Human Tissue Modeling Targets Patient Comfort and Health

Researchers at Frankfurt University use Abaqus FEA for in-depth study of stress and strain on bodies at rest

Pressure sores are a costly challenge to the healthcare industry (an estimated $4 billion a year in the U.K., according to one study) and the problem may be growing globally due to aging populations.

The medical care industry and bed mattress manufacturers are highly aware of the problem and diligently looking for solutions. Researchers into body mechanics are finding that the answer goes deeper than the latest "miracle foam."

"Current techniques for pressure mapping of mattresses don't adequately evaluate the underlying supporting foam materials—or how the human body interacts with them." says Gerhard Silber, professor of Materials Science at the Center of Biomedical Engineering (CBME) at Frankfurt University.

Prof. Silber and a group of researchers at the university have taken on the challenge from the inside out, using Abaqus finite element analysis (FEA) technology, in conjunction with magnetic resonance imaging (MRI), to study the dynamics between cushion materials and human skin, fat, muscle, and bone. Their findings bring significant insight into the causes of bedsores. Their work also holds implications for biomechanical design optimization beyond mattresses to wheelchair cushions, operating room table covers, airplane seats, saddles, and even sports shoes and helmets.

The original motivation for Silber's work was a request from a mattress manufacturer looking for a foam cushion that would prevent bedsores. Also called pressure sores or ulcers, these can appear anywhere on the human body but are most often found on a person's buttocks, where up to 40 percent of body weight is concentrated when lying down.

To provide realistic simulation of the mechanics of body/bed interaction, Silber's group turned to Abaqus finite element analysis software. "With Abaqus FEA we can create computer models that let us look inside both the mattress material and human tissues to evaluate internal stresses and strains," Silber says. "This is extremely important because most pressure sores develop from deep within tissue outwards to the skin."

Modeling the human body

Abaqus FEA is proving to be an extremely useful tool for understanding human tissue response as the software provides complex material models, contact, multiphysics (for fluid-structure interaction), and high-performance parallel processing, among other capabilities.

But collecting the data needed to build, and then validate, a human FEA model requires a different methodology from what an automaker or cell-phone design engineer might use. In the world of product development, graphs showing close agreement between FEA simulations and prototype tests are commonplace because the verifying data can be derived from real-world physical testing of inanimate objects. But in the case of human tissue modeling, confirming FEA stress/strain predictions with direct measurements from deep within a living body is not physically possible.

Modeling mattress foam was a fairly straightforward process for Silber's group. The engineers obtained the data they needed for FEA through laboratory testing using a device that would load, hold, and then unload different kinds of foam samples while directly recording force and indentation displacement. This procedure ensured a distinct separation of the elastic from the inelastic material properties of the foam.

But in order to "see" the hard-to-reach human tissues they were modeling, the researchers used magnetic resonance imaging technology to provide the data they needed. First, human test subjects were MRI-scanned to obtain an undeformed tissue configuration of the buttock region. Next, loading was applied during an MRI scan. Working in an inverse fashion from the MRI images, the researchers were able to derive metrics that could be used as constraints in an optimization process to reveal the distinct mechanical properties of different tissue types.

"We needed to find the appropriate material parameters for in-vivo fat and muscle tissue that would reflect the test conditions of tissue indentation," says Silber's research associate, Ph.D. candidate Christophe Then. "So we parameterized the material constants and simulated the models iteratively until the force-displacement and simulation output coincided." Then the researchers were able to accurately describe skin/fat and muscle tissue parameters, build their FEA models describing body-support interactions, and simulate the effects of various support materials/designs on the different tissue types.

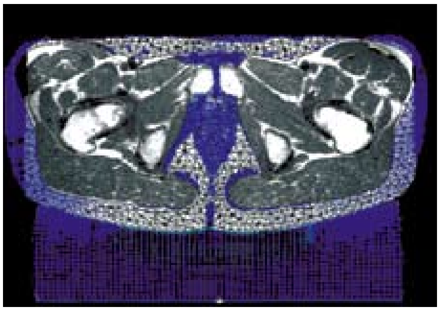

Figure 1: Abaqus FEA overlay of MRI image was used to validate the body/foam interaction model. Shown is an FEA-mesh of a cross-section of a human pelvis MRI (upper grey and white area) resting on a foam cushion (square purple meshed portion at bottom). Using imaging techniques in this way is key for verifying the accuracy of biomechanical modeling of living subjects.

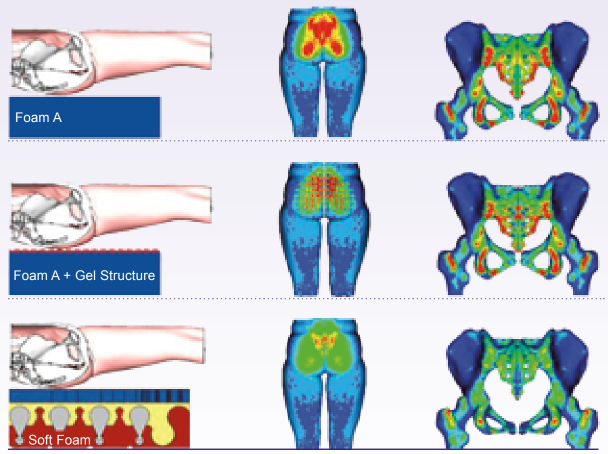

Figure 2: Body-Optimized-Simulations-Systems (BOSS) models of human pelvis and thigh resting on three different types of foam mattress (left column); corresponding Abaqus FEA images showing resulting interface stress on lower torso (center column); and FEA imagery of pelvis bones (right column) showing areas where strain is greatest. The mattress design/material configuration at lower left produces the least amount of loading.

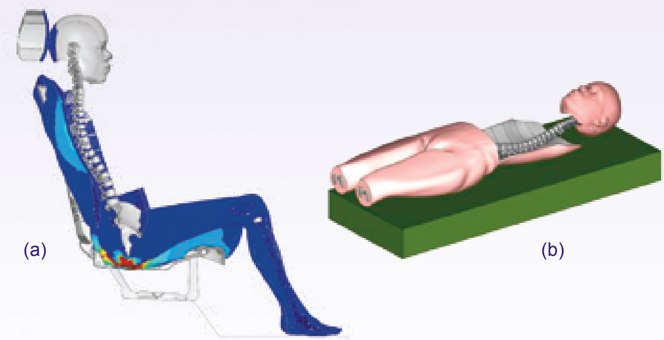

Figure 3: Abaqus FEA analysis of seated (a) human figure and recumbent (b) BOSS MODEL are used by the Center for Biomedical Engineering at Frankfurt University as part of an ongoing program to develop a research methodology that can be applied to products interacting with any part of the human body.

MRI helps validate FEA results

To validate their FEA models of body/foam interaction, the researchers again turned to MRI (Figure 1). "By superimposing a simulation result over the corresponding MRI image—both of them at the same deformed state—we were able to compare the boundaries of the human tissue and the outer surface of the foam we were testing," says Silber. "Using imaging techniques in this way is essential for biomechanical modeling; it provides key information for validation."

Prof. Silber's results clearly supported clinical observations of where bedsores arise. The Abaqus FEA results showed highest stress/strain concentration near the bones of the lower back and pelvis—the ischial tuberosity, the posterior superior iliac spine, and the sacral and tail bones—exactly below where visible bedsores are clinically observed to occur most frequently on the skin surface.

Even more important than the location of the sores was their origin within the body. "FEA showed areas of greatest stress and strain at the deep interface between muscle and bone, not in the surface skin/foam support interface," says Then. The researchers theorize that this is due to the normal "irregularities" of the human skeletal structure. "Tissue movement is restricted at the relatively small, prominent surface of a bone," explains Then. "As loading causes the tissue to displace 'around' a bone prominence, stresses and, even more significant, strains increase particularly in the immediate neighborhood of that prominence." These results are also consistent with surgical findings that show cone-shaped necroses, with the base located near the bone surface, in the majority of cases of severe deep tissue pressure sores.

"Clearly, healthcare products require better design to effectively reduce or eliminate bedsores and improve the quality of life for patients," points out Silber. "Our research is providing data that can be a foundation for that kind of design." With continued funding from foam manufacturers and healthcare companies, the team has expanded the initial scope of their work to model many different mattress configurations and materials to analyze and compare their impact on human tissue models (Figure 2). They are also studying the effects of biological variability of mechanical human soft tissue characteristics—taking into account gender, age, and physical condition—on tissue displacement under loading.

FEA enables biomechanical product development head to toe

Following the success of their work on gluteal tissue/support modeling, the team is exploring other areas in which the FEA/MRI combination can benefit the development of products for human use. "These tools can be applied to biomechanically optimize many new products for minimal stress and strain inside living tissue," says Prof. Silber. "We can now approach comfort-related questions by considering discomfort to be related to pathologically high tissue stresses and strains over a prolonged period of time."

The researchers are now extending their scope beyond the human gluteal area to larger "BOSS (Body-Optimized-Simulations-Systems) Models" in seated and recumbent postures, with the addition of leg and spine FEA (Figure 3). "Our BOSS Models let us explore such areas as mattress/heel impact and car seat vibration," says Then. "The kind of research methodology we have developed could be applied to products interacting with any part of the body such as feet and running shoes, or heads and helmets."

"Abaqus FEA with its visualization options has allowed us to get a feeling for very complex processes which one could not imagine otherwise," says Silber. "With this knowledge we can achieve a better understanding of what is actually occurring in the human body and develop new ideas that serve both comfort and health."

For More Information
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