Lower Extremity Review
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STEPS AHEAD:
Advances in foot and ankle biomechanics

Foot and ankle experts from across the globe gathered in Sydney, Australia, in April for the third International Foot & Ankle Biomechanics (i-FAB) congress. LER's exclusive coverage of this event starts with the ever-controversial topic of barefoot running and goes on to examine clinical and scientific progress related to plantar pressures, diabetes, pediatrics, unstable shoes, and osteoarthritis.

By Jordana Bieze Foster

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Biomechanist challenges idea that forefoot strike pattern reduces runners' injury rate

Cites lack of conclusive evidence

Joseph Hamill, PhD, is an avid runner who runs with a natural forefoot strike pattern. But Hamill, professor of kinesiology at the University of Massachusetts Amherst, says he wouldn't recommend that running technique for most people, despite recent claims that the forefoot strike pattern associated with barefoot running is associated with a lower risk of injury than rearfoot-strike running.

Those claims, Hamill said in the opening keynote address at the i-FAB congress, are not based on conclusive evidence and, in fact, are likely false.

"Running injuries are multifactorial. I think it's very simplistic to say that injuries result from one or two factors," Hamill said. "From a biomechanical perspective, there does not seem to be a benefit to barefoot running or, to me, forefoot running."

UMass researchers have demonstrated that, although forefoot strikers do not experience a vertical ground reaction force "impact peak," they do experience impacts during running, albeit at lower frequencies than rearfoot strikers. This research, presented last summer at the American College of Sports Medicine meeting in Denver, suggests that because those lower frequencies are attenuated by muscle tissues, while higher frequencies are attenuated by bone, forefoot strikers may actually face a higher risk of muscle injury than rearfoot strikers.

Claims that loading rate is significantly lower in forefoot strikers than rearfoot strikers also may not be entirely accurate, Hamill said. He cited research from Iowa State University, scheduled to be presented in August at the annual meeting of the American Society of Biomechanics, suggesting that when natural forefoot strikers switch to a rearfoot strike pattern, their loading rate actually decreases.

Research, most notably the oft-cited Harvard study published in *Nature* in 2010,

have found higher magnitudes of ground reaction force in rearfoot strikers than in forefoot strikers. However, Hamill noted, the heel is a much less delicate structure than the forefoot and therefore may be better suited to absorb higher forces.

A study from the University of Wisconsin-Milwaukee, presented separately at the i-FAB congress, raised the question of whether changes in foot mobility associated with different running techniques also affect injury risks. In 14 runners (five women), the Wisconsin researchers found that barefoot running, which is typically characterized by a forefoot strike pattern, was associated with more range of motion in several segments of the foot than running in flat sandals.

"Barefoot running may have more mobility, but does that mean more injury risk? said Robin L. Bauer, a graduate student in the Department of Kinesiology at UWM who presented the findings at the i-FAB congress.

A UMass study e-published this month by *Proceedings of the Royal Society, Biological Sciences* suggests that different strike patterns may serve different biomechanical purposes: rearfoot-strike running for maximum energy efficiency and forefoot-strike running for maximum speed.

To Hamill that means a forefoot strike pattern is not the one best suited to most purposes.

"For some people it might work," he said, "but I don't think across a population that I'd recommend it."

Sources:

Gruber AH, Davis IS, Hamill J. Frequency content of the vertical ground reaction force component during rearfoot and forefoot running patterns. Presented at the 58th annual meeting of the American College of Sports Medicine, Denver, June 2011.

Miller RH, Umberger BR, Hamill J, Caldwell GE. Evaluation of the minimum energy hypothesis and other potential optimality criteria for human running. Proc Biol Sci 2012;219(1733):1498-1505.

Lieberman DE, Venkadesan M, Werbel Wa, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. Nature 2010;463-(7280):531-535.

Bauer RL, Joshi MN, Klinkner TR, Cobb SC. The effect of footwear on multi-segment foot kinematics during running. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Research links lower extremity symptoms of overuse to kinematics, training habits

Lower extremity kinematics and training habits affect risk of overuse injury in runners, according to research from the University of Tubingen in Germany.

Investigators performed baseline kinematic testing on 104 healthy runners and followed them prospectively for 12 months or until diagnosis of an overuse injury, whichever came first. Thirty-five runners developed overuse injuries, including 12 in the knee and 18 in the foot.

Injured runners ran more kilometers per week than their uninjured counterparts and were more likely to have training regimens that emphasized fast endurance training and deemphasized slow regenerative exercise. Slow training accounted for up to 25% of training sessions in the uninjured runners.

"Changes in training habits seem to have the most influence on the development of overuse injuries," said Tobias Hein, a researcher in the Department of Sports Medicine at the university, who presented the group's findings at the i-FAB congress.

Foot injuries were associated with increased ankle range of motion (ROM), decreased rearfoot eversion ROM, and decreased maximum rearfoot eversion velocity. Knee injuries were associated with increases in rearfoot eversion and plantar flexion ROM and rearfoot eversion and plantar flexion velocity.

Source:

Hein T, Janssen P, Wagner-Fritz U, Grau S. Do lower extremity kinematics and training variables affect the development of overuse injuries in runners? A prospective study. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Footwear customized with pressure data fails to reduce diabetic reulceration rates

But ulcer severity may be decreased

In a Dutch randomized controlled trial of 171 high-risk diabetic patients, using plantar pressure measurements to confirm offloading below 200 kPa did not result in lower rates of ulcer recurrence over 18 months compared to standard custom shoes.

The Dutch research team, from the University of Amsterdam in the Netherlands, is only the latest group to be frustrated by the ongoing efforts to link therapeutic footwear to positive diabetic foot ulcer outcomes. However, the recent RCT findings do suggest that footwear customized using plantar pressure data may result in fewer complicated ulcers than standard custom footwear.

"We found no clinical benefit of improving offloading with custom footwear by approximately twenty percent, but it does seem to decrease ulcer severity," said Sicco Bus, PhD, senior investigator and head of the Human Performance Laboratory at the university's Department of Rehabilitation, who presented the results at the i-FAB congress. The findings were subsequently e-published on April 30 by *Diabetes Medicine*.

All patients in the trial had diabetic peripheral neuropathy and a history of a healed ulcer within the 18 months prior to enrollment. Eighty five patients were randomized to the test intervention, in which footwear customization was specifically designed to offload any areas where plantar pressure exceeded 200 kPa at baseline. The remaining 86 patients received standard therapeutic footwear, which in the Netherlands is still custom-made but not based on pressure data.

After 18 months, ulcer recurrence had been documented in 39% of patients in the intervention group and 44% of those in the control group, a difference that was not statistically significant. However, complicated ulcers developed in six patients in the control group but none in the intervention group, a difference that was statistically significant.

Multiple studies have documented the ability of therapeutic footwear to significantly reduce plantar pressures, including a July 2011 study from the same Dutch group that was published in *Diabetes Care* (see "Pressure-based diabetic footwear modifications reduce plantar loads," June 2011, page 15). But researchers have been stymied in their efforts to demonstrate that those pressure reductions lead to a reduced risk of ulceration. As Bus and colleagues detailed in a 2008 review article in *Diabetes Metabolism Research and Reviews*, several previous studies have found no effect of footwear on ulceration rates but have been criticized for methodological shortcomings; two oft-cited RCTs in particular did not measure plantar pressures.

The threshold level of 200 kPa used for pressure reduction by the Dutch researchers is based on the findings of a Swedish study published in *Diabetes Medicine* in 2009 that did not track ulceration outcomes. Greater levels of offloading may be required to significantly affect ulceration recurrence rates in high-risk patients, Bus said.

Differences between patient groups in terms of adherence and activity levels also may have influenced the results. Patients in the intervention group had lower levels of at-

home compliance and higher levels of activity, especially while at home, than those in the control group.

Sources:

Waaijman R, Arts ML, Haspels R, et al. Pressure-reduction and preservation in custom-made footwear of patients with diabetes and a history of plantar ulceration. Diabet Med 2012 Apr 30 [Epub ahead of print]

Bus SA, Haspels R, Busch-Westbroek TE. Evaluation and optimization of therapeutic footwear for neuropathic diabetic foot patients using in-shoe pressure analysis. Diabetes Care 2011;34(7):1595-1600.

Bus SA, Valk GD, van Deursen RW, et al. The effectiveness of footwear and offloading interventions to prevent and heal foot ulcers and reduce plantar pressure in diabetes: a systematic review. Diabetes Metab Res Rev 2008;24(Suppl 1):S162-S180.

Owings TM, Apelqvist J, Stenstrom A, et al. Plantar pressures in diabetic patients with foot ulcers which have remained healed. Diabet Med 2009;26(11):1141-1146.

Sham debridement matches scalpel for relief of painful plantar calluses

Scalpel debridement of plantar calluses in elderly patients does not reduce plantar pressures and is no more effective than sham treatment for relieving pain, according to an Australian study.

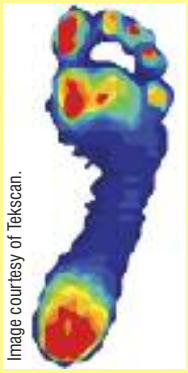

Image courtesy of Tekscan.

Researchers from La Trobe University in Bundoora, Victoria, analyzed 80 patients aged 65 years or older who had painful forefoot plantar calluses. All patients rated their pain at least 20 mm on a 100-mm visual analog scale (VAS).

Forty-one patients were randomized to scalpel debridement, while the remaining 39 patients underwent a sham procedure in which the scalpel was simply turned over and its blunt edge used to simulate debridement.

Barefoot plantar pressures did not differ significantly from baseline in either group and did not differ significantly between groups at any time point. Both groups experienced immediate significant decreases in pain (up to 41.9 mm) that had returned almost to baseline levels by five weeks. Pain reductions were slightly greater in the scalpel debridement group but the difference between groups was not statistically or clinically significant, according to Karl Landorf, PhD, a senior lecturer and research coordinator in the Department of Podiatry at the university, who presented the group's findings at the i-FAB congress.

"There's this remarkable 'nonintervention effect' that clinicians especially need to take into account," Landorf said.

Source:

Landorf KB, Morrow A, Spink MJ, et al. Scalpel debridement has minimal effects on painful plantar calluses in older people: a randomized trial. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Gait changes associated with footwear may explain foot complaints in children

Studies assess school shoes, flip-flops

Researchers from the University of Sydney in Australia have identified gait changes associated with pediatric footwear that may help explain foot complaints that have been reported in children.

In one study presented at the i-FAB congress, Oxford-style school shoes were associated with changes in variables related to pronation, but those changes varied throughout the gait cycle. In a second study, flip-flops were associated with significant gait alterations in the sagittal plane.

Both presenters cited a 2010 survey-based study, also conducted at the University of Sydney, in which parents of children between the ages of four and 12 reported that 28% of those children had experienced a foot problem in recent weeks and that 26% of those problems resulted in cessation of activity. Nearly half the parents surveyed said they thought their children's foot problems were related to footwear.

In the school shoes study, investigators analyzed 20 children (11 girls) who walked and ran on a 12-m walkway at self-selected speeds while barefoot and while wearing leather lace-up Oxford style shoes with polyurethane midsoles and outsoles.

During loading, the shoe condition was associated with significantly greater ankle range of motion (ROM) than the barefoot condition in both the sagittal and transverse planes. However, during midstance, the only significant difference was that the shod condition was associated with less ankle ROM in the frontal plane. And, during propulsion, the researchers found significantly greater ankle ROM in the sagittal plane but significantly less ankle ROM in the frontal plane compared to barefoot.

The findings suggest the shoes are facilitating pronation during loading but limiting pronation during midstance and also limiting resupination during propulsion, said Caleb Wegener, BAppSc(Pod) Hons, a doctoral student in exercise and sports science at the university, who presented the results at the i-FAB congress.

"School shoes have a mixed effect on rearfoot pronation, and this may be beneficial or it may be detrimental," Wegener said. "The changes are small, but as a percentage they are fairly significant."

In the study on flip-flops (or thongs, as they are known in Australia), researchers analyzed 13 children (eight girls) as they walked and jogged on a 12-m walkway while barefoot and while wearing flip-flops.

The investigators found the footwear was associated with significantly less hallux dorsiflexion than the barefoot condition at three timepoints during walking: prior to heel strike, at toe off, and during swing. These findings were consistent with those of a study presented by the same group last year.

The current study also found that wearing flip-flops was associated with significantly more midfoot plantar flexion than the barefoot condition throughout stance, during both walking and jogging. Ankle angle also indicated more plantar flexion at heel strike for the flip-flop condition during both walking and jogging.

The observed gait changes, however, were small, according to Angus Chard, a podiatrist and doctoral student in exercise and sports science, who presented the findings at the i-FAB congress.

"If we had fatigued the children before testing, we might have seen more pathological effects," Chard said.

Sources:

Wegener C, O'Meara D, Hunt AE, et al. Three dimensional ankle kinematics in children's school shoes during running. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Chard A, Greene A, Hunt A, et al. Effect of thong-style flip-flops on children's midfoot motion during gait. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Penkala S, Harris L, Hunt A, Naughton G. Foot complaints of children aged four to twelve years, sex differences and activity—a cross-sectional survey of parents. J Sci Med Sport 2010;12(2):Abstract 218;e107.

Chard A, Smith R, et al. Effect of thong-style flip-flop footwear on children's hallux sagittal plane motion during gait. Presented at the International Society of Biomechanics meeting, Brussels, July 2011.

Hand tremor as predictor of calf cramp in CMT patients perplexes researchers

Researchers from the University of Sydney remain perplexed by the emergence of hand tremor as a predictor of calf cramp in children with Charcot-Marie-Tooth disease but theorize that the relationship may involve fatigue.

As reported in the December 2011 issue of *Neurology*, the investigators analyzed 81 children with CMT type 1A and found that 26% suffered from calf cramps. Variables that were significantly associated with calf cramp included older age, presence of hand tremor, increased foot inversion, eversion, dorsiflexion and plantar flexion strength, fist grip strength, and better performance on long jump and a manual dexterity test. However, the only independent predictors of calf cramp were age and hand tremor.

The significance of hand tremor is unclear, said Fiona E. Blyton, BAppSc(Pod), a lecturer in podiatry at the University of Newcastle, Australia, and graduate student at the University of Sydney, who presented the group's findings at the i-FAB congress.

Hand tremor is a marker of disease severity in patients with CMT, but other such markers were not strongly correlated with calf cramp in the study. Tremor may result from a combination of muscle weakness and impaired stretch reflexes, but strength was not an independent predictor either.

"Both calf cramp and tremor are affected by fatigue. That may be a factor," Blyton said.

Source:

Blyton F, Ryan MM, Ouvrier RA, Burns J. Muscle cramp in pediatric Charcot-Marie-Tooth disease type 1A: prevalence and predictors. Neurology 2011;77(24):2115-2118.

Factors other than static curve influence rollover shape with rocker-bottom shoes

Data confirm kinetic, EMG changes

The static curve of a rocker-bottom shoe does not correlate strongly with its rollover shape during gait, suggesting that other factors such as material stiffness may also contribute, according to research from the University of Salford in the UK.

Investigators analyzed rollover shape in 20 individuals walking at a self-selected speed under four footwear conditions: a flat control shoe, a weighted flat control shoe, a Masai Barefoot Technology (MBT) rocker-bottom shoe, and a prototype rocker-bottom shoe.

Foot-shoe rollover patterns were more curved when participants wore the rocker-bottom shoes than when they wore the flat shoes. However, the only condition for which foot-shoe rollover shape significantly correlated with static sole radius was the MBT condition, and even that correlation was low ($r = .32$).

This suggests that variables other than the static curve shape are affecting foot-shoe rollover shape during gait, according to Saeed Forghany, a graduate student at the university's Centre for Health, Sport and Rehabilitation Sciences Research, who presented the group's findings at the i-FAB congress. One such factor might be that the MBT shoe sole is more compressible than that of the prototype shoe, Forghany said.

The Salford researchers found that curved soles affected foot-shoe rollover shapes but not ankle-foot or knee-ankle-foot rollover shapes, suggesting that the shoes could potentially be used to alter distal gait mechanics without requiring significant changes in coordination strategies proximally.

"These types of footwear might be useful for rehabilitation in patients who have lost some 'rolling over' capability," Forghany said.

In a related study, also presented at the i-FAB congress, the Salford group assessed the effects of curved-sole footwear on kinematics, kinetics, and electromyographic (EMG) muscle activation in the same 20 participants under the same four footwear conditions.

The point of contact with the ground shifted anteriorly in the rocker-sole shoes, which contributed to reduced ankle range of motion and decreases in peak ankle dorsiflexion and plantar flexion moments during early and midstance.

"We're interested in looking at clinical populations, for example patients with arthritis, whereby modifying some of these variables you can play with the ankle moments," said Christopher Nester, PhD, director of the center, who presented the second set of findings at the i-FAB congress.

Nester and colleagues also found that curved soles were associated with significant increases in gastrocnemius and soleus EMG during early stance, along with decreased tibialis anterior EMG. These finding are consistent with those of previous studies, in particular a Swiss study published in the January 2006 issue of *Clinical Biomechanics*.

However, Nester noted, previous studies had limitations, including failure to control for shoe characteristics other than sole curvature. In the current study, the control shoes featured the same last and upper as the prototype rollover shoe, and the weighted control shoe was matched to the weight of the prototype shoe. (Shoe weight was not found to affect any gait parameters.)

Sources:

Forghany S, Nester C, Richards B. The relationship between sole curvature of roll over footwear and changes in gait. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Forghany S, Nester C, Richards B, Hatton A. Effect of rollover footwear on metabolic cost of ambulation, lower limb kinematics, kinetics, and EMG muscle activity during walking. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.

Romkes J, Rudmann C, Brunner R. Changes in gait and EMG when walking with the Masai Barefoot Technique. Clin Biomech 2006;21(1):75-81.

Benefits of variable-stiffness footwear may go beyond reducing knee OA risk

Variable-stiffness shoes may have performance benefits for athletes in addition to addressing kinetic risk factors for knee osteoarthritis, according to research from the National University of Singapore.

Investigators analyzed 30 participants (16 women) as they walked, ran, and jumped while wearing experimental athletic shoes with variable-stiffness soles or control shoes with uniform sole stiffness. The sole material in the experimental shoes was the same stiffness as the control shoes on the medial side and 1.6 times stiffer on the lateral side. Previous research from Stanford University has demonstrated that this design effectively reduces peak knee adduction moment, which has been associated with severity and progression of medial knee osteoarthritis (see "OA research: It's all about the shoes," July 2009, page 51).

Consistent with previous studies, the Singapore investigators found that shoes with variable-stiffness soles were associated with significantly lower external knee adduction moments during walking, running, and jumping compared to the control shoes. However, they also found that the experimental shoes were associated with significantly higher levels of anterior ground reaction force during running, which could have implications for forward propulsion and acceleration, according to Jin Huat Low, a bioengineering student at the university who presented his group's findings at the i-FAB congress.

Source:

Teoh J, Chen W, Lee T. Influence of variable stiffness shoes in sports performance and protection of lower extremity injury. Presented at 3rd International Foot and Ankle Biomechanics Congress, Sydney, April 2012.