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LOWER EXTREMITY REVIEW
January 15 / volume 7 / number 1

TELEMEDICINE:

BRINGING DIABETIC FOOT CARE TO THE SMALL SCREEN

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REHABILITATION
SENSORY-TARGETED STRATEGIES FOR CHRONIC ANKLE INSTABILITY

SPORTS MEDICINE
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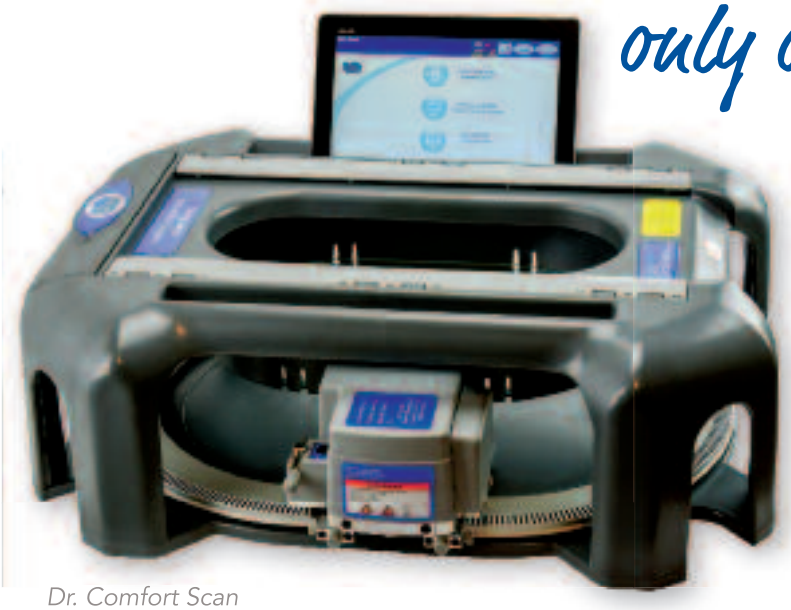

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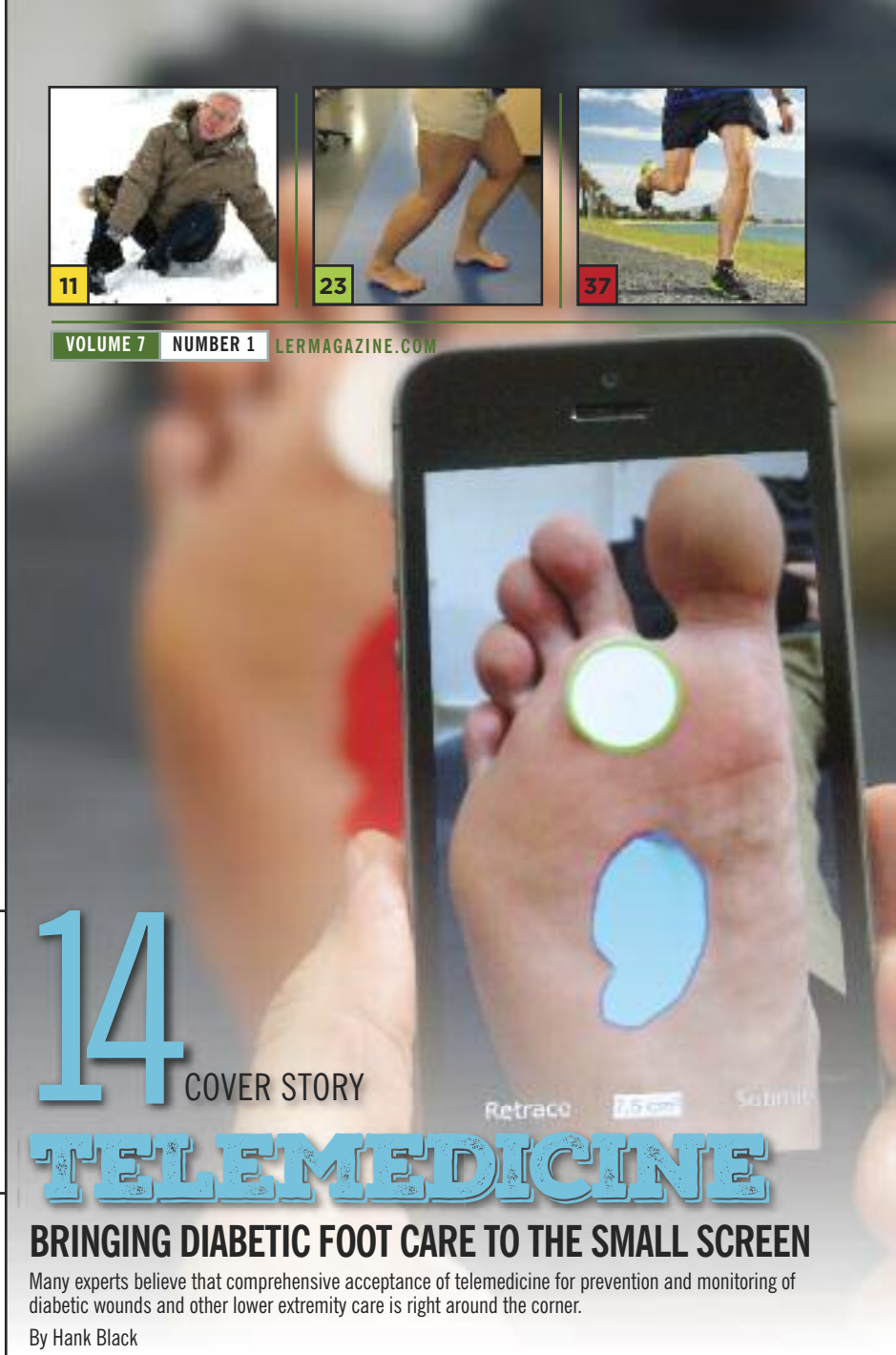

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Publisher
Richard Dubin | rich@lermagazine.com

Editor
Jordana Bieze Foster | jordana@lermagazine.com

Associate editor
Emily Delzell | emily@lermagazine.com

Contributing editor
P.K. Daniel | pk@lermagazine.com

Social media consultant
Kaleb S. Dubin | kaleb@lermagazine.com

New products editor
Rikki Lee Travolta | rikki@lermagazine.com

Graphic design & production
Christine Silva | MoonlightDesignsNC.com

Website development
Anthony Palmeri | PopStart Web Dev
webmaster@lermagazine.com

Circulation
Christopher Wees | Media Automation, Inc

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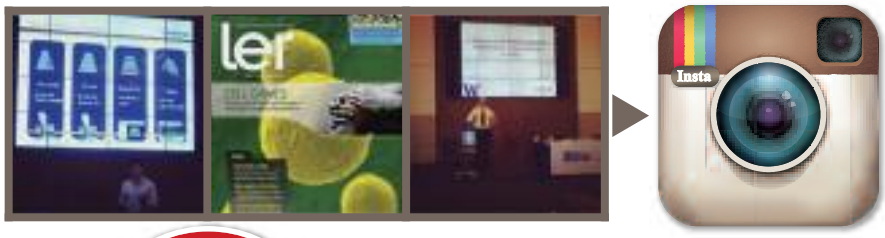

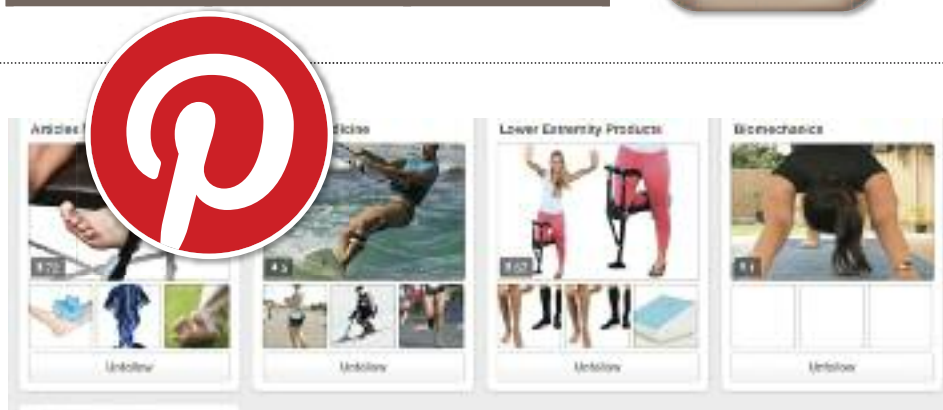

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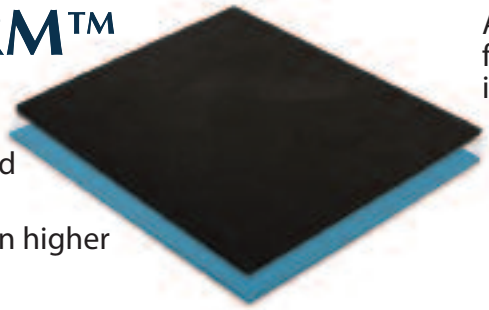

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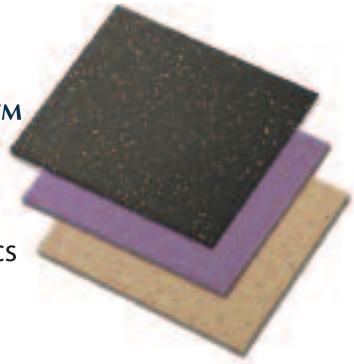

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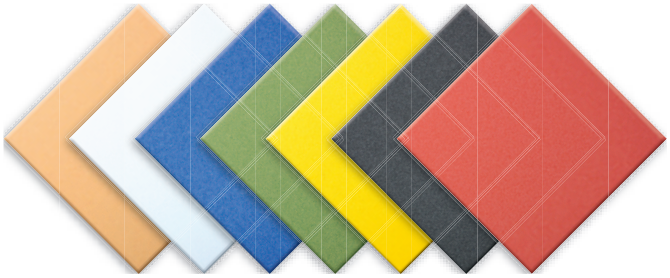

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out on a limb: Muscling in on diabetes

There are already plenty of good reasons for individuals with diabetes to exercise. But here's one more: Strengthening the intrinsic foot muscles just might reverse the development of diabetic peripheral neuropathy (DPN) even before it becomes clinically apparent.

Multiple studies have established that patients with DPN demonstrate significant intrinsic foot muscle atrophy compared with healthy controls. But new research is revealing that patients who have diabetes but do not have DPN also have significant intrinsic foot muscle atrophy relative to controls. A study from India, epublished in December by the *Journal of Diabetes*, and a study from China published in August by the online *Journal of Diabetes Research*, both arrived at similar conclusions.

The presence of intrinsic muscle atrophy in the absence of clinically detectable peripheral neuropathy supports the theory that the earliest stages of the DPN spectrum occur at a subclinical level. And that means clinicians shouldn't have to wait until a patient presents with significant sensory loss to start taking steps to reduce the risks of ulceration and amputation.

Ideally, it also means interventions targeted at DPN specifically can be implemented even earlier. And it suggests that at least one aspect of those interventions should include exercises to strengthen those atrophied intrinsic foot muscles.

Few studies have looked at the effects of exercise on lower extremity-specific variables in patients with DPN—at least in part because it wasn't until recently that research confirmed the loads involved in exercise would not, as many feared, increase the risk of neuropathic ulceration (see "Exercise and neuropathy: Not mutually exclusive," July 2011, page 22). But, in a Brazilian study published in April 2014 by the online journal *BMC Musculoskeletal Disorders*, a 12-week multimodal physical therapy program was associated with significant improvements in both intrinsic foot muscle function and Michigan Neuropathy Screening Instrument scores in patients with DPN.

So there's at least some reason to believe that strengthening could have an independent positive effect on neuropathic symptoms in patients with DPN. And, if that's the case, it's certainly plausible that strengthening interventions in patients with subclinical DPN—those with intrinsic muscle atrophy—could help delay or prevent the clinical emergence of those symptoms.

The authors of the Indian and Chinese studies both suggested that musculoskeletal ultrasound could be used to screen patients for intrinsic muscle atrophy. To me, while ultrasound makes sense as a research tool, it doesn't seem practical or cost-effective to use it to regularly screen every patient with diabetes.

> Strengthening interventions in patients with subclinical diabetic neuropathy could help delay or prevent symptoms.

But, if researchers can identify the point in the DPN spectrum at which muscle atrophy typically becomes apparent (in the Chinese study, the duration of diabetes in the no-DPN group was six years, so that's a start), then it would make sense to screen patients with diabetes starting at that time. Or it might make sense to simply implement foot-specific exercise programs at that time point for all patients with diabetes, even without the formality of screening.

It's no secret that early intervention is the key to prevention. Now clinicians who treat patients with diabetes can take that philosophy to the next level.

Jordana Bieze Foster, *Editor*

By P.K. Daniel

Breaking bad

Ankle fracture study highlights mortality

Is ankle fracture in the elderly the new hip fracture? Hip fractures in older adults have often been linked to high mortality rates, and a recent study suggests the same may be true of ankle fractures, given that some of the same variables are at play.

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Preexisting health issues, complications related to surgery, immobility, and rehabilitation limitations are contributing factors in mortality rates among older adults after hip or ankle surgery. For example, elderly patients with ankle fractures and multiple medical problems are vulnerable to deep vein thrombosis and pulmonary embolism following prolonged periods of non-weightbearing.

Of 11 patients older than 60 years who had experienced low-energy, open-ankle fractures and had been treated at the University of Florida in the College of Medicine's Department of Orthopaedic Surgery and Rehabilitation in Jacksonville, more than a quarter (27.2%) died in less than three months.

But the study, epublished in December 2014 by the *Journal of Foot and Ankle Surgery (JFAS)*, also found that 81.81 % of the 11 patients had three or more medical comorbidities, including hypertension, diabetes, coronary artery disease, congestive heart failure, chronic obstructive pulmonary disease, or a combination of these conditions.

"Overall, these patients are indeed sicker at the time of presentation," said lead study author William Peyton Toole, MD, an orthopedic surgeon at the University of Florida.

In addition to comorbidities jeopardizing patients, the loss of mobility and conditioning from being non-weightbearing impedes the healing process, said Christy M. King, DPM, an attending foot and ankle surgeon

Continued on page 12

Home-based walking program boosts mobility but does not alter rate of falls

While walking is a popular form of exercise among the elderly that improves mobility, a home-based walking program does not curb the risk of falling, according to an Australian study.

Researchers from multiple institutions in New South Wales recruited 386 people aged 65 years and older from the Sydney area and randomized them to two groups. The intervention group received a series of three printed manuals guiding participants through a 48-week self-managed walking program, starting at a level appropriate for sedentary individuals and progressing through increased levels of frequency and duration. The walking program also included eight telephone-based counseling sessions during the 48 weeks. The control group received general health information unrelated to falls. Monthly calendars were used to record falls and other information.

The study, epublished in January by *Age and Ageing*, found no difference in fall rates between the two groups, although the participants in the intervention group spent significantly more time walking for exercise than those in the control group and in general were more physically active.

Source:

Voukelatos A, Merom D, Sherrington C, et al. The impact of a home-based walking programme on falls in older people: the Easy Steps randomised controlled trial. Age Ageing 2015 Jan 8. [Epub ahead of print]

Rate of torque development in the hip differentiates fallers from nonfallers

Rate of torque development (RTD) in the hip extensor muscles is an outcome that could be key to identifying patients at risk for falling, according to a study epublished in December 2014 by *Aging Clinical & Experimental Research*.

Researchers from Kent State University in Ohio examined the torque characteristics of the hip extensor muscles in healthy, recreationally active older women with and without a history of falls.

Six women with a history of falls (mean age, 73 years) and nine women without a history of falls (mean age, 71 years) performed two isometric maximal voluntary contractions of the hip extensor muscles. Peak torque and absolute and relative rate of torque development at the early (0–50 ms) and late (100–200 ms) phases of muscle contraction were examined.

Absolute and relative RTD during the early phase of contraction for women with no history of falls were significantly greater than in those who did have such a history. No differences were observed for any variable during the late phases of contraction, nor for peak torque during the early phase.

Source:

Palmer TB, Thiele RM, Williams KB, et al. The identification of fall history using maximal and rapid isometric torque characteristics of the hip extensors in healthy, recreationally active elderly females: a preliminary investigation. Aging Clin Exp Res 2014 Dec 25. [Epub ahead of print]

Continued from page 11

with Kaiser Permanente in the San Francisco Bay Area.

"It may be that keeping them non-weightbearing causes a rapid decline in their conditioning and makes it a much harder battle to fight when reconditioning," King said. "This may contribute as much to the risk of mortality as the comorbidities."

Orthopedic surgeons and physical therapists realize the risks associated with hip fractures and therefore try to get patients out of bed and moving as soon as possible after surgery, King noted.

"It may be time for foot and ankle surgeons to consider earlier weightbearing in our high-risk populations," she said.

While surgery-related complications contribute to mortality risk, there currently isn't another treatment option, particularly with an open ankle fracture, which typically requires open reduction and internal fixation (ORIF) to realign the fractured bone.

In this study, all of the ankle fractures were the result of low-energy falls, ie, those from a standing or sitting position. One patient, Toole noted, sustained an open ankle fracture while getting up after using the toilet. The study findings offer more evidence of the need for fall prevention in older adults.

"These patients sustain devastating and potentially catastrophic injuries from low-energy falls," said Toole. "I think this study provides further credence for fall prevention in the elderly population, such as smart homes." A smart home allows its occupants to control lighting, heating and electronic devices remotely by phone or computer.

King agreed fall prevention and safety should be paramount to help patients avoid these low-energy injuries.

"Gait training is important, and making sure patients are protected when weightbearing with a walker or assistive device," she said.

King also stressed that, since it's more challenging to prevent falls in patients with dementia, these patients need more attention.

"It is important to have assistants around who can help watch these patients so they don't get up confused and injure themselves," she said.

Reducing obesity in older adults can also help prevent falls, King said. Bone mineral density is thought to be higher in obese individuals than in their normal-weight counterparts, but the percentage of lean body mass is lower in obese patients, so the relative bone mineral density is also lower—which may increase the risk of ankle fragility fractures in the elderly, she said. In the *JFAS* study, the average BMI was 35.93, which is considered severely obese.

Toole plans to undertake expanded research using data pooled from multiple medical centers across the US.

"We hope to better be able to study associations with particular medical problems, risks, etc," he said.

Sources:

Toole WP, Elliott M, Hankins D, et al. Are low-energy open ankle fractures in the elderly the new geriatric hip fracture? J Foot Ankle Res 2014 Dec 5. [Epub ahead of print]

Lynde MJ, Sautter T, Hamilton GA, Schuberth JM. Complications after open reduction and internal fixation of ankle fractures in the elderly. Foot Ankle Surg 2012;18(2):103-107.

TELEMEDICINE

BRINGING DIABETIC FOOT CARE TO THE SMALL SCREEN

Many experts believe that comprehensive acceptance of telemedicine for prevention and monitoring of diabetic wounds and other lower extremity care is right around the corner.

By Hank Black

In 2005, Howard Umansky, DPM, of St. Petersburg, FL, founded the Diabetic Rural Outreach Project (DROP International), which utilizes telemedicine to remotely monitor patients with diabetic wounds in China, the Caribbean, and the US. He started with relatively simple technology—furnishing basic computers with webcams and using services like Skype. Where no Internet was available, landline-linked videophones sufficed.

"Today, smartphones have decreased our cost and provided a host of even better options for imaging and monitoring diabetic complications," Umansky said in a recent podcast.[1] "In almost ten years, and across thousands of patients, our team has experienced only one amputation due to a lower extremity wound, and I credit that largely to telemedicine."

Umansky's relatively small organization uses a simple "see it, snap it,

With Healogram telehealth technology, wound surface area is automatically calculated using a disposable calibration sticker and computer vision techniques. (All images courtesy of Healogram.)

send it" model for monitoring of wound care and prevention of additional wounds.

"Prevention is the best alternative, of course. Wounds don't usually start out five centimeters across but as a small red dot or series of dots that coalesce, so daily self-examination is critical in order for us to intervene at the earliest possible stage," he said.

But giant systems like the US Department of Veterans Affairs (VA) have set up linked platforms that enable a nurse to take and securely transmit even 3D images for evaluation by specialists. And, between home visits, veterans' diabetes and wound data are regularly transmitted to a dedicated patient alignment team watching for danger signs that would necessitate an intervention.

Those examples and others illustrate the potential of telemedicine to revolutionize delivery of diabetic foot care around the world. In research labs and high-tech business incubators across the nation, countless more projects are in development for the next generation of advances.

Into the mainstream?

Lower extremity healthcare practitioners and researchers and officials from health organizations, state legislatures, and telecommunications enterprises are among many who believe that comprehensive acceptance of telemedicine for prevention and monitoring of diabetic wounds and other care is right around the corner. Is this the year that federal and other insurers will finally cover, in a comprehensive manner, medical services delivered remotely? Bean counters in cash-strapped state governments, millennials pursuing the next "killer app," and practitioners who see parity in quality of care from telemedicine are joining a chorus of other hopefuls who say the promise will become reality soon, and telemedicine will finally integrate into the medical mainstream.

And none too soon. As an aging "time bomb" ticks away in advanced societies and epidemics of obesity, diabetes, and other chronic diseases loom while numbers of practitioners are stretched thin, the delivery of healthcare from a distance is seen as a promising strategy for confronting these threats.[2]

Plenty of hurdles remain before this happens—none more difficult to solve than whether, as currently constituted, telemedicine is financially viable—but technological advances, plus the lure of providing standard-of-care healthcare to off-site and underserved patients with the cost-efficiency of electronic communications, are spurring rapid growth in the field, say many experts.[3,4]

Telemedicine (or telehealth, a broader term) takes many forms. To the American Telemedicine Association (ATA), it is the exchange of medical information from one site to another via electronic communications to improve a patient's clinical health status. It includes the use of two-way video, email, smart phones, wireless tools, and other telecommunications technology. It may include consultations between practitioners and may use live interactions or store-and-forward transmission of images, vital signs, patient data, and the like. Consumer medical and health information and professional medical education may also be included.[5]

The government-funded National Telehealth Resource Center says that, in principle, no regulatory distinction should exist between telehealth services and those delivered in person. Quality and practice standards should be the same for both, and as both types of services merge, the "tele" prefix should disappear.[6]

Recent changes in the ATA's operational guidelines make it clear that telemedicine is no longer considered fringe care.[7]

"Telemedicine has been around some twenty-five years and is becoming very much mainstream, reimbursable in certain circumstances," said former ATA President Elizabeth A. Krupinski, PhD, professor and vice chair of medical imaging research at the University of Arizona in Tucson. "One major change we have made is that telemedicine is no longer considered to be research, so we dropped the idea of informed consent for patients in favor of enhanced patient and provider education. Patients sign the same forms pertaining to consent to care, HIPAA [the Health Information Privacy and Accountability Act], and others as they would if they were in the doctor's office."

Umansky points to the increasing ability to remotely collect patients' biometrics through nanofiber sensors in bandages and other means as a dramatic improvement in wound care.

"The pace of technology today is phenomenal—from smartphone attachments such as a dermatophone or an ankle brachial index cuff to the wearable sensors that can transmit temperature and other changes in a wound," he said. "The ability to monitor blood flow is coming soon, and that will be an added game-changer. The ability to monitor depth, volume, and temperature of diabetic ulcers, along with a wide host of other innovations, gives us a wealth of data that makes us ever more secure in our management of these wounds."

Getting in the game

Some envision a gold rush on the tech side as numerous start-up companies jostle for prominence and established telecommunications giants integrate platforms and applications to tie health systems together.[3]

New enterprises that seek to disrupt the traditional healthcare model with telemedicine applications are flooding high-tech incubators around the country. At least one mobile platform that helps practitioners remotely monitor healing of postsurgical and other types of wounds has entered pilot studies to assess the cost savings of remote versus in-person follow-ups, quality of care, and patient and clinician satisfaction.

Large information and technology communications companies are in the game too, wooing providers and patients with application portfolios based in cloud servers that are HIPAA-compliant. The American Diabetes Association's free 24/7 app that gives users help in monitoring their disease is included in Microsoft's HealthVault and others. AT&T has boosted the ability of hospital networks to centrally manage radiologic images and collaborate with other networks and practitioners. And Verizon is only one of several companies that has launched Federal Drug Administration-approved remote patient monitoring platforms that en-

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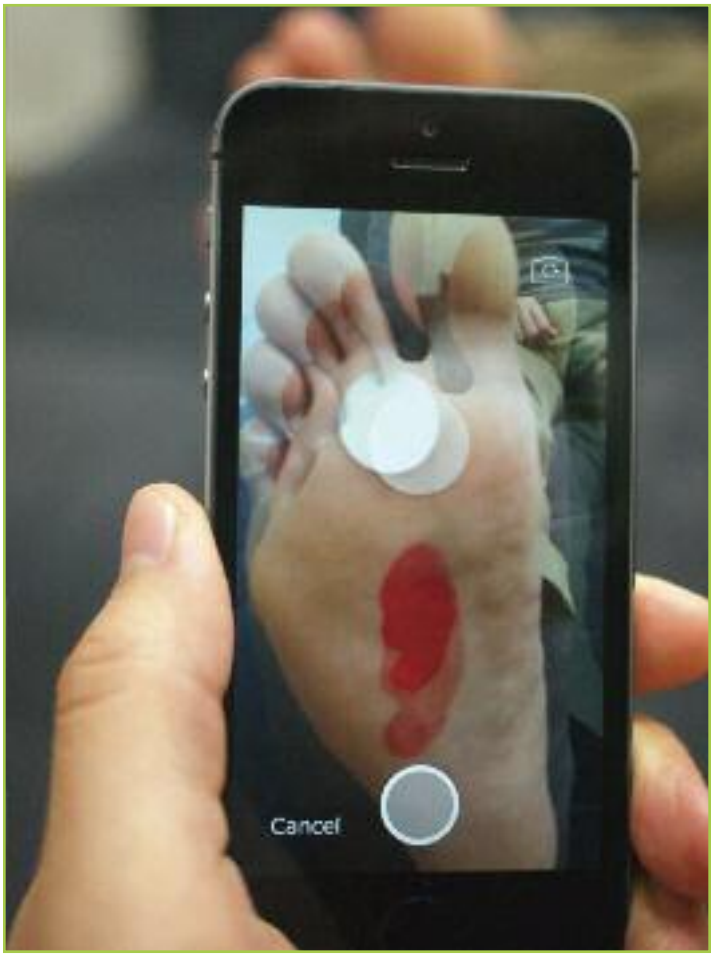

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able use of biometric devices to automatically send patient data to its secure cloud.[3]

In some other countries, practitioners can rely on simpler technology without having to jump through HIPAA and other US privacy hoops. The issues of device and privacy regulations are moot in China, for example. That enables Umansky's nonprofit organization to operate on a model that merely asks patients with diabetes to examine their skin daily and send pictures of even minor changes with their name to one of two wound centers for evaluation.

"Everybody in Chongqing and Wuhan has a smartphone, so it's simple, cheap, and cost-efficient by preventing major problems from developing from the simplest epidermal change," he said.

Mississippi, which has high poverty levels, a low ratio of physicians to residents, and some of the worst rates of obesity and diabetes in the US, uses patient-based smartphones or tablet computers and a care management application to monitor glucose and other pertinent data from patients remotely and connect them with providers. Kristi Henderson, DNP, chief telehealth and innovation officer at the University of Mississippi Medical Center in Jackson and head of its Diabetes Telehealth Network care management program, said these tools help give many people with diabetes in the rural Delta region control of their illness for the first time since diagnosis.[8]

And from a patient satisfaction point of view, Henderson said, "We're hearing from patients, 'Don't take this away.'"

Mississippi officials began adopting telehealth several years ago to help a state in which 65% of people have to go more than 40 miles to see a specialist. That state's regulatory and policy changes have made it one of only seven in the nation to receive an A rating from the ATA, Henderson said. For example, telehealth appointments are reimbursed on par with in-person visits by all public and private payers in the state. Henderson said many other states have not overcome resistance to change due to fears about the quality of telehealth and outdated policies.[9]

Numerous projects have demonstrated that telemonitoring and telehealth interventions, however low-tech, can improve clinical outcomes for people with diabetes. Even texting has been shown to have the ability to sustainably improve diabetic health metrics in both rural and urban populations, and across multiple languages.[10-12]

If low-tech solutions can keep diabetic symptoms under control, remote diabetic wound care is heavily dependent on observation of images by expert practitioners, and better images and transmission usually mean specialists can provide a more accurate clinical report. No providers are ahead of the VA in employing these capabilities.

Patients are now beginning to receive the benefit of the latest technology to image wounds in both 2D and 3D for remote transmission to specialists. David Chmielewski, MBA, the VA Cleveland Facility telehealth coordinator, said the programs will be piloted this year in the 14 VA primary care clinics in Ohio before being rolled out across the country.

"The mobile wound management system will be incorporated into our home telehealth program to provide a 2D imaging system in the form of a dedicated smartphone for use by patients in their homes. Patients or a family member or neighbor will be trained in their use by nurses in the home or in a clinic visit," he said.

A separate, portable system uses stereography to record 3D images taken by VA employees in the patients' homes, Chmielewski said.

"Those pictures of wounds will automatically upload to a secure website for specialists to review on a desktop computer," he said. "Our intent is to avoid the exacerbation of wounds that often occurs when patients travel to primary care clinics or specialized centers."

He explained that both 2D and 3D systems eliminate unnecessary visits to clinics and specialized centers.

"Home telehealth modalities save two thousand dollars per patient, and even more when wound management is involved, because foot ulcers in particular get worse with movement travel. A patient may have a wound rated a three on a scale of one to ten when they leave the house, but it may be a six or seven by the time they get to clinic because of all the movement involved," Chmielewski said. "That raises the cost associated with seeing the patient in a clinic, so that's a major impetus for us to roll out a program to remotely monitor wounds. It's not just the cost of getting to the clinic but the cost of more expensive treatment for a wound that is even more advanced."

Minimizing the need for patient transportation is also a priority at the Louis Stokes Cleveland VA Medical Center in Ohio, said Richard Strozewski, telehealth master preceptor.

"If a patient has a neuropathic ulcer in the bottom of the foot and has to drive even a couple of miles to the primary clinic or two to three hours to a specialized center and then walk in, this obvi-

Continued on page 18

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Continued from page 16

For self-monitoring scenarios, pop-up reminders prompt users to perform 'virtual check-ins.'

ously will irritate the wound. The best-case scenario is to get the image right out of the patient's home," Strozewski said. "This is where we start to combine technologies based on patient needs. The image is taken at the home and the doctor may then want to do a live video visit with the patient about how they are feeling, or a nurse may be on site in the home and may be asked to do some palpations, or other diagnostic tools may come into play."

Almost one-third of patients in the Ohio VA system participate in some form of telehealth or telemedicine, and about half are in some form of virtual care, Chmielewski said. The former category includes the home telehealth program, clinical live (synchronous) video telehealth, and store-and-forward telehealth. Virtual care also includes a patient portal MyHealth eVet, E-Consult, and an education program for primary care physicians called Specialty Care Access Network (SCAN).

While one stereography system is getting a major boost through the VA, others are not far behind. A system that provides a portable 3D color representation of a wound with several different measurement tools, including color analysis, although not intended for use by patients, has undergone considerable evaluation with published results,[13,14] and the UK's National Health Service has authorized it for further development as a promising technology.

The more complex and physically larger systems are designed both to assess wound images and maintain wound records for a large number of patients, with an associated high acquisition cost, and are thus not intended for self-utilization by patients. Other products seek to fill that niche or are in the pipeline. The advanced systems are costly and require on-site professionals to take the images. However, advances in smartphone technology are prompting researchers to develop more patient-friendly products.

Thinking inside the box

Peder C. Pedersen, PhD, professor of electrical and computer engineering at Worcester Polytechnic Institute in Worcester, MA, said the computational capability of current smartphones has spurred his research group to develop a wound imaging and analysis system for patients with chronic foot ulcers. The smartphone system allows patients or their caregivers to capture consistent images of their wound, at regular intervals, on a smartphone combined with a low-cost image capture box containing specifically positioned mirrors. The box was built in his laboratory for about $100, he said.

"You clip the phone on the box, put the affected foot on the rectangular opening on the box, and take the picture with a voice command. Once FDA regulations are met, the system can automatically transmit the data to the patient's electronic health record at the wound clinic," Pedersen said.

The system employs simple algorithms that calculate the outline of the foot and the wound boundary and assesses quantitative healing status based on color spectral analysis. Pedersen said a pilot study of the system's efficacy will be carried out in 2015.[15]

Early adopters of telemedicine such as the VA are

A view of the clinicians' electronic dashboard, which gives care teams a quantitative population-level snapshot of how their wound patients are faring by territory, facility, and other measures.

seeing transformations in remote care for diabetic and other wounds coming sooner rather than later. Technologies now in early release or under development that are being evaluated for utility include stereography; holography, as in vector imaging; the advancement of devices in products like Google Glass; and multiple other wearable technologies.

"In addition, through developing and incorporating the use of smartphones and their apps for telehealth, we can provide patients with better tools and give them the ability to be active participants in managing their healthcare," Strozewski said.

For example, that might involve transmitting data to guide footwear modifications in patients at risk for neuropathic foot ulcers. The patient might stand on an instrumented platform that could collect pressure and temperature data and transmit it to a specialist who would then make the appropriate modifications to the shoe, he said.

"As digital technologies evolve and become more cost-effective and user-friendly, we continuously evaluate how they can be incorporated into telehealth as tools that collect current, pertinent, and useful data that can be delivered rapidly in summarized forms to providers, allowing them to make better, more precise, and quicker clinical decisions," Strozewski said.

Reimbursement is key

Reimbursement is seen as the key impediment to telemedicine that, once conquered, will carry it into the healthcare mainstream.

"Telemedicine will explode in the next couple of years because everything is falling into place for when Medicare rolls out a reimbursement schedule; insurers will then follow suit and the last barrier will fall," Umansky said.

In fact, the Centers for Medicare and Medicaid Services (CMS) is incrementally loosening requirements for reimbursement and use of telemedicine services. In December 2014, CMS proposed waiving certain restrictions on the use of telemedicine by the nation's 330 Accountable Care Organizations, which are responsible for managing care for large groups of patients under what is labeled "population management." The ATA recently called on CMS to use similar flexibility in Medicare's managed care plans.[16]

As for Medicaid, a patchwork of insurance requirements and various payment streams does not allow providers and patients to take complete advantage of available telemedicine services. Each state has different policies. Nevertheless, a recent ATA analysis of gaps in reimbursement and policy showed the number of states with laws giving parity to telemedicine and traditional healthcare models has doubled in the past three years.[17]

With payers coming on board, and technology improving exponentially, it is apparent the future of medicine will include telemedicine. There are barriers, but as Mississippi's Henderson said, they are not insurmountable.

"We have overcome them here with visionary leaders. And if you can do it in Mississippi, you can do it anywhere," she said.[9]

Hank Black is a medical writer in Birmingham, AL.

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Managing Finger and Toe Wounds

The closing and healing of all wounds involves establishing and maintaining optimal wound healing conditions. Managing wounds on fingers and toes can be difficult due to the need to reduce edema without a good way to accomplish the goal. Additionally, a caregiver is often required to apply dressings in a way that limits the digit's range of motion, further interfering with the healing process. Dressings applied to the finger or toe often need to be changed frequently because they slip off due to movement. In patients with vascular or diabetic co-morbidities, digit wounds can be especially slow to heal and often require multiple medical interventions.

A recent poster,[1] highlighting four patients with digit wounds on either the hand or foot, demonstrated the use of Ferris Mfg. Corp.'s latest product, the PolyMem® Finger/Toe dressing. The dressing was developed to be easily applied and removed and contains the same formulation of all PolyMem dressings, helping ensure less pain and more healing.

Patient 1 was a 78-year-old diabetic male with a below-the-knee right leg amputation. He bumped his left foot during a transfer from his wheelchair to the toilet. The trauma resulted in three blood-filled blisters on the second toe of the left foot and swelling of his left lower extremity became a healing obstacle. Due to increased susceptibility to infection, the silver version of the PolyMem Finger/Toe dressing was applied to the blisters. His wife performed the dressing changes and his blisters dried under the dressings in less than two weeks, using only two dressings.

The Silver Finger/Toe dressing was easily applied.

Patient 2 was a 71-year-old diabetic male with a history of poor vascular perfusion, below-the-knee amputation of the right leg, and venous stasis ulcers. The hook-and-loop fastener of a post-operative shoe created a friction wound on the top of the toe on his remaining foot. The periwound skin became edematous and macerated. Using the PolyMem Finger/Toe dressing, he was able to do his own dressing changes and the periwound maceration, swelling and weeping decreased. The wound, which originally measured 0.5 cm x 0.7 cm x 0.1 cm, was closed in 14 days. Only two PolyMem dressings were used to close this wound.

Patient 3 was a 56-year-old paraplegic female whose shoe came off when her foot fell from the wheelchair footrest, resulting in an avulsion of the second toenail of the left foot. The periwound skin became slightly erythemic and edematous. Her dressing changes were performed by home health and the wound closed in only three days.

Patient 4 was a 56-year-old male who suffered an amputation at the proximal joint of the first finger of his right hand while operating a hydraulic log-splitter. A surgical flap was attempted, but it was unsuccessful. The periwound skin was swollen, macerated and warm to the touch. He received whirlpool baths to the wound twice weekly by physical therapy. He changed his own dressings when required and when no whirlpool treatments were scheduled. The macerated periwound skin resulting from the whirlpools was managed with a barrier cream. The pain during the whirlpool treatments was managed with oral analgesia. All these wounds healed rapidly using PolyMem Finger/Toe dressings.

PolyMem is a multifunctional polymeric membrane dressing and contains components that draw and concentrate the body's natural healing substances into the wound bed to promote rapid healing. PolyMem Silver has all the unique properties of the standard pink PolyMem dressings with the additional antimicrobial properties provided by elemental silver.

The Finger/Toe dressings, like all PolyMem products, help to reduce edema, bruising, pain and inflammation when applied to either open or closed injuries. The dressings help relieve both persistent and procedural pain that is associated with injury and are effective throughout all stages of the healing process. The dressings fit securely over the finger or toe while allowing freedom of movement; encouraging range of motion; helping reduce pain, swelling, bruising and inflammation; and providing cushioning protection.

After application of PolyMem dressings, all these patients experienced significant swelling reduction in the affected digits and saw rapid resolution of any previously present periwound skin complications. Nurses, patients and caregivers found the dressings easy and convenient to use. Finger/Toe dressings were shown to be cost effective when compared to other approaches as the number of dressings used was significantly decreased, the time needed for dressing changes was minimal and the home health nurses made fewer visits. PolyMem dressings provided optimal healing environments, which resulted in rapid wound resolutions.

The entire dressing was applied to cover the the knuckle as well as the wound in order to help reduce the swelling faster.

Reference:

1. Harrison J. Successful Healing of Digit Wounds with One Dressing. Poster 6130. Wound Ostomy and Continence Nurses Association (WOCN). June 9-13, 2012. Charlotte, NC, USA.

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Sensory-targeted ankle rehabilitation strategies

Current treatments for chronic ankle instability (CAI) may be ineffective in reducing its development and recurrence. To help address this issue, the authors have proposed a new treatment paradigm based on a theoretical model of CAI as an organismic constraint on the sensorimotor system.

By Patrick O. McKeon, PhD, ATC, CSCS, and Erik A. Wikstrom, PhD, ATC, FACSM

Ankle sprains are the most common injuries associated with physical activity and athletic participation,[1,2] accounting for approximately 60% of all injuries that occur during interscholastic and intercollegiate sports.[1-5] Medical costs for ankle sprains have been estimated to be approximately $4 billion annually.[6,7] Thus ankle sprains, while often viewed as mild injuries, represent a significant public health problem[7,8] and a major healthcare burden.

Further, about 30% of those who suffer a first time ankle sprain develop chronic ankle instability (CAI); some have reported this number to be as high as 75%.[9-11] This means at least one out of every three individuals who sprain an ankle will go on to suffer residual symptoms indefinitely. Indeed, the residual symptoms that define CAI significantly alter an individual's health and function by causing them to become less active over time. CAI is also a major contributing factor in the development of post-traumatic ankle osteoarthritis,[12] for which there are no effective conservative treatments.

It is apparent, based on the information presented above, that CAI presents a major obstacle affecting the maintenance of regular physical activity for Americans and the prevention of post-traumatic ankle osteoarthritis. Further, high recurrence rates,[9-11] incidence of post-traumatic ankle osteoarthritis,[12] and consequent healthcare burdens[6,7] clearly indicate that current treatments for CAI may be ineffective in reducing its development and recurrence. To help address this issue, we have proposed a new treatment paradigm based on a theoretical model of CAI as an organismic constraint on the sensorimotor system.

In the sensory-targeted ankle rehabilitation strategies (STARS) paradigm, interventions include ankle joint mobilization, plantar massage, and triceps surae strengthening.

The theoretical model

The human body is a system capable of accomplishing movement goals in a variety of ways.[13] The dynamic nature of this system (ie, its ability to adapt to changing demands) is often described by what is referred to as the dynamic systems theory of motor control. According to this theory, the organization of the sensorimotor system

Continued from page 23

Figure 1. The interacting constraints that influence sensorimotor control. Sensorimotor system (SMS) freedom is contextually dependent on the interaction of the organism, the complexity of the task, and the predictability of the environment.

is constrained, or shaped, by the interaction of organismic, task, and environmental constraints (see Figure 1).[13,14] The theory states that the sensorimotor system develops and changes strategies (ie, self-organizes) based on its current state and on interactions with the environment as they relate to a particular movement goal.[14] Thus, a healthy sensorimotor system can accomplish a movement goal in a variety of ways even if changes in the task, environment, or both occur. Increasing numbers of possible solutions (ie, degrees of freedom) translate to an enhanced ability to successfully accomplish the movement goal and cope with change.

CAI can be viewed as an organismic constraint, potentially because the damaged mechanoreceptors in the lateral ligaments cannot be used for movement solution development, thus reducing the functional variability and ability of the sensorimotor system to accomplish movement goals.[15] This constraint has been proposed to increase the risk of recurrent injury.[14] Injury epidemiological evidence supports this framework in that the primary risk factor for an ankle sprain is a previous history of the same injury.[16] Further, poor sensorimotor control is also a risk factor for ankle injury.[17]

The hallmark of CAI is self-reported disability in combination with experiences of the ankle giving way during functional activities.[18] Those with CAI have also demonstrated alterations in both sensory and motor aspects of sensorimotor control, including plantar sensation threshold deficits,[21] increased joint position sense errors,[22] decreased dorsiflexion range of motion,[21, 22] impaired muscle reaction time,[23] decreased balance,[24] and gait and landing alterations.[25-29] Thus, it appears that there is a continuum of disability (see Figure 2) associated with sensorimotor control that modulates self-reported activity limitations and participation restrictions experienced by those with CAI.[15,30]

To gain understanding into this continuum, research is needed to elucidate the link among constraints, sensorimotor control, and injury risk.

While the exact neurophysiologic mechanism of CAI remains unknown, it has been hypothesized that damaged structures from

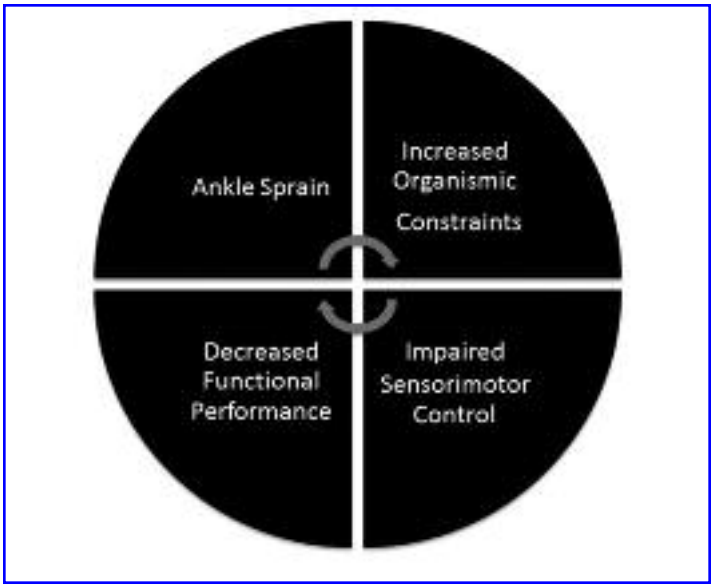

Figure 2. The continuum of disability. Ankle sprains introduce increased organismic constraints to the body, which in turn impair sensorimotor control. This in turn decreases functional performance, which increases the risk of a subsequent ankle sprain.

the ankle sprain relay absent or inappropriate afferent information to the central nervous system (ie, sensory dysfunction).[31] In healthy individuals, organization of movement solutions arises from the abundance of degrees of freedom from both sensory and motor sources.[13] As a movement is executed, sensory information "tunes" motor output, and actual movement itself serves to "tune" sensory input. If a source of sensory input is impaired, as in the condition of CAI, the sensorimotor system dynamically reprioritizes other inputs available to compensate for the loss of information,[32] as we have previously shown.[33,34] We have evidence to support this hypothesis;[21,27, 35-41] that this dysfunction limits an individual's ability to self-organize (ie, cope with changes in the environment or with increased activity demands) due to an inability to appropriately modulate movement based on information from internal and external sources (see Figure 3). The consequence is a reduction in the total degrees of freedom available from sensory inputs to detect and cope with change.

It may be that the motor issues related to CAI—including poor balance, gait alterations, and episodes of giving way—are related to sensory deficits. This is consistent with the original hypothesis of Freeman et al,[31] who suggested the recurrent instability that those with CAI experience was due to deafferentation of the lateral ankle ligaments as a consequence of injury. This loss of afferent information was then thought to manifest as the diminished ability to balance on one leg and as self-reported episodes of instability. Therefore, the constraints experienced by those with CAI may be related to alterations in the sensory degrees of freedom available to the sensorimotor system for tuning motor output.

The paradigm shift

Traditionally, rehabilitation strategies for CAI have focused solely on motor impairments within the sensorimotor system, with little attention paid to the role of sensory inputs in the regulation of function. We hypothesize that, due to the CAI-related disruption of sensory information, the sensorimotor system is more reliant on other

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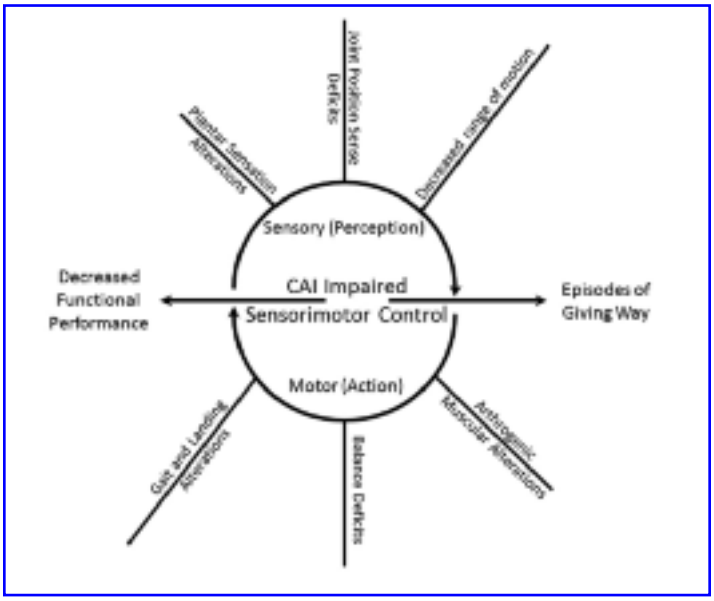

Figure 3. The relationship of sensory and motor impairments associated with CAI. On the sensory side, deficits in plantar information, joint position sense, and range of motion may contribute to alterations associated with the motor output of the system. Typically, research has evaluated the quality of motor output as it relates to CAI; however, a growing body of literature suggests sensory issues are present and may be driving the dysfunction associated with the condition.

sources of somatosensory input (ie, plantar cutaneous receptors, muscle spindles, posterior ankle articular receptors) available to tune movement.[33] From a dynamic systems perspective, targeting and manipulating sensory information sources will have a very beneficial effect on rehabilitation outcomes in those with CAI.[42] Targeting sources of sensory information will allow the patient to optimize movement patterns to cope with changing conditions—a marked limitation of existing treatment paradigms that target only motor impairments. Investigating the effect of therapeutic interventions that address this sensory phenomenon may offer individuals with CAI the opportunity to better self-organize (ie, compensate) for the loss of sensory information from damaged structures and resolve motor impairments.

Manual therapies, such as ankle joint mobilizations, plantar massage, and stretching, are hypothesized to target specific sensory inputs such that CAI-associated dysfunction will improve through enhanced afferent and global function (see Figure 4). Targeting certain sensory pathways to improve the quality and quantity of sensory information provided to the sensorimotor system may enhance the output on the motor side of the system. This has led us to the development of a new treatment paradigm for CAI known as sensory-targeted ankle rehabilitation strategies (STARS). In this paradigm, we have explored the effects of ankle joint mobilizations, plantar massage, and triceps surae stretching on patient-, clinician-, and laboratory-based outcome measures that are representative of sensorimotor function and disability in those with CAI. The outcome of this research has potential to generate a paradigm shift for treatment strategies in this population.

STARS interventions and initial evidence

The STARS interventions include ankle joint mobilization, plantar massage, and triceps surae strengthening. (See Table 1 for images

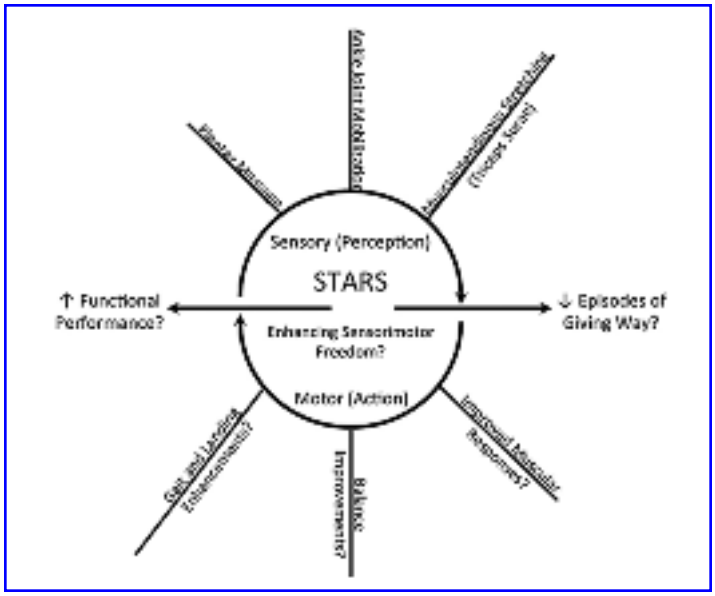

Figure 4. The STARS project focuses on examining how manual therapies at each sensory entry point affect the motor output and functional performance of those with CAI. By developing an understanding about how these treatments affect the system, more robust treatment strategies for CAI patients can be tailored to their sensory issues.

and additional descriptions of each modality.)

Ankle joint mobilization. In the STARS paradigm, we and others have begun using anterior-to-posterior Maitland grade III joint mobilizations. As an example, we are using a treatment period of five minutes to stimulate the surrounding ankle capsuloligamentous receptors. Each treatment consists of two sets of joint mobilizations, two minutes each, in which one-second grade III oscillations are performed, with one minute of rest between sets. While the parameters might vary with regard to number of oscillations, patient positioning, and number of treatments, ankle joint mobilizations consistently improve ankle joint range of motion,[43,44] as well as postural control and self-reported function,[43] in patients with CAI. A recent systematic review has also demonstrated improvements in patient-, clinician-, and laboratory-based outcomes with greater effectiveness with multiple treatments compared with single treatments in those with a history of ankle sprains.[45]

Plantar massage. The plantar cutaneous receptors play an important role in the maintenance of postural control and those with CAI may rely more heavily on their information. To capitalize on this source of information, we built a protocol in which patients receive five minutes of foot massage, which combines effleurage and petrissage techniques, on the plantar surface of the foot. Similar to joint mobilizations, we have used two two-minute sets of plantar massage with one minute of rest in between each set. Previously, a similar protocol demonstrated that those with CAI experienced improved postural control after undergoing a single treatment session.[46] Similar results have also been shown in the elderly, a patient population that also has organismic constraints.[47]

Triceps surae stretching. Research also suggests the muscle spindles within the gastrocnemius-soleus complex (triceps surae) are important for maintenance of postural control.[48,49] Using the STARS paradigm, it would be possible to use this treatment modality to improve outcomes associated with a history of ankle sprains. In our study, we used a protocol of two sets of heel cord (calf) stretching.

Continued on page 28

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Continued from page 26

Table 1. STARS Interventions

Intervention	Description	
Ankle joint mobilization	Two two-minute sets of joint mobilizations in which one-second large amplitude (grade III) oscillations are performed. Over the course of the five-minute treatment, patients receive approximately 60 oscillations.	
Plantar massage	Five minutes of foot massage that combines effleurage and petrissage on the plantar surface of the foot. Similar to joint mobilizations, use two two-minute sets of plantar massage with a one-minute rest between each set.	
Triceps surae stretching	Two sets of heel cord (ie, calf) stretching with a slightly flexed knee to target the soleus. Each set will consist of three 30-second stretches with 10-second rests between stretches and one minute between sets.	

Each set consisted of three 30-second stretches, with 10 seconds of rest between stretches and one minute between sets. While little research has been done on the effectiveness of stretching in those with CAI, a recent systematic review demonstrated that stretching was an effective modality for improving dorsiflexion range of motion in those with a history of ankle sprains.[50]

To date, a number of studies from several different labs have demonstrated the effectiveness of different sensory-targeted ankle rehabilitation strategies on a variety of patient-, clinician-, and laboratory-based outcomes.[51] However, no investigation has systematically compared different STARS interventions against each other on a wide range of outcome measures. Thus, the purpose of our investigation was to determine the effectiveness of STARS for facilitating immediate and prolonged improvements in subjective and objective outcome measures of clinical disablement and sensorimotor dysfunction in those with CAI. More information about this study (NIAMS 5R03AR061561) can be found at clinicaltrials.gov. Specific outcome measures for the STARS project included the changes due to each STARS on the Foot and Ankle Ability Measure[52] and self-reported episodes of giving way, the weight-bearing lunge test,[43] the single-limb balance test,[53] time-to-boundary measures of single limb balance,[34,36] gait initiation,[54,55] and plantar cutaneous sensitivity.[56]

Future research and clinical implications

There are several important clinical questions that will need to be answered regardless of the existing literature and our own results. As a result, future research is needed to determine the dosage needed to optimally improve subjective and objective sensorimotor outcomes in patients with CAI. Similarly, while STARS treatment has been associated with improvement in a number of outcomes, there remain an even larger number of possible variables that may better illustrate how STARS results in improved function for those with CAI. Most important, in the age of personalized medicine, future research is needed to establish predictive criteria that would allow a clinician to select the most effective intervention or interventions for those with CAI based on a simple initial evaluation. Lastly, the existing knowledge and our results will begin to form a framework for the systematic investigation of combination therapies for patients with CAI, such as combining STARS with more traditional motor-focused interventions such as balance training.

Clinical take-home points:

1. The sensorimotor system relies on both sensory and motor sources to tune its behavior in the presence of changing task and environmental demands.
2. Damaged or limited sensory information may result in a more constrained sensorimotor system.
3. By targeting certain sensory pathways through manual therapy interventions, it may be possible to provide the sensorimotor system greater freedom to cope with change and enhance functional performance in those with CAI.
4. The STARS interventions are delivered across a five-minute treatment session six times over the course of two weeks. These low-cost treatment strategies can be implemented in any healthcare setting with little to no equipment needed. ler

Patrick O. McKeon, PhD, ATC, CSCS, is the clinical education coordinator within the Athletic Training Education Program at Ithaca College in New York. Erik A. Wikstrom, PhD, ATC, FACSM, is an associate professor within the Department of Kinesiology at the University of North Carolina at Charlotte.

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Knee OA as a long-term consequence of injury

A knee injury can have painful and disabling long-term repercussions, such as the early onset of knee osteoarthritis (OA) or accelerated knee OA. Injury prevention and effective interventions may help reduce the risks, but patient education and monitoring after an injury are also warranted.

By Jeffrey B. Driban, PhD, ATC, CSCS; Brian Pietrosimone, PhD, ATC; Nicole M. Cattano, PhD, ATC; Matthew S. Harkey, MS, ATC; and Brittney A. Luc, MS, ATC

Many patients and clinicians focus on immediate outcomes following a knee injury, such as decreasing pain and disability, as well as restoring muscle strength, physical function, and preinjury activity levels. However, the long-term implications following a knee injury are becoming increasingly apparent, and there is a need to educate patients about long-term risks.

A patient with a history of knee injury is three to six times more likely than those without such a history to develop knee osteoarthritis (OA),[1] one of the leading causes of disability.[2,3] Furthermore, a patient with a history of joint injury tends to be diagnosed with OA approximately 10 years earlier than individuals without a history of joint trauma.[4] For example, Frobell et al found that 26% of individuals aged an average of 31 years had radiographic knee OA just five years after an anterior cruciate ligament (ACL) injury, regardless of initial treatment strategy.[5] Within 10 to 15 years following an ACL injury, individuals have a 50% chance of developing knee OA, especially if the meniscus was compromised at the time of the injury.[6-9] In fact, individuals who undergo an ACL reconstruction and a meniscectomy are 3.5 times more likely to have knee OA approximately 10 years after an ACL injury than those without a meniscectomy.[9] Accordingly, individuals with a history of joint trauma may be burdened by OA for more than half of their life, leading to a greater risk of developing comorbidities,[10] as well as significant psychosocial and economic consequences (eg, healthcare expenses, work loss).

The early onset of OA should not be an acceptable outcome for our young patients, and we need to take steps to protect the long-term health and wellness of those younger patients. Moreover, we need to recognize that knee injuries can have dramatic long-term implications for older adults, as well.

Knee injuries may also be a catalyst for the onset of accelerated knee OA among adults older than 45 years. Accelerated knee OA

> Using examples from other health disciplines might help clinicians explain to patients why they should take steps to prevent knee OA.

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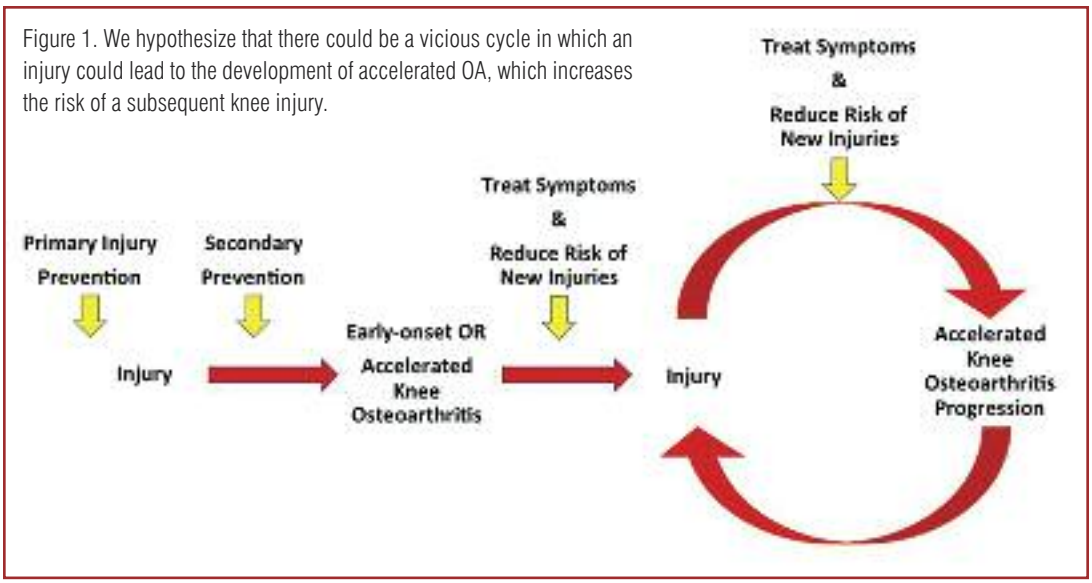

Figure 1. We hypothesize that there could be a vicious cycle in which an injury could lead to the development of accelerated OA, which increases the risk of a subsequent knee injury.

is characterized by a rapid progression from a normal appearance to end-stage disease within four years, and sometimes progresses to end stage in as little as 12 months.[11] A recent study evaluated the relationship between injuries and accelerated knee OA using data from the Osteoarthritis Initiative, a large cohort study of individuals older than 45 years with or at risk for knee OA.[11] The accelerated knee OA study found that individuals who developed end-stage disease because of accelerated knee OA were three times more likely to report sustaining a knee injury within the preceding four years than those who did not develop knee OA. Furthermore, individuals who developed accelerated knee OA were nine times more likely to report having sustained a knee injury in the year before they presented with end-stage knee OA compared with those who did not develop knee OA.

Thus, certain acute injuries may initiate a dramatic, accelerated deterioration in joint health in patients older than 45 years within a period as short as one year. The first year after an injury within this population may be a critical time period to monitor a patient's joint health to determine who is most susceptible to developing accelerated knee OA.

Another possible interpretation of these findings could be that the onset of accelerated knee OA increases the risk of an additional knee injury. Hence, we hypothesize that there could be a vicious cycle in which an injury could lead to the development of accelerated OA, which increases the risk of a subsequent knee injury (see Figure 1). An additional knee injury consequently causes further progression of knee OA.

All of this highlights the importance of listening to our older patients when they report a knee injury. We cannot afford to ignore the warning sign of a patient reporting a knee injury, and we should be prudent in determining the nature of the injury, including its type and severity. Subsequently, we should monitor changes in the patient's joint health by scheduling frequent follow-up appointments to monitor changes in joint symptoms and function, as well as performing periodic radiographic assessments for at least 12 months. Hopefully, in the next few years we will gain a better understanding of how the type or severity of injury, as well as the subsequent treatment, may modify the risk of OA.

Injury prevention

The high risk of early onset OA and accelerated knee OA following a knee injury in both younger and older patients demonstrates that it is vital for clinicians to take steps to ameliorate these risks. But how can clinicians prevent knee OA? The first line of defense may be implementing primary injury prevention programs, which could reduce the risk of an acute injury (see Figure 1). We could prevent 15% to 25% of symptomatic knee OA cases if we could prevent knee injuries.[12] Fortunately for our younger, physically active patients, we know that primary injury prevention programs can prevent more than 40% of lower extremity injuries.[13-19] Therefore, we need to encourage youth sport leagues and schools to implement primary injury prevention programs for young, physically active people. In addition to preventing injury, injury prevention programs could save healthcare costs,[20,21] improve performance,[22-24] and reduce the risk of long-term disability related to early onset OA.

More research is needed to see if primary injury prevention


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Continued on page 34

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Continued from page 32

programs could be adapted for an older at-risk population. It is encouraging that exercise programs that incorporate balance, strengthening, or both can reduce the risk of falls.[25-27] Older patients may also receive additional benefits from these supervised exercise programs beyond just a reduced risk of knee injuries (eg, reduced risk of falls, mental health benefits, improved cardiovascular function). For example, an exercise program for older adults that includes strength training, a common component of injury and fall prevention programs, can also help to improve muscular power and strength,[28] walking speed,[29] balance,[29] blood pressure,[30] body composition,[30,31] cognitive reasoning,[32] and reduce the risk of falls.[33] Furthermore, mind-body exercise programs (eg, tai chi) that incorporate balance and neuromuscular control can help improve balance,[29] reduce the risk of falls,[34] decrease depression,[35] and improve cognitive function.[36] Supervised exercise programs can also be a great opportunity for older adults to socialize with peers, become more physically active, and improve their quality of life.

Intervention following injury

Unfortunately, we will not be able to prevent every injury. Therefore, we also need to understand how our current therapeutic interventions following an acute injury ameliorate or worsen the long-term outcomes after an injury. The first randomized clinical trial comparing individuals who received either an ACL reconstruction or conservative care with an optional delayed ACL reconstruction found that both groups of patients had similar rates of knee OA five years post injury.[5] Recently, two systematic reviews also evaluated the long-term outcomes of patients who received an ACL reconstruction or remained ACL deficient. Harris and colleagues focused on four studies that directly compared 140 individuals with an ACL reconstruction and 240 individuals who remained ACL deficient.[37] At an average follow-up of approximately 12 years, both groups had a high prevalence of knee OA, and there was no definitive evidence that surgical or nonsurgical treatment after an ACL injury could ameliorate the risk of knee OA.

Luc and colleagues assessed 38 studies that included more


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than 2500 individuals with an ACL injury. Among individuals with an isolated ACL injury, a higher percentage of those who had undergone an ACL reconstruction went on to develop knee OA (42%) than those who were ACL deficient (29%).[38] However, among participants with a meniscectomy, individuals with an ACL reconstruction were slightly less likely to have knee OA (52%) than those who remained ACL deficient (59%). Luc et al found some evidence that graft type (eg, hamstring or bone-patellar tendon-bone autografts) and surgical technique may have been an important aspect of determining risk for knee OA. However, this remains a controversial topic, since some randomized clinical trials support this hypothesis[39,40] and others do not.[41-43]

One of the main challenges in understanding the risk of OA after an ACL injury is that the surgical and rehabilitation strategies continually evolve at a pace faster than outcomes can be collected. The data from previous studies may not be applicable to today's patients, since they are undergoing slightly different surgical interventions. Despite this limitation, it is crucial for us to explain to our patients their potential risk for OA. While we don't know how the type or severity of injury may influence the risk of developing OA, patients should be encouraged to consider some general precautions.

Despite our lack of information about how our treatment strategies can ameliorate or exacerbate a patient's risk for OA, there are some general steps that may be beneficial. During the rehabilitation process, we should identify neuromuscular inhibition and deficits, which could alter joint mechanics that could increase the risk of joint damage. The identified deficits can then be targeted in an attempt to restore normal neuromuscular function and proper movement patterns. Providing patients with strategies for reducing their risk factors for developing OA may be crucial. For example, we should encourage patients to maintain a healthy lifestyle and body weight, since high body mass index is a risk factor for accelerated knee OA.[11] We should also highlight the importance of continuing to engage in therapeutic exercise programs even after patients are discharged from supervised care. We may even need to monitor these patients for aberrant neuromuscular function or movement patterns after they return to their regular activities.

While this may be a new approach to thinking about patients after an injury, it is not a dramatic departure from other health professions in which practitioners carefully monitor patients who present with risk factors for other chronic conditions, such as cardiovascular disease. Using examples from other disciplines might also help us explain to patients why they should take steps to prevent OA, even though they may be currently asymptomatic. After all, they probably do not think twice about brushing their teeth to prevent tooth decay, or taking medication to manage high cholesterol or blood pressure along with having routine follow-up appointments with their physicians to monitor their health status.

Conclusion

In conclusion, a knee injury is more than a short-term problem. It represents an important catalyst that can lead to early onset or accelerated OA. The consequences of knee injury could be dramatic because it can greatly alter patients' future function and quality of life. Many factors may influence who develops OA after their injury, such as type and severity of injury, treatment strategy, and patient characteristics (eg, body mass index). We still need to learn more about how to ameliorate the risk of OA after an injury, and there is currently no accepted intervention to slow, stop, or reverse OA progression.

Despite the limitations in our knowledge, we must recognize that we need to talk to our patients about the risk of OA after an injury, be prudent with our treatment strategy, and plan for the long term. Because many of our patients and their families and friends will be focusing on short-term goals—such as restoring function and returning to activities—we must also think about the patient's long-term health and well-being. Educating our patients can only help in the long-term battle against OA by making the patient an informed participant in the process. Together, we can improve our understanding of OA risk after a knee injury and make efforts to improve long-term outcomes. ler

Jeffrey Driban, PhD, ATC, CSCS, is an assistant professor at Tufts Medical Center and Tufts University in Boston. Brian Pietrosimone, PhD, ATC, is an assistant professor at University of North Carolina at Chapel Hill. Nicole M. Cattano, PhD, ATC, is an assistant professor and athletic trainer in the Department of Sports Medicine at West Chester University of Pennsylvania. Matthew Harkey, MS, ATC, and Brittney Luc, MS, ATC, are doctoral students at the University of North Carolina at Chapel Hill.

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Implications of reduced stride length in running

Decreasing stride length during running has been shown to result in biomechanical changes that are associated with reduced loading of biological tissues and, by extension, also may reduce the risk of injuries such as stress fractures, iliotibial band syndrome, and patellofemoral pain.

By Melissa A. Thompson, PhD, and Kristine M. Hoffman, DPM

Running is one of the most popular fitness activities, yet it is associated with a high incidence of lower extremity musculoskeletal injury. Injury rates as high as 79% have been reported in runners,[1] with patellofemoral pain, iliotibial band syndrome, and stress fractures being some of the most commonly reported events.[2] Given the high injury risk, numerous running technique alterations have been suggested in an effort to decrease injury rates.

One gait alteration that has been proposed to reduce running-related injury risk is reducing stride length. Decreasing stride length during running has been associated with several biomechanical changes that may underlie reduced injury rates. Further, there is evidence to suggest that reducing stride length during running may improve symptoms associated with certain clinical conditions, such as chronic exertional compartment syndrome, iliotibial band syndrome, and patellofemoral pain.

Overuse injuries are dependent on loading magnitude, type of load, and the number of loading cycles, as well as the health and condition of the relevant biological tissue.[3] When running, the body's mass is repeatedly decelerated, resulting in forces that travel through the musculoskeletal system. These forces are actively attenuated by eccentric activation of muscles crossing lower extremity joints[4,5] and passively attenuated by structures such as the ground, shoe midsole, heel pad, articular cartilage, intervertebral discs, and menisci.[6,7] The repetitive attenuation of impact forces during running is thought to contribute to overuse injuries.[8-11] The magnitude of loading of biological tissue (eg, bone, tendon, ligament, and cartilage) during the impact phase of running is determined by the combined effects of the ground reaction forces (GRF), lower extremity kinematics, and muscle activation.[12]

> Studies suggest the biomechanical changes associated with reduced stride length include reduced ground reaction forces and ankle, knee, and hip joint moments.

Decreasing stride length

Decreasing stride length during running has been shown to result in several biomechanical changes that are associated with reduced loading of biological tissues and, by extension, also may be associ-

Continued from page 37

ated with reduced injury risk. Specifically, decreasing stride length has been shown to reduce GRFs, joint moments, impact accelerations, and leg stiffness, factors that have been associated with a greater risk of running-related injury.[1,12,13]

GRF magnitude provides an estimate of the forces that are transmitted to the musculoskeletal system during running. When running at moderate speeds the vertical component of the GRF has peak values approximately three times body weight.[14] During running the vertical GRF often has two peaks, the impact peak that occurs at initial ground contact and the active peak that represents the forces at midstance. Research has shown that decreasing stride length decreases the impact peak[15] and active peak of the vertical GRF,[16-20] and has found that reducing stride length results in a decreased vertical loading rate of the GRF.[15]

There is evidence to suggest that greater vertical impact peaks and loading rates are associated with an increased incidence of tibial stress fractures[21-24] and plantar fasciitis.[25] Thus, decreasing stride length may help reduce these types of injury.

Joint moments represent the net effect of muscles and ligament acting across the joint, and are commonly used to assess joint loading during running. Increased stride length has been associated with greater ankle, knee, and hip joint moments.[4,17,20,26] While research regarding the relationship between joint moments and running-related injuries is sparse, it is generally thought that higher joint moments increase risk for joint and other musculoskeletal injuries.

In addition to measuring GRFs and joint moments, loading on the body during running can be assessed by measuring accelerations caused by impact.[27] Body segment acceleration is dependent on the GRF magnitude and the damping effects of the body's passive and active shock absorbers.[4] It has been suggested that greater impact accelerations result in increased prevalence of running-related injuries. Studies have shown that tibial accelerations decrease when stride length is reduced.[4,28-30] This further suggests that decreasing stride length may reduce running-related injuries.

Lastly, decreasing stride length has been shown to alter leg stiffness, which may have implications for injury. The mechanics of running on the leg is often described as a spring supporting the body's mass. The musculoskeletal system can alter the stiffness of this spring system, and research has shown that decreasing stride length reduces leg stiffness.[16,18] It appears likely that there is an ideal level of leg stiffness that minimizes injury risk, with increased stiffness associated with bony injuries and decreased stiffness associated with soft tissue injuries.[31]

Further, barefoot running, which typically results in decreased stride length, has also been associated with reduced GRFs and joint moments.[32] Thompson et al had individuals run in barefoot and shod conditions with stride lengths that were both greater and less than their preferred shod stride length. They found the reduction in joint moments and GRFs was a function of stride length rather than shoe condition.[20] The decreased sagittal plane joint moments can be explained by a decrease in the moment arm relative to the resultant GRF, a reduction in the magnitude of the GRF, or both. Decreasing stride length results in the foot being located more directly under the body at initial contact and leads to reductions in hip and knee flexion,[17] factors that reduce moment arms relative to GRF.[4]

Confounding factors

While there is evidence to suggest that reducing stride length leads to biomechanical changes associated with reduced risk of running-related injury, there are several confounding factors that should be considered. First, decreasing stride length—particularly if it is achieved by switching from shod to barefoot running—may result in individuals contacting the ground initially with the forefoot rather than the rearfoot. In terms of injury risk, rearfoot ground contact requires tibialis anterior activation to decelerate plantar flexion as the foot is lowered to the ground. Correspondingly, rearfoot ground contact has been associated with increased pressures in the anterior compartment of the lower leg.[33] Alternatively, when runners contact the ground with the forefoot, the triceps surae muscles activate to slow dorsiflexion, which has been associated with higher Achilles tendon strain and plantar flexor moments.[34] Therefore, if reducing stride length is accompanied by a switch from a rearfoot-strike pattern to a forefoot strike pattern, the reduced risk of some running-related injuries could also mean an increased risk of other types of injuries.

Second, running velocity is the product of stride length and stride frequency. Therefore, stride frequency must be increased to maintain a given running velocity when stride length is reduced. Although decreasing stride length may reduce acute loading, increasing stride frequency means a greater total number of ground contacts. It is possible that lower loads applied more frequently may also increase injury risk. In terms of tibial stress fracture, Edwards et al reported that strain magnitude plays a more important role than the total number of loading cycles in stress fracture development.[13] Additionally, Willson et al found that patellofemoral joint stress was lower with decreased stride length and, despite more strides per mile, patellofemoral joint stress per mile was also reduced.[35] However, other musculoskeletal injuries may be more sensitive to the number of loading cycles.

Continued on page 40

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Continued from page 38


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Injury implications

While there is fairly extensive biomechanical research that supports the argument for runners adopting a shorter stride length, there is limited clinical research showing that gait retraining to attain shorter stride length is a successful modality to treat or prevent running-induced musculoskeletal injuries.

The earliest studies looking at the effect of stride length on musculoskeletal injury examined the effects of training male and female military recruits together. Jones et al found short female recruits had the greatest risk for running- and exercise-related injury and recommended that short women march at the front of columns to reduce their need to overstrike to keep pace with their taller colleagues.[36] Additionally, Hill et al and Oxburn and Nichols found an increase in the number of pelvic stress fractures in female recruits that were attributed to the combined training of male and female recruits, which forced women to increase their stride length while marching.[37,38] As a result of Hill et al's research, the stride length for the Army Training Regiment was reduced to from 30 to 27 inches and researchers noted a resulting decrease in pubic ramus stress fractures.[37]

More recent studies have shown that gait retraining with reduction of stride length can be both a treatment modality and a means to reduce the risk of certain running-related musculoskeletal injuries. Given that the knee is the most frequent site of running-related musculoskeletal injury, several studies have examined the effect of reduction in stride length on clinical conditions surrounding the knee. Lenhart et al and Willson el al, respectively, examined the effect of decreased stride length during running on patellofemoral joint forces and joint stresses.[35,39] Both groups found that decreasing stride length greatly reduced patellofemoral loading. Thus, it was

suggested that decreasing stride length when running might be an effective means to change biomechanical factors that can contribute to patellofemoral pain.[39] Additionally, Allen et al examined the effect of gait retraining with step rate manipulation as a treatment for iliotibial band syndrome.[40] In this study, the authors found that a 5% increase in step-rate (resulting in decreased stride length) was an effective treatment for a single runner with iliotibial band syndrome when combined with a home exercise program that included stretching and strengthening.[40]

There is also evidence suggesting that decreasing stride length may help reduce the risk of stress fractures and muscle soreness in runners. Edwards et al used a finite element model to examine the effect of a reduction in stride-length on the probability of tibial stress fractures.[13] The authors found that reducing stride length by 10% decreased the probability of stress fracture by up to 6%.[13] Lastly, Rowlands et al examined the effect of stride-length manipulation on strength retention and muscle soreness with repeated bouts of downhill running.[41] They found reducing stride length during downhill running decreased exercise-induced muscle damage and provided protection against muscle soreness.[41]

Indirect evidence

While not examining the effect of stride length directly, much of the research looking at the effect of barefoot running and minimalist shoes indirectly evaluates stride length, as barefoot/minimalist runners tend to adopt a reduced stride length. Clinical studies suggest that barefoot/minimalist running, and the resulting decreased stride length, may help reduce the risk of tibial stress fractures, patellofemoral pain, and plantar fasciitis.[42] Further, forefoot-strike running, which is also associated with decreased stride length, has been shown to improve chronic exertional compartment syndrome.[33] However, despite the reduction in stride length, barefoot/minimalist running may also lead to injury.[43]


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Continued on page 42

Continued from page 41

Barefoot/minimalist running has been associated with metatarsal stress fractures,[44,45] and the transition to minimalist running has been associated with the development of foot bone marrow edema, a marker of added stress to the foot.[45] It is possible that these injuries are due to a lack of cushioning under the foot. Additionally, forefoot ground contact, which is associated with decreased stride length and barefoot/minimalist running, has also been associated with higher Achilles tendon strain[34] and increased risk of Achilles tendinopathy.[46,47]

Evaluating the literature on barefoot and minimalist shoe running can be difficult, as running in minimalist shoes is often thought to mimic barefoot running, but has in fact been found to have biomechanical characteristics more similar to shod running. Several studies have shown significant differences between barefoot running and running in minimalist shoes. Bonacci et al examined joint kinematic and kinetic variables in runners in barefoot and three shod conditions (minimalist shoe, racing flat, and regular athletic shoe).[48] Their results showed significant differences between barefoot and shod conditions for kinematic and kinetic variables at the knee and ankle, but no significant differences between the three shod conditions.[48] Further, McCallion et al compared several spatiotemporal variable of athletes running barefoot, in minimalist shoes, and in conventional running shoes.[49] They found stride duration, flight time, and contact time were greater in conventional running shoes and minimalist shoes compared with barefoot running.[49]

Conclusion

In conclusion, decreasing stride length has been proposed as a method to treat and prevent running-related musculoskeletal injuries. While not directly examining the effect of stride length, research examining the effect of barefoot running and minimalist shoes indirectly evaluates stride length, as barefoot/minimalist runners tend to adopt a reduced stride length. Evidence suggests that decreasing stride length results in biomechanical changes, including reduced GRFs and joint moments, that can contribute to reduced injury risk. Clinical studies indicate that reducing stride length may help decrease the likelihood of stress fractures, iliotibial band syndrome, and patellofemoral pain.

Further research, including long-term prospective studies aimed at determining the effectiveness of decreasing stride length for successful treatment for specific musculoskeletal conditions, is needed. Additionally, studies examining running injury risk in barefoot/minimalist shoe conditions, and the resulting decrease in stride length, are needed to determine if shoe gear changes and the resulting gait changes are a successful means of reducing running-related injury risk, or if they could potentially lead to increased risk of certain injuries due to lack of forefoot cushioning. ler

Melissa Thompon, PhD, is an assistant professor of exercise science at Fort Lewis College in Durango, CO. Kristine Hoffman, DPM, is a podiatrist in private practice with Boulder Valley Foot and Ankle Clinic in Colorado.

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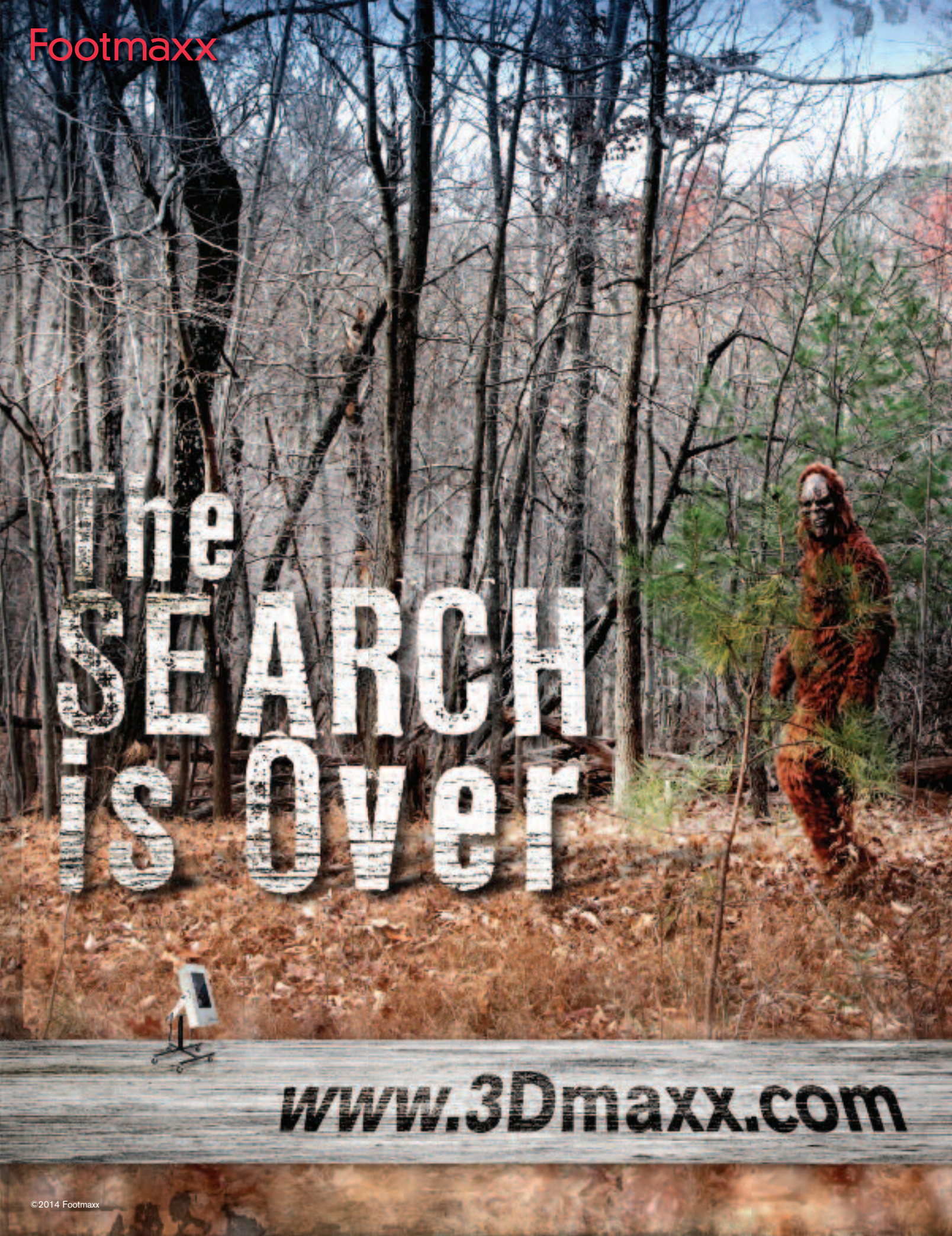
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Clinical utility of the FMS and its component tasks

Although some research has found that using the composite score for the seven component tasks of the Functional Movement Screen is a reliable way to predict risk of injury in athletes, other studies suggest that evaluating the individual task scores may be more appropriate.

By Erin Hartigan, PT, DPT, OCS, PhD, ATC; Nicole Chimera, PhD, ATC, CSCS; and Sarah Lamberton, NSCA-CPT

The Functional Movement Screen (FMS) is a preparticipation screening tool used to assess a person's ability to perform foundational movement patterns that are essential to sport. The FMS attempts to assess and rank movement patterns using seven individual tasks: a deep squat, a hurdle step, an in-line lunge, a shoulder mobility test, an active straight leg raise, a trunk stability push up, and a rotary stability test. Each task requires both mobility and stability, based on proprioceptive and kinesthetic awareness principles.[1,2]

The seven tasks of the FMS are designed to assess the fundamental movements of an individual.[3] When the FMS is used as part of a comprehensive assessment, performance can be observed to reveal any weaknesses, balance deficits, asymmetries, or all of these. Identifying these deficits or asymmetries may allow for customized recommendations intended to improve a given individual's functional movement patterns.[2] Each component of the FMS is scored from 0 to 3, with 3 being the best possible score, for a maximum composite score of 21 (Table 1).[2]

Reliability

Many studies have explored the inter-rater and intra-rater reliability of the FMS. Inter-rater reliability can be defined as the degree of agreement among different raters.[4] Intra-rater reliability can be defined as the degree of agreement among test-retest measurements obtained by the same rater.[4] In general, evidence suggests the FMS has acceptable to excellent inter-rater reliability for scoring, regardless of years of experience with the FMS.[5-9] For intra-rater reliability, however, some studies suggest that experience matters. Gribble and colleagues[10] found that intra-rater reliability increased with years of professional experience and years of experience with the FMS. Contrary to these findings, Smith and colleagues[6] found that intra-rater reliability does not increase with experience. In fact, a certified FMS tester had the lowest intra-rater reliability when compared with an entry-level physical therapy (PT) student with no FMS

> When looking at just the composite score, deficits in individual movement patterns may be masked, and similar composite scores may be obtained in different ways.

Continued from page 45

Table 1. FMS Scoring

Score	Rationale
0	Pain at any point throughout movement or in a clearing test (where applicable)
1	Unable to complete movement, or unable to assume position of movement
2	Requires compensatory movement to complete task
3	Completes task correctly without compensatory movement

experience, a certified athletic trainer with a PhD in biomechanics but no FMS experience, and an entry-level PT student who had completed 100 FMS tests but was not a certified tester.[6]

When considering inter-rater reliability studies, it is worth noting the differences among those that were conducted in real time and those using video analysis. Two studies used videos for scoring individuals[5,9] and four studies scored the FMS tasks in real time.[6-9] Scoring the FMS in real time is more clinically applicable than scoring the screen using off-line video analysis. Video analysis is 2D, whereas during real-time analysis the rater can assess the motion from different vantage points. Interestingly, both studies[5,10] that used video analysis had similar reproducibility, indicating that inter-rater and intra-rater reliability were acceptable and that reliability increased with experience. When studied in real time, acceptable levels of inter-rater and intra-rater reliability were also reported;[6-9] however, the study by Smith and colleagues[6] did find that different professionals with varying experience can consistently and reliably score the FMS after just one two-hour training session.

When considering intra-rater reliability studies, the findings of Frost and colleagues[11] should be examined. Twenty-one firefighters were told raters were observing their movements as they performed the FMS. Raters then gave immediate feedback on how to achieve a perfect score and asked participants to repeat the FMS. FMS scores significantly improved and, interestingly, of nine firefighters who received scores below 14 on the initial FMS, only one individual scored below 14 on the second screen. The significant and meaningful changes in FMS scores indicated that eight firefighters were no longer "at risk for injury." Although no directed feedback was provided, they improved just by receiving knowledge of the scoring criteria. Therefore, Frost and colleagues[11] caution against directing efforts to improve individuals' performance on the FMS, as participants accomplished their gains artificially and without impacting their initially demonstrated and likely preferred movement patterns. Furthermore, visual observations during this low-demand screen did not correspond to an individual's performance during simulated occupational tasks (eg, simulated hose advance). Lastly, though individuals may achieve perfect squat and in-line lunge scores, ideal frontal plane knee mechanics did not transfer to higher-level tasks, bringing into question the use of the FMS to determine the readiness to return to sports or high-demand jobs.[11]

Validity

Much of the research on the FMS has been conducted in primarily male cohorts, including firefighters, professional football players, and marine officer candidates.[12-14] However, in their study, Schneiders and colleagues[8] included 209 participants, 108 of whom were women, and found no statistically significant difference in composite FMS scores between male and female participants. Another study by Loudon and colleagues[15] that included 43 runners, 16 of whom

were women, also found no significant difference in composite scores between male and female runners.

However, other studies suggest that, while male and female athletes may obtain similar composite scores, they obtain these scores in very different manners. Chimera and colleagues[16] compared FMS performance between 81 female and 89 male Division I athletes and found male athletes performed significantly better on trunk and rotary stability tests and female athletes performed significantly better on the in-line lunge, straight leg raise, and shoulder mobility tests. Letafatkar and colleagues[17] found similar results, in that male athletes performed significantly better on trunk and rotary stability tests, while female athletes performed significantly better on the shoulder mobility and straight leg raise tests. These findings suggest the FMS composite score may be used to compare individuals in mixed gender populations; however, caution should be used, as male and female individuals appear to obtain similar composite

Table 2. FMS studies

Study: Minick et al[5]
- Participants: 40 college students, 23 women, 17 men; average age, 20.8 yrs; 13 varsity athletes
- Number of raters: 4
- Real time/video: Video
- Level of experience: Experts: helped develop the FMS; 10 yrs of FMS experience. Novice: introductory training with <1 yr FMS experience
- Relative reliability measure: 14/17 tests demonstrated excellent inter-rater agreement for each test
- Conclusion: Scorers should be trained in the standardized FMS program.

Study: Gribble et al[10]
- Participants: 3 university community members, 1 woman, 2 men; average age; 20.33 yrs
- Number of raters: 38
- Real time/video: Video
- Level of experience: Athletic training students (ATS) with no FMS experience; athletic trainers (ATC) with no FMS experience; athletic trainers (ATC-Exp) with at least 6 months of FMS experience
- Relative reliability measure: Intra-rater ICC: ATS: .37, ATC: .76, ATC-Exp: .95
- Conclusion: Reliability increased from the ATS to the ATC to the ATC-Exp.

Onate et al[7]
- Participants: 19 physically active people, 7 women, 12 men; average age, 25 yrs. (Physically active = exercising at least 3 times a week for 30 minutes)
- Number of raters: 2
- Real time/video: Real time
- Level of experience: Primary rater: ATC, CSCS, FMS-certified specialist. Secondary rater: CSCS with no FMS training or certification
- Relative reliability measure: Intra-rater intersession ICC: .92. Inter-rater reliability ICC: .98
- Conclusion: The FMS can be performed with good inter-session and inter-rater reliability across each task with caution warranted for the hurdle step component.

Smith et al[6]
- Participants: 19 people from a university physical therapy program, 9 women, 10 men; average age, 26 yrs
- Number of raters: 4
- Real time/video: Real time
- Level of experience: Rater 1: Entry-level PT student who has completed 100 FMS assessments but is not certified. Rater 2: Certified FMS tester. Rater 3: ATC and PhD in biomechanics with no FMS experience. Rater 4: Entry-level PT student with no FMS experience
- Relative reliability measures: Intra-rater ICC: R1: .90; R2: .81; R3: .91; R4: .88. Inter-rater ICC: Session 1: .89; Session 2: .87
- Conclusion: Various professionals can reliably and consistently score the FMS after a 2-hour training session. Intra-rater reliability doesn't increase with experience.

Teyhen et al[9]
- Participants: 64 active-duty service members, 11 women, 53 men; average age, 25.2 yrs
- Number of raters: 8
- Real time/video: Real time
- Level of experience: DPT students with 20 hours of FMS training
- Relative reliability measure: Inter-rater ICC: .76. Intra-rater ICC: .74
- Conclusion: The FMS has acceptable reliability when assessed by novice raters.

Letafatkar et al[17]
- Participants: 100 active college students, 50 women, 50 men
- Number of raters: 2
- Relative reliability measure: Inter-rater ICC: .877-.932. ICC for composite scores: .92
- Conclusion: Pilot testing using 20 individuals indicated high reliability for each task. The ICCs for composite scores were also high for 100 individuals.

Schneiders et al[8]
- Participants: 209 volunteers from the student population, sports club, and general public, 108 women, 101 men; age range, 18-40 yrs
- Number of raters: 2
- Real time/video: Real time
- Level of experience: Training on administration and scoring of the FMS
- Relative reliability measure: Inter-rater ICC: .971
- Conclusion: Excellent inter-rater reliability when the screen is being administered to large groups.

Abbreviations: ICC = interclass correlation coefficient; PTS = physical therapy student; PT = physical therapist; ATS = athletic training student; ATC = certified athletic trainer; ATC-Exp = certified athletic training with FMS experience; CSCS = certified stretch and conditioning specialist; DPT = doctor of physical therapy

Continued on page 48

Continued from page 47

scores with different movement patterns.

The ability of the FMS to identify aberrant movement patterns and asymmetries makes it a useful tool for identifying injury risk.[18] Evidence suggests that a predetermined cutoff score for the composite FMS score may be predictive of risk of injury. The highest possible composite score is 21. A composite score of less than 14 was predictive of risk of injury in football players,[18] Marine Corps officer candidates,[19] and female college athletes.[20] Additional analyses on Marine Corps officer candidates indicated that combining poor three-mile run times and poor FMS scores (< 14) increased the ability to predict injury; those who scored poorly on both tests were 4.2 times more likely to experience an injury.[21] Another study[14] on a cohort of firefighters found that two of the FMS tasks, the deep squat and stability pushup, were predictive of risk of injury. Additionally, a study on a cohort of female collegiate athletes found the FMS was able to identify compensatory movement patterns resulting from contralateral imbalances, which indicated an increased risk of injury.[20] However, there is still uncertainty in using the FMS composite score to predict injury, as the study by Kazman and colleagues[13] found that high composite scores can also be predictive of injury because of low internal consistency among the seven tasks. Li and colleagues[22] also found no evidence for unidimensionality of the FMS in elite athletes. Given the implications of low internal consistency among the tasks of the FMS, more attention should be paid to the score of each task rather than to interpretation of the composite score.

When determining the clinical utility of the FMS to predict injury, it's important to consider the definition of injury. Kiesel and colleagues[18] defined injury in football players as having been on the injured reserve list for at least three weeks. Butler and colleagues[14] used a generic musculoskeletal definition of injury and were successful in using the FMS to identify firefighters who were removed from the academy because of said injury. In their study of female collegiate athletes, Chorba and colleagues[20] defined musculoskeletal injury as having occurred during practice or competition and having provoked the athlete to seek some form of medical attention or advice. All of these studies[14,18,20] found a composite score of 14 or less was predictive of increased risk of injury.

In Marine Corps officer candidates a score of less than or equal to 14 predicted injury with a sensitivity of .45 and a specificity of .71, and a serious injury with a sensitivity of .12 and a specificity of .95.[19] However, Warren et al[23] were unable to maximize the sensitivity or specificity of a range of FMS scores to identify injury risk in collegiate athletes when the injury was defined as a noncontact injury. Furthermore, when using the previously suggested score of 14 or less to identify injury risk, there was no statistically significant association between FMS composite score and injury (odds ratio = 1.01, 95% confidence interval, .53-1.91). There was also no differences in FMS composite scores between those who were injured and those who were not injured.[23]

Additionally, recent evidence suggests that perhaps a composite score of 17 should be used, as this cut-off score was found to maximize sensitivity (.645) and specificity (.780); athletes who scored less than a 17 on the FMS had approximately a 4.7 times greater risk of suffering a lower extremity injury that kept them out of participation for at least one full practice or game.[17] Collectively, the literature shows the FMS demonstrates good reliability,[5] but may lack specificity in iden-

tifying individuals at risk for noncontact injury.[18,20,23]

Composite scores also may be affected by a history of previous injury, surgery, or both, as athletes with a history of hip, hand, and elbow injury and shoulder surgery performed significantly worse and had significantly lower FMS composite scores than those without similar injury histories.[16] Further, movement pattern analysis revealed a variety of differences in performance based on individual injuries; for example, a history of knee surgery was associated with poorer performance on the rotary stability test, and a previous hip injury was associated with poorer performance on the deep squat.[16] Additionally, Letafatkar and associates[17] reported that FMS performance in athletes with a previous history of ankle and knee injuries differed significantly from the performance in a group with no previous injuries.

There is a lack of conclusive research on the association between the FMS and athletic performance. Researchers did a comprehensive analysis of multidirectional speed (eg, 5-, 10-, and 20-m sprint intervals), modified T-test, turn difference, and multidirectional jumping (eg, bilateral and unilateral vertical, long, and lateral jumps) and FMS tasks and composite FMS scores from male athletes.[24] They stratified athletes into high, intermediate, and low performers, and did analyses to identify movement deficiencies that would affect performance. Limited significant relationships indicated that the FMS appears to have few associations with the aforementioned performance measures.[24] Yet, the findings do suggest that greater deep overhead squat scores correlated with smaller difference between turns (eg, the 505 agility test, a test of 180° turning ability) and greater bilateral vertical height and long jump distances.[24] One study[25] specifically evaluated the relationship among the in-line lunge component of the FMS and center of pressure, maximum jump height, and a 36.6-m sprint time; that study found performance on the in-line lunge test was not related to balance, power, or speed. However, another study[26] found that in-line lunge scores explained 47% of the variance in reactive strength index (eg, jump height [mm]/ground contact time [ms]) and 38% in reactive agility cut performance (eg, the time required to complete an unanticipated cut) in youth soccer players. Lloyd and colleagues[26] also found significant relationships between the composite FMS total score and individual tasks (deep overhead squat, in-line lunge, active straight leg raise, and rotary stability tests) and all three performance measurements (squat jump, reactive strength index, reactive agility cut) in these youth soccer players.[26]

Another study[27] found significant positive correlations between the hurdle step, stability pushup, and rotary stability test scores and the backward overhead medicine ball throw (BOMB). The BOMB test was chosen to measure total body power. Yet, this study did suggest that the FMS may not have a meaningful association with performance, particularly given that it was designed to identify potential injury risk.[27]

There are two ways of interpreting the FMS scores, either as individual tasks or as a composite score.[1,2] A composite score of either 14[12,20,28] or 17[17] has been found to be the cutoff for predicting injury in some studies. When using the FMS to examine functional movement, each FMS task has its own emphasis; however, some of the tasks share similar movement patterns.[1,2] When looking at just the composite score, deficits associated with individual movement patterns may not be apparent, and treating the composite

Continued on page 50

Continued from page 49

score as a single factor also may not be valid. Studies have used Chronbach's alpha and exploratory factor analysis to determine the internal consistency and factor structure of the FMS in a group of Marine Corps officer[13] candidates and elite athletes.[22] If the FMS as a whole was constructed around a single factor, one would expect to find a high internal consistency among the seven tasks. However, both studies[13,22] found there was a low internal consistency among these tasks, and concluded that results did not support the validity of the FMS composite score as a 1D construct. Chimera and colleagues[16] and Letafatkar et al[13] also found that, while male and female individuals were obtaining similar composite scores, they were obtaining those scores in different manners. Therefore, evidence suggests that individual scores for each movement pattern may be more clinically meaningful and relevant than a composite score of all seven tasks.

Conclusion

The FMS was designed as an instrument to assess functional movement.[1,2] It was created as a screening tool to identify stability and mobility deficits and asymmetries that could be linked to an increased risk of injury.[2] The findings of inter- and intra-rater reliability related to scoring the FMS suggest that it can be reliably scored by various professionals.[5-10]

Previous research has found the FMS is a valid tool for identifying individuals who are at an increased risk of injury, though injury is operationally defined in different ways across studies.[14,18,20] However, the work done by Warren and colleagues[23] is inconsistent with previous research findings, as there was no statistically significant association between the composite scores and risk of noncontact injury. Research questions the validity of the FMS as a tool in predicting performance levels, and therefore it should not be used to determine readiness to return to sports.[11,25,27]

Although some research has found that using the composite score for the seven tasks of the FMS is a reliable way of predicting risk of injury[18] other research has found the seven tasks have a low internal consistency[13,22] and that similar composite scores may be obtained in very different ways and appear to be sex-specific.[16,17] This suggests the FMS is not a 1D construct, and evaluating individual scores may be more appropriate than evaluating the composite score.[13,22]

Because of new revelations, more research needs to be done on the efficacy of predicting injury from a composite FMS score. Similarly, more research should be done to determine the most appropriate way of evaluating scores.

Erin Hartigan, PT, DPT, OCS, PhD, ATC, is an assistant professor of physical therapy at the University of New England in Portland, ME. Nicole Chimera, PhD, ATC, CSCS, is an assistant professor of athletic training and program director in the Athletic Training Program at Daemen College in Amherst, NY. Sarah Lamberton, NSCA-CPT, will graduate from the University of New England in 2015 with a bachelor's of science in applied exercise science.

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Effects of unstable shoes: Many questions remain

Current research suggests that relatively small but statistically significant changes are associated in the short term with the use of unstable shoes. However, it is unclear if those changes are clinically meaningful, or whether long-term use would yield greater or diminished results.

By Jacob Gardner, PhD

In the past few years the use of unstable (rocker-bottom) shoes has been a topic of hot debate. Researchers have suggested that using unstable shoes has the potential to improve static and dynamic stability during gait.[1,2] Companies promoting unstable shoes have made substantial claims of health benefits and muscle toning outcomes that in many cases appear too good to be true. Examples include claims that these "toning shoes" are burning more calories than conventional athletic shoes, toning lower limb muscles, improving posture, and reducing joint stress.[3] However, to date, there is not enough evidence to confirm these shoe companies' sizable claims. Some are now including disclaimers on their websites to indicate that certain assertions have not been clinically demonstrated.

The majority of research done on the topic has been conducted on Masai Barefoot Technology (MBT) shoes.[2,4-10] However, since the introduction of these shoes, many other companies with their own unstable shoe styles have joined the ranks, and further research has been done on some of the different shoe variations, including Skechers Shape-ups, Dockers Active Balance, New Balance True Balance, Reebok EasyTone, and several others. With so many companies interested in unstable shoes, it raises the question: Does the unstableness of the shoe really deliver an advantage over a regular shoe? After all, the shoe's underlying concept seems to have some validity: If a surface is made more unstable, wouldn't the leg muscles need to work harder to maintain equilibrium? And, if the leg muscles are working harder, wouldn't more calories also be expended? The answers to these questions, however, may not be so clear.

The small acute biomechanical changes associated with current unstable shoes are promising results that may be made more useful with improved shoe designs.

Spatiotemporal changes

A few earlier studies of footwear with an unstable design showed the shoes did affect some spatiotemporal variables during walking, decreasing walking speed, stride length and stride time, and step length compared with a control shoe.[1,2] Interestingly, when walking speed is controlled across conditions, differences in spatiotemporal variables seem to disappear.[11] Thus, it is more difficult to assess

Continued from page 53

shoe-related differences accurately when walking speed is not consistent.

Postural control

An important question related to shoe design is how the shoes affect the stability of the wearer. The variable most researchers use to test for stability is the trace of the center of pressure either during standing (static) or walking (dynamic) as a measurement of postural sway. During both static and dynamic conditions, studies have shown that unstable shoes either slightly increase the postural sway[6,12-18] or have no effect;[14-17] thus, postural sway appears to be greatly dependent on the specific unstable design of the individual shoes. The majority of these studies tested postural sway in an acute scenario. To test the long-term effects of the unstable shoes on participants' balance, Ramstrand et al split 31 women older than 50 years into either a test group (unstable shoes) or a control group (their usual shoes) and instructed them to wear the shoes as much as possible for eight weeks.

The researchers used three separate tests to determine the training effect of the unstable shoe on balance. At the end of the eight weeks, both groups improved significantly in the three balance measures, but there was no significant difference between groups;[9] indicating no advantage of the unstable shoe over the control shoe.

Joint kinematic changes

The most notable kinematic changes researchers have found to be associated with wearing unstable shoes involve the ankle. For example, research has shown that, compared with a control shoe, wearing unstable shoes is associated with an increased dorsiflexion angle at heel strike,[1,2,13,18] a decrease in plantar flexion range of motion during early stance,[13,18] an increased[11] or decreased[2] dorsiflexion angle in late stance, and an increase in ankle eversion range of motion.[13,18] Additionally, a few researchers have noted some kinematic changes in the knee and hip in participants wearing unstable shoes, but again, these results are ambiguous. For example, the earlier studies of rocker-bottom shoes showed the unstable design was associated with decreased peak knee flexion, hip extension and flexion, and knee and hip range of motion.[2] However, in more current studies, in which walking speed was controlled, only a decreased knee extension angle and decreased hip extension angle were evident when wearing one unstable shoe,[11] and differences were nonexistent in another brand of unstable shoe.[18] A study of trunk kinematics has also shown a few kinematic changes associated with wearing unstable shoes, including increased midthoracic flexion and velocities of angular displacement in the low back.[5] These changes were also accompanied by an increase in erector spinae muscle activity, which may provide some benefits related to trunk support.

Joint kinetic changes

An analysis of joint kinetics can provide researchers with a more complete picture of unstable shoes' effects on the ankle, knee, and hip joints. In the ankle, research has shown that the use of unstable shoes is associated with decreased plantar flexor[11,18] and dorsiflexor moments,[18] as well as an increased peak inversion moment, compared with a control shoe.[6,27] Results have also suggested a reduced peak knee flexion moment, as well as an increase in hip abduction moment.[27] It has been suggested that the net moments across each of these joints have implications for increased or decreased muscle activity to control the ankle, knee, and hip joints during unstable gait. It may be possible to detect these muscular differences by monitoring muscular activity with electromyography (EMG).

Muscle activation

Researchers studying the effects of unstable shoes are often seeking to determine whether the shoes' effects on muscle activation result in a "toning effect." Currently, studies show ambiguous results. One of the earlier studies on unstable shoes, published by Romkes et al in 2006, showed that wearing the unstable shoes was associated with increased muscle activity at the gastrocnemius and decreased activity at the tibialis anterior (TA) during stance, followed by increased TA activity during swing when compared with the individual's regular shoes.[2] The authors concluded that wearing unstable shoes could be used as a training method to strengthen the leg muscles. Zhang et al[18] in 2012 showed that, in men wearing a different brand of unstable shoe than in Romkes et al, there was a decrease in TA activity associated with unstable shoe wear that was similar to the results reported by Romkes et al; however, they noted no changes in activity for any other lower extremity muscles for unstable shoe wear compared with a neutral control shoe.

One study did find small increases in the muscle activity of the peroneus longus and soleus muscles when walking in an unstable sandal,[14] and another found increases in tibialis anterior, peroneus longus, and lateral gastrocnemius activity when walking in a shoe with round surfaces embedded in the forefoot and heel of the sole of the shoe.[19]

Other EMG studies conducted on unstable shoes found no differences in muscular activity compared with a control shoe. For

Continued on page 56

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example, Branthwaite et al[20] in 2013 analyzed the muscular activity of women wearing an unstable shoe compared with activity in their own trainer shoes. While some variation in muscle activity did exist, the differences between shoe conditions were not statistically different. Similar results were also noted by Sacco et al[21] in 2012 for women walking in an unstable shoe, by Santo et al in 2012 during a 10-minute walk performed by men and women in unstable shoes,[22] and by Demura et al in 2012 during a 10-minute walk performed by men in two different types of unstable footwear.[23]

Interestingly, the aforementioned studies focused on acute changes when donning the unstable shoes for the first time. There are few studies that have considered the long-term effects of the unstable shoes over six- and even eight-week periods. One example of such a study, published by Sousa et al in 2014, found that unstable shoes were associated with an increase in medial gastrocnemius muscle activity during an acute bout of walking compared with a conventional shoe. However, after eight weeks of use, muscular differences no longer existed.[24] These results tend to suggest that long-term use of the unstable shoes may not have a substantial effect on muscle strength or tone.

> Whether the increased forefoot pressures experienced during standing would negate the benefits of forefoot pressure alleviation during gait remains to be determined.

Plantar pressure and joint pain

It is common in clinics to use hard nonflexible rocker-soled off-loading boots to help alleviate pressure beneath the feet. Generally these boots may be used in patients with foot ulcers secondary to peripheral neuropathy or other foot injuries that might benefit from pressure redistribution. Research has suggested that perhaps a soft-soled rocker-bottom shoe such as the examples described in this review might be a good solution to alleviate foot pain and underfoot pressures, especially in the forefoot.[12,25,26] The results of studies designed to address this issue are, again, slightly ambiguous, but may be a little clearer than previously discussed variables.

Several studies have shown pressures under the forefoot during gait are reduced when wearing unstable shoes compared with a control shoe,[12,25,26] while the pressure under the heel may be increased.[26] This may have positive implications for patients requiring forefoot pressure alleviation. However, it has also been shown that, during standing, pressures are dramatically increased in the forefoot, while heel pressures are reduced.[27] Whether the increased forefoot pressures experienced during standing would negate the benefits of pressure alleviation in the forefoot during gait remains to be determined. Additionally, it has been suggested that an unstable shoe is not necessarily a safe option for patients with peripheral neuropathy due to its effect of reducing perception in the feet; introducing an unstable shoe may actually increase their risk for

Continued on page 58

Continued from page 56

falls.[28] More plantar pressure research is necessary to determine if unstable rocker bottom shoes might be beneficial for patients with various foot injuries.

Considerations

As this review indicates, it is clear from the research that unstable shoes do have some effects on the body during standing and walking. It is important to note, however, that in nearly all circumstances, the changes reported in each of these studies are relatively small and typically acute. For example, consider the small change in the mediolateral center of pressure associated with one type of unstable shoe compared with a control shoe—an increase of approximately 1 cm.[13] It is true that this change was statistically significant, but it is unclear if 1 cm translates to a clinically meaningful difference. Similar examples can be pulled from nearly all sources referenced in this article.

This makes it difficult to determine just how effective unstable shoes are at producing an unstable effect. It also makes it difficult to determine if a training effect (even a small effect) is truly present. Will these small changes add up and be intensified over long periods, or do these differences tend to diminish as the body gradually adapts to an unfamiliar shoe? These questions have yet to be answered definitively with long-term studies, but some current "long-term" research (eight weeks) might suggest the latter is true.[24]

It is also important to consider that not all unstable shoes are created equal, as is suggested in the ambiguity of results reviewed here. Thus, the design of the shoe is an important factor when considering the effects of unstable shoes. Most shoes promote anterior-posterior instability, but newer shoes are emerging that have a greater impact in the mediolateral direction, as well. Thus, another question must be asked: How much of a change in the sole of a shoe is necessary to produce the desired results? Perhaps the current shoe designs are not unstable enough to create a long-term training effect and thus simply result in acute temporary changes. We certainly do not want to increase the risk of ankle sprains or other injuries, but the small acute changes associated with wearing unstable shoes are promising results that may be made more useful with improved shoe designs.

Conclusion

Current research suggests that relatively small changes are associated in the short term with the use of unstable shoes. However, it is unclear if long-term use would yield greater or diminished results. Initial studies seem to indicate that results are not long lasting; thus, the unstable shoe design will probably not have as large an impact as various shoe company claims might suggest. ler

Jacob Gardner, PhD, is an assistant professor of kinesiology at Biola University in La Mirada, CA.

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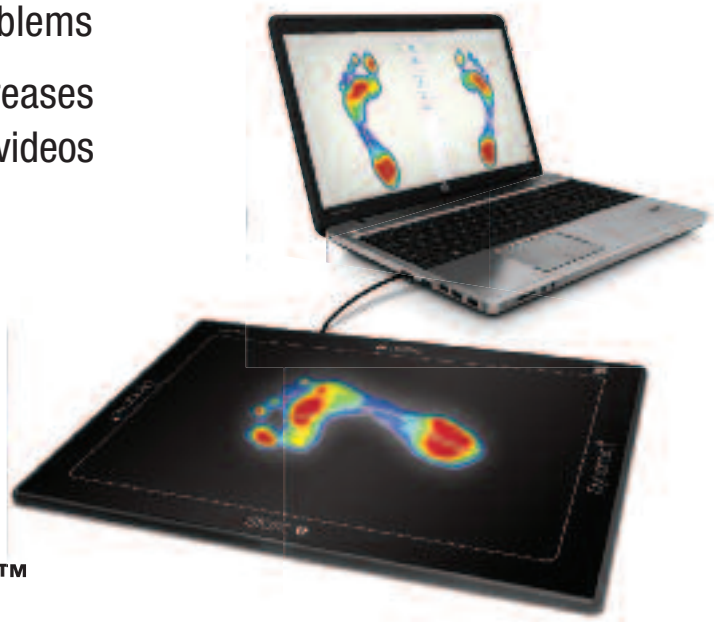

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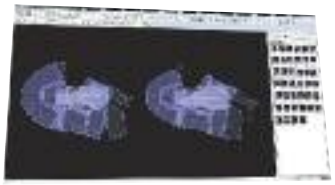

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market mechanics

By Emily Delzell

Brace demand grows while market for knee arthroplasty remains static

With only 10.5% of US patients with knee osteoarthritis opting for surgery in 2013, a percentage that has not increased in 10 years, medical device manufacturers are working to meet the clear demand for solutions that delay unwanted surgery, according to a November report from London, UK-based GlobalData.

The US market for knee braces and supports was estimated to be $676.7 million in 2013, said Jennifer Ryan, GlobalData's analyst covering medical devices. She noted that, while the 2013 US market for knee reconstruction surgery was valued at a considerably greater $4.2 billion, the high percentage of patients refusing or delaying the procedure is indicative of significant opportunities for orthotic devices in this treatment space.

She noted that braces and supports are an important part of orthopedic treatment in the developing world, with a third of global market revenue generated by historically smaller markets in Africa, South America, and the Middle East.

Valued at $2.3 billion in 2013, the global orthopedic braces and supports market is expected to continue growing as physician and patient adoption increases, she said.

Long-time pedorthist Bill Meanwell dies

Bill Meanwell, CPed, died on November 14, 2014, in Broken Arrow, OK. He was 63. A long-time pedorthist, most recently in private practice as owner of Corethotics in Tulsa, OK, Meanwell also taught at the Oklahoma State University Institute of Technology in Okmulgee and at the International School of Pedorthics, which he founded, in Broken Arrow.

He also supported the McLean, VA-based Pedorthic Footcare Association's continuing education programming.

In a "statement of memory" Meanwell's colleagues Matthew Doring, sales manager for Newton, NJ-based Engineered Silicone Products; Pat Chappel, owner of Lake Forest, CA-based Rybo Medical; and Bruce McDonald, owner Pine Tree Orthopedic Lab in Livermore Falls, ME, noted, "Bill Meanwell was a man who dedicated his life to education and training in the field of pedorthics. Bill had a knack for making the most boring material interesting with his one liners and puns—the ultimate pun master. Bill left a positive impression on many people's lives inside and outside of the industry and he needs to be remembered for his dedication, sense of humor, and willingness to help anyone."

Meanwell is survived by his wife, Kathy; daughters, Melissa Decker and Christina Rotramel; and grandchildren, Gabrielle Meanwell, Zoe Headley, and Evan and Kenyon Decker.

Össur opens women's leadership effort

Foothill Ranch, CA-based Össur in November launched its Össur Women's Leadership Initiative, a program to encourage greater diversity and inclusiveness in the O&P field.

In 2015, the Össur Women's Leadership Initiative will feature an array of resources, including an educational webinar series, a dedicated blog, and ongoing focused content.

Registration is free and open to all women in the O&P field, including orthotists and prosthetists, pedorthists, mastectomy fitters, techs, and students.

Get more information and register at ossur.com/owli.

Playground build to open AAOS meeting

The American Academy of Orthopaedic Surgeons (AAOS) will kick off its 2015 Annual Meeting on March 24 in Las Vegas with a one-day build of a playground designed with input from children from the local church community program Palabra Viva Las Vegas.

Children from the program, which provides educational, charitable, and recreational services to more than 1500 Spanish-speaking adults and children each week, put their imaginations to work during interactive exercises in December, sharing ideas about their ideal play space. AAOS has sponsored a one-day volunteer playground build to open its annual meeting since 2000. Its goal is to leave a legacy of safe and accessible playgrounds to its host cities so children with and without disabilities can play together safely. This year's build is in partnership with KaBOOM!, a national nonprofit dedicated to bringing play to kids who need it most.

The 2015 Annual Meeting will be held at the Venetian/Sands Expo March 24-28.

BiOM gets $6M for bionic development

Bedford, MA-based bionics company BiOM announced in December 2014 that it had recently raised $6 million from Dutch and US venture firms, bringing its total funding to $48 million, according to the *Boston Business Journal (BBJ)*.

The company's founder and chief technology officer is bionic limb innovator Hugh Herr, PhD, who directs the MIT Media Lab's Biomechatronics Group in Boston. Herr is a double below-knee amputee and rock climber who wears prostheses of his lab's design.

These are sold through his company as the BiOM T2, an ankle-foot prosthetic device that uses both passive and actively powered components to emulate biological function throughout the stance phase of the gait cycle.

The BiOM T2 is currently the company's only product, but *BBJ* reported that a second device, a powered orthosis for poststroke patients with toe paralysis, is in clinical trials at the US Army's Center for the Intrepid in San Antonio, TX.

Delcam expands technology forums

Birmingham, UK-based Delcam announced in December that its popular technology forum will expand its scope in 2015 to include orthopedics. The change is reflected in the event's new name, the Ortho Technology Forum (OTF), which reflects the inclusion of technologies for orthopedic footwear, as well as those for orthotic devices. (The event was formerly called the Orthotics Technology Forum.)

Due to the continued popularity of the OTF, Delcam will host two conferences this year, one in Canada and a second in Australia.

In North America, the 2015 OTF will be held as a presymposium event to the 2015 Pedorthic Association of Canada (PAC) Symposium in partnership with PFOLA (Prescription Foot Orthotic Laboratory Association). The event is scheduled to be held at Westin Bayshore in Vancouver, Canada, April 16-18. The Australian OTF is scheduled for May 6-8 and will be part of the Australian Podiatry Council's (APodC) 2015 Conference, to be held at the Gold Coast Conference and Exhibition Centre in Queensland.

For more information about the 2015 events, go to ortho-tech-forum.com.

Continued on page 66

Continued from page 65

IDEO study calls for military participants with post-trauma foot, ankle weakness

The Major Extremity Trauma Research Consortium (METRC) on January 2 called for participants for a Department of Defense-funded study examining the benefits of an integrated orthosis and rehabilitation program that incorporates the Intrepid Dynamic Exoskeletal Orthosis (IDEO) and the Return to Run physical therapy program, both developed by the US Army.

Prospective participants must be service members or veterans who had a serious leg injury while on active duty two or more years ago, and who experience lingering foot and ankle weakness.

The study will enroll 90 participants at three locations: Walter Reed National Military Medical Center in Bethesda, MD; San Antonio Military Medical Center/Center for the Intrepid; and the US Naval Medical Center San Diego. Participants must live or stay near their treatment center.

Researchers will determine eligibility with a questionnaire and fit selected participants with a custom IDEO. Performance testing will take place at several times during the study, which is expected to last 12 months.

For details about participation requirements, or to complete the initial eligibility questionnaire, visit prioriti-mtf.org. ler

DJO Global donates $25K for PT center

Alexandria, VA-based DJO Global reported December 30 that it has donated $25,000 to the Foundation for Physical Therapy's planned Center of Excellence (COE).

The donation marks DJO's renewal as a platinum-level partner in support of the project, which seeks to create a COE for health services and health policy research that will expand the number of physical therapist investigators studying the delivery, organization, and financing of care, as well as analyses of outcomes.

The foundation has raised more than $3.1 million to fund the COE and support research grants and scholarships through its internal funding mechanisms and plans to announce the recipient of the $2.5 million COE grant in February at the American Physical Therapy Association Combined Sections Meeting in Indianapolis, IN. ler

USATF honors Team Spenco runner Gray

USA Track & Field (USATF) recognized elite mountain runner and Spenco-sponsored athlete Joseph Gray with its "Mountain Runner of the Year" title on December 4 during its annual meeting in Anaheim, CA.

As a member of Team Spenco, Gray wears the Waco, TX-based company's cushioning Ironman Race insoles during races, uses its medical products, like the 2nd Skin Blister Kit, and wears Spenco's line of supportive shoes and sandals for after-race recovery.

Gray lives and trains in Colorado Springs, CO, and is a six-time North American Central American and Caribbean (NACAC) champion, an eight-time USA National champion, a 15-time USA National team member, the first African American to win the USA National Mountain Running Championship, and the first athlete to win NACAC titles in Cross Country and Mountain Running. This is the fifth time Gray has been named Mountain Runner of the Year. ler

Brenau U pre-accredited for DPT program

The Alexandria, VA-based Commission on Accreditation in Physical Therapy Education announced on December 11 that it has granted candidacy for accreditation to Brenau University's doctoral degree program, which is recruiting candidates for the class that begins in May 2015.

The program can't receive full accreditation until after the first candidates receive doctoral degrees in May 2018, but pre-accreditation represents a significant step in the evolution of Brenau's physical therapy program, said Department of Physical Therapy Chair Kathye Light, DPT.

The Gainesville, GA-based university made a deal with city leaders in 2011 to spend at least $6.7 million to renovate a decades-old convention center and equip and staff the program. The university completed the build-out of the physical therapy space last March, and Light and her staff moved in early July.

The DPT program is Brenau's third clinical doctorate program, joining nursing and occupational therapy. ler

Freedom Innovations, Parker collaborate

Irvine, CA-based lower extremity device manufacturer Freedom Innovations and Cleveland, OH-based motion control technology company Parker Hannifin Corporation announced on December 9 that the companies have completed a minority equity investment agreement.

The agreement expands a partnership that began in July 2013 with a technology collaboration related to intelligent powered orthotics and prosthetics, and builds on Parker's position in the market through the development of the Indego, a powered lower limb orthosis, or exoskeleton. Parker hopes to launch the Indego commercially in Europe this summer and in the US later in the year.

Financial terms of the transaction were not disclosed. ler

Amputee Coalition, AAOS offer new tool

The Manassas, VA-based Amputee Coalition and the American Academy of Orthotists and Prosthetists (AAOP) in November released a new tool designed to help amputees and their families and caregivers ask the right questions and communicate their needs when working with their healthcare team.

Consumers and O&P facilities can access the "Working Together for a Successful Outcome," tool for free at Amputee Coalition (amputee-coalition.org) or AAOP (oandp.org) websites.

The Amputee Coalition's website gives O&P facilities the paid option to personalize the brochure by adding the name of their business to its cover. ler

Ruelle recognized for diabetic wound care

The National Alliance of Wound Care and Ostomy (NAWCO) honored Anna Ruelle, DPM, WCC, in November at its 11th annual Wild on Wounds Conference for her efforts in promoting diabetes education, volunteering her time to the treatment of diabetic wounds, and for recruiting and mentoring diabetic wound care professionals.

Ruelle, who has received NAWCO's 2014 Outstanding Work in Diabetic Wounds award at the conference's closing session, is a podiatrist at the Cheshire Medical Center/Dartmouth-Hitchcock Keene's Orthopedic Department in Keene, NH. ler

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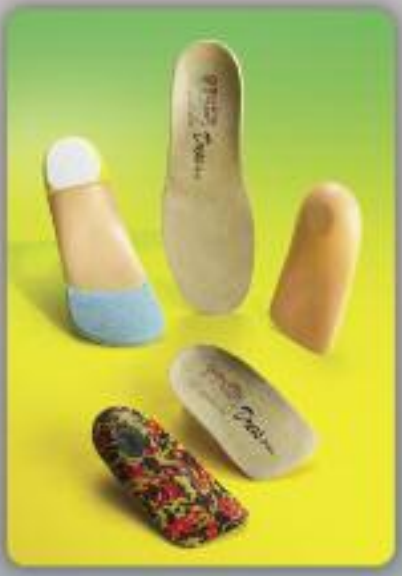

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