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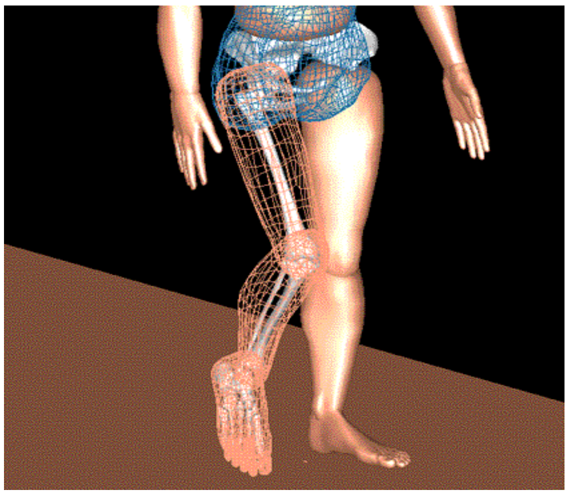
Optimizing orthotic designs with FEA

Engineers are customizing finite-element-analysis software to support biomechanical designs that correct lower-limb abnormalities.

By Dan Deitz, Associate Editor



Walk this way: Using leg and foot measurements plus the patient's age and weight, a customized version of ADAMS simulates his gait, with limbs displayed as realistic solid models or in skeletal form.

THERAPISTS AND TECHNICIANS have traditionally corrected their patients' foot or ankle abnormalities by recommending an orthotic insert, which is worn for several weeks, then adjusted incrementally until the pain is eliminated or at least reduced to a tolerable level. However, it can take months before any results are observed. Moreover, the orthotic inserts sometimes merely displace stress to other bones and joints so that other problems surface years later. A patient with foot pain might be helped for a few years, for example, only to develop knee problems later.

"There are just too many variables to consider," said Brent Konantz, president of Prothotics Corp. in Winnipeg, Manitoba. "A patient going to 20 different clinics will get 20 different orthotic devices to correct the same problem."

Konantz knows from personal experience. In l983, a ruptured Achilles tendon ended his career as a sprinter for provincial and national running teams in Canada. In working with a team of health-care professionals during rehabilitation, Konantz was fascinated by the way they corrected pressure on lower-limb bones and joints through the use of orthotics, which change the angle the foot hits the ground during walking and running.

By raising or lowering various areas of the feet, orthotic inserts ease the pain experienced by patients with sports injuries as well as foot and ankle anomalies related to arthritis, diabetes, and other debilitating diseases. Orthotics also help promote proper muscle function during rehabilitation for those with disabilities, such as cerebral palsy, stroke, and head injuries.

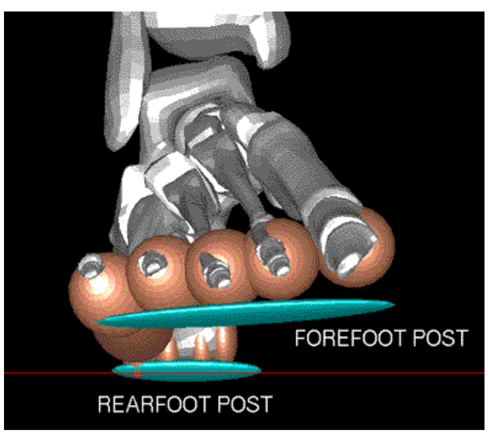
Konantz became so interested in orthotics that he trained as a pedorthist --- professional who designs and manufactures corrective footwear prescribed by a physician. Konantz quickly saw the limitations in the way in which inserts are sized and positioned.

"I soon realized that orthotic design was more of a craft based on experience and on trial and error than a science," he said, "so I set out to find a way of using computers to quantify and simulate a patient's movement."

CUSTOMIZED SOFTWARE

After founding Prothotics, Konantz selected mechanical simulation software to put orthotic design on a more scientific basis. One software firm he approached to write a program for the new company was Mechanical Dynamics Inc. in Ann Arbor, Mich., which developed the Automatic Dynamic Analysis of Mechanical Systems (ADAMS) package for simulating the motion of mechanical systems. Engineers around the world use AL)AMS to create virtual prototypes of products with moving parts: automobiles, aircraft, off-highway equipment, industrial machinery, home appliances, sports equipment, and other devices.

Shawn McGuan, a biomechanics research scientist at Mechanical Dynamics, worked closely with Konantz to customize ADAMS for orthotic-design applications. The resulting package simulates a patient's walking and running gait based on leg and ankle measurements. Based on these simulations, clinicians can immediately visualize the effects of various orthotic insert designs to find the best one for each patient without going through the time and expense of making and trying one after another until pain subsides.



By raising or lowering various areas of the feet, these fore- and rear-foot posts change the foot's angle as it hits the ground to relieve pressure on lower-limb bones and joints.

"This approach has the potential to revolutionize the way we treat lower-limb pain, disability, and rehabilitation," Konantz said. "We've already used the software to help hundreds of patients and have plans to expand operations to clinics in other cities. This is possible because of our ability to simulate biomechanical systems with ADAMS, and the expertise and willingness of Mechanical Dynamics staff to customize their software for our application."

When used in traditional mechanical applications, ADAMS enables users to build a computer model of a mechanical system, then simulate the action of its moving parts as well as compute loads and forces on the components. In this way, users can quickly analyze multiple design variations until they arrive at an optimal design. This reduces the number of costly physical prototypes that must be built and tested, improves design quality, and reduces product-development cycles--essentially the same goals in making orthotic design more scientific and reliable.

"If ADAMS can simulate the moving parts of a mechanical product," Konantz said, "then why not people's feet, ankles, knees, and hips?"

McGuan worked with Konantz to develop an interface that enables an orthotic clinician with little or no computer training to enter patient data and interpret results easily. Specifications compiled by Konantz for the project include parameters defining the movement for "medical normal" limb functions gathered from interviews with doctors and measurements of human anatomy. Also included are results of cooperative research with Nike and other footwear manufacturers.

From this information, McGuan wrote the required interface subroutine in six months. Program development was performed on a Silicon Graphics Indigo2 Extreme workstation. The software was then tested and verified, and it is now in use by Konantz and other clinicians at Prothotics' clinic.

GAIT SIMULATION

The software developed for Prothotics uses patient information gathered by a clinician as the initial input. This input includes age, gender, weight, and measurements including leg diameter and length as well as foot length and width.

On the basis of this information, the software simulates the gait of the patient and compares that replication with the normal gait as determined by the computer for a numerically average individual of similar age, weight, and proportions. The software automatically determines the orthotic required for the patient's gait to be as close to normal as possible.

"Basically, the computer shows the clinician how the patient is walking, how he or she is supposed to be walking, and what can be done to get the walking equivalent to what is considered normal," Konantz said.

Output from the software includes animated graphic images showing the patient walking and running at various speeds, which can be slowed or magnified for closer study. The animation shows the full gait, from heel strike to toe-off, and can display limbs as realistic solid models or in skeletal form. The software also provides graphed data, such as stresses and velocities on certain bones, and forces and torque rotations on joints.

Output of data and images is provided for the patient's present condition plus the medical normal profile and the predicted gait if the suggested orthotic inserts are implemented. Of course, these suggested orthotics can be overridden or modified by the clinician, and the simulation can be rerun to see the effects of other inserts as determined by the clinician.

"You never want to make the system so fully automatic that you take flexibility away from the orthotic clinician," Konantz said. "The software is a tool, and if the clinician wants to try something different based on patient experience, we want to have the capability to support such individuality."

After the orthotic device is refined, the system produces instructions for making the appliance on a numerically controlled milling machine. The patient can then wear the orthotic, usually on the same day as the evaluation visit.

Prothotics' gait-simulation software is the first part of Konantz's 10-step, five-year plan to license turnkey orthotic systems around the world for use by clinics, healthcare facilities, professional sports teams, and rehabilitation centers. In Konantz's plan, manual measurements of limbs will be replaced by signals from a force plate on which the patient stands to obtain specific loads on critical pressure joints of the foot. Also, magnetic-resonance-imaging scans will be used to more accurately depict the structure of bone mass as well as ligaments, tendons, and muscle groupings.

This future software may also have the capability to "age" the gait simulation model to investigate probable long-term effects of the problem or dysfunction. Such a capability is particularly important in predicting and studying chronic, repetitive stress associated with osteoarthritis.

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