significantly cut costs, reduce time-to-market, and make medicine more accessible to patients around the world, Lacroix feels. The FDA is already aware of this potential and is accepting simulation data for appropriate applications.

It will be interesting to see what other technological developments will play a role in the future of medicine, how Insigneo will incorporate them into student curriculums at Sheffield, and how current and future clinicians will put them to good use on behalf of patients. Insigneo and Dassault Systèmes’ SIMULIA have recently signed a Memorandum of Understanding that ensures their activities continue to develop in parallel.

**For More Information**

http://insigneo.org
TAILORING TREATMENT TO THE INDIVIDUAL PATIENT
Simulation helps clinicians choose the best option for a successful artery repair

The 19-year old patient was in trouble. Born with an initially undetected congenital malformation of the aorta, the major artery of the heart, he had a metal stent implanted at eight years of age to widen the blood vessel and restore normal flow. At first the treatment to correct his coarctation of the aorta (COA) was a success. But, despite re-dilation six years later, the supporting structure of the stent narrowed again, fracturing in places and allowing the aorta to form a small but potentially dangerous aneurysm (a bulge in the vessel wall that could burst).

Many types of congenital heart abnormalities can be corrected in very young babies through open-heart surgery. But sometimes such problems aren’t identified until a person is older. Even repairs made at birth can occasionally fail over time. Balloon angioplasty—the insertion via catheter, of an inflatable balloon that widens the blood vessel—became an accepted (and much less invasive) corrective procedure in the 1980s for older children or adults. Starting in the 1990s, adding a stent into a balloon-widened artery (as was done with this patient when he was eight) proved to be an effective way to stave off further complications.

But doctors who were monitoring this patient’s condition realized by the time he was 18 that complications had, in fact, developed. An echocardiogram and examination through a catheter-guided system revealed that the COA had recurred and was now accompanied by a threatening aneurysm. A covered stent is usually placed to protect the aneurysm, but in this patient, another important artery bringing blood to the right arm was starting from the site of implantation and could not be risked. As the patient turned 19, the cardiologists began planning to replace the defective stent and repair the blood vessel wall in order to keep the young man healthy. But what would be the best route to success?

SIMULATION HELPS ENGINEERS AND CLINICIANS COLLABORATE
Modern body-scanning technologies clearly show that no two people’s anatomies are alike. Fortunately, this individuality can now be translated into patient-specific computational modeling, which is becoming a powerful, recognized tool to help clinicians plan complex interventions. Although not widely employed for treatment planning yet, use of such
simulation methodology is starting to produce real-world results as engineers and physicians increasingly collaborate on patient cases.

Researchers from Clinical Cardiovascular Engineering at University College London Institute of Cardiovascular Science had the capabilities to help the young patient and his doctors at Great Ormond Street Hospital for Children. Embedded in the hospital’s cardiology department, they have expertise in computer simulation that helps bring the power of virtual problem solving to real-life patient cases. In addition to Abaqus finite element analysis (FEA) from Dassault Systèmes’ SIMULIA, their toolkit includes computational fluid dynamics (CFD), and image post-processing software.

**MODELING THE PATIENT’S CHALLENGES**

“In order to create computer models that accurately reflected this patient’s condition, we needed to start from his unique geometric data,” says Silvia Schievano, Ph.D., researcher at UCL. The shape details and anatomical relationship between the different structures was captured by a computed tomography (CT) scan. Magnetic resonance imaging (MRI) provided a way to visualize the current haemodynamics (blood flow), with two-dimensional phase-contrast images taken to assess flow measurements of the ascending and descending aortas and all the associated smaller arteries.

Next the CT images were used to create in silico patient-specific 3D geometry, and flows and velocities were extracted from the MRI data. Catheterization angiograms coupled with echocardiographic measurements were used to guide plans for reconstructing the narrowed (stenotic) site.

With structural and CFD working models of the patient’s current condition in hand, the team could now simulate the insertion of different sizes of a replacement stent (a CP™ covered one from NuMED) into the aorta, and predict the effects of each one on blood flow and pressure—with the goal of identifying which would be best to recommend to the young man’s doctors.

**CHOOSING THE RIGHT SIZE STENT MAKES ALL THE DIFFERENCE**

Four virtual stents were virtually tested in the patient geometry—14, 16, 18 and 20 mm. The simulations revealed that the 14 mm device didn’t completely contact the interior walls of the blood vessel. The 20 mm stent obstructed part of the origin of the arm artery. The 16 and 18 mm stents showed safe anchoring to the arterial wall, no obstruction of the arm artery and protective coverage of the aneurysm as well. The researchers suggested to the patient’s cardiologist that either the 16 or 18 mm diameter stents would work well.

The procedure was successfully carried out with a 16 mm diameter stent. Follow-up angiograms of the patient showed that the blood flow was restored, the aneurysm was excluded and that the aberrant portion of the artery was functioning well.

“The overall results of the recommended procedure were well predicted by the FEA and CFD analyses we performed in advance,” says Research Associate, Claudio Capelli, Ph.D. “Our modeling techniques provided important supplemental information to the clinicians that improved their confidence in the treatment.”

**VIRTUAL TREATMENT PLANNING PRODUCES BETTER OUTCOMES, COST-EFFECTIVELY**

“Finite-element models such as this allow inexpensive testing of different scenarios within a virtual reality that can realistically replicate an individual patient’s condition,” he says. “Not only could everyone involved visualize the predicted results together, the clinicians could also use the numerical data generated by the simulation to compare different strategies for providing safe anchoring and aneurysm treatment.”

“When engineers and physicians collaborate like this, through the use of simulation to provide personalized medicine, patients could truly benefit by informed decision making and more efficient treatment,” says Schievano.

The patient in this example is now 23 years old and doing well.

For More Information
www.ucl.ac.uk/cardiac-engineering
Since the dawn of civilization humans have sought new methods to improve quality of life when part of their body could not function as required. Direct study of the human body and its many functional parts have revealed many of the engineering feats that nature has built into the human body via thousands of years of trial and error. Consider the big toe— with every step we take the big toe is the last part of the foot to push off, and while doing so it carries about 40% of the body’s weight. This stubby digit is crucial in our ability to walk, run, and even maintain balance. By understanding structures like the big toe, doctors today are better prepared to offer solutions for people who experience impaired mobility, disease, birth defects, accidents and more.

In the year 2000 scientists stumbled upon the world’s oldest known prosthesis when they discovered an Egyptian mummy with a fake big toe. Since the discovery, researchers have conducted multiple tests with toeless volunteers, having them walk in Egyptian sandals while wearing a replica of the ancient toe. Amazingly the prosthetic toe allowed one of the volunteers up to 87% of the flexion of his real big toe on the other foot. Though a great feat (in the world of feet), we can only imagine the time and effort to create the hundreds of prototypes it may have taken the Egyptians to develop this one device. Even today, most doctors and device developers take a similar approach when developing modern medical solutions through testing, time, and good old trial and error.

Advances in medical imaging have opened the door to a new era of engineering, enabling precise multiphysics simulation of humans and other natural forms (known as biomimicry). This is a revolution in engineering, breaking the dependency on CAD-driven structures and product development environments with little understanding of the humans who will use or host them. It is now possible to rapidly take conventional medical image data, convert it directly to 3D meshes and import directly into solvers such as Abaqus to optimize design of medical devices, consumer products and 3D printed prostheses.

SIMULIA in collaboration with Hewlett-Packard Enterprise, Materialise, Inc., and Synopsys Inc. have been hosting a first-of-its-kind, world-wide seminar and workshop series titled “Advanced Biomedical Modeling: From Image to Simulation.” Each full-day workshop showcases applications and provides hands-on training, demonstrating the seamless integration between image segmentation tools such as MIMICS by Materialise or Simpleware ScanIP by Synopsys, Inc. and SIMULIA’s Abaqus Unified FEA portfolio. The morning typically features the latest applications from local biomedical and cardiovascular experts and the afternoon allows attendees to learn firsthand methodologies to develop custom human simulation models directly from CT/MRI scan data and perform predictive analysis.

Engineers and researchers in the medical device, healthcare or consumer oriented high tech industries interested in using realistic human models in their design, evaluation and testing process are invited to join these free, 1-day seminars (see back cover). Over the course of the day they will not only gain an understanding of the progress in this developing field, but also learn the complete workflow to take a heart model from start to finish, beginning with 2D Scans and ending with a dynamic, 3D beating heart model. Knowledge of Mimics, Simpleware ScanIP or Abaqus is useful but not required. Join us and learn how you can leverage this technology to help patients of tomorrow walk like an Egyptian!

For More Information
www.simulia.com/biomedical_modeling
INTEL AND SIMULIA PARTNERSHIP HELPS UNLOCK THE SECRETS OF THE LIVING HEART

Healthcare costs represent an alarming and unsustainable share of national wealth across the world, and show no signs of slowing. In the US, they now represent over 17% of GDP and could grow to 35% by 2050. A digital revolution in healthcare is needed to bring costs under control while improving both quality of care and access in poorly served parts of the world.

For Intel, this is just part of a larger initiative for enabling a new age of life sciences and precision medicine. For Dassault Systèmes, this was addressed by honing in first on cardiovascular disease, which remains the number one cause of death worldwide, and bringing together a multidisciplinary team of experts to form the Living Heart Project. Participants from industry, academia, clinical practice, and regulatory bodies are collaborating toward a unifying technology platform that can collect and synergize diverse cardiovascular knowledge. The ultimate goal is the development of improved products and treatments that will benefit patients and save lives.

Intel joined the Living Heart Project to lend its decades of expertise in high-performance computing and related technologies to help make this groundbreaking biomedical engineering a reality. Working with partners such as SIMULIA, Intel is helping to quantify biological systems using large-scale data.

The potential benefits of this transformation are profound, to cardiovascular medicine and beyond. Advances in healthcare analytics will reveal patterns that can guide precise treatment and preventive care for individuals and improve handling of public-health issues. As part of this digital revolution, the Internet of Things will create communication between patient sensors, medical devices, and provider networks to improve efficiency and cost effectiveness; these new data flows will demand new and improved solutions. It will not be long before genomic markers will allow treatments to be tailored directly to an individual’s genetic profile, and Intel will be there with the computing foundation to support it.

As Steve Levine, Executive Director of the Living Heart Project put it, “In the future, performance improvements will be measured in number of lives saved.”

Intel has helped quantify these improvements through their powerful Intel Xeon processor E5-2600 v4 product family. Because the Living Heart is a sophisticated and flexible simulation of the heart it requires more powerful compute capabilities. Time is critical when designing new life-saving devices or providing patient care. To help with its computationally intensive nature, use of the LHM benefits dramatically from the extensive optimization work through the Intel and SIMULIA partnership to accelerate the underlying Abaqus software. In particular, the solution takes advantage of Intel® Advanced Vector Extensions 2.0, which doubles the number of floating-point operations per cycle compared to the first generation of the technology.

The combination of the Intel Xeon processor E5-2600 v4 product family and SIMULIA Abaqus software has shown a speedup of approximately 1.37x compared to the previous processor generation. While the workload used to generate this particular result is not the Living Heart, it illustrates the value of ongoing hardware advances and software optimizations to this important work. Performance enhancements to the LHM enable simulations based on richer data sets to be conducted in less time and more cost effectively. Looking ahead, researchers are now turning their attention to simulating cardiac disease states and complete digital testing of new and more-effective treatments.

Intel and SIMULIA continue to work together to revolutionize medicine to transform the world within us more rapidly than ever thought possible.

SIMULIA* Abaqus/Explicit* Performance Increase

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For More Information
www.intel.com

www.3ds.com/simulia
SIMULATING STANFORD STUDENTS

Dr. Ellen Kuhl and her Living Matter Laboratory Group uses Abaqus to explore subject-specific changes in the human body.
Times have changed dramatically in the world of engineering since the baby boomers were in college, especially as simulation has grown to become such an integral part of the design process. Slide rules, mechanical calculators, even meshing by hand are a thing of the past and current Millennial engineering students are inspired to push the boundaries of innovative technology ever further.

One Stanford University professor, Dr. Ellen Kuhl, is helping drive such innovation alongside her students in the Living Matter Laboratory. Her group works with 10 students using personalized finite element models to predict the interplay of form and function throughout the human body.

Dr. Kuhl has used SIMULIA’s ABAQUS finite element analysis tool ever since she took her first finite element course at the Leibnitz University in Hanover, Germany—and her Living Matter Lab at Stanford follows suit. “I’ve been using ABAQUS for 20 years now,” she says.

Following her studies of computational, civil, and aerospace engineering in Hanover, Stuttgart, and Delft, Dr. Kuhl became an assistant professor in the department of Mechanical Engineering at the Technical University of Kaiserslautern. In 2007 she moved to Stanford, where she is currently a professor in the department of mechanical engineering with courtesy appointments in bioengineering and cardiothoracic surgery.

With a passion for living-matter physics, Dr. Kuhl focuses her work on the precise prediction of the response of living structures to environmental changes. “My specific interest is the multi-scale modeling of growth and remodeling, the study of how living matter adapts its form and function to changes in mechanical loading, and how this adaption can be traced back to structural alterations on the cellular or molecular levels,” she says.

“When I came to Stanford, a few students who were working in cardiac surgery contacted me to help with their simulation,” says Kuhl. “One student was interested in understanding atrial fibrillation. That’s how we got into modeling the heart. We connected with heart surgeons who had collected great data and we started modeling the electromechanical interaction in the heart.”

After she began her heart simulation work, Dr. Kuhl reached out to SIMULIA and asked if they would be interested in implementing biology into the software—without knowing that the Living Heart Project was already in the works. “As we had already developed similar software, we had some experience with it,” she says, “so the timing couldn’t have been better.”

Since then, the students in the Living Matter Lab have studied different parts of the human body, often using their own medical images. Attracted by the wide range of medical problems, students from multiple disciplines came on board.

“The classes that we offer attract undergraduates who are future medical students, human biologists, and engineers,” says Kuhl. “There’s a broad mix of people and that’s what I like the most. I’ve even had some business and education students; what’s interesting is that when you show them a simulation, they have very different ideas than our engineering students.”

Not surprisingly, Dr. Kuhl is affectionately known by many of her students as “Dr. Cool.”

Below are some highlights of recent work by students within the Living Matter Lab:

**TENNESSEE AND TWISTED BONE GROWTH**

Students had heard about a tennis player at the University who was having problems with his shoulder and recognized that he would be an ideal subject to see if they could simulate the physical changes to the bone resulting from overuse of a player’s dominant arm.

The team chose to study the humerus because of its structural simplicity and the convenience of being able to use the non-dominant arm as a control. “With a high-speed video recording of the player’s motions during a serve, and bone density scans available, the students created a finite element model and determined the muscle force vectors, muscle attachment points, and boundary conditions,” explains Kuhl.

The results showed that, due to torqued loadings on the player’s arm during his serve, the bone was growing in a twisted manner—which explained why the Stanford athlete was experiencing pain in his dominant arm. Armed with this insight, the group suggested ways to optimize training strategies so tennis players could avoid such irregular bone growth.

“It’s important that academia and commercial groups work together hand in hand, and I believe that SIMULIA understands that as well.”

—Dr. Ellen Kuhl, associate professor, Department of Mechanical Engineering, Stanford University
Case Study

ASYMMETRIC LOADING IN A LINEMAN AND A PUNTER

Two students in Dr. Kuhl’s class—both players on the University’s Division 1 football team—decided to model and study their own bodies. The students had very different body types; one was a defensive lineman and one a punter. They wondered whether or not they had asymmetric loading in their bones due to their positions (see Figure 1).

They put themselves in a density scanner and recreated their body geometries. “We then asked them stand on a force plate that measures the forces on the feet when making a specific motion,” says Kuhl. “We used these forces along with the geometries to create finite element models of their femur. We asked ourselves “how is the density in the bone distributed in response to loading?”’ The results were surprising. The students found that there was indeed a marked asymmetry: the right lineman had a stronger left leg, the punter had a stronger plant leg. (see Figure 2).

HIGH HEELS AND SHORT MUSCLES

The idea that our day-to-day behavior can change the structure of our bodies is not limited to extreme conditions. One of Dr. Kuhl’s students always wore high heels to class and chose to study the effect of doing so on her legs. She had her leg scanned both with and without her high heels on and created finite element models from those scans. The team also performed ultrasound imaging to visualize the muscle fiber orientation and used a new technique, developed by a colleague of Dr. Kuhl, to image the sarcomere microstructure.

Simulations of the calf muscle and the tendon showed that, when wearing high heels, the leg muscle shortens. The body senses this change in length and the muscle actually shrinks over time. When switching back from high heels to flat shoes, the muscle becomes overstretched and triggers pain (see figure 3).

“What’s great about finite element modeling is that it can predict where exactly the deformation is largest,” says Kuhl; all deformation from wearing heels was found in the center region of the muscle, not in the periphery or in the tendon. This insight explains why it is not healthy to wear high heels over long periods of time.

AIRWAY OBSTRUCTION IN THE LUNGS

Many people have studied airway obstruction in the lungs, but most studies only look at an idealized circular cross-section of the airway. When a student in the Living Matter Lab at Stanford studied the effects of asthma and bronchitis on the lungs, she instead used the real geometry of an actual bronchial tree. “With this study we were able to show that very small changes in the geometry can have large effects on airway wall collapses,” says Dr. Kuhl (See Figures 4-5).

The student created an airway modeled from medical scans to show that the real airway actually collapses much earlier than previously predicted. Her study highlights the importance of using anatomically realistic models, something that has only become feasible recently with the development of high-performance computing.

PERSONALIZED BRAIN FORCES

Most recently, Dr. Kuhl’s team started to investigate the role of mechanical forces in human brains. Their work began as a fairly simple class project: magnetic resonance images of their own brains to compare size and shape. But then the project expanded. They created an Abaqus model of a brain—Dr. Kuhl’s own—and one student even 3D printed the brain for use in surgical training (See Figure 6).

A postdoctoral researcher in the group simulated the brain in different scenarios and clinical procedures including a
decompressive craniectomy. In this procedure, the surgeon opens the skull to allow a swollen brain to bulge outward and release an elevated pressure. “What was most surprising,” says Kuhl, “is that our simulations revealed that a small swelling volume of only 50ml can generate local strains of 30% and more. This can be extremely detrimental.” This study could help neurosurgeons to optimize the size and location of the skull opening and minimize tissue damage.

**SIMULATION AIDS STUDENTS BEYOND THE CLASSROOM**

By using simulation to understand such real-world examples of human body form and function, the Stanford students are expanding their own horizons as to what they can do with their careers as future engineers—where using simulation may well be an every-day occurrence.

The divisions between academia and commerce are softening, Dr. Kuhl feels. “My view of academia is that it is inspiring the basic scientific development of ideas,” she says. “It is here in the University where students ask the basic science questions. When these ideas are commercialized they reach a much deeper level. It’s important that academia and commercial groups work together hand in hand. SIMULIA understands this very well. This is why working within the Living Heart Project is so extremely exciting.”

With engineering and medical students becoming members of the Living Matter Lab, Abaqus has been a powerful tool in helping them understand one another. “When our engineering students take their first course with our group, they don’t know much about the biology,” says Kuhl. “They often know that there is a problem and they can describe it by an equation, but they don’t really know what it means. By using finite element simulations they can visualize what’s happening, for example by looking at an electric wave traveling across the heart. This helps them better understand the biology behind it.

“On the other hand, medical students are used to memorizing information but often don’t ask themselves, ‘why is that?’ Visualizing biology through finite element simulations allows them to gain a better insight of the things that they would otherwise just memorize, for example, reading the traces of an electrocardiogram.”

**WHAT’S NEXT FOR THE LML?**

The Living Matter Lab has spent considerable time on the heart. Going forward, they plan to focus also on studying the brain. “We now have a ton of students interested in working on the brain,” says Kuhl. “The brain is mechanically challenging: it is extremely soft, it is constrained to move within the limited space of the skull, and it has many unique and unexplored problems. We believe this is a field where we will make a great impact.

“I personally want to use computation to integrate knowledge from different scales and disciplines. Studying the brain could bring together biology, physics, engineering, neuroscience, neurosurgery, and even behavior sciences. I think it’s important to study our body across all scales—the larger scale talks to the surgeon, while the smaller scale has more of an impact on basic science. Ultimately, I aim to bridge those two things together through computation.”

It will certainly be interesting to see what else personalized simulation will tell Dr. Kuhl’s students about the human body. The team at Stanford is clearly eager to find out.

For More Information
http://biomechanics.stanford.edu/Main_Page
SKIN DEEP IN MODELING
Georges Limbert¹,² and Maria Fabiola Leyva-Mendivil¹
¹University of Southampton (UK), ²University of Cape Town (South Africa)

Beyond its physiological importance as the largest and one of the more complex organs of the human body, the skin plays a crucial role in how we interact our external environment, as well as with each other. At the primal level, and through mostly subconscious cues, the skin tells a story about our age, health, past traumas, emotions, ethnicity, and our social and physical environments.

The skin is a highly dynamic and adaptive hierarchical biological structure which hosts complex physical and biological processes. Although we might not consciously appreciate these highly desirable characteristics we all experience them daily and over the course of a lifetime. Think about it: how valuable would be a coat that can protect you against mechanical, thermal, biological, radiological and chemical insults, is waterproof, crease-proof, warns you about external dangers through a complex neural sensory network, regulates your temperature, synthesizes essential biochemical compounds like vitamin D, self-repairs and can last over 80 years with reasonable care?

The skin can be viewed as our interface to the world, and, as such, is involved in a wide range of contact interactions that operate at different spatial scales and typically feature coupled physics phenomena¹. These surface interactions are an essential part of the physical world and also of how humans perceive their environment for cognitive awareness, social interaction and self-preservation. Besides medicine, surgery and medical devices², understanding the physiology and biophysics of the skin in health, disease, ageing and trauma is fundamental for many industrial applications ranging from consumer goods (e.g. shaving, personal care, incontinence products) and cosmetics (e.g. tribology of skin lotion and their subsequent effects on skin mechanics and wrinkles) through the design of advanced fabrics, sport equipment and electronic tactile surfaces to electronic “wearables” as well as the development of automotive airbags that minimise friction-induced burn injuries during their deployment.

There is an intimate relationship between structure and function of the skin³ and, as a corollary, a strong non-linear interplay between its material and structural properties⁴,⁵ which constantly evolve with age and alterations of environmental conditions. The formidable complexity of such a multiphasic, multiscale and multiphysics structure can be systematically investigated using the advanced modelling capabilities offered by the SIMULIA brand products (e.g. Abaqus) in combination with dedicated experimental and imaging techniques (Figure 1-Figure 2). Simulating the mechanics...
and physics of skin in general is one of the most demanding applications of computational physics: material, geometrical and contact non-linearities, strongly anisotropic properties, near incompressibility, damage, surface instabilities, coupled physics and multiple length and time scales. This calls for advanced element and contact formulations as well as robust non-linear solvers and stabilization algorithms, all available in Abaqus. For example, anatomically-based micromechanical models developed in Abaqus enabled us to gain a quantitative and mechanistic understanding of how changes in relative humidity affect the interplay between skin microstructure and variations of the mechanical properties of the stratum corneum which is the upper-most layer of the skin. It was also demonstrated that the skin surface micro-topography made of ridges and valleys provides an efficient mechanism to modulate macroscopic strains.

Over the last decade, the significant increase in the number of scientific papers dedicated to experimental and computational modeling aspects of the skin is testimony to the emergence of a new field of research, computational skin biophysics. The celebrated features of computer simulations, repeatability, the power and flexibility of “what if” scenarios in conducting hypothesis-driven research, low cost, speed and reduction of the need for animal experiments offer exciting prospects for the future of skin research. Ultimately, this could lead to new treatments and diagnosis tools, to better products that would be more comfortable to use or, perhaps more exhilaratingly, to make us look younger. In the mean time, let’s develop advanced realistic simulations!

REFERENCES


For More Information
www.biotribology.org
SIMULATION-DRIVEN PERSONALIZED MEDICINE

DIGITAL ORTHOPAEDICS

In current practice for foot surgery, surgeons take an almost purely “geometry” approach. They start with the principle that a normal person has a “normal” geometry resulting in painless motion and low stresses in the foot. A patient with foot pain therefore has a “deviated” geometry that needs to be restored to provide relief.

Digital Orthopaedics is an innovative startup that is convinced that orthopedic treatment and outcomes can be significantly improved through the advanced use of imaging, modeling, and simulation. To succeed, they understand the critical need to bring together engineering and medical teams—in fact, the company founders include leading orthopedic surgeons and experienced engineers with the common goal to transform orthopedic treatment.

The company has been building a comprehensive Clinical Decision Support System (CDSS) for musculoskeletal pathologies that can provide caregivers, surgeons, patients, and medical device companies with optimal personal treatment and surgical therapeutic plans. This transformative CDSS will include the following components:

1. A Knowledge Base and Diagnostic Support platform to allow healthcare professionals and patients to review clinical reports to understand the pathology and choose treatments based on expert knowledge.

2. A Personalized Surgical Simulation platform to assist orthopedic surgeons in developing surgical plans tailored for the patient’s disease and anatomy. This platform will also enable virtual design and clinical studies for new devices.

3. A Machine Learning and Clinical Cases platform that will allow improved outcomes based on knowledge gathered on the Diagnostic Support and Personalized Surgical Simulation platforms.

BIOSERENITY

Bioserenity’s NEURONAUTE® is the first connected textile based diagnostic solution able to capture over 45 biometric measures simultaneously. The first application of this technology is in epilepsy, a neurological disease that affects over 50 million people around the world. Legacy systems have three disadvantages: high cost, fixed infrastructure and limited recording time. Using personalized smart clothing, a smartphone app and the 3DEXPERIENCE platform, Bioserenity can overcome all these issues. The system allows mobile and continuous electroencephalogram (EEG) recording giving neurologists a tool for reducing the time for an accurate epilepsy diagnosis. With 15 patents and innovations in the textile, electronics and software side, Bioserenity has been the recipient of more than 10 awards, including the worldwide Innovation Contest and the International Innovation Award.

Bioserenity’s cloud-based remote analysis solution has been deployed in just a few months at over 20 hospitals in Europe. In collaboration with Dassault Systèmes, the company is working with EXPLeAD on improved EEG analysis using big data analytics and machine learning to interpret the vast amount of data collected so doctors can read the signals efficiently.

Leveraging its unique technology into cardiovascular disease, Bioserenity’s team is now collaborating with SIMULIA to link patient-generated cardiac signals, this time recorded from ECG wearables with the realistic simulation capability of the Living Heart. If successful, this work has the potential to give physicians a near real time immersive view of their patient’s heart wherever they may be.

For More Information
www.digital-orthopaedics.com

For More Information
www.bioserenity.com
OPTOQUEST

OptoQuest offers software and hardware solutions for patient-specific corneal and refractive surgery screening, treatment planning, and outcome prediction for clinicians and industry partners. OptoQuest’s flagship product is SpecifEye™. OptoQuest (a Cleveland Clinic Company) is the culmination of decades of research and development in ocular computational modeling (FEA) and non-invasive, ocular biomechanics measurement. We lead the simulation-based medicine revolution in anterior segment surgery.

Founded by William J. Dupps, M.D., Ph.D., of the Cole Eye Institute and incubated by Cleveland Clinic Innovations, OptoQuest works with key ophthalmic industry partners to drive technology that allows personalized patient care. Dr. Dupps is an international leader in corneal biomechanics with extensive industry consulting experience. OptoQuest has a distinguished international scientific advisory board. The company’s board of directors and development team leverage decades of expertise at some of the largest healthcare and medical device companies in the world. OptoQuest aims to set new standards for care in patient-specific, anterior segment surgical planning by developing next-generation, high quality technologies for researchers and physicians.

SPECIFEMY™

The FEA based corneal surgical guidance software, SpecifEye, uses personalized corneal 3D geometries to analyze the structural impact of the corneal interventions. SpecifEye uses complex material formulations that account for the cornea’s preferred collagen fiber orientation and elasticity in pre- and post-operative states. SIMULIA is OptoQuest’s FEA solutions partner. SpecifEye predicts refractive outcomes of surgeries utilizing whole eye ray tracing methods. SpecifEye can be securely used directly by physicians or integrated into onsite, diagnostic or treatment devices. SpecifEye is currently for investigational use only.

www.3ds.com/simulia
Case Study

PREDICTING THE BEST WAY TO FIX A BROKEN BONE
Munich University of Applied Sciences Researchers Model Different Alternatives with Simpack

Almost everyone damages their shoulder—the blade, collar bone or upper arm bone—at some point in their life, according to the American Academy of Orthopedic Surgeons (AAOS). If you’re lucky, you just get a bad bruise or sprain, but you can break the upper arm bone—the proximal humerus—fairly easily. The AAOS says that a fall, a collision, or a motor vehicle accident are the most common causes of such a fracture. The elderly are particularly susceptible to injury due to the loss of bone density, i.e. osteoporosis, with age.

Most fractures of the proximal humerus can be treated without surgery if the bone fragments are not shifted out of position; casts and splints can be employed to support and stabilize the bone from outside the body.

But if the fragments are out of alignment, surgery is usually required. This involves fixation of the fractured fragments with plates and/or screws to immobilize the bones as they heal. The advent of sterile surgical procedures has greatly reduced the risk of infection, allowing doctors to set and stabilize fractured bones internally with excellent results.

As described by the AAOS, during a surgical procedure to set a fracture, the bone fragments are first repositioned (reduced) into their normal alignment. They are held together with special implants, such as biocompatible stainless steel or titanium plates secured by screws or nails. Internal fixation allows shorter hospital stays, enables patients to return to function earlier, and reduces the incidence of improper healing and positioning of broken bones.

The surgical procedure that stabilizes and joins the ends of fractured bones with implanted mechanical devices is called osteosynthesis. While osteosynthesis can be highly successful in restoring normal shoulder function, “choosing which type of implant to use at the break is critical to long-term success,” says Martin Ott, B.Sc., Munich University of Applied Sciences. “In the last few years more so-called ‘angular locking implants’ are being used.” Locking means a fixed, rigid connection that doesn’t allow any movement between a plate implant and its locking screws.

The latest surgical techniques may not benefit elderly patients

“In general this type of implant produces an increase in the connectivity between the bone and the prosthesis as well as higher stability,” says Ott’s colleague, Dr. Stefan Lehner. “But, particularly when the patient is older and has osteoporosis, we see an increased number of metal/bone screw ‘cutouts’ happening.”

A screw cutout occurs when the neck-shaft angle of the screw collapses inward, leading to extrusion of the screw from the bone. Seen most often in elderly patients, this complication often requires a second surgery to repair it, leading to more discomfort and a longer recovery time.

For his Bachelor of Science thesis, Ott wanted to explore bone-repair alternatives to help surgeons decide which surgical options would be best for older patients. “The in vivo stresses of different implants are almost unknown,” says Ott. “We wanted to investigate these stresses to see if we could predict which methodology produces the optimum results.” He teamed with Lehner, a lecturer in biomechanics at the university, on the project.

The researchers set up a study to compare the biomechanics of an angular locking nail osteosynthesis versus an angular locking plate osteosynthesis in terms of the risk of a bone screw cutout at the head of the proximal humerus. They were able to obtain CT scan data from actual patients that provided measured in vivo loads. “This way we could simulate realistic activities and measure the displacements of the stabilizing interacting bodies,” says Lehner.

![X-Ray of three fragment facture of the proximal humerus and humerus with implanted bone plate.](image)

![Model and X-ray of humerus with implanted bone plate.](image)

![Left) Humerus with implanted intramedullary nail system. (Right) Model and X-ray of humerus with implanted bone plate.](image)
SIMPACK HELPS VISUALIZE MOTION OF MULTI-BODY MODELS WITH FLEXIBLE COMPONENTS

For their numerical simulation, the team used SIMULIA’s Simpack to create a detailed multi-body model of an experimental test set-up that included a fractured human humerus. Simpack provides dynamic analysis of any multi-body mechanical or mechatronic system, enabling engineers to generate and solve virtual 3D models that help them predict and visualize motion by coupling forces and stresses.

Simpack is particularly useful for creating complex non-linear models with flexible bodies; both an intramedullary nail system and a bone plate were modeled as flexible, as were the bone screws themselves. The humerus bone was modeled as a rigid body, based on 3D-scan data of actual implants made available to researchers. A medical-grade Titanium alloy was used for the material properties of all the implants.

Experimental 3-point bending tests verified the flexible Simpack models of the nail system and the bone plate. “Our models demonstrated comparable bending properties as measured in the test setups,” says Ott. Since good alignment of either a nail system or a bone plate is one of the main influencing factors for positive clinical results for a patient, the models were set up with the implants positioned in the most realistic way.

Both surgical procedure models were digitally “implanted” in the same fractured-bone model and one of the most frequently treated fracture types—a three-segmented break—was simulated. This kind of break is often the result of the type of “bad bone” quality that older patients can suffer from. “Three segmental fractures like this often include a comminution zone that can’t transmit load,” says Lehner. “This kind of situation is a ‘worst-case’ scenario for implants being fixated in the bone segments.” To model the fixation of the screws within the bone segments, the engineers used spring-damper elements with stiffness varied to simulate different bone densities.

DAILY ACTIVITIES PUT DIFFERENT DEGREES OF STRESS ON POST-SURGICAL BONES

Now it was time to apply realistic loads that a patient might experience during daily living activities, using data from an in vivo database (www.orthoload.com) and forces measured in three directions using an instrumented shoulder implant.

The first load case used in vivo measurements was from a shoulder joint for a patient on crutches, an activity that puts significant stress on that part of the body. Walking with crutches showed a maximum resulting force of about 60% of body weight. The second load case involved lifting a 10 kg mass (a crate of water) while in a standing position. This time the force was almost 95% of body weight.

“Our simulations were designed to consider only the mechanical aspects of the shoulder-repair alternatives, not the operational or medical ones,” says Ott. But the engineers did gain important insights, observing dramatic differences between the two surgical option models: The deformation of the bone plate in the patient walking with a pair of crutches was twice as high as that of the nail. And during the lifting of the 10 kg mass, deformation in the bone plate was eight times higher than in the nail.

The engineers also saw that the location of the deformations was different for the two implant types. In the bone plate most was in the proximal part, in the nail example, a small deformation was seen in the distal part.

OPPORTUNITIES TO USE SIMPACK FOR OTHER BIOMEDICAL SIMULATIONS

“In both scenarios, the way the different screws deform depends strongly on their location within the implant, and especially on the direction of the applied forces,” says Lehner. “We want to examine the loading situation in these screws in more detail in the future.” His team plans to create models with varying numbers and arrangement of screws, and then pay particular attention to the ratio of screws to damaging cutouts of the humerus bone head.

“Using flexible components with Simpack opens further possibilities for biomedical simulations,” says Ott. “Our developed and validated model may be of use to surgeons for analyzing other clinical problems with osteosynthesis systems in more detail.” Having completed his degree with the research described here, Ott is now working for a German "notified body," which evaluates the conformity of non-active medical devices to existing regulations.

For More Information
www.3ds.com/products-services/simulia/products/simpack
Science in the Age of Experience

SIMULIA PRODUCTS HELP DRIVE CUSTOMER INNOVATION AND MEET RIGOROUS SAFETY STANDARDS

This year’s Science in the Age of Experience event united the SIMULIA and BIOVIA user communities, bringing focus on fundamental and applied science and engineering. Virtual Human Modeling (VHM) was very visible at the conference with nine papers covering a broad range of applications. As evidenced by the work presented by our customers, the need for modeling and simulation is becoming more critical within the Life Sciences and other industries.

The medical device industry is highly regulated, as patient safety is of paramount importance. Devices must perform as designed from the time of manufacture, through shelf life, and during use. For example, plastics used in medical devices under constant load such as prefilled syringes, are susceptible to creep deformation, and physical testing for creep can be time-consuming. Analysts at Unilife Medical Solutions Inc. used the parallel rheological framework to predict the short- and long-term behavior of polycarbonate components in the Unifill Finesse Integrated Safety Syringe. After successfully calibrating the model against experimental data and performing a four-year shelf life simulation of the syringe, they validated the results against real device data demonstrating a significant reduction of device design time.

Researchers at the University of Massachusetts Lowell and RWTH Aachen presented their work using multiscale modeling to predict the in vivo behavior of a textile-reinforced tissue engineered heart valve. Traditional cardiac prostheses often need reinforcement to withstand in vivo pressures. Tubular knitted textile reinforcements are sometimes used to stiffen the structure but greatly complicate numerical modeling. In a multiscale modeling approach, individual components of the composite structure are modeled using simple and easy-to-calibrate material models, while a homogenization technique is used to transfer material properties from lower to higher scales. Using different models for the fiber, knit, textile, and whole valve levels, the team was able to demonstrate the applicability of multiscale modeling for complex biocomposites.

While VHM is critical in the Life Sciences industry, it is also finding applications in consumer driven industries such as the competitive world of sportswear and athletic equipment. Engineers at ASICS developed a highly detailed model of the human foot to simultaneously improve the performance and comfort of their running shoes. Using an inverse dynamics methodology driven by running measurements from real people, they were able to obtain realistic ankle loading conditions and apply them to the foot-shoe FE models to improve runner stability and relieve pressure.

Footwear design isn’t the only key to running comfort as demonstrated by a team from Toyobo and MDRC. Properly designed clothing pressure can improve exercise performance as well as favorably influence the nervous and circulatory systems. Using a multilayer material model for a T-shirt with a human body model to represent anatomically realistic running movements, the team was able to quantify contact state and pressure changes of sportswear on a human in motion. This methodology is now being used to develop smart clothing capable of monitoring biometric information for athletic and medical applications.

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MATERIAL CALIBRATION OF HUMAN TISSUE

For the computational analyst, one of the most important steps in building a model is ensuring the appropriate constitutive behavior is chosen to replicate the “real world” material behavior of the item being virtually evaluated. Even after the appropriate constitutive law is chosen, determining the input parameters is often a non-trivial task, depending on the complexity of the material behavior.

This is especially true for computational models involving human tissues, as they are often nonlinear and anisotropic in nature. Calibration of these materials “by hand” can often be time-consuming and inaccurate. Therefore, an automated process to explore the appropriate material parameters is often much more efficient and accurate. The Data Matching capability in Isight is ideally suited for determining the material input parameters for even the most complex constitutive laws.

As an illustrative example, the mechanical behavior of human skin is calibrated using a combination of Abaqus and Isight.

Step 1: Create the Abaqus Simulation of the In Vivo Testing of Skin Tissue

Briefly, a 40 mm diameter circular area of shell elements (S4R and S3) represents the tested area. The nodes along the circumference were fixed in all translational and rotational degrees-of-freedom. A central region of 4 mm in diameter represents the area of contact between the experimental probe and skin. The thickness of the shell elements is 1.5mm, representing a typical skin thickness of the arm. The movement of the probe is simulated by applying the appropriate displacement and rotational boundary conditions to the nodes within the probe contact area.

The material is assumed to be nonlinear elastic and isotropic; therefore, the Ogden strain energy potential of order 2 is chosen. Additionally, the material is assumed to be viscoelastic; therefore, the basic hereditary integral formulation for linear isotropic viscoelasticity is included in the material definition.

Step 2: Material Identification using Isight

There are 8 parameters resulting from the constitutive behavior assumptions (2 components of initial stress, 4 Ogden parameters ($\mu_i$ and $\alpha_i$, $i=1,2$), and viscoelastic parameters ($g$ and $\tau$). In order to determine the numerical value of these parameters, we will use optimization techniques found within Isight to match the Abaqus simulation results to in vivo experimental results. An Isight workflow is created using two components:

![Figure 2. Isight Workflow for parameter identification for human skin material model.](image)

The Abaqus and Data Matching components are utilized sequentially to run the simulation and compare those results to in vivo experimental values, respectively. The optimization technique utilized is Hooke-Jeeves. After 40 iterations through the workflow, the error of the difference between simulation and in vivo results reduces significantly:

![Figure 3. The Error between the Abaqus simulation and in vivo experimental results for human skin.](image)

Further, if we compare the load-deflection between initial and final simulation results to the in vivo experimental data, a much improved response after the Data Matching exercise is observed:

![Figure 4. Comparison between the initial and final simulation results as compared to in vivo experimental results of human skin.](image)
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