



Emerging Orthotic and Footwear Technologies

Highly accessible scanners, 3D-printed custom orthotics, mass footwear customization, and personalized insoles will change the way podiatry is practiced.

BY PAUL LANGER, DPM

Anyone who has been in practice for even a few years has seen significant technology changes. Innovations such as digital x-rays, EMRs, and foot scanners are replacing manual processes and making it easier to share information, improve efficiencies, and thereby save time and money. Some of these technologies are in their relatively early stages but are proving to be an avenue for bigger changes down the road. Foot scanners, in particular, are becoming less expensive and more available to not only clinicians but also footwear retailers and consumers. When combined with additive manufacturing (AM) technologies such as 3D printing, they are enabling a paradigm shift in footwear and foot orthotic manufacturing.

The significance of this is that the current paradigm of footwear manufacturing, from fitting to customizing to even foot orthotics, is changing, and it is not just podiatrists who have access to the enabling technology. Footwear manufacturers, retailers, and really anyone who has an interest now has the capability to produce custom footwear. This “de-



Figure 1: Volumental scanner relays the results of the scan to a tablet. It provides 9 measurements and ranked footwear recommendations based on a weight-bearing scan of the feet and can be used for customization as well. (Photo credit: Volumental)

mocratization” of manufacturing, as some have called it, will move manufacturing from large, remote factories to smaller, centralized and scalable

technology and manufacturing.

There are significant health benefits to comfortable and properly-fitting footwear, and there is also evidence

edge of this change. In fact, an industry report stated that it is expected that 3D printed footwear will become the largest 3D printed consumer product segment by 2029.¹ What’s interesting is that this revolution is not being led just by the major manufacturers such as Nike and Adidas. Smaller companies that aren’t known as shoe companies are innovating in this space. Hewlett-Packard (HP), Materialize, and even unknown start-ups are pushing the boundaries of

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mini-factories, even to clinics, retail stores, and small businesses.

Manufacturing will also move beyond just the capability for mass production to one of mass customization of many consumer products. The footwear industry is on the leading

that improperly fitting footwear is not only very common but also associated with pain and disability.^{2,5} Podiatrists, footwear retailers, and manufacturers are aware of this, and the general public is starting to understand this

Continued on page 72



Footwear Technologies (from page 71)

concept better as well. Increasingly, professional athletes are benefitting from technology-driven custom footwear, including Olympic gold medalist Alison Felix and marathon world record holder Eliud Kipchoge. Consumer demand for comfortable footwear is increasing, according to Beth Goldstein of market research company NPD Group, who wrote in *Footwear News*, “Comfort is not just an added benefit, it is a necessity to today’s shopper.” Newer technologies are providing the opportunity for the medical and footwear industry to provide healthier and more comfortable footwear options for the public through precision fitting and customization.

Scanners and Additive Manufacturing

An overview of two important technologies, scanners and additive manufacturing, is in order before we move on to discussing how the footwear and foot orthotic landscape will change.

Scanners

Scanning is the enabling technology for mass customization. Once a 3D model of the foot has been created from the scan, it can then be used to fit off-the-shelf shoes or used to produce custom orthotics or footwear via additive manufacturing. Foot scanners are familiar to most of us after becoming available in the 1990s, and they have continued to evolve. The lasers, structured light, and stereophotogrammetric scanners, while very accurate, are bulky and expensive. More recently, digital 3D reconstructions of the feet can be achieved with taking a few measurements and/or pictures of the feet and then a data-driven algorithm uses a mathematical model to create a digital image of the feet.⁶ This can be done with tablets and smart phones.⁶

As anyone who has ever worn a shoe knows, measuring the length

and width of a foot with a Brannock device does not provide adequate information for fitting shoes well. Scanners can capture much more than length and width—they can capture the shape and create a 3D model of the entire foot. Volumental (Figure

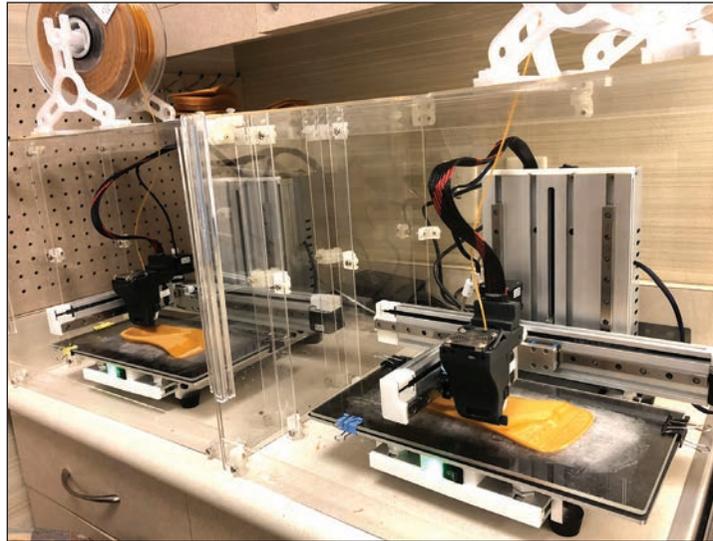


Figure 2: A pair of 3D printers producing foot orthotics. The monofilament material is on the spool at the top and is fed into a heated extruding tip which melts the material and lays it down in thin layers until the orthotic is built. (Photo credit: OLT Footcare)

1) is a Swedish company that has placed more than 1200 scanners in retail stores globally, and to date, done more than one million scans. Their system uses eight cameras to create a digital model of the foot for preci-

phone app called “3D Avatar feet” (available in Apple and Android app stores) which uses the phone’s camera to obtain foot measurements. According to their research, 2D optical scanners that capture the foot shape and plantar surface characteristics of the foot have proven accurate enough to be useful for custom foot orthotic manufacturing.^{8,9} Retailers and manufacturers can license this technology to then be used to fit footwear virtually and/or to produce custom footwear. Some orthotic labs have been using the *3DsizeME* iPad app in combination with Occipital’s Structure sensor laser to scan for custom foot orthotics and prosthetics.

There are a few companies using phone apps to measure feet for online shoe purchases and/or to produce insoles and sandals. Recently, Dr.

Scholls partnered with Viiv to produce custom insoles via an app, and *Nike’s Fit* app can be used to purchase the proper size of any Nike footwear. These smart phone methods are not as accurate as high priced scanners

Additive manufacturing (AM) is a manufacturing process which builds three-dimensional objects by first modelling them digitally with a computer program and then producing them.

sion measurement in less than 10 seconds and can be used to rank shoes in order of best fit for foot shape—not just size. Some footwear manufacturers are also using Volumental’s system to design custom shoes.

The more accessible scanners are, the more demand there will be for customization. This is why some technology companies are banking on the capabilities of a smart phone.⁷ The Instituto de Biomechanica de Valencia (IBV) has developed a smart-

but they are much more accessible, and as IBV’s research suggests, may be accurate enough for fitting and/or customization.

Additive Manufacturing (AM)

AM is a manufacturing process which builds three-dimensional objects by first modelling them digitally with a computer program and then producing them. AM can be achieved with different methods—3D printing,

Continued on page 74



Footwear Technologies (from page 72)

photo polymerization, and injection molding, among others. Each method has its benefits and limitations but, in general, each method is less wasteful than traditional “subtractive” manufacturing such as CNC milling. Foot orthotics and other footwear components can be manufactured with a number of different 3D printing methods which add layer down upon layer of material in very small increments.

One method of 3D printing is called Fused Deposition Modelling (FDM) which melts a thermoplastic monofilament and then lays it down in layers that are 0.25mm thick (Figure 2). The long-term potential for AM is that it can reduce production costs and allow for customization. Some 3D printers are relatively inexpensive, small enough to be set up on a counter in a clinic, and are capable of producing a pair of orthotic shells in a few hours. Industrial-scale printers can cost hundreds of thousands of dollars or more and require a large facility, but can produce up to one million pairs of shoe midsoles per year.¹⁰

Scanners and additive manufac-



Figure 3: HP's Fitstation is a technology platform consisting of a foot scanner, pressure mat, and software package. It has capabilities for virtual fitting of footwear, production of personalized insoles, and slides, as well as custom foot orthotics. (Photo credit: Superfeet)

Go4-D to provide precision fitting, personalized insoles and slides and custom foot orthotics. Each of the 32 NFL teams has a Fitstation in their locker rooms for fitting cleats and producing personalized insoles and recovery slides. A number of running retailers have Fitstation systems in their store in the U.S. as well.

through cloud-based software) who then creates a virtual model of the orthotic, makes modifications in terms of arch height, posting, shell density, and then prints it in his or her own clinic.

Once started, the printer can print unattended, allowing the clinician to see patients or go home at the end of the day while the printer finishes a job. After printing, the orthotic may need minor finishing work such as adding top covers, metatarsal pads, or other modifications at the clinician's discretion. This process, while requiring a capital investment and some training, results in more control of the final product and the ability to shorten turn-around time for more urgent orders, and significantly lowers costs.

The modelling fee charged by a partner company to convert the file to print format may be \$10-\$30 and the materials cost, depending on material type, could be as low as \$18 per pair. So the per-pair cost of a finished orthotic would be \$28-\$50. The author is using two printers in clinic and can print one pair in two to three hours, which allows for a capacity of two to three pairs per day. A clinician could scale up production as needed by adding more printers. OLT Footcare is the only commercially available system currently on the market that the author is aware of using this business model.

Another clinic scenario, for those who prefer not to do their own production or purchase their own system, would be to partner with an orthotic lab that has a high-capacity centralized AM production facility. After scanning (and for some systems obtaining pressure mat data) in clinic with a proprietary technology, a digital file is created and the orthotic can then be designed by the clinician before sending the file to the orthotic lab partner for production. The finished orthotic is then shipped to clinic.

Retailers

Retailers are increasingly competing with online sales and manufacturers who are selling direct to consumers. They are looking for opportunities

Continued on page 76

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turing technologies are opening the doors for new products and manufacturing methods, but no one can predict an emerging market with 100% accuracy. There are simply too many unknowns. There are some clues about how mass customization is starting to emerge and how it will change not only clinical foot and ankle care but also footwear retail and manufacturing. Clinicians, retailers, orthotic labs, and manufacturers are partnering with technology companies to make the transition.

One example of this is HP's Fitstation platform (Figure 3) which is being used by Brooks, Superfeet, and

Clinicians

Podiatrists and other foot and ankle specialists can tap into the mass customization market in a number of ways. They can purchase scanners, printers, and materials to produce orthotics in clinic, or they can scan and have a lab produce the orthotic (or sandal) and then ship it. Some in-clinic systems start for less than \$7,000. An example of a process for in-clinic production would be: a podiatrist scans a patient and uploads the file to a partner company that converts the scan file to a format for printing. The print file is emailed back to the clinician (or accessed



Footwear Technologies (from page 74)

to create unique in-store experiences to get buyers in the door. Precision scanning technologies and customization options can provide that experience. Aetrex, New Balance, and the previously mentioned Volumental and HP are some of the companies providing scanning technologies for retailers.

The scanners can be used for precision fitting of shoes or insoles or for customization. Fleet Feet, a running shoe retailer with 181 stores, is now using Volumental's scanner to fit shoes and has plans in progress to customize footwear in the near future. HP/Superfeet's Fitstation is in some U.S. retailers as well. Once a customer has been scanned in the store, they have a 3D model with measurements of the feet and shoe recommendations available.

For personalized insoles or slides, they can order and have their product in one or two weeks, or they could make purchases at a later date online from their foot scan which is stored in the cloud. This "omni channel" method of retailing allows brick and mortar stores to better compete with the Internet and manufacturers. An addi-

fitting and customization will be the ones to gradually bring mass customization to the masses.

Orthotic Labs

New technologies are creating opportunities for orthotic labs as well.

Computer aided design and manufacturing (CAD-CAM) technologies have improved orthotic manufacturing speed and efficiency but further changes will be needed as consumer demand for custom footwear increases. To date, there is no research that shows superior outcomes of orthotic therapy

using AM versus standard orthotic manufacturing methods. However, AM manufacturing has some capabilities that standard manufacturing methods do not.

For example, in contrast to uniform density shells via vacuum forming or direct milling, 3D printing can

some orthotic labs could become footwear manufacturers as well. Some foresee labs potentially doing less manufacturing but serving as a technology partner where they provide hardware/software to clinicians and then a modelling service for the

orthotics, whereby the clinician sends a scan to the lab and the lab converts the file to a printable format and then sends it back to the clinician to produce the orthotic in clinic.¹¹

Manufacturers

All shoes prior to the second industrial revolution were

handmade. Mass production brought shoes to the world at a lower cost but without customization. New digital processes will slowly be moving mass production of footwear back to customization but on a larger scale. Some predict this will occur over the next five to ten years. Most footwear manufacturers are moving in this direction, but because the manufacturing process will need to change dramatically and expensive infrastructure changed significantly, it is akin to turning a battleship.

As the manufacturing process evolves, the two main limiting factors, cost and speed of production, will improve and mass customization will then become more accessible. Brooks, New Balance, Superfeet, Ecco, Adidas, and Nike, among others are starting to introduce customized and/or 3D printed footwear. OLT Footcare and Wiiv are two start-up companies starting to make inroads as manufacturers as well. The early move to mass customization is starting with custom insoles/orthotics in off-the-shelf shoes and custom sandals. Sandals, because they are easier to manufacture than shoes, will likely be the first widely available fully custom footwear (Figure 5).

There are many possibilities to consider as the technology emerges.

Continued on page 78



Figure 4: Lattice structure of a 3D printed orthotic shell from GO 4-D.

Computer aided design and manufacturing (CAD-CAM) technologies have improved orthotic manufacturing speed and efficiency but further changes will be needed as consumer demand for custom footwear increases.

tional advantage is that retailers using this technology to customize footwear can engage in on-demand manufacturing instead of forecasting and stocking inventories of shoes which tie up space and capital.

Scanning technologies also lead to data acquisition and data mining which will further refine and improve the process. "Sit and fit" retailers such as running shoe stores like Fleet Feet and comfort retailers like Eneslow in New York City have been the first to embrace this technology because it fits in nicely with what they already do. Those retailers with expertise in

produce a lighter lattice structure of the orthotic shell that can be varied in density as needed to address foot morphology, pathology, or comfort (Figure 4). For example, the orthotic could be manufactured with a (denser) stiffer proximal arch and (less dense) more flexible distal arch or vice versa based on the clinician's preference.

In addition, manufacturing custom sandals could be done by most labs with only a few changes to their manufacturing process by utilizing digital and additive manufacturing technologies. It is not unrealistic that



Figure 5: A sequence of customization for sandals. The feet are scanned, a digital model of the feet is created; next a digital model of the sandal foot bed is modelled and matched to a model of the foot and then printed. Finishing work involves laser-cutting a custom outsole, then gluing on a top cover, outsole, and straps. (Photo credit: OLT Footcare)

Footwear Technologies (from page 76)

As mentioned above, it is difficult to predict the timing of these events and how they will manifest, but it is undeniable that technology will change. Clinicians, manufacturers, and retailers now all have access to the same technology. No longer is it necessary to invest large amounts of capital into a manufacturing facility. Production can be scaled to any level that is prof-

footwear problems and new technologies give them access to options right on their phones and in retail settings.

As mass customization becomes more accessible, consumers' expectations will increase.¹² In the medical setting, patients will expect clinicians to offer not only foot orthotics but also other options or at least know about footwear precision measuring and customizing technology. In the retail setting, customers will expect

⁵ Nigg, B. M., Baltich, J., Hoerzer, S., & Enders, H. (2015). Running shoes and running injuries: mythbusting and a proposal for two new paradigms: 'preferred movement path' and 'comfort filter'. *Br J Sports Med*, 49(20), 1290-1294.

⁶ Parrilla, E. et al. (2015), "Low-cost 3D foot scanner using a mobile app", *Footwear Science*, Vol. 7, Iss. suppl.

⁷ <https://www.ibv.org/en/news/3d-foot-scanning-technology-in-your-pocket>. Accessed 6/15/2019

⁸ Parrilla, E. et al. (2015), "Low-cost 3D foot scanner using a mobile app", *Footwear Science*, Vol. 7, Iss. suppl.

⁹ BALLESTER, Alfredo, et al. "Fast, Portable and Low-Cost 3D Foot Digitizers: Validity and Reliability of Measurements." *Proceedings of 3DBODY.TECH 2017 8th International Conference and Exhibition on 3D Body Scanning and Processing Technologies*, Montreal, Canada, 11-12 Oct. 2017.

¹⁰ <https://www.forbes.com/sites/andriacheng/2018/05/22/with-adidas-3d-printing-may-finally-see-its-mass-retail-potential/#4c3a6b1a4a60>

¹¹ Spooner, Simon "3D Orthotic Printing: Fad or Game Changer?", *Podiatry Today*, Vol. 29 Issue 12, P.30-37, December 2016

¹² Boër, Claudio Roberto, and Sergio Dulio. *Mass customization and footwear: myth, salvation or reality?: a comprehensive analysis of the adoption of the mass customization paradigm in footwear, from the perspective of the EUROShoE (Extended User Oriented Shoe Enterprise) Research Project*. Springer Science & Business Media, 2007.

Even with these technologies being readily available, consumers will still need the expertise of medical professionals.

itable—large or small. Podiatrists may choose to be their own orthotic lab or may partner with retailers to offer custom footwear. Orthotic labs may move into footwear production and/or may provide digital orthotic modelling services that allow clinicians to manufacture in clinic. Retailers will utilize the technologies to create a better in-store experience while also creating opportunity for online sales. Footwear manufacturers will certainly be offering more custom footwear options.

Even with these technologies being readily available, consumers will still need the expertise of medical professionals. There are certainly going to be some growing pains as this paradigm changes, and each practitioner will have to decide on their own when might be the right time to jump in. But one consideration is that while medicine is a competitive business, technologies will only increase the competition because consumers often try to solve their own foot and

those offering custom shoes to be able to address concerns with fit, common foot conditions, and comfort issues. Manufacturers will look to build brand loyalty by producing shoes that are customized not only for aesthetics but also for comfort. **PM**

References

¹ <https://www.3dprintingmedia.network/footwear-industry-leads-in-race-for-3d-printed-consumer-products>, May 16, 2019, David Sher

² Kinchington, M., Ball, K. & Naughton, G. (2012). Relationship between lower limb comfort and performance in elite footballers. *Physical Therapy in Sport*, 13, 27-34.

³ Mundermann, A., Stefanyshyn, D. J. & Nigg, B. M. (2001). Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Medicine and Science in Sports and Exercise*, 33, 11, 1939-1945.

⁴ Buldt, A. K., & Menz, H. B. (2018). Incorrectly fitted footwear, foot pain and foot disorders: a systematic search and narrative review of the literature. *Journal of foot and ankle research*, 11(1), 43.



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