AFO stiffness can help optimize patient function

Lori Roniger.

Decisions related to the stiffness of an ankle foot orthosis (AFO)—whether they involve device design or the materials from which it’s fabricated—can help lower extremity clinicians customize stability, biomechanics, and muscle function to meet individual patients’ needs.

By Lori Roniger

While practitioners and researchers have proposed devices, algorithms, and methods for determining the appropriate ankle foot orthosis (AFO) and stiffness for individual patients, choosing the right AFO stiffness remains more art than science than many in the field would prefer.

LER spoke with researchers and clinicians to learn more about how the stiffness of an AFO affects its function in different patient populations and ways to determine the most appropriate AFO stiffness for each patient.

The importance of stiffness
Practitioners and researchers concurred that AFO stiffness has been getting more attention in recent years and that they are trying to better quantify stiffness so that AFOs can be prescribed more accurately.

Elisa S. Arch, PhD, a research assistant professor of kinesiology and applied physiology at the University of Delaware in Newark, researches AFO stiffness and believes there is now a better understanding of how it influences gait.

Her research suggests AFO stiffness can replace lost ankle muscle function and provide functional gains. In the study, two patients who had experienced stroke wore a passive-dynamic AFO designed to be worn without a shoe, with bending stiffness personalized for their level of plantar flexor deficit. At the baseline visit, 3D landmarks on each patient’s lower leg were digitized and used to customize their AFO’s fit. Compared with walking while wearing shoes only, wearing the customized AFO was associated with increases in net peak plantar flexion moment and natural ankle pseudostiffness (the amount of joint resistance when a moment is applied); in addition, the AFO’s bending stiffness added to but did not substitute for existing plantar flexor function. The AFO also helped to improve the patients’ paretic knee and hip joint kinematics during mid and late stance but excessively reduced dorsiflexion excursions.

“The key question now is how do we customize the level of AFO stiffness to optimize each individual’s function,” Arch said.

Goals related to stability or improved gait can present a trade-off for lower extremity clinicians in determining the appropriate AFO stiffness for a particular patient.

Choosing the right stiffness

The patient’s plantar flexion strength is important to consider when determining AFO stiffness, according to David G. Wilson, MPO, CPO, LPO, instructor in the Prosthetics-Orthotics Program at University of Texas Southwestern School of Health Professions in Dallas. He pointed to the example of drop foot.

“It doesn’t take much force to hold up someone’s foot in the air,” said Wilson, who spends most of his time with patients who have neuromuscular issues—such as multiple sclerosis, Parkinson disease, stroke, or peripheral neuropathy. “It takes more to hold up body weight.”
So, one brace may be more appropriate for an older person using it at home or in the office, while another may be more suited to someone with a very high activity level who is running and jumping.

A patient’s height is also another key factor, Wilson said.

“Things need to be a bit stiffer if the leg is longer,” he said. “But we’re not trying to lock people up in ski boots.”

He explained that clinicians want to ensure the patient has a normal range of motion but at least have the ability to provide some limit, restriction, or soft stop if needed without causing any other gait abnormalities.

“The key is understanding the gait cycle,” he said. “If the only issue is foot drop, for example, then I’m treating a swing phase condition primarily. Thus the AFO only needs to be stiff enough to maintain the foot in a neutral position during swing, and should have limited effect on the foot and leg during stance, besides providing a more controlled foot flat at loading response to prevent foot slap.”

Factors like strength, range of motion, and spasticity can vary significantly between patients with the same condition and affect stiffness requirements, practitioners and researchers said.

“You have to look at each patient as an individual,” Wilson said.
“The material choice may be determined by patient weight, but often we need to look at where the stress points are likely to be and consider reinforcing or allowing flexibility where applicable,” Nathan said. “Using dynamic strut designs to shift yield points in AFOs has allowed me to reduce failures in some patients’ AFOs.”

**Stability before gait?**

Goals related to stability or improved gait can present a trade-off for clinicians in determining the appropriate AFO stiffness for a given patient. Efficiency in gait might be preferable for a patient who is more active, whereas stability would be a greater concern if a patient has poor balance and a history of falls, Wilson said.

“AFO stiffness can often help to provide control across joints and influence more proximal joints but can equally be problematic if the stiffness is too great for some patients,” Nathan said. “A very stiff AFO may, for some patients, allow very stable standing but hinder their ability to progress their limb. This is where manipulation of materials, joints, and their stiffness needs to sometimes compromise for the best outcome.”

If gait efficiency is the goal, device stiffness may need only to provide stability during stance, rather than the entire gait cycle, she said.

“If we can provide improved propulsion then we gain greater efficiency,” Nathan said. “Stiffness may be required to provide stance phase stability but may not be required in late stance.”

**Stroke and stiffness**
Toshiki Kobayashi, PhD, RPO, professor of prosthetics and orthotics at Hokkaido University of Science in Sapporo, Japan, has conducted research on AFOs for poststroke patients for around 10 years.

“The effects of AFOs, particularly their mechanical properties, ie, stiffness and alignment, on gait are still poorly understood and underestimated in the clinical setting,” Kobayashi said. “We want to raise more awareness that design and mechanical properties of AFOs matter.”

An advantage of articulated AFOs, he said, is that the mechanical properties within the joint can be adjusted without affecting other parts of the AFO. Changing the properties of a nonarticulated AFO often requires the adjustment of trimlines, which is irreversible. However, articulated AFO joints tend to be bulky and may not be suitable for many patients, especially women and children.

“Articulated AFOs that can adjust their stiffness are ideal, but a lot of work needs to be done to make them compact enough to be acceptable in most of the patient populations,” Kobayashi said.

He emphasized the importance of AFO stiffness in these patients, even though other mechanical characteristics, such as alignment, trimlines, and articulated versus nonarticulated design, are also key.

“Our recent work clearly suggested that, by appropriately tuning the plantar flexion resistance of an AFO, AFOs could reduce knee moments that lead to hyperextension of the knee,” Kobayashi said. Kobayashi and colleagues performed gait analysis on six stroke patients with genu recurvatum using an articulated AFO with adjustable plantar flexion resistance. Other recent research Kobayashi has conducted used gait analysis with poststroke patients wearing an articulated AFO and found that changing the plantar flexion resistance of the AFO affected both ankle and knee joint angles and moments. He is now investigating the effect of plantar flexion resistance and dorsiflexion resistance and alignment of AFOs in the same population.

A pilot study conducted at Becker Orthopedic in Troy, MI, investigated the effects of AFO stiffness and alignment on lower extremity kinematics in two stroke patients and one multiple sclerosis patient. Two patients wore a custom acrylic composite AFO with therapeutic sandals, and one patient wore a customized double upright AFO with a walking shoe. Both AFOs featured an ankle joint with high stiffness in the coronal and transverse planes and adjustable alignment. During each trial, one of three ankle joint settings (plantar flexion resist, dorsiflexion resist, or alignment) was changed while the other two were held at their optimal values.
Ankle adjustments had varying effects on kinematics. In quiet standing, the ankle alignment setting had a smaller influence on knee angle in patients with greater spasticity. During walking, the ankle alignment setting affected ankle and knee kinematics throughout the gait cycle. Gastrocnemius length and spasticity may have influenced the effect of alignment and plantar flexion resist on ankle-knee coupling in stance and late swing.

Device designs that allow for more flexibility around the ankle may necessitate more stiffness in the rest of the AFO, said Nicholas LeCursi, CO, chief technology officer at Becker.

“The design of an AFO involves control of three fundamental attributes: shape, material stiffness, and compressibility of interface materials both intrinsic and extrinsic to the AFO,” LeCursi said. “This compressibility also includes the stiffness of the shoe sole. We recommend using more rigid materials and higher stiffness interface materials for the AFO and shoe, then using an adjustable ankle joint to tune the stiffness and alignment of the AFO.”

Shoes and stiffness

Kobayashi is investigating the effects of the mechanical properties of shoes on AFO-shoe combinations. He explained that shoe design can significantly affect AFO function by influencing stiffness as well as alignment.

“Shoes are used in combination with AFOs, but their influence is often neglected or underestimated,” he said.

Elaine Owen, MSc, MCSP, a pediatric physical therapist at the Child Development Center in Bangor, North Wales, UK, has worked for decades with children, many of whom have cerebral palsy. Her center has a gait lab and custom makes AFOs, and she has published algorithms for the design and tuning of AFO-footwear combinations (AFOFCs) based on shank kinematics.² “You apply that to every patient, as it is independent of diagnosis but dependent on the gait pattern and clinical presentation,” she said.

Patients who have normal shank kinematics in stance phase but a swing phase/initial contact problem may be prescribed a posterior leaf spring or hinged AFOFC, while those with abnormal shank kinematics in stance receive various types of fixed-ankle AFOFCs, depending on factors including insufficient or excessive incline in midstance, terminal stance, or both.

The amount of AFO stiffness required of a fixed-ankle AFO can differ depending on gait type and patient size. Patients typically receive fixed ankle polypropylene AFOs with varying designs.

“If they’re bigger with very severe crouch gait, then it’s going to be a much stiffer AFO,” Owen said.

Some patients will require fixed metatarsophalangeal joints and a stiff-soled shoe, Owen said.

“People sometimes fail to control crouch gait if they use a fixed ankle AFO but not the right footwear,” she said.

The materials used, trimlines, depth at the ankle, and use of corrugation can affect stiffness.

She noted that working with children who are growing and typically have a congenital neurological disability can be completely different from working with adults, like stroke patients, with an acquired disability.

Adults with acquired disability typically have a normal mature skeleton and foot, she explained, whereas typical skeletal development may not occur in children with congenital disability due to neuromuscular and biomechanical effects. Orthotic devices can protect against these abnormal
forces and help the skeleton—particularly in the feet—develop normally, she said, and optimizing device stiffness can be an important part of that process.

How to customize

A number of researchers and companies are investigating the best way to customize AFO characteristics for each patient.

“My ultimate goal is to develop objective prescription models that, based on any individual’s impairment profile, determine what characteristics, such as stiffness level, the AFO should have and the design needed to achieve those characteristics,” Arch said.

Some patients do not need stiffness in both dorsiflexion and plantar flexion, so knowing the stiffness of a brace in each direction would help the clinician to tailor an intervention and produce a greater benefit, Nathan said.

Michael Orendurff, PhD, director of the Motion and Sports Performance Laboratory at Lucile Packard Children’s Hospital Stanford in Palo Alto, CA, has collaborated on some of Kobayashi’s research on stroke patients. He spoke of the importance of collecting and providing objective data for clinicians.

“Some of these patients don’t have very good feedback or sensation and have a hard time saying what feels good,” Orendurff said. “What you’d like to do is come into a realm that’s close to their right prescription.”

A patient may respond in a stair-step manner until reaching a plateau at which gait is smoother, but adjusting beyond that doesn’t have any effect; the goal should be for clinicians to identify when small adjustments can make a difference, Orendurff said. This could involve an instrumented device that can measure and make these adjustments and, together with feedback from the patient, pick the optimized setting, he said.
Material world

The types of materials used to fabricate AFOs, in combination with device design, significantly affect AFO stiffness.

Arch designs and conducts research on passive-dynamic AFOs, in which stiffness is largely determined by the strut that goes up the back of the leg and connects the cuff and footplate; both the thickness of the strut and the material the strut is made of affect stiffness.

She currently uses AFOs made of polycarbonate or a carbon fiber composite. For both of these materials, the thicker the strut, the stiffer the AFO. For the carbon fiber composite, other design features, such as the fiber orientation, also influence stiffness level.

Varying stiffnesses can also be achieved with plastic. Although generally thicker plastic and more circumferential trimlines will produce a stiffer AFO, some will use very thin plastics, often only 2 mm thick, in a bivalve circumferential design to gain stiffness without increasing bulk, Nathan explained.

“Clinicians need to know the properties of materials so they can manipulate them for their relative properties. Trimlines can always be trimmed back to make an orthosis more flexible, but you will need to remake the orthosis if it is not stiff enough,” she said. “Sometimes we need to fail to succeed and try different combinations to find the right stiffness.”

Wilson has been doing bench testing and material properties investigations, with future plans to include patients, on the use of carbon fiber and prepreg materials for AFOs and how to fine-tune them to maximize efficiency, effectiveness, and durability. He is hopeful about the promise of 3D printing and its potential for being able to offer more standardization in AFO stiffness.

“You can get to the same brace design ten different ways,” he said. “It’s a bit secretive. Everyone has a secret sauce that no one exactly knows. We’re trying to standardize some of that: the thickness and how to cut back the trimlines.”

He also recommended working closely with a physical therapist.

“It’s not that the AFO itself is magic and solves every problem,” he said. “It’s how to use it so the patient can reach his potential.”

Back in the lab
Fan Gao, PhD, associate professor of health care sciences and Wilson's colleague at UT Southwestern, is bench testing AFOs while manipulating the designs, materials, and construction to evaluate mechanical properties.

A study Gao and colleagues published this year used a motorized device with an inline torque sensor and optical encoder to cycle an AFO through dorsiflexion and plantar flexion. The researchers found that a posterior leaf spring AFO fabricated with nine-ply carbon-infused polypropylene composites demonstrated more dynamic mechanical properties (indicated by increased stiffness and decreased index of hysteresis) than standard homopolymer polypropylene orthoses. This decreased energy loss and provided a rigid toe lever at preswing.

“Though many things (eg, stiffness) could be quantified in the research lab, it is hard to transfer this knowledge directly to clinical practice,” Gao wrote in an email. “The mechanical properties are not only related to thickness/construct/design. They are also altered throughout the fabricating procedure [eg, thermoforming].”

Kobayashi thinks it’s important to characterize the properties of AFOs, in research as well as in the clinic. He said many studies still compare orthoses without characterizing their properties, including stiffness.

“It is difficult to generalize outcomes of AFO studies without knowing the properties of the AFOs,” he said.