PATHOLOGICAL CONDITIONS REQUIRING THE USE OF CUSTOMIZED LASTS

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A customized last is a last used for a subject whose pathological condition does not allow the use of a mass-manufactured last. This paper evaluates foot pathomechanics that can influence the design of customized lasts for therapeutic footwear. It investigates ways of evaluating a pathological condition that causes morphological changes that require the use of customized lasts. The result of this study is a method of defining pathological conditions that lead to consideration of morphological parameters which are not required for mass-manufactured lasts. Designing the customized lasts necessary for medical shoes only based on the mass-manufactured last design system leads in most cases to failure. In conclusion, the customized last designer must have knowledge regarding the evaluation of those pathological conditions that require customized lasts. In the absence of such knowledge the customized last can only be the basis of a final functional and comfortable therapeutic product after a lengthy process based on gaining experience through trial and error.

Keywords: therapeutic footwear, pathological conditions, customized last

INTRODUCTION

There are numerous studies on the use of sophisticated data processing techniques in last design. For this purpose, work has been focused on different directions of development such as:

- anthropometrics: by using anthropometric foot measurements to define the optimal last shape that meets the comfort criteria (Luximon and Luximon, 2009),
- techniques of deforming the virtual last structure (Leng and Du, 2005),
- fuzzy systems for comfort analysis based on last shape (Peng *et al.*, 2009),
- CAD-CAM systems for designing shoe lasts for people with diabetes (Bernabéu *et al.*, 2013),
- customized footwear - "mass customization". In this sense, "customized" is viewed as the possibility of the customer to choose footwear and last properties from a given number of options (Leng and Du, 2006).

It is noteworthy that the vast majority of this work is oriented towards mass-produced lasts and not lasts for footwear used in the treatment of foot pathomechanics. The issues most often discussed are the anthropometric ones (size and morphology). René Rigal (1991) defines the last as "a piece of wood, plastic or metal, representing the volume of the foot and is used in the manufacture of footwear." Although there is a rich literature oriented towards CAD-CAM last design, we can see that it is not oriented towards customized last design for orthopedic footwear, given that the experience of the last technician plays an essential role in this case (Bernabéu *et al.*, 2013). Work on therapeutic/orthopedic footwear insists on anthropometric and morphological aspects, namely the required sizes and shapes as basic information for last design. While older works insist on the traditional methods of making lasts for orthopedic footwear, recent works focus on biomechanical aspects specific to pathologies for which footwear is designed. In this respect, some authors suggest, in terms of design elements, the technical parameters of lasts to be modified depending on the biomechanical objective that the shoes must meet (Bernabéu *et al.*, 2013). Thus, in the case of diabetic footwear, dimensional parameters of the last such as toe girth, toe width, instep girth, heel girth, etc., are correlated with meeting biomechanical objectives such as minimizing friction in the forefoot area, minimizing stress in Achilles tendon and pressure under the forefoot, minimizing pressure on the back of forefoot and toes, minimizing pressure under metatarsophalangeal joint heads 1-5 and hallux.

What is very important to note is that the above mentioned authors believe that the medical specialist is the one who “measures biomechanical characteristics” required to design the last, this measurement being performed in the orthopaedic shop (Bernabéu *et al.*, 2013). The footwear also is delivered and tested in the orthopaedic shop. This is in full accordance with Directive 93/42/EEC concerning medical devices, transposed into national legislation by Law no. 176/2000, in which the “custom-made device” is referred to as “any device specifically made in accordance with a duly qualified medical practitioner's written prescription which gives, under his responsibility, specific design characteristics and is intended for the sole use of a particular patient. The abovementioned prescription may also be made out by any other person authorized by virtue of his professional qualifications to do so”.

This paper addresses the way in which the evaluation of foot pathomechanics can influence customized last design for orthopedic footwear. This evaluation of pathological conditions must be correlated with the design features of customized lasts.

METHOD

The education system focusing on the design of mass-manufactured footwear offers no solutions to investigate ways of evaluating a pathological condition requiring the use of customized lasts. These solutions must be sought both in the medical field and in the field of biomechanics of the musculoskeletal system. Depending on the morphology resulting from pathology evolution, it is required to use footwear designed based on customized lasts or based on normal lasts in terms of structure but whose volume allows insertion of different types of medical devices (orthotics and prosthetics) for the lower limb. In the second case the footwear is referred to as “depth shoe”, being essentially a normal shoe but with an increased inner volume. It must also be mentioned that in the case of certain pathologies, more than a single type of footwear may be indicated, as there is always a relation between “depth shoes” and customized ones according to the size of the morphological changes that occur. In the Romanian footwear industry a number of geometrical parameters (lengths, widths, angles) are used, defined based on an orthogonal reference system of the plantar footprint in bilateral orthostatic position. In terms of destination, the “deformities” category is generally mentioned; in some cases pathologies such as “flat feet” (pes planus), “hollow foot” (pes cavus), neurological disorders, diabetes and bunions are mentioned. The correlations between these parameters and the pathological condition and how these correlations can influence last design are present to a very small extent and generally with no scientific basis. Unlike this situation, in the field of podiatry a definition system for pathologies was created which, based on the definition of “normal” and “pathological” states in relation to a set of criteria for normality, makes a prediction of how a certain pathology will influence gait biomechanics. Even if this system of thinking was fought over time and has led to the emergence of new operational models for the foot (Petcu and Colda, 2012), evaluating pathological conditions in relation to this system can influence the design of customized lasts.

RESULTS AND DISCUSSIONS

In the operating model of the foot around the neutral position of the subtalar axis M. Root suggests that the normal and pathological shape of the bone structure determines the type, degree and direction of movement in different foot joints (Petcu and Colda, 2012). Moreover, the bone structure plays a decisive role in how the muscular system provides foot mobility and stability. Based on personal clinical experience and published research when developing this model, Root introduces, as the central concept of his classification system for normal and pathological foot structure, the concept of subtalar joint neutral position, a position in which the foot is neither in pronation nor supination. In this system structural deformations of the foot can be identified and measured and their influence on foot function can be estimated during walking. Another key element of Root's paradigm is to establish criteria for normality, the differentiating element from other systems being the neutral position of the subtalar axis. To assess dysfunctions caused by a pathology, the frontal plane was mainly chosen due to the reduced range of motion in this plane, required to “absorb” the negative effects of imbalances. Normality criteria set forth by Root and his colleagues represents the ideal relationship between bone segments of the lower limb that must be met for gait to be performed with maximum efficiency. Also these relationships are the basis for evaluating the existing deformation degree in a certain pathology.

According to this system, the criteria for normality (Figure 1) are as follows:

- the distal third of the lower limb is vertical,

- the subtalar axis is placed in neutral position: neither in pronation nor supination,

- the bisector of the posterior surface of the calcaneus is vertical or in eversion of about 3-4 degrees from the vertical,

- the mediotarsal joint is in full pronation position,

- metatarsophalangeal joints are positioned in a transverse plane perpendicular to the calcaneal bisector and contain the distal end of the medial calcaneal tubercle (Figure 1a).

- the foot is rotated outwardly (abduction) with a mean angle of 7-10 degrees,

- there are no abnormal rotational or torsional influences in the lower limb.

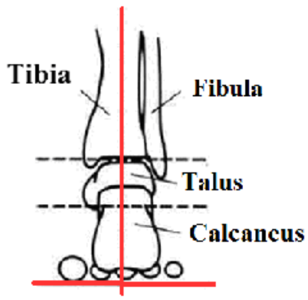
Deviations from normality criteria of the biomechanical system can generate abnormal movements that induce additional tension in the lower limb structure. These additional tensions may cause pathologies over time. It can be seen that the perpendicularity relationship between the bisector of the rearfoot and the forefoot line is also found in normal lasts (Figure 1b).

Thus, relative to the fundamental criterion of Root's model – the neutral position of the subtalar axis –the following types of foot pathology are identified:

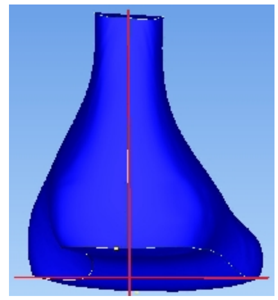
1. Forefoot in inversion (“forefoot invertus”)

1a. forefoot varus - is a specific fixed deformation, in which the forefoot plane is in varus position relative to the calcaneal bisector when the subtalar joint is placed in neutral position and the midtarsal joint is fully pronated relative to both axes.

1b. forefoot in supination - is an acquired deformation (contraction) of the forefoot around the longitudinal axis of the midtarsal joint.



a)



b)

Figure 1. a) Schematic representation of normality criteria; b) transposition of normality criteria to the last

2. Forefoot in eversion ("forefoot evertus")

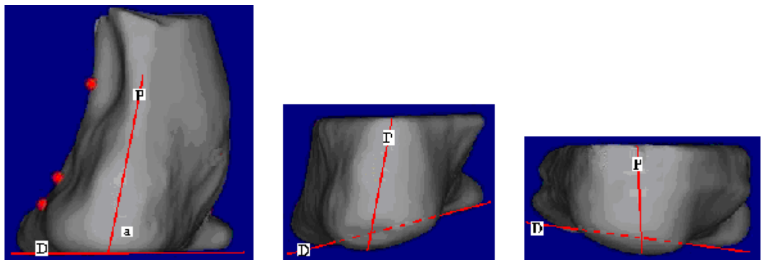
2a. forefoot valgus - is a fixed congenital bone deformation, in which the forefoot is placed in eversion relative to the calcaneal bisector given that the subtalar joint is in neutral position and the mediotarsal joint is fully pronated.

2b. first ray in plantar flexion represents a deformation in eversion of the forefoot that can be congenital or acquired.

3. Rearfoot varus - is a structural deformation in which the calcaneus is positioned in inversion relative to the support surface when the subtalar joint is in neutral position.
4. Rearfoot valgus - is a structural deformation in which the calcaneus is in eversion relative to the support surface when the subtalar joint is in neutral position.

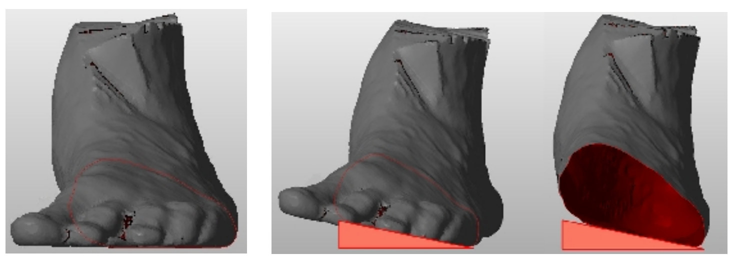
Pathologies associated with deformations described above could be hallux abductus and hallux abducto-varus; mediotarsal joint subluxation; deep callosity under the 2nd metatarsal head; friction callosities under the 2nd, 3rd and 4th metatarsal heads; tibialis posterior disorders; genu valgum; hammer toes, hallux limitus, hallux valgus, interdigital neuroma, plantar fasciitis, tarsal tunnel syndrome, tailor's bunion, tendinitis, callosities under the metatarsophalangeal joint heads, etc.

As an example, in figure 2 a, b, c, a forefoot varus associated with rearfoot valgus is shown, whose plantar surface has been captured by three different methods: 3D scanning, moulding with suspended foot, and foam molding (Petcu *et al.*, 2010). One can see the differences between the appearance of the plantar surface of the same foot area depending on the method of capturing it. These differences will be undertaken by the medical device inserted in the shoe, with a direct effect on the internal volume of the shoe. An objective of conservative treatment in this case may be to limit excessive pronation movement of the subtalar joint during the gait cycle by supporting the forefoot varus deformation. It is important to note in this case that the measurement of the toe girth and its transfer it in the last girth, without taking into account the objective of the treatment, namely of supporting the first metatarsal head, may result in a shoe that creates a high pressure on the back of the first metatarsal phalangeal joint and an abnormal functioning of the foot.



a) b) c)

Figure 2. Comparison between three methods of capturing the 3D surface of a rigid flat foot (left foot). The line of MF joints and rearfoot direction. P - calcaneal axis, D - forefoot direction, a - scanned foot, b - mould of suspended balanced foot, c - mould of partially loaded foot



a) b)

Figure 3. Foot position in the case of a forefoot varus in relation to biomechanical assessment leads to reconsidering the toe girth: a) position during scanning, b) position according to treatment objectives

At the same time, reducing last girth in the metatarsophalangeal joint area (basic operation in designing mass-manufactured lasts), without taking into account the shape of the medical device to be placed in the shoe, will cause high pressure in this area, conditioning the functionality of footwear and decreasing the chances of a successful conservative treatment. A last built with a toe girth calculated on the criteria found in mass production will force the foot to adopt a non-functional position while walking. Also one can observe that in this case, a shoe built on a last with vertical rear side (Figure 1b) can create problems related to adjustment of the foot in the shoes and also promote abnormal biomechanics during walking.

CONCLUSIONS

The last represents a fundamental element of the design process for orthopedic footwear with major implications in successful conservative treatment using this type of medical devices.

Several conclusions can be drawn from this work:

- Last definitions take into account anthropometric, morphological and design aspects, reflecting an orientation towards mass-produced lasts for the normal foot and not for a customized last specific to pathological conditions;

- The conventional last design system is based on an orthogonal reference system without a connection with biomechanical and ergonomic aspects of using footwear in the conservative treatment. The last designer must adapt his thinking to a system that would allow him to understand the pathological condition and the prescribed conservative treatment;

- Last changes can be influenced by the type of existing pathology. Anthropometric measurements performed without taking into account the specific pathology and treatment objectives generally lead to failure or to achieving positive results after a large number of trials without a thorough understanding of the causes that have led to success. The last designer must have a good understanding of pathology definitions in terms of functionality, and of the implications they have on gait biomechanics.

REFERENCES

Bernabéu, J.A., Germani, M., Mandolini, M., Mengoni, M., Nester, C., Preece, S. and Raffaeli, R. (2013), "CAD Tools for Designing Shoe Lasts for People with Diabetes", *Computer-Aided Design*, 45(6), 977–990, doi:10.1016/j.cad.2012.12.005.

Leng, J. and Du, R. (2005), "A Deformation Method for Shoe Last Customization", *Computer-Aided Design & Applications*, 2(1-4), 11-18.

Leng, J. and Du, R. (2006), "A CAD Approach for Designing Customized Shoe Last", *Computer-Aided Design & Applications*, 3(1-4), 377-384.

Luximon, A. and Luximon, Y. (2009), "Shoe-last design innovation for better shoe fitting", *Computers in Industry*, 60(8), 621-628.

Peng, W., Xu, F. and Zhang, W. (2009), "Fuzzy Comprehensive Evaluation of Shoes Comfort Based on Shoe Last", Proceedings of the 2009 International Symposium on Information Processing (ISIP'09) Huangshan, P. R. China, August 21-23, 250-253.

Petcu, D. and Colda, A. (2012), "Foot Functioning Paradigms", *Proceedings of the Romanian Academy*, Series B, 14(3), 212–217.

Petcu, D., Karavana, H.A. and Berijan, Gh. (2010), "Change of the Foot Morphology depending on the Plantar Surface 3D Capture Method", *Revista de Pielarie Incaltaminte* (*Leather and Footwear Journal*), 10(2), 5-18.

Rigal, R. (1991), *La forme: terminologie, caractéristiques et principe de conception*, CTC.