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LOWER EXTREMITY REVIEW

April 17 / volume 9 / number 4

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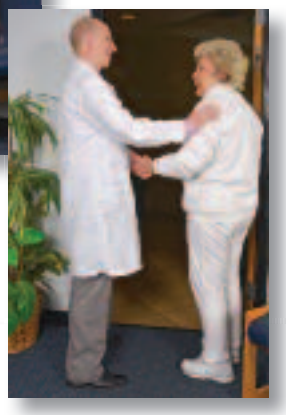

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Lower Extremity Review informs healthcare practitioners on current developments in the diagnosis, treatment, and prevention of lower extremity injuries. LER encourages a collaborative multidisciplinary clinical approach with an emphasis on functional outcomes and evidence-based medicine. LER is published monthly, with the exception of a combined November/ December issue and an additional special issue in December, by Lower Extremity Review, LLC.

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out on a limb:
Workload roulette in the NFL

A recent study reported that National Football League (NFL) running backs with more than 300 carries in a season are not more likely to miss time with an injury the following season than those with considerably fewer carries. For fantasy football players, this is great news. But for sports medicine experts, it's a reminder that injury risk rarely can be boiled down to a single parameter.

Conventional wisdom in football holds that any running back older than 30 years is a risky proposition, due to the extremely physical nature of the position, and many NFL teams are reluctant to sign older running backs to large contracts even if they have been consistently productive.

That's why the recent study findings, published in February by the *Orthopaedic Journal of Sports Medicine,* are somewhat surprising. One might assume the running backs with the most carries per season are those most likely to take a beating over time and, eventually, those most likely to spend some time on the disabled list. But in fact, the study found running backs with 300 carries or more missed fewer games due to injury the following season than running backs who carried the ball between 150 and 250 times (despite similar mean ages for both groups).

But coaches and clinicians who work with football players know the number of carries in a season is not necessarily reflective of a running back's workload. A running back is often involved in far more plays than just the ones in which he is given the ball. And, even if a running back doesn't end up with the ball, his blocking assignment for that play could easily be just as physical and the injury risk just as high. It would be interesting to see whether a running back's injury risk is associated with total snap count, rather than just number of carries.

That said, an even more important determinant of injury risk involves not just the previous season's workload but how that previous season's workload compares to the athlete's current workload. As Australian sports scientist Tim Gabbett, PhD, discussed in a keynote presentation in Monaco at the recent IOC World Conference on Prevention of Illness and Injury in Sport, a growing body of research suggests the ratio of acute-to-chronic workload is strongly associated with injury risk in certain athletes. Workload spikes—going from limited activity to high activity within a short period of time—are of particular concern.

> Recent findings on NFL running backs and injury risk will make fantasy football players happy, but may not tell the whole story.

And another recent study from the UK found that three workload-related factors were associated with injury risk in rugby players: a high number of matches in the previous year, a low number of matches in the previous year, and a low-moderate number of matches in previous year followed by intense play in the recent past.

It's possible that maintaining a high workload over time really is protective against injury in NFL running backs. But until that theory has been effectively tested, running backs like LeGarrette Blount (who had 299 carries for the New England Patriots last season) might not want to get too comfortable.

Jordana Bieze Foster, *Editor*

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Protecting hip implants

Gait patterns help predict wear rates

By Katie Bell

Patient-specific implant wear rates following total hip arthroplasty (THA) are more strongly associated with gait patterns than component positioning, according to research from Chicago that suggests implant wear could be reduced with the use of predictive wear models.

"This study demonstrates the power of gait as a [mechanical] biomarker," said study author Markus A. Wimmer, PhD, the Grainger Director of the Rush Arthritis & Orthopedics Institute and professor for research in the Department of Orthopedics at Rush University Medical Center in Chicago. "Knowing the association for a specific patient could help to define the follow-up period. Those with more wear should be seen more often. Gait modifications with the help of a physical therapist could be considered."

The study included data on 43 men and 30 women, with an average age of 69 years and an average body mass index (BMI) of 27.3 kg/m^2. All participants underwent a primary unilateral THA, performed a gait test 10 months or more after surgery, and had a series of standing radiographs taken more than one year after surgery, with a minimum of three years of clinical follow-up. All received the same implant, which featured a 28-mm metal head and a hip cup made of noncrosslinked polyethylene.

Implant wear rates were calculated based on the femoral head's displacement relative to the cup using a computer-assisted x-ray

Continued on page 14

Hallux valgus angle and pain improve after year of custom toe separator use

A custom-molded silicone toe separator can help reduce hallux valgus angle and pain in patients with hallux valgus, according to research from Thailand.

Investigators from Siriraj Hospital in Bangkok analyzed 79 patients with moderate hallux valgus who were randomized into two groups. Both groups received foot care, footwear recommendations, and pain medications for one year; the 40 patients in the intervention group also were instructed to wear a toe separator, custom molded from room-temperature vulcanization silicone, for six hours per night.

After one year, the mean hallux valgus angle for the patients in the intervention group had decreased by 3.3°, while in the control group it had increased by 1.9°; in both groups, the change from baseline was statistically significant.

The patients in the intervention group also experienced a significant decrease in hallux pain between baseline and one year.

The findings were epublished on March 20 by *Prosthetics & Orthotics International*.

– Jordana Bieze Foster

Source:
Chadchavalpanichaya N, Prakotmongkol V, Polhan N, et al. Effectiveness of custom-mold room temperature vulcanizing silicone toe separator on hallux valgus: A prospective, randomized single-blinded controlled trial. Prosth Orthot Int 2017 Mar 20. [Epub ahead of print]

Even in older women, mechanical loading leads to Achilles adaptation

Fourteen weeks of mechanical loading is associated with Achilles tendon adaptations in senior women, according to German findings suggesting older age should not exclude patients from exercise-based Achilles rehabilitation.

Researchers from the German Sport University Cologne analyzed 34 women (mean age, 65 years) with no history of Achilles injury in the previous five years; 21 completed 14 weeks of high-strain cyclic loading exercises, while the remaining 12 women formed a control group. Twelve members of the exercise group continued the intervention for 1.5 years.

Exercises emphasizing isometric plantar flexion contractions were done three times per week for the first 14 weeks and twice a week thereafter, for about 50 minutes per session.

After 14 weeks of loading, the women experienced significantly increased Achilles tendon stiffness, hypertrophy, and a 22% increase in ankle plantar flexion moment. However, no further improvement was noted after 1.5 years.

The findings were published in March by the *Journal of Experimental Biology*.

– Jordana Bieze Foster

Source:
Epro G, Mierau A, Doerner J, et al. The Achilles tendon is mechanosensitive in older adults: adaptations following 14 weeks versus 1.5 years of cyclic strain exercise. J Exp Biol 2017;220(Pt 6):1008-1018.

Continued from page 13

wear-analysis suite. The investigators established three groups: Low wear was classified as less than .1 mm per year, moderate wear was between .1 and .2 mm per year, and high wear was more than .2 mm per year.

No group differences were found for positioning and gait, with the authors suggesting that different wear rates result from a combination of factors rather than single variables. The findings were epublished by *Clinical Orthopaedics and Related Research* in March.

A linear discriminant analysis model correctly predicted the wear level in 80% of participants with low wear, 87% of those with moderate wear, and 73% of patients with high wear. For each wear level, multiple linear and nonlinear regression showed strong associations among gait biomechanics, implant positioning, and wear rate, with the nonlinear model having a higher prediction accuracy.

Notably, flexion-extension range of motion and hip moments in the sagittal and transverse planes explained 42% to 60% of wear rate. Meanwhile, positioning factors, including cup medialization and cup inclination angle, were less predictive, explaining just 10% to 33% of wear rate.

BMI did not emerge as a wear predictor. Although patient activity level was not assessed directly, it should be reflected in the combinations of age and gait variables that were analyzed, Wimmer said.

"We believe that the results of this study are translatable to patients of all age ranges," Wimmer said. "However, the importance of wear predictors [ie, specific gait and implant positioning variables] may differ dependent on age."

Dana Judd, PT, DPT, PhD, an assistant professor in the Physical Therapy Program at the University of Colorado Anschutz Medical Campus in Aurora, said the postoperative gait variables associated with implant wear are likely reflective of preoperative gait abnormalities and the experience of undergoing surgery rather than a product of any particular surgical technique. The findings also are consistent with those of a different Chicago research group, in which preoperative gait variables were predictive of clinical response after THA (see "Gait and THA outcomes: Hip mechanics have predictive value," June 2016, page 15).

However, because the trauma associated with surgery can affect muscle performance and mobility, Judd suggested that interventions to address THA wear rates be implemented postoperatively.

"Interventions might address strength training targeting the hip and abdominal musculature to stabilize the pelvis, as well as balance and neuromuscular reeducation programs to promote healthy movement and stabilization," she said. ler

Sources:

Ardestani MM, Amenábar Edwards PP, Wimmer MA. Prediction of polyethylene wear rates from gait biomechanics and implant positioning in total hip replacement. Clin Orthop Relat Res 2017 Mar 2. [Epub ahead of print]

Foucher KC. Preoperative gait mechanics predict clinical response to total hip arthroplasty. J Orthop Res 2017;35(2): 366-376.

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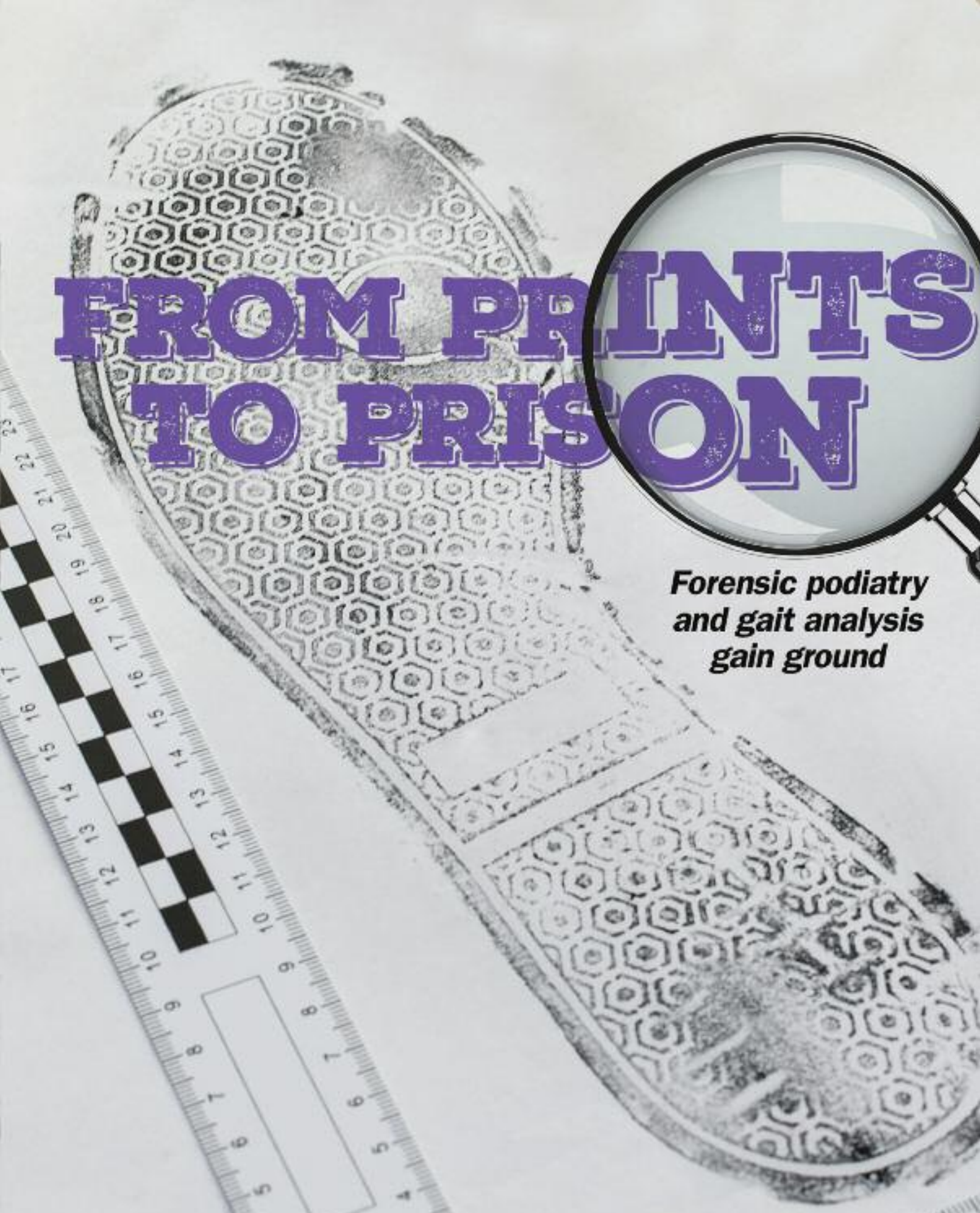
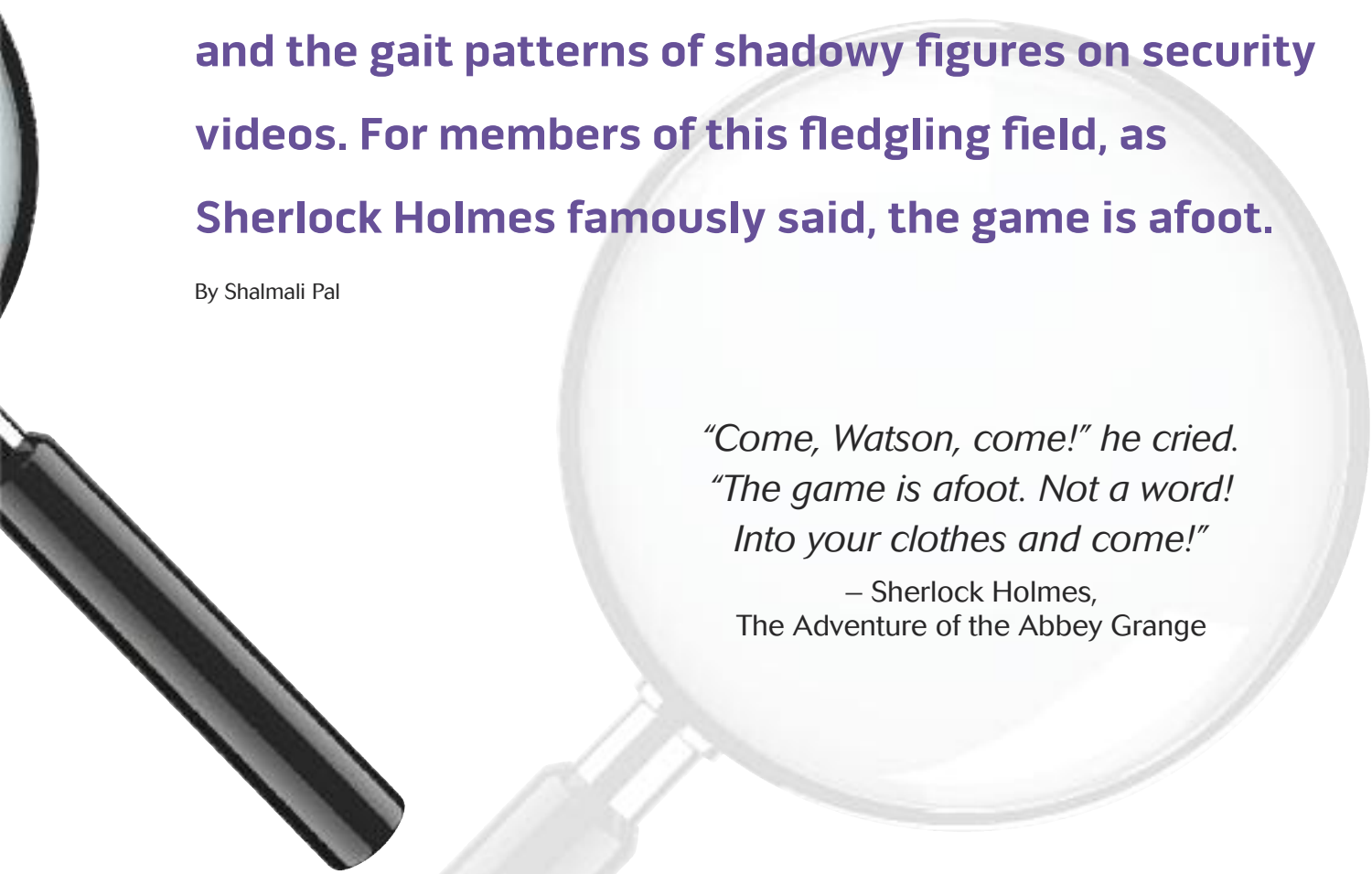


FROM PRINTS TO PRISON

Forensic podiatry and gait analysis gain ground

INCREASINGLY, lower extremity experts are being called on to assist with crime scene investigations by analyzing footprints, shoe prints, and the gait patterns of shadowy figures on security videos. For members of this fledgling field, as Sherlock Holmes famously said, the game is afoot.

By Shalmali Pal



"Come, Watson, come!" he cried. "The game is afoot. Not a word! Into your clothes and come!"

– Sherlock Holmes,
The Adventure of the Abbey Grange

The in-person diagnosis of lower limb conditions, or assessing foot and gait mechanics, is second nature to lower extremity practitioners. But what happens if the assessment required involves a foot that isn't actually in the exam room—say, a shoe print embedded in the mud under a window, a footprint left in blood on a kitchen floor, or closed-circuit television (CCTV) footage of an otherwise unidentifiable person walking away?

What kind of deductions could be made about the absentee owners of those shoes or feet, the way they walk, and—importantly—their potential level of involvement in a crime? That's when forensic podiatry and gait analysis enter the scene.

The now-deceased Norman H. Gunn, DPM, of Canada is credited with introducing the concept of forensic podiatry in the early 1970s; about two decades later, an introductory article on the subject appeared in the *Journal of the American Podiatric Medical Association*.[1] The Bandon, OR-based American Society of Forensic Podiatry (ASFP) was established in 2003, and four years later, a forensic podiatry subcommittee was established by the Hollywood, FL-based International Association for Identification (IAI).

"The field of foot evidence is relatively new," said John DiMaggio, DPM, ASFP, founder and president, and a retired podiatrist who has practiced in Arizona and Oregon. "Forensic podiatry can offer additional information when a case isn't conclusive, based on anatomy, biomechanics, morphology, and pathology. We can offer more details about a person and his feet."

ASFP currently has 25 practicing podiatrist members, along with 15 podiatry residents and 70 students, both in podiatry and in other disciplines (eg, anthropology, medical examiners), said DiMaggio, who is a coauthor of the second edition of *Forensic Podiatry: Principles and Methods*.[2]

LER spoke with DiMaggio and other experts in the field about what they do, how forensic podiatry and gait analysis work, and how lower extremity practitioners can become involved.

Footprints and footwear

Although TV shows and mainstream media outlets tend to use the terms synonymously, there is an important distinction between footprints and shoe prints.

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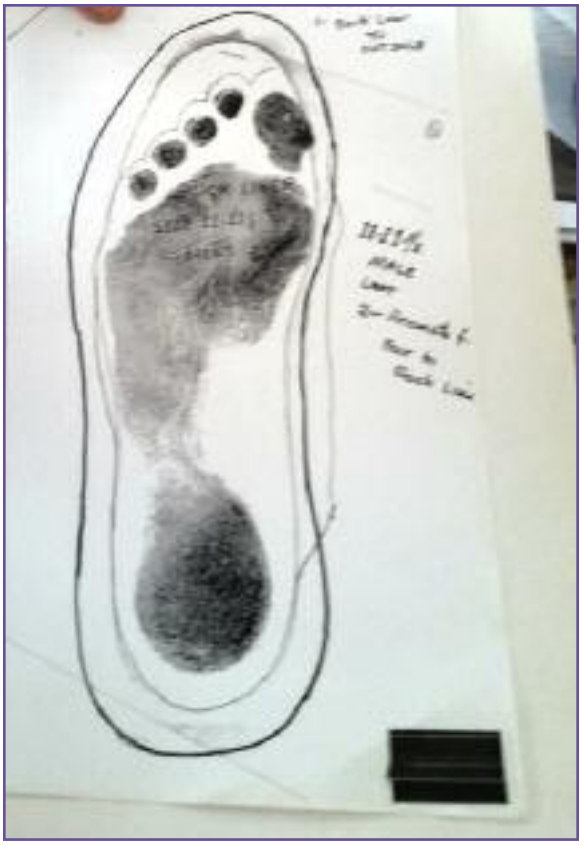

Figure 1. A comparison of a footprint with a shoeprint left at the scene of a crime. (Photo courtesy of John DiMaggio, DPM.)

"If you are looking to match a suspect to a shoe print, the foot examiner is the main person to go to," explained Michael Nirenberg, DPM, founder of Friendly Footcare in Crown Point, IN, ASFP vice president, and a contributing author to the *Forensic Podiatry* textbook. "If you are looking to match a suspect to a potential footprint, then the forensic podiatrist is the right person for that. You need a knowledge of the foot to make that comparison."

Footwear examination has become more prevalent in crime scene investigation in the last two decades, and that expertise is typically limited to outsoles, DiMaggio agreed.

"When I hear the word 'footprint,' I think of the foot and not the shoe, and that's where the podiatric expertise lies. As a forensic podiatrist, I can still examine the outsole, looking for heel wear or wear under the ball of the foot, but I can also examine the upper of a shoe and see where the wearer has a bunion deformity. Looking only at the shoe's outsole would not reveal that kind of information."

One case that was a win for forensic podiatry was the overturned conviction of Ray Krone, of Phoenix, AZ, for the 1991 murder of a woman named Kim Ancona in a local bar. His initial 1992 conviction was based primarily on expert testimony that his teeth matched bite marks on Ancona's breast and throat.[3]

When that conviction was overturned by a state court in 1996 because of legal technicalities, Krone was retried and found guilty once again, based on the bite marks but no other physical evidence. While Krone was in prison (10 years overall, with two years on death row), his attorneys began reworking the case to prove his innocence. That's when DiMaggio got involved.

A shoe print estimated as coming from a men's size 10 to 10.5 sneaker was found at the crime scene, but this piece of evidence was not included in initial court cases. DiMaggio was called in by the defense attorneys to evaluate that shoe print and to make a cast of Krone's foot. He submitted a report verifying that Krone's shoe size was an 11 to 11.5 and that his foot could not have fit into the shoe that left the incriminating print.

The forensic podiatry evidence was part of the overall package, including new DNA evidence, that ultimately led to the conviction of the real killer and brought about Krone's release in 2002.[3]

"Was the information about Krone's foot the deciding factor that got his conviction overturned? I wouldn't say that," DiMaggio said. "I think the foot analysis that I performed added to the weight of evidence."

A high-tech field?

While technologies such as 3D scanning have made inroads in the clinic, they haven't quite caught on in forensic podiatry. That may be because the field is quite small and quite new, DiMaggio noted.

But technology is part of its founders' vision. Nirenberg proposed the use of a fiber-optic arthroscopic camera for examining the inside of a shoe.

"The insides of shoes and boots often contain wear patterns and impressions," Nirenberg wrote in the *Journal of Forensic Identification* in 2008.[4] "These wear marks contribute to individuality and aid in linking a given shoe or boot to a specific person's foot."

Such wear marks may appear on the shoe's insole or the upper, often in the form of an imprint left by the wearer's foot. The inside of the footwear may also contain materials (eg, soil or blood) that could help place a suspect at a crime scene, Nirenberg explained.

Traditional examination of the inside of footwear involved using a small dental mirror or cutting the footwear open—what Nirenberg called a "shoe autopsy." To examine the inner shoe with an arthroscopic camera, he advised starting at the posterior aspect and working forward to the toebox, noting "the arthroscope will allow the relationship between the foot's impression on the insole and on the toebox to be clearly seen."

Nirenberg told *LER* that arthroscopic examination also allows for preservation of the footwear, along with a record of the exam process.

"You can see a lot more detail with the fiber-optic camera," he said. "You also can record the exam process in case the jury wants to see the inside of the shoe before it's disassembled. The jury can see how you examined the inside of the shoe and any impressions of the foot."

Going by the gait

Gait analysis for forensic purposes is defined as "the analysis, comparison, and evaluation of human gait including the components and features of gait, to assist the process of identification or to answer any other legal question concerning gait," according to *Forensic Podiatry*.[2]

"Gait analysis works with what we call 'class characteristics.' These are features that show consistency and compatibility, but are not unique," explained Wesley Vernon, OBE, PhD, DPodM, coauthor of *Forensic Podiatry* and retired head of podiatry services at Sheffield Teaching Hospitals NHS Foundation Trust in England. "As such, gait analysis can be used with varying degrees of certainty to suggest how likely or unlikely it is that the unknown person captured on CCTV is the same [as a potential suspect]."

These class characteristics include elements with which all lower extremity

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Figure 2. The FBI Bureau Reference Scale, developed by the agency's footwear examiners, is considered the gold standard for determining size from an image. (Photo courtesy of John DiMaggio, DPM.)

practitioners are familiar—the gait cycle, including stance and swing phases; single- and double-support phases; and any deviations from a typical gait cycle because of functional anomalies and compensation from underlying pathologies.[1]

In 2007, Peter K. Larsen, PhD, a researcher in the section of forensic pathology, department of forensic medicine, at the University of Copenhagen in Denmark, and colleagues published a checklist for forensic gait analysis in the *Journal of Electronic Imaging*.[5] Lower extremity areas of interest for forensic gait analysis are:

- General: Long or short steps, stiff or relaxed, signs of pathology
- Feet/ankle joint: Outward rotation, inversion/eversion, degree of "push-off" at toe-off
- Knee: Varus/valgus, knee flexion during stance
- Hip/pelvis: Abduction/adduction, rotation, tilt

These elements are then paired with upper body assessments, such as positioning of the shoulder, neck, and head.

Larsen's group applied this checklist to help solve a 2004 bank robbery in Noerager, Denmark. They analyzed CCTV footage of the perpetrator walking in and out of the bank and standing during the robbery. They started by evaluating the general characteristics of the person's gait and then analyzing each of the joint rotations. They noted the person on the footage had a "stiff gait with 'heavy' feet; marked outward rotation in the foot and ankle joint; neutral varus/valgus knee; and very little pelvic rotation."

Once a suspect was picked up by the police, the gait analysis of the perpetrator on the footage was deemed a positive match with another gait analysis of a suspect by Larsen's group. The gait analysis was further bolstered by a posture analysis, leading Larsen's group to conclude "the perpetrator and suspect might well be identical to each other, but we stressed that these methods did not constitute identification in terms of...DNA typing or fingerprinting."

That is one of the crucial points to remember with forensic gait analysis: It's a tool that can help increase the likelihood of pinpointing a suspect, but it cannot make a definitive identification or offer information beyond the limits of the lower extremities. For instance, when asked if gait analysis could be used to corroborate an eyewitness statement regarding a person seen fleeing a scene, potentially confirming or refuting that account, Vernon answered "yes," but cautioned that the witness statement would have to include some description of the suspect's gait.

"Forensic gait analysis utilizes our knowledge of gait and, as such, a forensic gait analyst would not report on height, weight, etc, with their opinions being restricted to areas that fall within their own particular expertise," he wrote in an email.

Other researchers offered similar caveats. A 2016 paper in the *Journal of Forensic Sciences* noted that analysis of gait patterns from CCTV footage, paired with photogrammetry (the science of making measurements from photographs), were important but challenging forensic tools. By way of example, the authors tested the feasibility of 3D reconstructions for forensic gait analysis, and found considerable interobserver variability in data interpretation.[6]

Larsen's group stressed that "in our work, we have both overt and covert recordings of the subject. There might be a potential problem in using overt recordings if the suspect consciously tries to modify the gait pattern during recording...at present, we do not find it possible to positively identify a perpetrator based on image analysis."

Ultimately, forensic gait analysis data are only as good as the footage provided for that evaluation, the experts agreed. Larsen explained to *LER* in an email that the frequencies of oscillations during normal walking range up to 6 Hz, so the 12 Hz to 15 Hz frequency that modern CCTV units use should be more than sufficient to clearly capture even the quickest ambulator.

In a 2014 study in *Science and Justice*, Vernon and colleagues showed that CCTV frame rate, which can vary from 25 frames per second to one frame every four seconds, can affect the ability of even the most experienced practitioners to identify gait characteristics on that footage.

"Every effort should therefore be made to ensure that CCTV footage likely to be used in criminal proceedings is captured at as high a frame rate as possible," they noted.[7]

Vernon acknowledged that new technologies, such as digital media, can be helpful for playing back an image at multiple speeds or looking at multiple images simultaneously on a single screen.

"Computer engineers are working on developing approaches that will do automatic gait analyses and comparisons, but these haven't yet been developed to the point where they can be used in [forensic] practice," he noted.

Data on what does and doesn't work for forensic gait analysis can be used to inform where cameras are placed in public venues. Larsen's group found most gait features can be examined using a frontal camera view and another in profile to record joint and segment angles in the sagittal plane. Some venues also have a camera positioned overhead to provide a transverse view of a perpetrator; this view can be helpful for assessing the degree of rotation of the feet and step length, but in general, is not as useful as the frontal view, Larsen said.

Vernon added that proper storage of high-resolution footage is always important to maintain the integrity of the evidence and support any related gait analysis.

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Figure 3. A shoeprint compared with a cast of a foot, used to illustrate that a suspect's foot was too big to fit into the specific shoes associated with a crime. (Photo courtesy of John DiMaggio, DPM.)

On solid footing?

Where does forensic podiatry fit into the overall landscape of usable or permissible evidence for solving a crime? Ruth Morgan, DPhil, director of the University College London Centre for Forensic Sciences, specializes in trace evidence dynamics, or "understanding the behavior of trace evidence in different contexts and within different environments over space and time," and the interpretation of evidence.[8]

"Footprint and gait analysis are most aligned with other pattern-based forms of evidence [like blood pattern analysis, for example]," Morgan told *LER* by email. "Our trace evidence dynamics work looks at trace evidence [particulates such as soils, gunshot residue, and other traces such as trace DNA] and how it transfers, persists, and is preserved under different environmental conditions."

For instance, Morgan's group authored a recent study in *Forensic Science International* that evaluated the generation of footwear marks in blood.[9] They reported that "footwear tread effects were also dependent on blood type, but the type of flooring did not affect the appearance of the mark."

"The study first looked at whether there was a difference in replicating a case scenario in which a blood mark was purported to have been made by a shoe making contact with a blood drop on the floor," she explained. "We tested human and animal blood, and the results were not consistent when the other variables remained the same. In comparison, if the same blood type was used, the type of flooring material did not appear to affect the blood pattern."

As with all evidence, data gleaned from forensic podiatry and gait analysis needs to fit into the big picture, Morgan added.

"Our interpretation of evidence work looks at the whole forensic science process—from crime scene, to laboratory analysis, to the interpretation of that evidence and its presentation as intelligence [to investigators] or as evidence [in court]," she said.

Forensic podiatry has a connection with the US Supreme Court, thanks to the *Daubert* standard.[10] In his chapter in *Forensic Podiatry*,[1] Nirenberg wrote

that the highest court in the land "explained in *Daubert* that evidence is admissible under [Federal Rules of Evidence 702: Testimony by Expert Witnesses] if 'it rests on a reliable foundation and is relevant.'"

In a 2014 case in Mt. Morris, WI, Robert Kasun was found murdered in a hotel room.[11] Investigators arrested Travis L. Peterson, who was staying in the room next to Kasun's, and he was charged with first-degree intentional homicide. At the crime scene, blood was found near the body, and chemical enhancement revealed a footprint. Nirenberg was asked for his expert opinion—could the bloody footprint have been made by Peterson?

Nirenberg's forensic podiatry analysis and report showed commonality between Peterson's foot and the footprint, including the shape of the toes. Nirenberg noted the bloody footprint exhibited a dark ridge on the second and third toes, which matched the morphology of Peterson's actual foot. The pattern made the footprint unique to Peterson, according to Nirenberg.

The defense attorneys challenged the validity of the forensic podiatry findings, so a *Daubert* hearing was held to determine if the footprint analysis, and Nirenberg's testimony, was admissible. The judge in the case green-lighted both, and Nirenberg testified at the Peterson trial. Peterson was found guilty and sentenced to life in prison.

"This was the first instance of forensic podiatry being the primary subject of a *Daubert* hearing," Nirenberg wrote in a 2016 *Journal of Forensic Sciences* case report.[12] "The hearing resulted in the court ordering this evidence admissible. The expert's testimony contributed to the suspect's conviction. It's a win for forensic podiatry, because that *Daubert* hearing showed that the evidence met the Supreme Court standards. In that sense, it's an important step for validating forensic podiatry as a subspecialty."

The case also highlights the fact that lower extremity professionals with an interest in the field cannot rely solely on their medical expertise—a knowledge of crime scene investigation techniques, the criminal justice system, and the basics of forensic science are essential.

"Interpreting elements of the foot is not like DNA or a fingerprint in terms of how definitive it is," DiMaggio noted. "It's important that podiatrists understand how to interpret evidence within the context of the criminal justice system."

To that end, the ASFP has plans to offer in-person seminars and webinars in the future.

"It's important to have the forensics foundation, and understand how forensics do and don't apply to issues of the foot that we as podiatrists are more accustomed to dealing with," Nirenberg said.

In the meantime, podiatrists who would like to learn more can visit the resources library at ASFP, or consider courses given through the IAI, the American Academy of Forensic Sciences, or the American Board of Criminalistics. The New York College of Podiatric Medicine in New York City, Temple University School of Podiatric Medicine in Philadelphia, and Barry University School of Podiatric Medicine in Miami Shores, FL, also have set up forensic podiatry groups for their students.

"We have very good, dedicated DPM members," DiMaggio noted. "It's at the student level that we have to get people interested if we are going to grow this field."

Shalmali Pal is a freelance writer based in Tucson, AZ.

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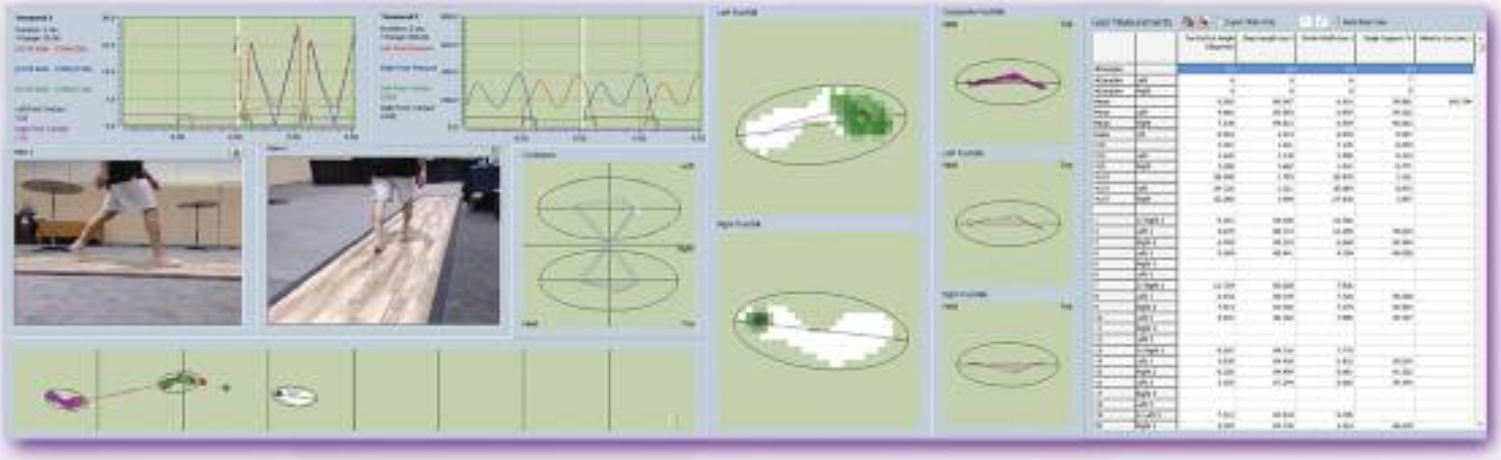

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MANY SPORTS, ONE GOAL: Joining forces for injury prevention

Athletes in all sports—from gymnastics to volleyball to running—struggle with injuries, and that means injury prevention is top of mind for the global community of sports medicine researchers and clinicians. In March, those experts convened in Monaco at the IOC World Conference on Prevention of Injury and Illness in Sport to develop strategies for taking sports injury prevention to the next level. *LER*'s exclusive coverage of this event focuses on lower extremity injuries, from ankle sprains to hamstring strains.

All articles by Jordana Bieze Foster


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Sports injury prevention experts revisit risk factors and advocate for adherence

Despite strides, gaps between lab and practice remain

It's an exciting time for clinicians involved in preventing sports injuries. Increasing numbers of studies are identifying risk factors associated with specific injuries and documenting the effectiveness of preventive interventions for reducing injury rates.

But in many ways, it's also a confusing time, especially when it comes to designing and refining evidence-based interventions. Studies can identify risk factors associated with an injury, but that doesn't necessarily mean those risk factors actually contribute to the injury or that targeting those risk factors will reduce injury rates. Other studies can demonstrate a preventive benefit of an intervention without offering any insight into why it works, or why it works for some athletes, but not others.

Such gaps between the sports injury prevention literature and clinical practice are not as wide as they once were, but still represent significant challenges for researchers and clinicians alike. During the triennial IOC World Conference on Prevention of Injury and Illness in Sport, held in Monaco in March, this theme was revisited continually—by keynote speakers, researchers presenting their latest findings, and attendees commiserating and collaborating during coffee breaks.

Wrestling with risk factors

As most sports medicine professionals are well aware, the model for sports injury prevention[1] introduced by van Mechelen and colleagues in 1992 proposes that, after identifying the need to reduce the risk of a particular injury (step 1), researchers should identify risk factors and mechanisms that contribute to that injury (step 2), after which they should develop preventive interventions (step 3), and rigorously evaluate the effect of each intervention (step 4).

But Willem van Mechelen, MD, PhD, now a professor of occupational and sports medicine at Vrije Universiteit in Amsterdam, opened the conference with a keynote speech noting many ways in which sports injury prevention has turned out to be more complicated than he and his colleagues envisioned. For one thing, there have been far more papers published on topics related to steps 1 and 2 of the model than those related to steps 3 and 4.

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Designing effective interventions based on identified risk factors, it turns out, is not as straightforward as experts had hoped. The reasons for this were explored in another keynote presentation by Roald Bahr, MD, PhD, professor in the Department of Sports Medicine at the Norwegian School of Sport Sciences, chair of the Oslo Sports Trauma Research Center, and head of the Aspetar Sports Injury & Illness Prevention Programme in Doha, Qatar.

The idea that identified risk factors should be used to screen athlete populations for those at the highest risk, and that interventions should be implemented based on risk factor based cutoffs, is particularly problematic, Bahr said—echoing the theme of a 2016 paper he published in the *British Journal of Sports Medicine*.[2]

"Identifying risk factors does not mean we can identify players at risk," Bahr said.

As an example, he cited a 2004 study in which athletes with a history of hamstring injury were 7.42 times more likely to suffer a future hamstring injury than those with no history.[3] Despite the impressive odds ratio, Bahr pointed out, only 10 of the 19 hamstring injuries in that study occurred in athletes with a history of injury, so screening based solely on that risk factor would have missed nearly half of the athletes who ended up being injured.

"When screening for injury risk, statistically significant association is not the same as prediction," Bahr said.

In Monaco, this theme was revisited multiple times during oral research presentations on risk factors, particularly those related to lower extremity injuries.

In a study of 306 youth basketball and floorball players, researchers from the UKK Institute for Health Promotion in Tampere, Finland, analyzed frontal plane projection angle during single-leg stance at baseline and then assessed new time-loss injuries for 12 months.[4] They found that a frontal plane knee projection angle greater than one standard deviation above the mean was associated with a 5.57 times higher risk of lower extremity injury and a 2.37 times higher risk of ankle injury.

But first author Anu Raisanen, PT, PhD, project coordinator for the Tampere Research Center of Sports Medicine, cautioned conference attendees in Monaco to consider the findings in light of Bahr's comments.

"As you know, an association does not equal prediction," Raisanen said. "So we have to keep that in mind. Most likely, we can use this [information] in combination with other factors."

Although a risk factor that is consistent across dynamic tasks would be ideal for injury prediction, a study from Liverpool John

Moores University in the UK found that most anterior cruciate ligament (ACL) risk factors are more strongly correlated with some tasks than others.[5] In 41 female athletes, knee abduction angle at initial contact had moderate to good correlations across multiple dynamic tasks (bilateral and single-leg drop vertical jumps, single-leg hops, and side stepping), but knee flexion angle at initial contact, peak knee abduction moment (KAM), and peak vertical ground reaction force had low to moderate correlations.

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Online counseling helps reduce injuries in highly specialized youth athletes

Early single-sport specialization in youth athletes is associated with increased risk of reinjury in addition to primary injury, but online counseling can help to reduce those risks, according to two studies from Atlanta presented at the IOC World Conference on Prevention of Injury and Illness in Sport, held in Monaco in March.

Both sets of findings were presented by Neeru Jayanthi, MD, a sports medicine physician at the Emory School of Medicine, who was the first author of a 2015 study that made headlines with its conclusion that injury risk was twice as high for highly specialized youth athletes than in those who participated in multiple sports.

In Monaco, Jayanthi presented three-year follow-up results for the same population, including the finding that nearly 70% of the reported injuries were reinjuries (approximately half of which were in the same location as the previous injury). Risk of reinjury was more than three times higher in youth athletes who were highly specialized than in their more diversified counterparts. Injured athletes were more likely than uninjured athletes to be female, to have started specializing at an age younger than 12 years, and to train for more than eight months of the year.

"Young athletes were more likely to develop a reinjury at follow-up if they had a high degree of specialization," Jayanthi said.

In a separate study, also presented by Jayanthi, the Emory researchers assessed the effectiveness of an online counseling program designed to educate youth athletes about associations between sport specialization and injury risk, as well as provide evidence-based recommendations to reduce that risk. Athletes between ages 8 and 17 years were randomized to a group that received online counseling or to a control group; both groups were monitored for one year.

Injured athletes accounted for similar percentages of each group at baseline. At six months, however, athletes in the intervention group had a significantly lower injury rate than those in the control group (27.7% vs 48%).

"We do think there's opportunity to do serial online counseling, and we do think it can be as effective as smoking or weight loss counseling," Jayanthi said.

Athletes were most compliant with the

recommendations to take one day off from sports per week, and to keep the number of hours of sports participation per week to less than the athlete's age. They were least compliant with the recommendation that the ratio of hours spent in organized sports versus free play should be less than 2:1.

"We can't change people's decisions," Jayanthi said. "What we try to do is provide information." ler

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Continued from page 27

"We all think a high load will be a high load regardless of the task, but we can see this is not the case," said Raihana Sharir, a doctoral student in the university's Institute for Sport and Exercise Science, who presented the findings in Monaco. "One variable can't tell us everything."

A second presentation from the Finnish group provided a more detailed analysis of a study published earlier this year, in which stiff landings were associated with ACL injury risk in 171 young female basketball and floorball players.[6] In the Monaco presentation,[7] peak hip flexion during landing from a vertical drop jump was negatively associated with noncontact ACL injury risk, with a hazard ratio of .6.

However, the area under the receiver operating curve for that risk factor was .54, suggesting that it would be nearly as likely to predict a false positive result as a true positive result, said Mari Leppanen, PhD, a researcher in the Tampere Research Center of Sports Medicine and first author of both studies, who presented the findings in Monaco.

"We are nowhere near saying we can predict ACL injury based on hip flexion," Leppanen said.


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Multimodal mysteries

The challenge of making the jump from identifying risk factors to preventive intervention wasn't the only one mentioned by van Mechelen in his keynote presentation. The increasing evidence that few injuries can be traced to a single risk factor would seem to support the use of multimodal interventions, such as the 11+ warm-up program (formerly known as the FIFA 11+)—and, in fact, such programs have been associated with reductions in injury rates, most recently a 4.25-fold decrease in ACL injuries in elite male soccer players.[8]

In such situations, however, researchers

Proximal and distal factors may affect 5th met fracture risk in soccer players

Clinicians looking to prevent fifth metatarsal fractures (Jones fractures) in soccer players may want to consider proximal as well as distal factors, according to studies from two separate Japanese research groups presented at the IOC World Conference on Prevention of Injury and Illness in Sport, held in Monaco in March.

A prospective study from Waseda University in Tokyo found that fifth metatarsal fracture was associated with lateralized plantar pressures during a heel raise and structural variables that also contribute to load lateralization.

Investigators prospectively assessed 310 male collegiate soccer players and followed them for one year. Those who went on to suffer a fifth metatarsal fracture were more likely to load the lateral aspect of both feet during standing weightbearing than those who were not injured. In addition, the injured foot was associated with more lateralized plantar pressures during heel raises at baseline than the contralateral foot.

Meanwhile, a second study from Jutendo University, also in Tokyo, found significantly reduced hip internal rotation—which can also lead to lateralization of plantar loads—in athletes with a history of fifth metatarsal fracture compared with those with no such history.

Researchers reviewed baseline biomechanical assessments for 20 professional soccer players who went on to experience a fifth metatarsal fracture and 40 players who did not. Hip internal rotation was significantly more limited in the injured players than the uninjured players, and in the injured players was also more limited in the hip corresponding to the injured foot than on the contralateral side.

The reduced hip internal rotation can lead to supination and lateralization of load in the foot, increasing the risk of fifth metatarsal fracture, said Yoshimoto Saita, MD, PhD, a researcher in the university's department of orthopedics and sports medicine, who presented his group's findings in Monaco.


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often have no way of knowing which aspects of such multimodal interventions are actually driving the outcomes. And the picture gets even more complicated when one considers that, even if an intervention is effective across a group of athletes, there will almost always be some athletes within that group who respond positively and some who do not.

This was underscored in Monaco by a presentation from the University of Delaware in Newark, in which collegiate women's soccer players performed the 11+ warm up at least three times per week for two seasons.[9] On average, peak KAM did not change over time for the intervention group or a control group. However, 14 of 39 players in the 11+ group did demonstrate a decrease in peak KAM; those athletes had smaller hip flexion moments and hip adduction moments than the nonresponders, said Amelia Arundale, PT, DPT, a physical therapist and research assistant at the university who presented the findings in Monaco.

Chasing adherence

Of all the challenges involved in sports injury prevention, perhaps the most vexing for van Mechelen is that even the best intervention will not be effective if athletes don't actually complete it. Too few intervention studies assess athlete adherence, he noted—likely because it isn't easy to document objectively, and self-reported adherence is likely to be inflated. But there's no question that it makes a difference.

In a 2011 randomized controlled trial from the Netherlands, for example, only 23% of athletes in the intervention group were fully compliant with a neuromuscular training program designed to prevent ankle sprain recurrence.[10] Although the program had no effect on the group as a whole, the relative risk of an ankle sprain was significantly lower in those who were adherent compared with those who were not, as well as compared with those in the control group.

"We can design interventions, and we know they are effective. But typically we have lousy adherence, which affects injury outcome," van Mechelen said.

The good news is that a growing number of sports injury prevention studies—including several presented in Monaco—are confirming that better adherence is associated with better outcomes.

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By itself, zero drop in a running shoe does not translate to barefoot-like gait

A zero drop is not enough to notably alter the biomechanics of running in a cushioned shoe but may affect injury risk in some runners, according to research from Luxembourg presented at the IOC World Conference on Prevention of Injury and Illness in Sport, held in Monaco in March.

The findings suggest that, although barefoot running by definition involves a zero drop from the heel to the toe, other design features may play a bigger role in determining the extent to which minimalist running shoes are associated with barefoot-like gait.

Investigators from the Luxembourg Institute of Health randomized 553 runners to six months of running while wearing one of three experimental cushioned shoe styles that differed only in terms of shoe drop: 0, 6, or 10 mm. The zero-drop shoes had a 21-mm cushion in both the toe and heel.

Gait was assessed in a subset of 59 participants at baseline and after five months or 500 km as they ran on a treadmill at a self-selected speed. Changes from baseline did not differ significantly between groups for any of the gait variables measured except for knee abduction angle at midstance, which decreased by 1° in the zero-drop group but increased by 1° in the 6-mm group and by .7° in the 10-mm group.

Although the changes over time were statistically significant, they were still very small in magnitude, noted Daniel Theisen, PhD, head of the Sports Medicine Research Laboratory at the Luxembourg Institute of Health, who presented the biomechanics outcomes in Monaco.

"We have to ask if this [knee abduction] is clinically meaningful at all, and I'm not so sure," Theisen said.

However, methodological aspects of the study may have affected the outcomes, he noted.

"We looked at shoe drop influence for normally cushioned shoes. It might be different if the zero-drop shoes were actually barefoot-like," Theisen said. "[Also] this is not a within-subject comparison for different shoe models; we compared different groups wearing different shoes. This may make it more difficult to see results."

In addition to the subgroup gait analysis, the researchers also followed up with all of the study participants with regard to injuries sustained during six months of running in the experimental shoes. For the group overall, shoe drop was not significantly associated with injury risk.

However, in occasional runners (those who said they had fewer than six months of regular running practice in the year prior to the study) shoes with a drop of 0 or 6 mm were associated with a lower injury risk than shoes with a 10-mm drop (hazard ratio [HR] = .48). And in those who ran more regularly, the two lowest shoe drop categories were associated with a higher injury risk than the 10-mm shoes (HR = 1.67).

"It seems safe to recommend low-drop shoes for occasional runners but not regular runners," said Laurent Malisoux, PhD, a researcher at the institute, who presented the injury risk findings in Monaco.

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In a study of more than 2400 youth rugby players,[11] researchers from the University of Bath in the UK found that a preventive exercise program was associated with a 15% reduced risk of match-related injuries compared with controls, which was not a statistically significant difference. However, in players who completed the program at least three times per week, the relative risk of match injury was reduced by 72%, according to Michael Hislop, MSc, a doctoral student at the university who presented the findings in Monaco.

In analyzing the effectiveness of the 11+ warm-up program for reducing injury risk in collegiate men's soccer players, the Delaware research group found four teams had low compliance (1-19 sessions per season), 14 teams had moderate compliance (20-39 sessions), and nine teams had high compliance (40 or more sessions).[12] Overall injury rate was 6.39 per 1000 athlete exposures in the high compliance group, 8.55/1000 in the moderate group, and 10.35/1000 in the low group. Differences between the groups were statistically significant, according to Holly Silvers-Granelli, MPT, a doctoral student at the university who presented the findings in Monaco.

Researchers from Waseda University in Tokyo reported an impressive 89% compliance rate among the 189 collegiate women's basketball players assigned to an education and hip-focused neuromuscular training program designed to reduce ACL injuries.[13] The incidence of ACL injury was .08/1000 athlete exposures in the intervention group, compared with .25/1000 in a control group.

The high level of adherence, however, won't help the Japanese researchers determine whether the intervention's effectiveness was related to changes in biomechanics, since those were not assessed, noted Yorikatsu Ohmi, RPT, MS, a researcher at the university who presented the findings in Monaco.

Sports injury prevention has evolved considerably since van Mechelen's model was introduced, but at least one theme has remained the same: Nothing is ever simple. ler

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Landing biomechanics may contribute to ankle sprain in basketball, volleyball

Two studies presented at the IOC World Conference on Prevention of Injury and Illness in Sport, held in Monaco in March, shed light on the complex ways in which aspects of landing contribute to risk of ankle sprain in volleyball and basketball—both sports in which ankle sprains often occur when one player lands on another's foot.

Because ankle sprains occur so quickly that patient recall about the mechanism of injury is often unreliable, researchers from Aspetar Orthopedic and Sports Medicine Hospital in Doha, Qatar, analyzed video footage of ankle sprains sustained by 24 elite male volleyball players for a more detailed analysis by five experts.

In most cases, attacking players rather than blockers were to blame for injuries—including back row attackers landing their front-row teammates, a situation that had not been previously reported in relation to ankle sprains, according to Christopher Skazalski, PT, DPT, an Aspetar researcher who presented the findings in Monaco.

In addition, video analysis revealed that inversion ankle sprains during landing did not typically occur with the ankle in plantar flexion—a finding that runs counter to popular belief among many ankle sprain experts.

"Typically ankle plantar flexion at initial contact involves relatively neutral inversion-eversion. As the ankle moves toward dorsiflexion, it rapidly everts. But the inversion actually does not occur during plantar flexion," Skazalski said.

Researchers from the Polytechnic Institute of Coimbra in Portugal analyzed landing mechanics in basketball players, who jumped onto an unstable surface to simulate landing on another player's foot. Players with a history of ankle sprain landed in greater knee extension at initial contact than those with no history of ankle sprain; this difference was particularly pronounced in women.

"Not only for prevention but also during rehabilitation, we should take into account knee position as well as ankle position during landing," said Maria Antonio Castro, PhD, a researcher with the institute, who presented her group's findings in Monaco. ler

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Protocol helps improve TKA outcomes, cut costs

A multidisciplinary joint replacement program is improving patient outcomes, decreasing complications, and shortening hospital stays, which helps to lessen clinical anguish following total knee arthroplasty as well as the financial burden on patients and the healthcare system.

By Katie Mullen, SPT; Jon R. Cook, PT, DPT; Meghan Warren, PT, MPH, PhD; and Tarang Jain, PT, PhD, DPT

Yelling and groaning. Those of us who have ever been in a physical therapy (PT) clinic while a patient's knee is being stretched following a total knee arthroplasty (TKA) have all heard the sounds that come with such an intensive process, and if you have ever been that patient, you know the pain that comes with it.

Although this may make TKA sound like a procedure to avoid, these surgeries have become increasingly popular over the last two decades. The life expectancy of our population continues to increase, as does the incidence of degenerative joint diseases and the demand for TKAs from patients, as these procedures have been shown to increase quality of life and decrease pain.[1] It is projected that 3.5 million TKAs will be performed annually by 2030.[2]

As the demand for these surgeries has increased, improvements in surgical technique, decreased complications, and earlier rehabilitation have contributed to the increased success of TKAs. But with the increase in success, technology, and demand comes an increase in price, as costs associated with TKA have also risen over the last 20 years.[1] Unfortunately for hospitals and healthcare providers, the rise in cost does not always match the rate of reimbursement. In 2006, the national average charge for total hip and knee arthroplasties was $38,447, but the national average reimbursement was $11,916.

This disparity may lead to a decrease in the number of hospitals offering total joint replacements,[3] which will pose a problem to our healthcare system if supply cannot match demand. Therefore, there is an increasing need to make TKAs more cost-effective. Physical therapists have a vital role to play in ensuring positive patient outcomes following TKA and in decreasing costs to the healthcare system.

As healthcare evolves and patients shop for the best outcomes at the lowest cost, multidisciplinary TKA programs will be positioned to provide results and savings.

Physical therapy and TKA

Physical therapists are involved throughout the recovery process following TKA, from acute postoperative care to outpatient discharge. The hospital discharge goal is a safe return to the home

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with referral to appropriate rehabilitation resources. This requires a patient to have functional mobility, which is typically gained through early mobilization. Aggressive PT following a total joint replacement has been proven effective;[4] even elderly patients can tolerate and achieve increased functional ability through early, aggressive PT. Additionally, PT immediately following a total hip arthroplasty (THA) has been shown to decrease costs and increase the likelihood of a patient being discharged home.[4]

However, variability still exists in the initiation and intensity of PT following such procedures.[4] A 2015 systematic review of randomized controlled trials by Artz et al found that following TKA, outpatient exercise therapy was initiated between two and 12 weeks postsurgery. The evidence supports the short-term effectiveness of PT after TKA with regard to decreased pain, improved function, and improved knee range of motion (ROM). There remains, however, a need to increase patient education prior to surgery so individuals have a greater awareness of what recovery will entail.[5] Research suggests patient expectations are significantly associated with total joint replacement outcomes.[6-9]

The Verde Valley JRP

Physical therapists and other healthcare providers at the Verde Valley Medical Center (VVMC) in Cottonwood, AZ, in response to the variability in TKA rehabilitation and the need for more preoperative education, have developed a joint replacement program (JRP) that aims to improve patient outcomes and decrease complications, with the goal of a safe discharge to the home.[3] The JRP involves a multidisciplinary team of healthcare professionals, the patient, and the patient's family. The program includes a preoperative class, standard pathways for medical care, comprehensive perioperative pain management, aggressive PT, and proactive discharge planning.[3]

The preoperative class aims to reduce anxiety and increase awareness of postoperative recovery, and includes the patient in goal setting and hospital discharge planning. Through this class, the patient learns about details of the procedure, the benefits of the aggressive rehabilitation program, appropriate pain management strategies, exercises provided by the physical therapist, and goals to be achieved prior to hospital discharge.[3]

In agreement with evidence supporting the functional benefits of early PT following TKA, the JRP includes initiation of PT between two and four hours postsurgery. During this visit, the physical therapist evaluates the patient and then begins exercises. Rehabilitation first focuses on gait training, bed mobility, balance, closed kinetic chain (CKC) exercises, and ROM, while abiding by precautions. In subacute rehabilitation, exercises are progressed to include increasing ROM, isometric and CKC exercises to improve strength, advancing gait training, stationary biking, and walking on the treadmill. Postacute exercises focus on enabling the patient to return to previous activities; this is accomplished by continuing to increase ROM, performing open kinetic chain exercises for strengthening, improving single-leg balance, introducing pool therapy, and employing task-specific movements. Starting the day after surgery, the patient is seen by a physical therapist twice per day in a group setting, and continues to work toward the PT goals of being able to safely transfer independently, walk more than 150 feet, and complete a home-exercise program; achieving these goals contributes to the determination of discharge readiness.[3]

Discharge data

Safe discharge to the home is not only a goal of the JRP; in our clinical experience, it is also most often the primary goal of patients, and a significant contributor to decreased costs to the healthcare system. El Bitar et al noted that a 1974 study reported the average length of a hospital stay following total joint replacement was 23 days; that number has now decreased to an average in the US of 3.7 days.[1]

Data we collected from April 2006 to November 2007, which assessed the effectiveness of the JRP at six-month follow-up, showed an even shorter average length of stay for the 74 included patients. Discharge within two days was achieved by 53% of patients, 39% went home within three days, and 7% were discharged within four days. The average length of stay was 2.5 days.[3]

Discharge to the home compared with discharge to a skilled nursing facility (SNF) has been shown to decrease the odds of hospital readmission within 90 days, which also contributes to cost savings.[10] In a 2008 study by Bini et al, data extracted from the Kaiser Permanente Total Joint Replacement Registry from April 2001 to

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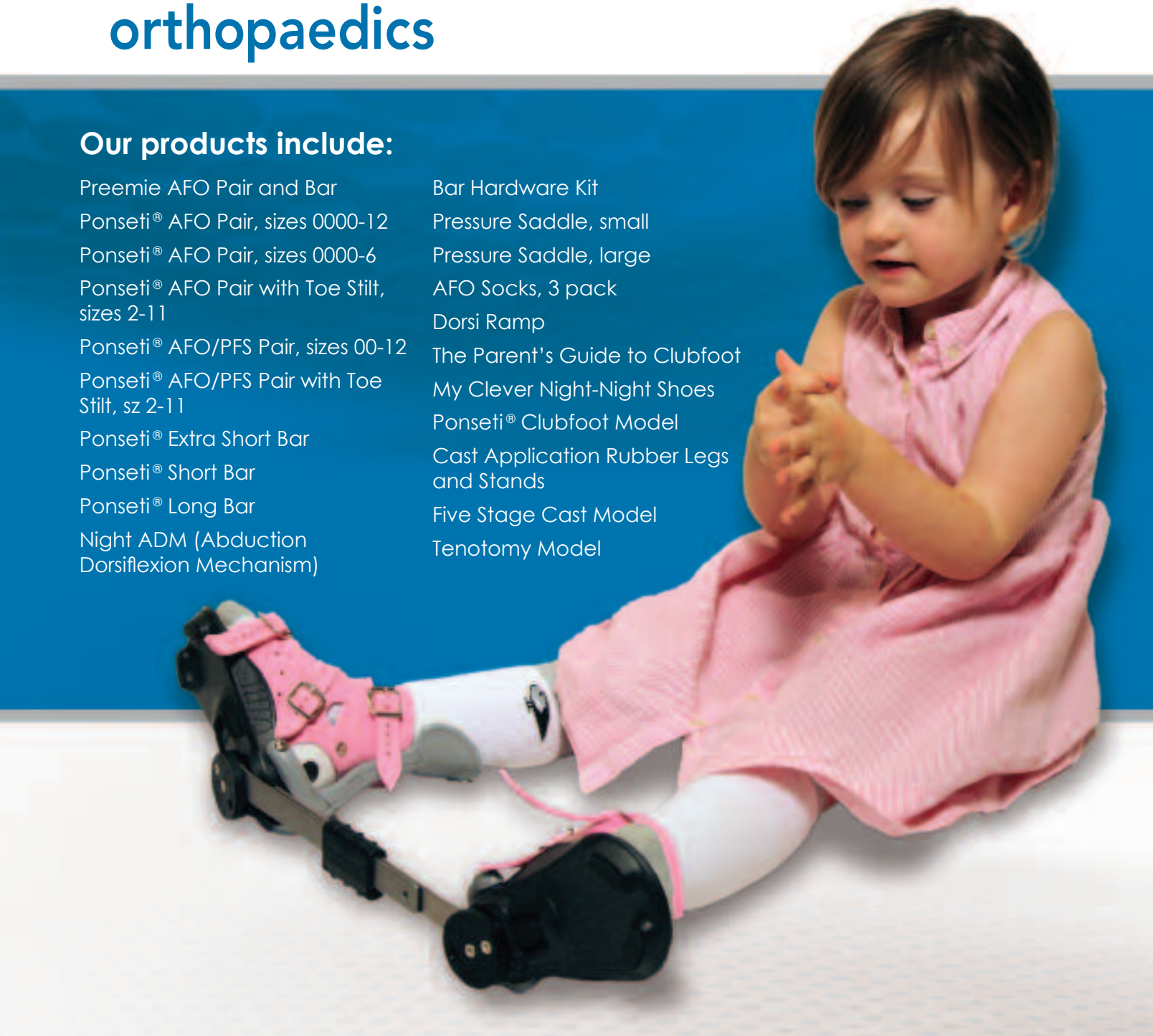

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December 2004 showed 15% of patients were discharged to an SNF following TKA.[10] In our VVMC study, only three patients (4%) were discharged to an SNF following JRP participation.[3]

Physical therapists play a beneficial role in rehabilitation after TKA, both immediately after surgery and after hospital discharge, as well, by helping patients continue to improve their ROM, strength, and functional ability. We analyzed data from July 2005 to January 2010 from our JRP to assess the program's impact on functional and clinical outcomes of direct referral to outpatient PT compared with referral to home health (HH) PT.[11]

Upon discharge home from the JRP, patients were referred to either outpatient PT (87 patients), or HH PT prior to outpatient PT (22 patients).[11] Patients were discharged home and referred to outpatient PT if the orthopedist, along with the multidisciplinary team, determined the patient had achieved medical stability (ie, no other known conditions that could lead to readmission), wound stability (ie, no signs of infection), appropriate blood coagulation values, pain control with oral medications, and progress toward PT goals. If the patient needed additional medical treatment, was unsafe with mobility, or had transportation issues, he or she was referred to HH PT or another appropriate postacute care center.[2]

Although the number of outpatient visits did not differ between groups, patients who went directly to outpatient PT had shorter recovery times in terms of days from surgery to PT discharge than those in the HH group. However, there were no significant between-group differences in the number of patients who achieved their knee ROM goals or in patients' walking endurance, self-reported pain, or quality of life at PT discharge. Given that these data show similar outcomes in both groups and a shorter recovery time for the outpatient PT group, outpatient PT following TKA may be more cost-effective than HH.

The JRP helps decrease expenditures through appropriate, direct referral of patients to outpatient PT. However, it is necessary to emphasize that patients can have similar outcomes postsurgery, even if HH PT is deemed necessary at discharge. These results are encouraging, as this may contribute to the JRP goals of patient safety and decreased complication rates, which still may result in cost savings.[11]

Future directions

While results from the JRP have been encouraging so far, more research is needed for this program to continue to be meaningful for patient recovery and for the healthcare system. At VVMC we are currently assessing the association between preoperative functional characteristics, such as self-reported disability, walking distance, 30-day readmission, and length of hospital stay and recovery following TKA.[2] This data will help the JRP team better understand which aspects of preoperative education and function should be prioritized before surgery to optimize recovery. Jon Cook, PT, DPT, coordinator of the Joint Replacement and Sports Medicine programs at VVMC and a coauthor of this paper, has noted the future of TKA rehabilitation will include "identification of prognostic indicators that may predispose patients to complications…" and the JRP team will utilize research to identify "…plans to resolve these."

Yelling and groaning: Delayed PT, complications, and lack of mobility all contribute to these grievances and to prolonged recovery following TKA. The JRP at VVMC is achieving improved patient outcomes, decreased complications, and shortened hospital stays, all of which help to lessen the clinical anguish that occurs following TKA. In addition to decreasing recovery time, the JRP is also contributing to decreased financial burden on patients and the healthcare system.

For patients in need of TKA, awareness of hospitals that use programs like the JRP is important, as this could contribute to a safer, quicker return to home and physical function, with an improved quality of life, at a lower cost, compared with traditional protocols. As our healthcare system evolves, patients are encouraged to shop for the greatest outcomes at the lowest cost, and programs such as this are in a position to provide both results and savings.

For physical therapists and other healthcare providers, it is necessary to understand the trends of TKA rehabilitation and be a part of the solution to the problems associated with such high procedural demand. As the reimbursement system shifts its emphasis toward outcomes as opposed to services rendered, all healthcare providers must use programs supported by evidence, like the JRP, to provide appropriate care and increase the value they provide to the healthcare system. ler

Katie Mullen, SPT, is a physical therapy student at Northern Arizona University in Flagstaff. John R. Cook, PT, DPT, is the coordinator of the Joint Replacement and Sports Medicine programs at Verde Valley Medical Center in Cottonwood, AZ. Meghan Warren, PT, MPH, PhD, is an associate professor and Tarang Jain, PT, DPT, PhD is an assistant professor in the physical therapy department at Northern Arizona University.

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Metatarsal morphology and injury risk in runners

Although it has not been shown to be a risk factor for stress fracture in traditional running, the presence of Morton's foot (a second metatarsal longer than the first) alters running mechanics in ways that may exacerbate the risks of forefoot injury associated with alternative running styles.

By Brian E Stoltenberg, DPT, OCS, CSCS; and Donald L Goss, PT, PhD, OCS, ATC

With nearly 17 million running event finishers recorded in 2016,[1] running remains a popular recreational activity across the US. Unfortunately, the incidence of lower extremity injuries associated with running can be substantial, ranging from 19% to 79% in published reports.[2] It is estimated that 15% to 20% of those injuries come in the form of a stress fracture.[3]

Stress fracture is the result of repetitive loading to bony tissue that leads to accelerated resorption during an otherwise normal reparative process. This creates cumulative microtrauma that contributes to progressive bone injury.[4]

The running gait cycle involves the transfer of load through the metatarsals as the limb progresses through the stance phase. Modeled as cantilevers, the metatarsals are subject to shearing forces and bending strain with each step. It has been suggested that during running the second metatarsal is where these mechanical demands are the greatest.[5] This may provide a partial explanation as to why forefoot stress fractures are most commonly sustained across the central (second and third metatarsals) region.[6,7]

A potential risk factor for second metatarsal stress fracture is the presence of Morton's foot.[6] First introduced in 1935 by Dudley Morton, MD, a foot structure with an abnormally short and hypermobile first metatarsal may cause an overloading of the central metatarsals during gait, creating a cortical thickening of the second metatarsal shaft[8] (Figure 1). Morton described an "axis of leverage" that, through a normal foot, runs from the calcaneus to a location between the heads of the first and second metatarsals. In the presence of a shortened first metatarsal, this axis is shifted toward the second metatarsal, making it the primary point of leverage.[9]

In studies conducted since his initial publication, Morton's theories of the pathologic foot have come under scrutiny.[9-12] It is possible that the technological limitations of Morton's era caused him to err in his conclusions, as more recent work has shown a lack of clinical utility with regard to measures of first ray mobility and

The question of whether a nonrearfoot strike pattern is a potential risk factor for injury in runners with Morton's foot structure deserves consideration.

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Figure 1. Characteristics of Morton's foot structure[8] include an abnormally short first metatarsal (protruding second ray), hypermobility at the first ray, and resultant cortical thickening of the second metatarsal shaft.

second metatarsal cortical thickening.[11,12] One portion of his theory that does still have support, however, is that peak pressure will be elevated under the head of a relatively longer second metatarsal.[13]

This alteration of mechanics may be worth consideration as the forefoot strike running pattern, often achieved through methods such as Chi,[14] barefoot,[15] or Pose[16] running, has become more popular. When runners aim to reduce heel strike at initial foot contact, the resulting forefoot strike pattern has been associated with lower vertical loading rates than heel strike running,[2] but the plantar flexed foot position in forefoot strikers may increase load on the forefoot during stance. For this reason, runners with a history of stress fracture of the foot are often discouraged from attempting to transition to a forefoot strike pattern.

It is estimated that 22% of the population has a Morton's foot, sometimes called "Morton's toe" or "Greek foot."[17] Considering this prevalence, the condition likely affects a considerable number of runners who are seeking to transition to a forefoot strike pattern. This raises two important questions: First, in the presence of Morton's foot, does transitioning to a forefoot strike running pattern magnify the biomechanical demands across the second metatarsal, increasing the potential risk of stress fracture? And second, should this foot type be a screening consideration prior to attempting such a transition?

Metatarsal mechanics

During normal walking, the heel is the primary loadbearing structure of the foot. Using plantar pressure measurements, Wearing et al[18] demonstrated that in healthy, young individuals the calcaneus reaches a peak force of 80% of body weight by approximately 20% of the stance phase of gait. As body weight is translated forward, load is borne equally between the heel and the second and third metatarsals at around 45% of stance. In terminal stance, the hallux sustains the majority of a 22% body-weight force across the digits, but the primary weightbearing structures late in the gait cycle remain the second and third metatarsals.

Wearing et al[18] also analyzed temporal relationships among their peak force measurements, demonstrating an interesting interaction among the medial three metatarsals. In terms of time to maximum force, the second and third metatarsals were positively correlated with each other ($r = .64$, $p = .01$). The time to maximum force for the first metatarsal, however, was negatively correlated with that of the third metatarsal ($r = -.63$, $p = .01$). These relationships suggest the first and third metatarsals may function to attenuate force across the less mobile second metatarsal.[18] Although these data were collected at a self-selected walking speed without differentiation of foot morphology, they do provide insight about the distribution of forces across the forefoot in terminal stance.

Seeking to define these weightbearing forces with respect to the presence of Morton's foot structure, Rogers and Cavanaugh[13] analyzed plantar pressure measurements during gait in a group of 45 individuals. Thirty of these participants had a Morton's foot structure, as defined by an in-clinic measurement of a second metatarsal longer than the first (8 mm more distally positioned metatarsal head on average). The remaining 15 participants were classified as having normal foot structure. An arch type index, calculated from plantar pressure measurements, did not differ significantly between the groups.

Across all participants, mean pressure under the second metatarsal head (294.6 ± 109.4 kPa) was greater than under the first (243.3 ± 83.1 kPa). The statistical significance of this comparison was not discussed. In terms of between-group differences, the authors noted that the pressure under the second metatarsal head was more distally positioned in the Morton's foot structure group than in the control group. Again, the authors did not quantify the potential statistical significance of this comparison.

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A relatively long second metatarsal may create two axes at the metatarsal break of the foot, and the second metatarsal may function as a hinge between the two.

Morphology and plantar pressure

The statistical significance of between-group differences in plantar pressure magnitude was discussed, however. Participants in the Rogers and Cavanaugh[13] cohort with Morton's foot structure had significantly higher plantar pressures under both the first and second metatarsal heads than those without the condition; statistical significance was maintained when these values were normalized to body weight. The authors described a biomechanical model in which a relatively long second metatarsal may create two separate axes at the metatarsal break of the foot (Figure 2). As body weight is borne by the forefoot during the latter half of the gait cycle, the second metatarsal may function as a hinge between the two axes, providing a potential mechanism for the heightened pressures observed at this location.

The description of increased plantar pressures at the second metatarsal head with respect to increased relative metatarsal length is also supported by a recent cadaveric study. Weber et al[19] performed laboratory-controlled plantar pressure measurements on six feet (without presence of Morton's foot structure) under a mechanically applied force equal to one quarter of body weight. Measurements were conducted under a control condition, then with subsequent 2-mm, 4-mm, 6-mm, and 8-mm aluminum spacers applied to the second metatarsal to lengthen it. A significant association was observed between increases in second metatarsal length and increases in peak pressure under the head of the second metatarsal ($p < .001$). Increases in pressure-time integral (defined as the product of peak pressure and plantar contact time) under the second metatarsal head were also significantly associated with increases in second metatarsal length ($p < .001$).

Force and bending strain

The previously mentioned Gross and Bunch[5] model of the metatarsals as rigid cantilevers during the stance phase of gait suggests the bone shafts are subject to bending strain from the weight of the body. In their study, Gross and Bunch[5] collected plantar force data on 21 healthy male distance runners. Force transducers were placed on the insoles of the running shoes, corresponding to the locations of the first, second, third, and fifth metatarsal heads, as well as the hallux (estimated by palpation). Forces were measured while the participants ran on a treadmill at 3.58 m/s, and the mean of five foot strikes was recorded.

Consistent with previously described observations, the greatest forces were observed at the second and first metatarsal heads (341.1 N and 279.1 N, respectively). After gathering morphologic data from multiple sources (accounting for bone geometry of the

Figure 2. Demonstration of the exaggerated separate axes at the metatarsal break in the presence of Morton's foot structure. A protruding second ray may be a mechanism for increased plantar pressure at the second metatarsal as body weight shifts between these two axes during gait.[13]

metatarsals), the investigators calculated bending moments, axial and shear forces, and bending strain for each of the metatarsals. The greatest shear force and bending strain were observed in the second metatarsal, while the greatest axial load was observed in the first metatarsal.

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The authors noted these data are somewhat paradoxical, as the structure of the first metatarsal (larger diameter and relatively shorter length) makes it the most structurally resistant to bending strain. But the first metatarsal sustains an estimated 6.9 times less strain during gait than the second metatarsal, where the smaller diameter and longer relative length actually make it less resistant, suggesting a substantial structural load across the shaft of the bone. The authors proposed this model as a potential mechanism for the incidence of stress fracture in the second metatarsal among distance runners.

Although mechanically it's intuitive that the presence of a relatively protruding second metatarsal would correspond to increased structural load across the bony structure, there is little support in the literature for an increased incidence of metatarsal stress fracture in those with Morton's foot structure.

Drez et al[10] analyzed files from 65 patients with confirmed metatarsal stress fractures (indiscriminate as to

Figure 3. Cantilever model of the metatarsals during stance and demonstration of the resulting bending strain. Running, shear forces, and bending strain have been calculated to be greatest across the second metatarsal. [5]

which bone) and compared them with 50 controls who did not have a history of foot injury. Efforts to match the groups with regard to any demographic were not described. Ratios of first-to-second metatarsal length were calculated from radiographs. No significant differences were observed between the metatarsal length ratios in the fracture group and the control group. Derived from their descriptive data, the authors proposed an objective definition of a "short" first metatarsal: A first-to-second metatarsal length ratio of less than 73% represents the range outside two standard deviations from the mean.

Proximal fracture patterns

Chuckpaiwong et al[20] focused their retrospective analysis on different stress fracture locations along the shaft of the second metatarsal and attempted to identify potential risk factors for the different sites. Nine patients with proximal stress fractures of the second metatarsal (four with bilateral injuries; 13 cases total) were compared with 45 age-matched patients with distal fractures of the second metatarsal. All patients reported their injuries were caused or exacerbated by sports. Nearly half (43.1%) were described as having a short first metatarsal as measured on radiographs.

Presence of a short first metatarsal in this study was associated with proximal stress fractures, but not distal stress fractures. Those with proximal second metatarsal stress fractures demonstrated a first-to-second metatarsal length ratio of 80%, while those with distal fractures showed a mean ratio of 95%.

Proximal second metatarsal stress fractures are traditionally considered rather unique to ballet dancers, who are routinely subjected to weightbearing forces in extreme plantar flexion.[21,22] However, in addition to Chuckpaiwong et al[20] documenting existence of these proximal injuries across recreational sports, Guiliani et al[23] described two cases in which proximal stress fractures occurred in very experienced runners within six weeks after switching from traditional cushioned-heel running shoes to barefoot-simulating shoes (neither runner was analyzed for Morton's foot). First-to-second metatarsal-length ratios were not collected on these cases. Instead, the authors proposed a mismatch between running style and footwear design. They speculated that, rather than adopting the forefoot strike pattern that is common in habitual barefoot runners, the runners maintained a traditional heel-strike running gait in their new footwear.

This theory would be supported when considering the observations of Lieberman et al.[24] A small group (n = 8) of habitually shod runners were asked to run across a 25-m track in both shod and barefoot conditions. Only one naturally transitioned out of a rearfoot strike running pattern during the barefoot trials. In contrast, approximately 60% of natural rearfoot strike runners in a larger cohort[25] (n = 41) immediately adopted a nonrearfoot pattern in a barefoot running condition without any cues to do so. It is well within reason that the two runners in the Guiliani et al[23] case series self-selected a foot strike pattern resulting in increased weightbearing on the anterior aspect of the foot. Particularly if the runners did not moderate their mileage during the transition, this may suggest a mechanism for their injuries, based on the repetitive bending strain described previously (Figure 3).

The results of Ridge et al[26] provide further support for the potential of bone stress changes when transitioning to barefoot-simulating footwear. Nineteen of 36 individuals were randomly assigned

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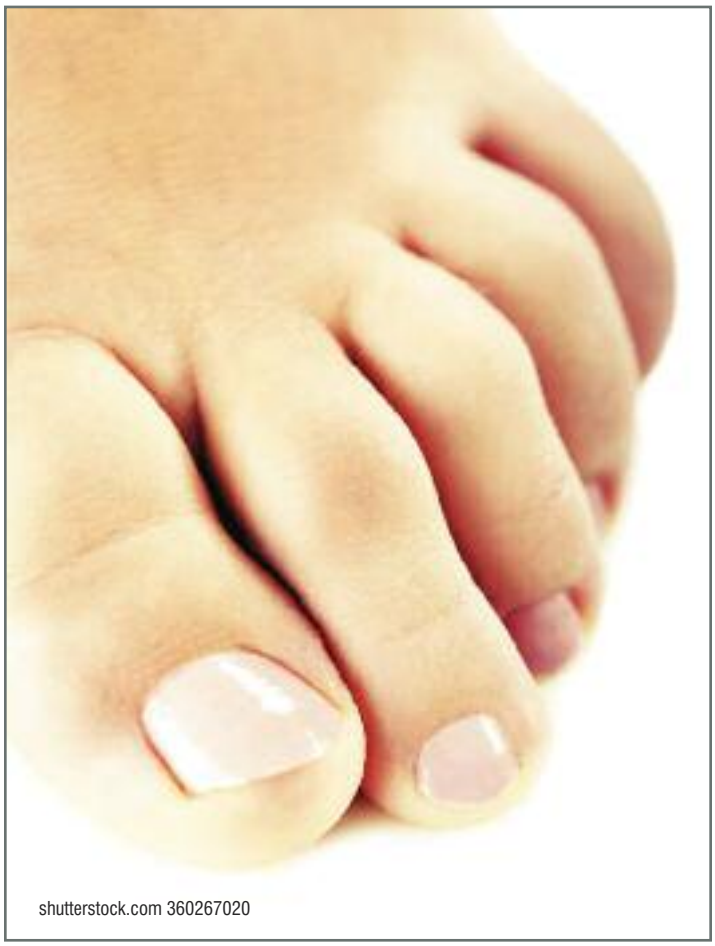
to make the progressive transition over a 10-week period. The other 17 continued their current footwear and training schedule, serving as controls. Magnetic resonance images of both feet were obtained pre- and postintervention. Blinded radiologists reported the presence of stress reactive changes or stress injury or fracture in 10 of the 19 that transitioned and only one in the control group. Foot strike pattern in these runners was not discussed. The authors did state that pain reports were variable (many of the stress changes were subclinical) and compliance logs were inconsistent, but their conclusion should be well received: They recommended the transition to barefoot-simulating footwear should be approached in a prolonged, controlled manner to minimize risk of bone stress injury in the foot.



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Foot strike and injury risk

Regardless of whether an alternative running style is intentionally sought or naturally self-selected when changing footwear, the question of whether a nonrearfoot strike pattern is a potential risk factor for injury in runners with Morton's foot structure deserves consideration. Although the literature on foot strike pattern in runners does not typically provide details about metatarsal morphology, study findings related to metatarsal mechanics in general may have implications for individuals with Morton's foot structure.

The work of Kernozek et al[27] investigated the plantar forces observed as runners transitioned from traditional cushioned-heel shoes to barefoot-simulating footwear. Thirty female runners were

advised to acclimate slowly to the new shoes over four weeks, and then return for an assessment with an in-shoe pressure sensor. Fifteen runners demonstrated a nonrearfoot strike pattern after transitioning. Logically, this pattern yielded reduced pressure at the rearfoot and greater pressure in the forefoot, most noticeably in the central metatarsal region.

In describing the effect of alternative running styles on foot contact pressure, Goss and Gross[28] defined pressure as applied force divided by contact area. Barefoot running has been shown to decrease the contact area of the foot by 25% to 63% compared with conventional shod running,[29] due to less rearfoot contact with the ground. If the applied force remains constant, this reduction in contact area will result in greater pressure. As pressure shifts to the forefoot, the reduction in contact area may counteract the potential benefits of the reduced vertical loading rates associated with alternative running styles.

Magee et al[30] described how making initial contact with the midfoot during running will concentrate the center of pressure (or Morton's "axis of leverage") more anteriorly than a traditional rearfoot strike pattern. Goss and Gross[28] suggested this can increase vertical ground reaction impulse stress (force multiplied by time) across the metatarsals, due to the proportionally longer duration of forefoot loading.

The advantages of a nonrearfoot strike in runners have become a recent point of emphasis. This is true in the clinical setting,[31] but also in recreational running as popularized by *Runner's World*.[32] Based on the aforementioned mechanics, it is common to exclude those with a history of foot stress fracture from transitioning to a forefoot strike running style. It is less common, however, to take relative metatarsal lengths into consideration when deciding if the transition is appropriate for a given individual.

Although it has not been shown to be a risk factor for stress fracture in traditional running, presence of "Morton's toe" or "Greek foot" is a simple clinical observation that may provide information on potential injury risk to the forefoot prior to adopting an alternative running style. Further research on this theory is required to help answer two questions that are more specific than the two posed earlier in this paper: First, in the presence of Morton's toe, does transitioning to a forefoot strike running pattern magnify the biomechanical demands across the second metatarsal, creating a potential risk for stress fracture? And second, should this foot type be a screening consideration prior to attempting transition of a runner to a forefoot strike? ler

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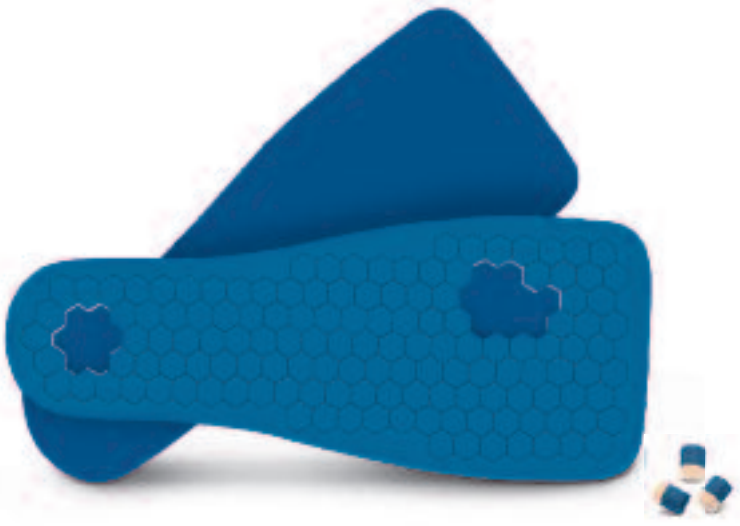

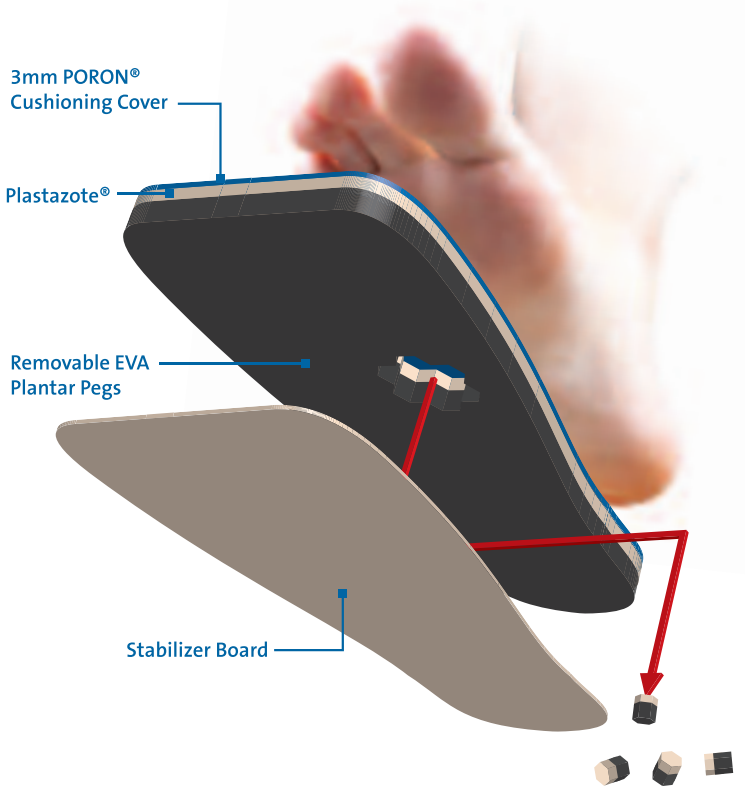

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The troublesome triad of diabetic ulcer healing

Uncontrolled deformity, deep infection, and ischemia-hypoxia make up the troublesome triad of confounders associated with healing challenges in patients with diabetic foot ulcers. Clinical examination and intervention in nonhealing patients should focus on these three elements.

By Anna Maria M. Tan, DPM; Michael B. Strauss, MD; and Lientra Q. Lu, BS

Diabetic foot ulcers (DFUs) are a common cause of morbidity and often require comprehensive multidisciplinary management. The cost of care imposes substantial economic burdens on the healthcare system. It adds an additional $9 billion to $13 billion dollars to the annual $245 billion spent for care of patients with diabetes mellitus in the US.[1] DFUs also are a major risk factor for lower extremity amputations.[2] The progression from preulcer to ulceration to infected nonhealing wound is a common course of events that in about 25% of cases leads to lower limb amputation.[3]

The majority of DFUs heal uneventfully with management that includes appropriate wound dressings, debridement, and offloading. There are usually identifiable reasons why a DFU does not heal. Often these reasons are multifactorial. We have observed that three confounding factors are responsible for failure of wound healing in more than 90% of cases.[4] We term these factors—uncontrolled deformity, deep infection, and ischemia-hypoxia—the "troublesome triad." Being able to identify these elements of the troublesome triad is essential to the evaluation of diabetic wounds, their management, and determining outcomes.

We grade outcomes on all wounds on a 0-to-2 scale as follows:

1) Healed = 2 points

2) Improved (chronic stable wounds, with patients pain-free, able to resume activities, minimal dressing changes, healthy-appearing wound base) = 1.5 points

3) No change (not good enough for inpatients but may be acceptable for outpatients) = 1 point

4) Worsening = .5 point

5) Lower limb amputation or death = 0 points

We consider healed or improved outcomes to be positive, and no change, worsening, or lower extremity amputation or death to be poor outcomes.

A variety of wound-dressing agents are available to help with wound management of diabetic foot ulcers, such as negative pressure wound therapy (NWPT), subatmospheric wound dressings,

> Clinicians should recognize and correct the troublesome triad before trying to heal diabetic ulcers using other interventions, particularly those that are expensive.

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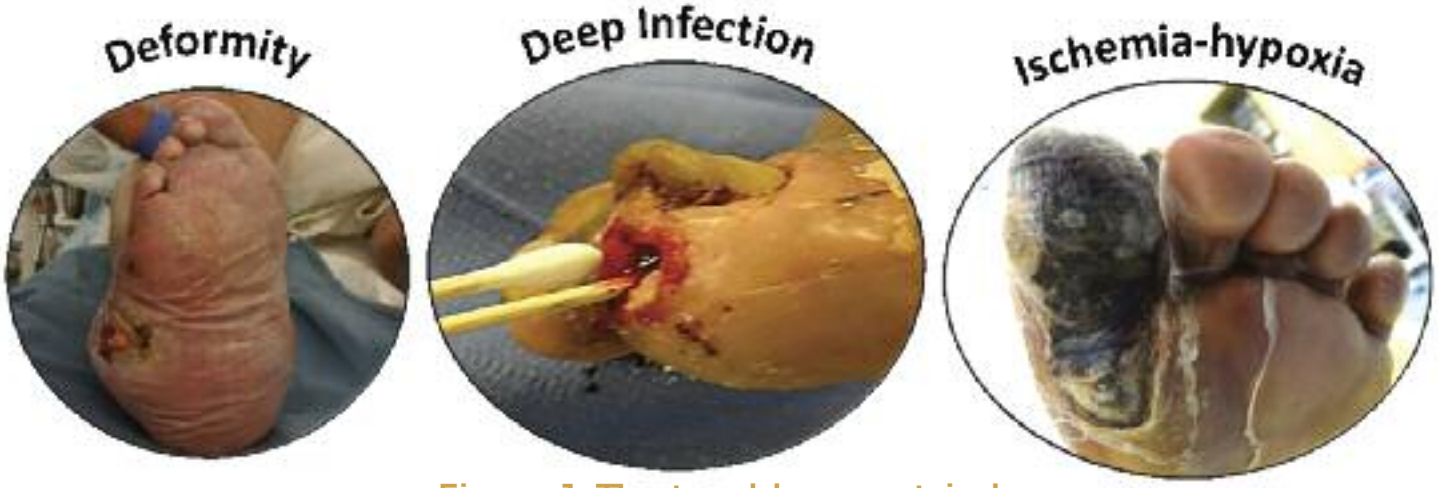

Figure 1. The troublesome triad

bioengineered wound coverings, antimicrobials (including those with silver), medica-grade honey, agents that absorb secretions, or combinations of these. However, when elements of the troublesome triad are present, healing is unlikely even if the most advanced therapies are used. Advanced wound therapies such as biologic agents and NPWT should only be used after the confounders of the troublesome triad have each been addressed.

The elements of the troublesome triad are detailed in Figure 1 and described in more detail below.

Uncontrolled deformity

Foot deformities can cause plantar pressures to concentrate in a focal area and can create biomechanical stresses, both of which contribute to DFUs.[5] Soft tissue breakdown follows repetitive cycles of pressure concentrations, shear stresses, or both, especially in patients with sensory neuropathy.[6] Deformities we frequently observe in the diabetic foot include claw, hammer, and mallet toes; hallux valgus, varus, or rigidus; forefoot abduction/adduction; midfoot pronation/supination; plantarward extrusion of midfoot bones; equinus contracture; rocker bottom foot; and combinations of these conditions.

Bony prominences underlying mal perforans ulcers often are a consequence of the deformities and are a reason DFUs do not heal.[7] In our experience, deformities can also occur secondary to Charcot neuroarthropathy bone destruction, motor components of peripheral neuropathy, malunion, cicatrix, and hypertrophic bursa formation. These complications often overshadow the extent of the underlying bony spur.

Cicatrix and bursa formation can develop as a type of defense mechanism by the body to provide padding over a deformity.[7] In our experience, this is often self-defeating, with the amount of cicatrix and/or bursa far exceeding the magnitude of the bone deformity. When the mass effect of the cicatrix and hypertrophic bursa exceeds the protection the padding attempts to provide, an ulceration develops.

If the DFU is superficial, coexisting deformity may be only a mechanical problem and may not contribute to deep infection. In such cases, we recommend surgical management of the deformity when the ulcer persists after a trial of offloading and/or protective footwear, with as much surgical attention being focused on removing the cicatrix and bursa as on eliminating the underlying bony deformity.

Total contact casting (TCC) is recommended for outpatient management of diabetic foot ulcers.[8] However, Frigg et al found an ulcer recurrence rate of 57% in patients treated with TCC, despite healing and compliant use of protective footwear.[9] When the ulcers occur in the midfoot and hindfoot, and especially if hospital management of the deformity is required, TCC is usually not sufficient and surgery is required.[9]

Deep infection

The second component of the troublesome triad is infection, which frequently occurs with diabetic foot ulcers. In an Institutional Review Board-approved prospective study of patients hospitalized with DFUs, we found residual deep infection was the most frequent confounder, being present in 61.3% of the patients.[4]

Infections that are pertinent to this component of the troublesome triad are those that are deep (ie, involving bursa, cicatrix, and/or bone) to the skin and base of the wound and involve bone, bursa, cicatrix, or combinations of these. These deep infections typically do not respond to antibiotics and require surgical debridement to achieve healing. Failure to adequately debride the tissues affected by deep infection often, in our experience, leads to nonhealing and the need for lower limb amputation.[7] Snyder reported in a retrospective study of diabetic patients with forefoot amputations that uncontrolled infection at the amputation site, even when concurrent or previously managed, was the reason 37% of the patients subsequently required a transtibial or above knee amputation.[10]

We have observed that deep infection includes persistence of infection even when treated with antibiotics and superficial debridement; induration and/or maceration around the wound margins; hypertrophic granulation tissue and/or recurrent highly keratinized callus around wound margins; persistent fibrous membranes and/or biofilm; a verrucous-cobblestone appearance or pale, atrophic appearance of the ulcer base; or combinations of these (Table 1). The hallmark of deep infection is the recurrence of findings at return clinic visits even when the wound appears improved after the superficial debridement. Often, these DFUs have been managed with a variety of advanced therapies before the decision is made to explore and debride the deep infection associated with bone, bursa, or cicatrix.

Continued on page 52

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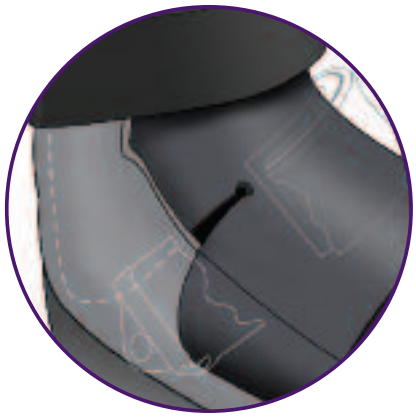

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Table 1: Signs of deep infection

SIGN	COMMENTS
Induration and/or maceration around wound margins	Reflects deep infection and/or production of exudate or transudate
Hypertrophic granulation tissue and/or recurrent highly keratinized callus around wound margins	Possible epigenetic influence from chronic infection on gene expression that regulates the formation of these tissues
Verrucous, cobblestone appearance of wound base	Biofilm reflects bioburden in wound; fibrous tissue formation is a body's response to the infection

Plain x-rays and nuclear medicine scans using a combination of indium and technetium and augmented with computed tomography are useful in identifying the source of a deep infection.[11,12] Magnetic resonance imaging (MRI) is helpful in delineating the soft tissue components of the infection, but tends to be over-read, as the interpretation of bone infection is based on bone edema.[13] Edema in bone can arise from inflammation of surrounding tissues and be interpreted as osteomyelitis on the MRI. Often, the radiologist will conclude "possible osteomyelitis" and suggest confirmation with a nuclear medicine study.

The definitive diagnosis of osteomyelitis is made with culture and sensitivity of a bone sample.[14] Probing to bone has an 85% sensitivity for osteomyelitis.[15]

Surgical management of deep infection requires removal of the infected bone, bursa, and cicatrix. Usually, all three components are involved when infection is the reason for nonhealing in a diabetic foot ulcer. Following adequate debridement, we recommend antibiotics be continued for a couple of weeks after surgery to sterilize the soft tissues adjacent to the debrided bone and soft tissues.

The use of hyperbaric oxygen (HBO) as an adjunct to management of deep infection associated with a DFU requires careful consideration. If ischemia-hypoxia is evident, it is possible the host factors will not be able to sterilize any residual infection in the bone or soft tissues, as the neutrophil-oxidative killing of bacteria and bone resorption by osteoclasts is highly oxygen-dependent. Hunt et al showed that 30-40 mm Hg oxygen tensions in the wound are required for healing to occur.[16] At lesser oxygen tensions, the tissues may not die, but will be unable to heal the wound or eliminate the infection.[17] HBO should be used as an adjunct to surgical and antibiotic management in such situations.

Ischemia-hypoxia

Perfusion that is not sufficient to meet oxygen requirements for wound healing and infection control is the third troublesome triad confounder. Pompers et al reported that 50% of patients with diabetic foot ulcers exhibit a component of ischemia.[18] And Apelqvist et al found that the likelihood of wound healing without a major amputation is inversely related to the severity of underlying peripheral arterial disease (PAD), in addition to the seriousness of the patient's comorbidities and the complexity of tissue involvement.[19]

The evaluation for PAD starts with a patient history and checking for symptoms of intermittent claudication and rest pain; these symptoms, however, may not be apparent because of sensory neuropathy. Components of the physical exam include checking for palpable

pulses at the hip, knee, and ankle levels, as well as for secondary signs of perfusion such as pedal hair growth, skin quality, coloration, temperature, and toe capillary refill time. In the absence of palpable pulses, wound ischemia-hypoxia can be confirmed with Doppler imaging.[20]

Based on clinical signs and symptoms, imaging studies and possibly transcutaneous oxygen measurements (TCOMs) can be done to screen for the severity of PAD and provide justification for interventions. PAD is a prominent risk factor for lower extremity amputation regardless of etiology.[21]

When diabetic foot ulcers fail to improve in the context of the clinical findings noted above, angiography is the next step in the evaluation of critical limb ischemia-hypoxia. Comparing juxta-wound TCOMs under normal indoor air conditions and with hyperbaric oxygen can provide objective data with which to determine whether hyperbaric oxygen is needed for wound healing in these situations. If the TCOM readings exceed 40 mm Hg in room air, wound oxygenation is sufficient for wound healing, and failure to heal is likely due to one of the other confounders, or an occasional biochemical problem (for example, matrix metalloproteins). If the TCOMs are lower than 30 mm Hg, healing is not likely to occur. However, in cases where the juxta-wound TCOMs increase to more than 200 mm Hg with HBO exposure, regardless of the room air readings, we have observed healing in 88% of our patients,[22] and similar findings were reported by Fife et al.[23]

Other interventions to mitigate wound ischemia-hypoxia should not be overlooked in this cohort of patients. These include edema reduction, optimization of cardiac function, and use of medications to improve blood rheology. Edema increases the diffusion distance of oxygen from the capillary to the cell along a gradient.[24] Improving cardiac function increases perfusion to the ischemic tissues.

Finally, rheological agents such as aspirin, clopidogrel, warfarin, heparin, pentoxifylline, and dextran improve perfusion through anticoagulation, decreasing the sludging of erythrocytes in the microcirculation, and/or improving red blood cell deformity.[25] When used as the only technique to improve perfusion, in our experience, they will not likely be adequate to achieve healing in an ischemic-hypoxic wound; consequently, we recommend they be used in conjunction with the other methods described.

Conclusions

Uncontrolled deformity, deep infection, and ischemia-hypoxia are the three elements that we have labeled the troublesome triad, and these confounders are associated with healing challenges in patients with DFUs (Table 2). Our prospective study found one or more troublesome triad confounders in 91.9% of 62 inpatients with DFUs.[4]

Each confounder has characteristic findings that can be confirmed with examination and remedied with interventions. These include surgical removal of the deformity and stabilization of the foot in a plantigrade position; debridement of infected bone, bursa, and cicatrix; and improving perfusion with revascularization techniques, hyperbaric oxygen, and medical interventions. Our 0-to-2 point grading system for wound outcomes is a useful tool to assess the effectiveness of our interventions to manage these cases.

We have observed "good" outcomes in nearly 80% of our patients (unpublished data) hospitalized with diabetic foot wounds when elements of the troublesome triad were addressed.

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Table 2: Characteristics of the troublesome triad

COMPONENT	DIAGNOSIS	MANAGEMENT	COMMENTS
Deformity	Inspection Plain x-rays	Offloading Surgeries: ostectomies, osteotomies, resections	The body reacts to deformities by forming bursa and cicatrix. When overwhelmed, ulcerations develop at the apex of the deformity
Deep infection	Physical exam Imaging studies*	Exploration and debridement	Infection occurs as result of bacteria tracking through ulcer base to deeper structures
Ischemia-hypoxia	History, pulses, Doppler, misc.**	Revascularization, hyperbaric oxygen (HBO), edema reduction, medications	If ischemia is primary concern, then revascularization should be done; if hypoxia, then HBO

*Plain x-rays; nuclear medicine scans (SPECT) for osteomyelitis; MRI for suspected cysts, fluid collections, and/or soft tissue lesions
**Edema reduction, medications (anticoagulants, antiplatelet, thrombin inhibitors). Local vasodilators (nitroglycerin).

We feel it is incumbent on clinicians treating these patients to recognize the components of the troublesome triad and to correct them before trying to achieve wound healing with other interventions, particularly those that are costly, as healing is unlikely to occur and persist when these confounders have not been addressed. In particular, interventions to target the troublesome triad confounders should not be ignored or deferred in favor of using advanced wound therapies. Recognition and management of these confounders can help conserve resources when attempting to heal diabetic foot ulcers.

In addition, it is important to recognize that not all wounds heal, and in our clinical experience, a patient may live with a chronic stable wound for several years. Addressing the troublesome triad allows clinicians to manage these chronic stable wounds with glycemic control monitoring and medication.

Anna Maria M. Tan, DPM, is chief resident of Podiatric Medicine & Surgery at Long Beach Memorial Medical Center in California. Michael B. Strauss, MD, is the former director of Hyperbaric Medicine at Long Beach Memorial Medical Center. Liantra Q Lu, BS, is a research coordinator at VA Medical Center Long Beach Healthcare System and administrative assistant at the Southern California Institute for Research and Education in Long Beach.

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Custom-made Edser eFlops

Edser unveils eFlops, a new line of the company's premium custom-made Flopthotics flip flops, which combine fashion and foot health. Designed and produced in conjunction with footwear specialists in Spain, eFlops are the first of a range of sophisticated custom devices to be rolled out in the next few years. Available in multiple colors and with a variety of adjustable straps, eFlops are manufactured from a 3D scan or plaster cast of the foot and can be fully customized to an orthotic prescription. New and improved adjustable leather straps help ensure comfort and stability without compromising style.

Edser Labs
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market mechanics

By Emily Delzell

EO_2 oxygen delivery device heals DFUs

Results of a randomized controlled trial presented in March at the Diabetic Foot Global Conference (DFCon) in Houston found continuous diffusion of oxygen (CDO) with San Antonio-based EO_2 Concepts' Trans Cu O_2 System was more effective for treatment of diabetic foot ulcers (DFUs) than standard approaches.

Investigators for the clinical trial randomized 100 participants with DFUs (79% male, aged 58.3 ± 12.1 years) to receive either active CDO therapy with the wearable TransCu O_2 device or an otherwise fully operational sham device that provided moist wound therapy without delivering oxygen.

They followed patients until wound closure or for 12 weeks, whichever was sooner. Patients, treating physicians, and independent evaluators were blinded to the study arm. All patients received identical offloading, dressings, and follow-up.

Mark Q. Niederauer, PhD, COO of EO_2, presented the results, which found significantly more people healed in the active arm compared with the sham group (46% vs 22%); this relative effect was greater in more chronic wounds (42.5% vs 13.5%). Patients using the active device also had significantly faster closures rates compared with the sham group.

The *Journal of Diabetes Science and Technology* published the study in February. ler

BOC manager, sales team win Stevies

The Owings Mills, MD-based Board of Certification/Accreditation (BOC) in March announced its receipt of awards in two categories at the 11th annual Stevie Awards gala, held February 24 in Las Vegas by the Fairfax, VA-based Stevie Awards group.

Cynthia Tolson, BOC business development manager, won a Gold Stevie as Business Development Professional of the Year. The BOC hired Tolson in 2014 to lead its new business development unit; she has since hired and trained a team that helped increase the number of BOC-accredited facilities by 10% in a shrinking marketplace, according to a BOC release.

The BOC also won a Bronze Stevie for Front-Line Customer Service Team of the Year. ler

Sigvaris marks North American expansion

Peachtree City, GA-based Sigvaris in March celebrated the grand opening of its expansion for its North American headquarters with a ribbon cutting ceremony that included local city officials, employees, and members of the company's founding family.

The expansion includes 40,000 square feet of additional office, manufacturing, and warehouse space and will create more than 70 new jobs over the next 10 years, with 18 new employees already hired, according to a company release.

Sigvaris in March also celebrated the grand opening of its new manufacturing facility in Holland, MI. ler

allardafo.com goes live, tells ToeOff story

Rockaway, NJ-based Allard USA announced in late March that its new website, allardafo.com, is live.

The site features the history of its ToeOff ankle foot orthosis, a "40 Reasons" section detailing the company's process from manufacturing to social responsibility, and links to Allard suppliers worldwide. ler

DonJoy introduces TriFit OA knee brace

San Diego-based DJO Global in March launched the OA Reaction TriFit Knee brace from DonJoy, the company's latest osteoarthritis (OA) knee brace designed to provide pain relief to those with moderate to severe knee OA.

TriFit by DonJoy features a Web Tech shock absorber to assist with full knee extension and patellofemoral tracking, Exos Tech for a heat-thermoformable custom fit that hugs the area around the knee, and Boa Tech, a microtension adjustment system that pulls everything together and provides 3D protection.

DJO Global also announced in March that its Exprt Revision Hip portfolio received market clearance from the US Food and Drug Administration. The system offers an anatomically inspired design that costs 40% to 70% of the price of comparable revision hip systems and has 80%-90% fewer instruments, according to a company release.

Visit exprtprecision.com for more information. ler

Paceline buys Orthomerica's Seal PVA biz

Matthews, NC-based Paceline in late March acquired Orlando, FL-based Orthomerica's Seal PVA business.

"The addition of the Seal PVA business adds to Paceline's growing portfolio of lamination products, including closed-end PVA [polyvinyl alcohol], resins, carbon, nyglass, FeatherStretch, and more," noted David Glontz, Paceline director of sales, in a company release.

Seal PVA item numbers will remain, and the only change effective immediately is that all new orders will now come from Paceline.

Contact Glontz at dglontz@paceline.com with any questions about the acquisition or the transition process. ler

ABC funds journal issue for AOPA papers

The Washington, DC-based American Orthotic & Prosthetic Association (AOPA) announced in March that the American Board for Certification in Orthotics, Prosthetics & Pedorthics (ABC) will sponsor the 2017 AOPA World Congress Presidential Papers, the top 10 clinical education submissions to the congress of original research backed by a full manuscript.

The *Journal of NeuroEngineering and Rehabilitation* will publish the Presidential Papers as a special supplement, and ABC will make the research available worldwide through the journal and accompanying search indexes such as Medline.

ABC will also be an official partner of the 2017 AOPA World Congress, which is scheduled to be held September 6-9 in Las Vegas. ler

Ottobock acquires BionX active ankle

Austin, TX-based Ottobock HealthCare in March acquired prosthetic foot and ankle maker BionX Medical Technologies, headquartered in Boston, MA.

BionX Medical Technologies produces an active prosthetic foot and ankle solution, the Empower Ankle, which replaces muscle and tendon function with an actively driven ankle joint and supports the user by supplying additional energy during gait, according to an Ottobock release. ler

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KD, OREF award orthopedic researchers

Kappa Delta Sorority and the Orthopaedic Research and Education Foundation (OREF) in March at the 2017 Annual Meeting of the American Academy of Orthopaedic Surgeons (AAOS) presented four awards of $20,000 each to scientists for conducting outstanding musculoskeletal research. The meeting took place March 14-18 in San Diego.

Robin Queen, PhD, associate professor of biomedical engineering and mechanics at Virginia Polytechnic Institute and State University in Blacksburg, and associate professor of orthopaedic surgery at Virginia Tech Carilion School of Medicine and Research Institute, won the Kappa Delta Young Investigator Award for her research on the impact of ankle osteoarthritis and total ankle replacement on gait mechanics and balance.

Matthew Dobbs, MD, won the Kappa Delta Ann Doner Vaughn Award for his research on advancing personalized medicine for clubfoot. Dobbs is the Dr. Asa C. and Mrs. Dorothy W. Jones professor of orthopaedic surgery at Washington University in St. Louis. The research was coauthored by Christina Gurnett, MD, PhD.

Henrik Malchau, MD, PhD, professor of orthopaedics at Harvard Medical School and vice chief orthopaedics and codirector of the Harris Orthopaedic Laboratory Massachusetts General Hospital in Boston, won the OREF Clinical Research Award for his research on the impact of arthroplasty implant registries throughout the world. The research was coauthored by Daniel Berry, MD; Charles Bragdon, PhD; Göran Garellick, MD, PhD; William H. Harris, MD, ScD; Peter Herberts, MD, PhD; Johan Kärrholm, MD, PhD; David Lewallen, MD; Lars Lidgren, MD, PhD; and Otto Robertson, MD, PhD.

Scott W. Wolfe MD, chief emeritus of hand surgery and attending orthopaedic surgeon at the Hospital for Special Surgery in New York City, received the 2017 Kappa Delta Elizabeth Winston Lanier Award for research on kinematics of the normal and injured wrist and the importance of the midcarpal joint. The research was coauthored by Joseph J. Crisco III, PhD. ler

HHS data validate KOOS JR. survey

Investigators from the Hospital for Special Surgery (HSS) on March 14 presented research at the 2017 Annual Meeting of the American Academy of Orthopaedic Surgeons (AAOS) in San Diego that confirms a seven-question survey developed at the Manhattan-based center is a valid and efficient tool for assessing patient outcomes following revision total knee replacement.

The survey, the KOOS JR. (Knee Injury and Osteoarthritis Outcome Score), is significantly shorter than the older 42-question knee replacement survey and has already been adopted by Medicare for its primary joint replacement bundled payment program. In the study presented at the AAOS meeting, HSS researchers looked at the results of 314 patients who underwent revision surgery following total knee replacement between May 2007 and December 2011 and completed KOOS JR. patient-reported outcome measure surveys before surgery and two years later. The KOOS JR. measures proved to be as valid, and have as much internal consistency, external validity, and other measures of reliability in determining outcomes for these patients as they did in patients who had primary total knee replacements. ler

Curbell aids high school prosthetic project

Orchard Park, NY-based Curbell Plastics in March provided technical expertise and donated material to students in the Technology and Engineering (STEM) Program at Wilson High School in West Lawn, PA.

The seniors enrolled in the Wilson Capstone Course in Engineering Design and Development had to identify and solve a systemic societal problem, and decided to develop a transtibial prosthesis that addressed the cost and comfort issues that plague many amputees.

They reached out to Jeff Wilson, Curbell business development manager of Orthotics, Prosthetics and Podiatry, and he worked with the students on selecting materials.

Curbell also donated the three blocks of copolymer acetal used to fabricate the prosthesis, giving students the chance to try out 3D modeling, 3D printing, computer-aided manufacturing (CAM), and computer-numerically controlled (CNC) milling and turning. ler

PCL brace reduces peak PFJ pressures

The *Journal of Experimental Orthopaedics* on March 31 published a study of Foothill Ranch, CA-based Össur's Rebound PCL (posterior cruciate ligament) brace, showing the device significantly reduced peak patellofemoral joint (PFJ) pressures in in PCL-deficient knees compared with no brace.

Investigators from the Kerlan Jobe Orthopaedic Clinic in Los Angeles tested PFJ pressures and force using a pressure mapping system via a lateral arthrotomy at knee flexion angles of 30°, 60°, 90°, and 120° in intact PCL-deficient and PCL/posterolateral corner (PLC)-deficient cadaveric knees under a combined quadriceps/hamstrings load of 400 N/200 N.

They then repeated the testing after application of the Össur PCL brace.

Brace application significantly reduced force, total pressure, and peak pressures in the PFJ in PCL- and PCL/PLC-deficient knees, most significantly at higher degrees of flexion.

Össur in March also opened registration for its second Annual Women's Leadership Conference for O&P professionals, scheduled for September 28-30 at the Össur Academy facility in Orlando, FL.

Registration is $50 per person and space is limited; get more information and register at ossur.com. ler

Tekscan launches gait analysis system

Boston, MA-based Tekscan on April 28 introduced the worldwide release of its Strideway gait analysis system.

The modular pressure measurement system provides kinetic, temporal, and spatial gait parameters, as well pressure and force data. It's constructed by clicking together modular tiles to form a platform, making the system easy to set up, move, and store, and customers can add length with additional tiles, according to a Tekscan release. It also features a wide active area and flush surface to minimize trip hazards and accommodate patients with mobility aids or gait dysfunctions.

The system made its debut in February at the American Physical Therapy Association Combined Sections Meeting in San Antonio.

Visit tekscan.com/strideway for more information. ler

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