

Refine Technologies to Create Active Orthotic Devices

TASK GROUP DESCRIPTION

Background

Current orthoses were developed ultimately to enhance function of people disabled by injury to the limb (traumatic transaction of muscle and peripheral nerve) or by disorders that interfere with the muscle-nervous system, such as muscular dystrophies, stroke, spinal cord injuries, and weakness from aging. With few exceptions, currently marketed orthotic devices are passive and designed to overcome the weakness and instability produced by the pathology as well as to maintain the limb in an optimum functional position. The most common example is the polypropylene ankle-foot orthosis (AFO) designed to keep the foot and ankle at 90° to optimize foot contact and prevent foot drop in swing phase. The thermoplastic AFO is often designed with an articulating element between the foot and shank segments, thus allowing the patient some ankle motion. More elaborate braces for persons with spinal cord paralysis generally include the thermoplastic AFO linked to metallic uprights on the inner and outer shank and thigh. The uprights can even extend to a waist belt or trunk support (e.g., knee-ankle-foot orthosis [KAFO] or hip-KAFO. Hinges interposed at the knee and the hip are typically actuated manually or by cable systems. Patient-based research shows that the functional advantage of using these orthoses are difficult to measure. This may underlie the observation that while many children wear orthoses, during the transition to adults the orthoses are abandoned. The bulky stiff plastics, while providing support for the joint

encompassed, interfere with body center of mass transition during walking. Furthermore, more elaborate braces, such as those spanning the hip to foot, are heavy so that energy requirements to move the brace are additive to the energy demands imposed by the disorder. Energy measures show wheelchair mobility to be more efficient than ambulation with current hip-KAFO systems.

On the other hand, considerable research has been devoted to development of exoskeletal devices that can be used to augment movement of military personnel in particular. Also, work has been done in the area of functional electrical stimulation and direct muscle stimulation to capitalize on the inherent efficiency of the existing human system and decrease bulk of the orthotics. Actuators include series elastic actuators already introduced in an orthosis to enhance knee extension and potentially allow stair climbing for persons with weakness. Fuel-power artificial muscles relying on electric and most recently chemical power sources are awaiting implementation in orthoses. Sensors in use today integrate muscle activity and foot contact forces and relay information from limb movements (potentiometers, accelerometers). Integration of the actuator and sensor technology requires computer algorithms to assure human movement stability. Motion laboratories are also required to appreciate the impact of the pathology and for testing the orthotic/exoskeletal devices.

Initial Challenges to Consider

- Adapt current lower extremity exoskeletal device for the elderly and persons with disability.

- Design a closed loop control system coupled to actuate an AFO at the “ideal” time of the gait cycle;
- Consider materials for orthotic fabrication that are light weight and durable; and
- Develop a model system to predict the effect of limb/joint actuation on stability of the person.

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TASK GROUP SUMMARY

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Summary

Imagine two patients who present themselves to an esteemed rehabilitation specialist. One has a leg amputation, while the other walks with a severe limp.

On sight, diagnosing the first patient is easy—his problem would most likely be best addressed with a prosthesis to replace his absent leg. But diagnosing the second is another story. Is he limping because he's in pain? Or perhaps he lacks the ankle strength in his bad leg to propel it forward with the required force? Maybe his nervous system does not provide feedback to help him adjust his gait. Does he suffer from an injury that could get better or a degenerative condition that could get worse?

Despite the fact that twice as many people use orthotics as prosthetics, orthotics has remained something of a red-headed stepchild in the rehabilitation field. While recent innovations in adaptive or robotic approaches have potentially improved available prosthesis technology, these same technologies have not been applied to orthotic design, and clinical options for patients who could benefit from an orthosis have changed little in the last three decades.

The hypothetical patients above in part explain why. To some extent the goal of designing a prosthesis is straightforward—replace a missing limb. But for an orthosis each patient's condition defines the device's task. The disabled limb is a wildcard for an orthotist: Both its function and its deficits are unique to each individual. Conversely, many of the innovations that have revolutionized prosthetics (such as the C-leg and the rheo-knee) cannot be easily applied to orthotics, because there is no place to put them—if you already have a knee, albeit a bum one, adding another can weigh down the system. Much of the task group's discussion focused on resolving these difficulties.

Recently, researchers have begun to develop more active approaches. For example, Hugh Herr, head of the Biomechatronics Laboratory at the Massachusetts Institute of Technology's Media Lab and one of the task group members, is working on an adaptive ankle-foot orthosis. The device is able to adjust joint impedance based on the

specific characteristics of an individual's gait. Exoskeleton systems such as BLEEX, developed by Homayoon Kazerooni, a mechanical engineer at the University of California, Berkeley, and a member of the task group, may also be used in an orthotic capacity.

However, most innovations have remained in the research realm, and are as many as 20 years from commercialization. The task group looked at ways to bring about an improvement over available technology within five years.

What's So Smart About That?

The first order of business in the task group was to define how active an orthotic could and should be. The team broke down the possibilities into three categories:

1. A completely passive device, such as those currently available, that could contain devices like springs that can store and release energy.
2. A quasi-passive orthosis that would contain elements that have actively controlled passive properties (e.g., controllable variable stiffness and damping).
3. A fully active system in which an actuator, such as a motor or engine, would generate force to augment or modify the patient's musculoskeletal movement. In the extreme case the system could control all of the movement and the patient would be carried along. The energy in this category comes from external storage, such as batteries or fuel. An exoskeleton would fall into this category.

A practical system may consist of a combination of the three categories. Because actuator technology remains heavy and weak, the energy storage concepts of categories 1 and 2 may provide insight into more efficient methods to accomplish category 3. Category 2 in particular requires an elegance and economy of design. Indeed, noted Herr, much of the difficulty lay in design: A powerful arrangement of springs, dampers, and perhaps small motors would store energy generated in the part of the movement a patient can make, to then be used in the stage where a patient's weakness lies. "It's like a hybrid car," he said.

The Taxonomy of Motor Control

As the discussion progressed, group members groped for a dose of practicality. Indeed, about half of the group had no experience with people who might use orthoses in their daily lives. Kazerooni noted that his lack of clinical awareness prevented him from seeing how to adapt his lab's exoskeleton to help people with disabilities. Other approaches, too, should be designed to solve a specific clinical problem, he said: "I'm trying to avoid developing a screwdriver and then looking for a screw."

Mark Abel, an orthopedic surgeon at the University of Virginia, showed a series of videos demonstrating movement deficits of children from his practice. In one, a boy with muscular dystrophy teetered forward on his weak legs unassisted. In another, a girl with arthrogryposis walked slowly with a cumbersome brace (reciprocating gait orthosis) on her lower body. The steel brace, said Abel, was the best technology could do, and yet she'd use less oxygen without the brace swinging her legs through with crutches alone. In many cases, he noted, it's the parents who want their kids to use the devices, because they approximate normal walking. Because they are so impractical, the kids themselves abandon their use by the time they hit their teens. "This little girl, if she doesn't walk by 12, she's always going to be in a wheelchair," Abel said, which in turn creates further lifelong health problems.

Based on the videos the group tried several ways to break down the problem. By disease was impractical; too many options. By a patient's degree of movement was inadequate, since the reason for a patient's impaired motor abilities would have to be key to the design. Finally, to loosely generalize the biomechanical task an orthosis would have to perform, the group decided on a mapping along two axes: neural control and muscle strength. The biggest needs, and the ones easiest to address with available technology, lay in the middle of the graph, the group decided—in patients who retained at least some of both muscle strength and neural control. This population includes a wide range of conditions, such as spina bifida, muscular dystrophy and cerebral palsy, and impairments associated with aging. The graph provided a way to break down the abilities

a particular patient retained; for example, a child with spina bifida may have functioning hip flexor muscles, so a device could be designed to take advantage of that.

Prioritizing Knowledge Gaps

In the second session a group leader emerged; a professor of mechanical engineer at the University of Illinois, Urbana-Champaign, who studies control systems, Andrew Alleyne, advised that the problem should be approached using classical design principles. He instructed each group member to identify the most pressing problem as they saw it. Ultimately, the group concluded that the key to a useful system was to create a set of modular design principles in which a basic device would address a general pathology, and components could be mixed and matched to an individual patient's needs.

By the final session the seminar room was wallpapered with five giant white sticky-notes, one for each key area where the previous day's discussion had pinpointed a research gap.

The needs in each area were defined as follows:

1. Control—we need a better understanding of how to take the right inputs and create the right outputs for a particular person with a disability.
2. Actuators—these must be smaller, lighter, faster, and stronger.
3. Power systems—better energy efficiency and management.
4. Sensors—better sensors of human activity would improve communication between the device and its wearer.
5. Materials—stronger and lighter substances that perhaps even contain functional features like actuators and sensors.

Prioritizing the five categories proved challenging, largely because they are so closely intertwined. Controls, actuators, and power systems are highly linked. Most orthotics frames are made largely of steel; if a lighter material were available, more weight could go to other hardware, such as the power supply. Power-to-weight ratio is less of a problem if the device can carry its own weight (including power systems) so the

patient is not weighed down with this technology. One approach is to “re-motize” the heaviest components, including power systems and actuators.

Vigorous debate focused on the need to harness advances achieved in other fields. Orthotics is a deeply underfunded area—one group member noted that just two graduate programs in prosthetics and orthotics exist. Yet some of the problems identified in the group as key for new technologies are already active areas of study in other fields. “Maybe we shouldn’t focus on energy supply,” said Andrew Hansen, a prosthetics researcher who studies ankle-foot biomechanics at Northwestern University. “There’s a whole Department of Energy. We should focus on issues specific to orthotics.”

On the other hand, without better actuators the field was stuck, said Edwin Iversen, vice president of research at a Utah prosthetics company Motion Control. Others also noted that progress wouldn’t be made unless solutions were specifically tailored for use in orthotics. Julia Chan, a chemist at Louisiana State University, Baton Rouge, who designs metal and ceramic synthetic materials, noted that she could think of possibilities for orthotics, but she and her colleagues had simply never considered the problem as they were not aware of the issues related to the field.

Much of the team agreed that the top issue was that of control—creating an intelligent way to channel feedback from both the device and the wearer into regulating the movement. “How do you drive a car when you don’t have a good driver?” asked Kazerooni pointedly. One crucial aspect of this, noted Kevin Granata, a biomechanics researcher at Virginia Tech in Blacksburg, is that too little is yet known about the mechanics of walking in able-bodied people to predict the signals such a controller should use. In a person with neuromuscular conditions, muscle recruitment and movements are often dysfunctional, so the movement patterns recorded from the patient cannot be used as a reliable reference to control a smart orthosis. Developing a reliable and active system for telling an actuator what to do would open up many possibilities. “We don’t know what to send to the computer,” Kazerooni summed up. “That’s the area of research.”