

# A Concept of Automated Selection of Orthopedic Shoes

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## ABSTRACT

There are various approaches to providing patients with orthopedic shoes. This may be the selection or customization of ready-made orthopedic shoes according to a specific deformation, or custom production of shoes. In any case, the selection of a shoe model requires an integrated approach, since when working with each new patient, specialists are faced with various factors. The most important indicator of the effectiveness of orthopedic shoes is the compliance of its inner shape with the parameters of the foot in the correction position. When selecting ready-made shoes, an assessment of the degree of compliance of shoe parameters with foot data is especially relevant, since it allows determining whether ready-made shoes are suitable or custom production is required. The aim of this study is to develop a scientifically based approach to the selection and customization of orthopedic shoes based on assessing the degree of compliance of its inner shape with the anthropometric data of the feet. One of the objectives of the study is to develop an algorithm for selecting shoes. To do this, an analysis of the selection of ready-made shoes and models for custom production was carried out taking into account various factors. The features of orthopedic shoes, methods for obtaining anthropometric information, technological features of production were also studied. As a result of the study, an algorithm for the selection and customization of orthopedic shoes was developed. The research results can be applied as a basis for the further development of approaches to the selection of shoes for mass production and mass customization using modern digital technologies.

**Keywords:** *automated footwear selection, customization, orthopedic shoes, remote fitting, shoe last*

## 1. INTRODUCTION

The inner shape of the shoe that does not correspond to the shape and size of the foot is often the cause of various pathologies and deformations of the feet [1–4]. When choosing shoes, the consumer faces various difficulties, such as the lack of the required size or width of the shoes, non-standard parameters of the foot, as well as the existence of feet deformations. The use of unsuitable shoes, especially when the person has various feet deformations, often leads to an aggravation of the condition of the feet and requires the use of orthopedic shoes that take into account pathological changes in the foot.

When there is no possibility of buying clothes and shoes **through a network** of retail stores for persons with limited mobility due to health conditions or other factors, it becomes especially important to ensure high-quality remote selection of products when they are purchased via the Internet.

According to Russian standard "Orthopedic footwear. General specifications" in terms of the manufacturing methods orthopedic shoes are divided into shoes with individual manufacturing parameters and ready-made shoes for selection.

Currently, orthopedic enterprises in Russia produce uncomplicated orthopedic shoes as selection shoes in order

to reduce time and production costs for custom production. Uncomplicated orthopedic shoes are intended for people with moderate impairment of statodynamic function and can be recommended to the patient by the doctor. The inside shape of such shoes is designed taking into account the average type parameters and characteristics of the foot anatomical changes of a group of consumers having identical homogeneous diagnosis. There are certain groups of deformations (pathologies) when the selection of uncomplicated orthopedic shoes is possible. Such deformations (pathologies) are: Hallux Valgus, diabetic foot syndrome, infantile cerebral paralysis (ICP).

It is possible to determine whether shoes are suitable for selection with a specific foot pathology during the shoes fitting under the supervision of a doctor. In the process of fitting, the consumer, relying on his own subjective feelings, cannot objectively assess the compliance of shoes with the foot, which does not provide a complete picture of the product comfort. Discomfort is often revealed later in the process of wearing shoes. It is physically difficult to assess the conformity of shoes to the feet when customers have diseases such as diabetes mellitus due to developing peripheral neuropathy [5, 6].

The quality and functionality of orthopedic shoes largely depend on a properly designed shoe last. Custom production, as a rule, involves a modification of the base orthopedic shoe last intended for feet with a particular deformation or pathology. However, the base shoe last is

not always suitable for the modification. The problem of evaluating which last available is more suitable for custom production arises, taking into account the characteristics of the pathology and individual parameters of the feet of a particular patient. At the same time, you need to understand how the model will constructively change as a result of choosing an alternative shoe last. The result is largely determined by the experience of the shoe last designer. It is necessary to develop a rational approach to solving this problem, which reduces the risk of errors.

The problem of selecting shoes that are optimal in their width and measurements to the feet of a particular consumer also affects Internet commerce, leading to frequent returns of goods. Today new technological solutions, such as the so-called "virtual fitting", become increasingly attractive. Such technologies are designed to provide the opportunity to select shoes remotely without preliminary fitting according to the parameters of the foot. However, the developments available in this field envisage the selection of standard mass-produced shoes and do not take into account the presence of possible deformations and pathologies of the feet.

This study aims to develop a science-based approach to the selection of rational shoes according to the foot. Currently, we are developing a methodology and algorithm for the automated selection of shoes.

## **2. HYPOTHESIS**

Automated selection is possible by comparing the data of the optimal and real inside of the shoe according to the given parameters, as a result of which the degree of compliance of the analyzed data is determined. The optimal shoe inside is calculated on the basis of anthropometric foot data using anthropobiometric transition principles [7].

When choosing shoes, the diagnosis of feet condition is mandatory, which involves both the selection of ready-made shoes and their customization according to individual anthropometric parameters of the feet, provided that modern digital technologies are used to enable remote interaction between the consumer and the manufacturer [8].

## **3. SELECTION AND ANALYSIS OF SIGNIFICANT SHOE PARAMETERS TO ENSURE THE RATIONALITY OF THE SHOE INSIDE**

Examination of the patient begins with the diagnosis of the feet condition and identifying the features of deformation or pathology of the lower limbs. According to the peculiarities of the deformation, the doctor (orthopedic technician) determines the necessary special orthopedic elements — supplementary or intermediate, their configuration and position in shoes. The constructive functionality of the shoe model directly depends on the type of special parts, primarily the degree of the shoe

upper opening and the type of fastening, and in the case of custom manufacture, the technological equipment used, including the type of the last, and manufacturing technology.

In accordance with the established requirements, possible types of shoes are determined, depending on the season of wearing.

Then, based on the degree of deformation, a decision is made whether to select ready-made or custom manufactured shoes.

The selection of ready-made shoes for medical reasons depends on several factors:

- availability of the required size;
- compliance of the proposed models with full-width parameters of the foot, including the ability to adjust the shoe width;
- competencies of the doctor and orthopedic technician in the selection of shoes;
- possibility of adjusting shoes by correcting inserted orthopedic elements.

In practice, in case of mismatch of models specific for a particular pathology, models designed for other deformations that meet the initial requirements for shoes can be considered. This may be due to non-standard parameters of the foot that do not fit into the parameters of the age and gender group feet for a given deformation.

An anthropometric indicator of orthopedic shoes quality, which characterizes the compliance of the shoe inside with the foot of a person is established in the standard of the Russian Federation R57890-2017 "System of quality indicators of prosthetic and orthopedic products. Orthopedic preventive footwear. Nomenclature of indicators".

The inside dimensions of orthopedic shoes must meet with the requirements of standard 3927-88 "Shoe lasts. General technical conditions (with Amendment No. 1)", which is also recommended for standard mass production shoes.

To develop an algorithm for selecting shoes, it is necessary to determine the parameters of the lasts that can be used to compare the rational and actual inside of the shoe, as well as those that are most important in terms of compliance with the parameters of the foot.

The shoe fitness is determined by many factors, the most significant of which are the length (size) and width of the shoe. The unfolded length of the shoe last sole  $L$  should take into account the elongation of the foot during bending when walking. In this regard, the minimum functional allowance for the sole should be provided, which depends on the type of shoes, gender and age group. If the length along the sole of the inside of the shoe is less than the length of the foot in the position with the maximum raised heel, then such shoes will lead to deformation of the foot, especially the forefront during wearing.

According to standard 3927-88, the main parameters of the shoe last include:

- sole width in the ball area at the 0.68  $L$  cross-section;
- sole width in the heel area at the 0.18  $L$  cross-section;
- girth in the middle of the ball at the 0.68/0.72  $L$  cross-section, characterizing the width;
- girth of the instep at the 0.55  $L$  cross-section.

Ensuring shoe fitness is directly related to the ratio of the girths of the foot and last cross-sections. For those areas where there are no intermediate rigid parts, depending on the type of shoes, a certain decrease in the values of the girth of the cross sections within certain limits is possible, in particular in the ball area. For reliable fixation, some compression of the foot by shoes is possible due to the mobility of the metatarsophalangeal joint and the properties of the materials used. Due to repeated bending, the shoe upper is inevitably deformed and, with the correct ratio of the foot and the last cross-sections, takes the shape of the foot. This provides a tight but elastic fit of the shoe upper to the foot. Deviation of the parameters of the inside volume in the ball area to a smaller side relative to the permissible values will lead to foot injury due to excessive pressure. In case of insufficient fixation due to excessive inside volume, the foot will “move out” to the forefoot, which can lead to injury and deformation of the toes, and the arising force in the metatarsophalangeal joint, preventing the movement of the foot inside the shoe, will lead to general muscle fatigue.

Thus, we can say that the value of the last girth in the ball area is the most important characteristic of the shoe width. Fixing shoes in the instep area of the foot greatly depends on the type of shoes and the type of fastening. For example, laces allow to adjust the width, while boots with a zipper require a more accurate compliance with the foot and shoes parameters. Therefore, this parameter may go beyond the permissible limits, provided that it is possible to enlarge the width.

According to standard 3927-88, lasts of three adjacent widths can be made with one unified sole across the width. This means that for the foot the width of the shoe sole in cross-sections of  $0.18 L$  and  $0.68 L$  can be made larger or smaller within the same shoe width.

The shoe comfort depends on ensuring the optimal distribution of shoe pressure on the foot in different areas, the value of which should vary from the maximum possible to zero. The nature of the pressure is largely determined by the parameters of the overall zones, especially in the heel and forefoot parts. Due to the existence of rigid intermediate parts that have reduced elastoplastic properties, the pressure in these areas should not have a traumatic effect on the foot and fall below the minimum values. The uneven distribution of pressure caused by the mismatch of the shapes and parameters of the foot and last leads to pathological changes in the foot, a decrease in shape stability and premature shoe wear.

The sole of the shoe last should provide an optimal distribution of pressure on the foot plantar surface under load. This depends on the shape of the sole profile, which should take into account the nature of the change in the deflection of the foot arches, depending on the heel elevation. The inner arch is known to perform a spring function during the movement of the foot, while the outer

arch is the support. To ensure the normal functioning of arches, depending on the type of shoe, the sole in the waist area corresponding to the inner arch of the foot should have additional space for arch movement under load.

Supporting comfort is also achieved through the use of profiled insoles for redistributing pressure along the plantar surface of the foot. In this case, the inner shape of the shoe should take into account the parameters of the insole.

Thus, we can say that fitness is a complex indicator of the compliance of the shoe inside with the parameters of the foot. It includes the compliance of shoes with the parameters of the sole, width and overall dimensions, which can be attributed to single indicators of the compliance of the shoe inside with the parameters of the foot.

#### **4. RESULTS AND DISCUSSION**

1. Automated selection is based on a comparison of the data of the rational and actual inner shoe shape (fig. 1).
2. To calculate the rational inner shoe shape, the most important selection parameters are chosen that correspond to the foot data. To assess the degree of conformity of the shoes shape and size with the foot data, selection criteria are established according to the chosen selection parameters.
3. Anthropometric data in the form of sections and projections of the foot surface are used as the basis for calculating the parameters of the inner shoe shape.
4. For the automated selection of shoe lasts and models, it is necessary to measure the lasts according to the chosen selection parameters and calculation formulas, and obtain information about the designs of shoe models from the database.
5. The conversion of the foot data to the parameters of the last depends on the type of shoe, its purpose and the materials used. Therefore, at the initial stage of selection for the calculation of rational inner shoe shape and subsequent analysis (selection), it is advisable to set preliminary requirements for the needed models. When using the word “model” we mean the combination of the given requirements that the inner shape of the shoe and its design meets. Selection of uncomplicated orthopedic or prophylactic shoes is carried out taking into account the design and parameters of the insole corresponding to a certain deformation of the feet.
6. Based on the parameters of the foot and the specified requirements related to the inner shoe shape, the parameters of the rational inner shoe shape and two ranges of acceptable values for each of the selection parameters are calculated: the first range is for the selection of ready-made shoes corresponding to the parameters of the foot;
7. The second one is for the selection of models that require minimal correction of orthopedic insert elements.

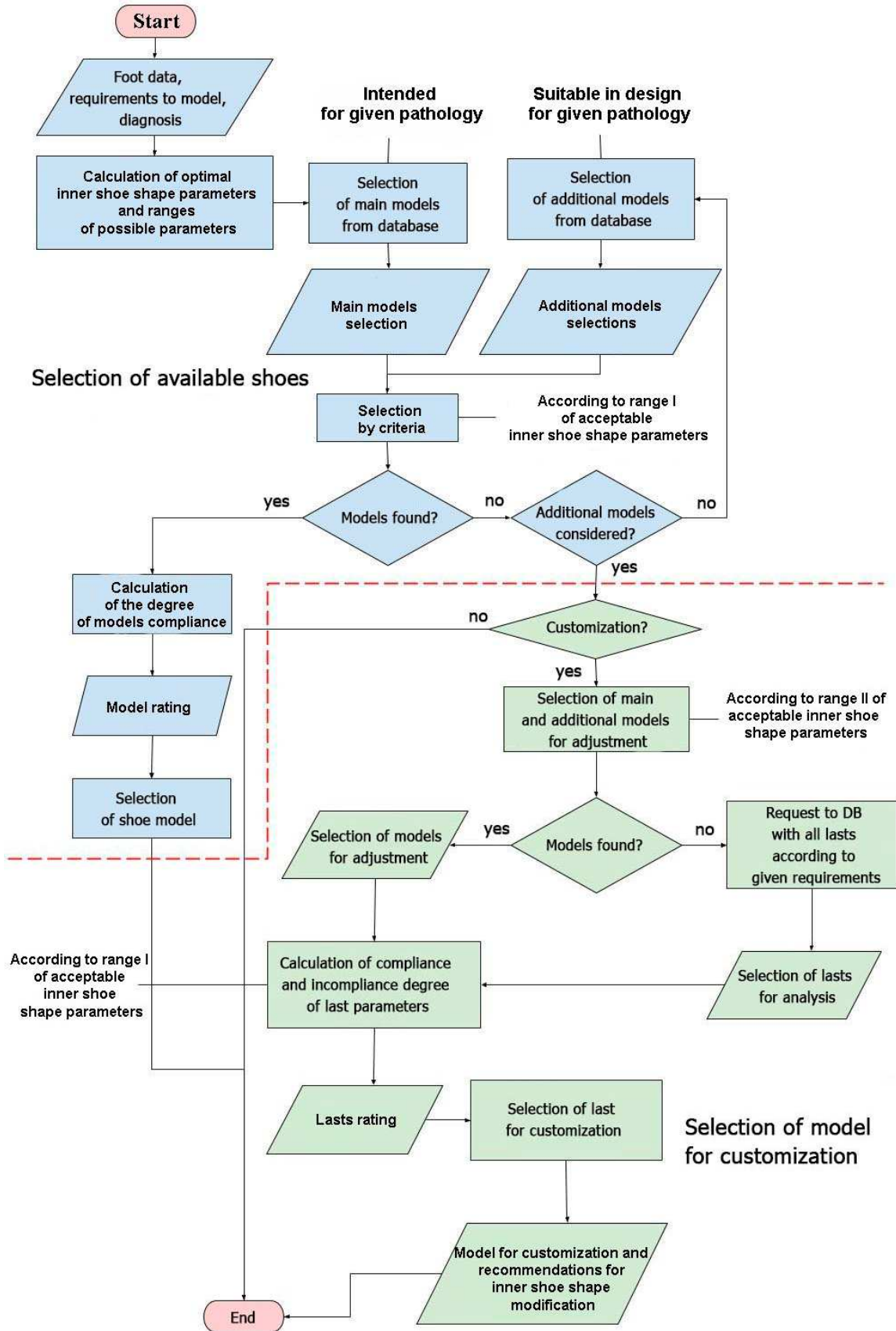


Fig.1. General scheme of the algorithm for the automated selection of orthopedic shoes

8. Based on the calculated parameters of the rational inner shoe shape and the ranges of parameter values, the selection of models can take place in two stages. At the first stage of selection, “basic” models of shoes designed for a given deformation are considered. As empirical experience shows, models that are not intended for a particular deformation can also be quite satisfactory. Therefore, in case of mismatch of basic models specially chosen for pathology, it is advisable to analyze models for other deformations that meet the foot parameters. For this, the shoe model should be suitable, first of all, in the design of the upper. Therefore, in the database, “main basic models” for a given deformation are marked as “additional (type of deformation/pathology)” if, by design of the upper, they can potentially be used for other deformations. Thus, both “basic” and “additional” models can be selected if the parameters of their lasts fit into the first range of acceptable values. If, as a result of comparison, any of the parameters goes beyond the permissible values, then the model is rejected and is not further analyzed as not meeting the specific selection criterion.

9. If the models are found as a result of selection, then the degree of their compliance with the parameters of a rational inner shoe shape is calculated. Thus, a rating assessment of the degree of compliance for each selected model is formed.

10. The selection of models for fitting is carried out through the analysis of the main and additional models using the second range of acceptable values for fitting, if the selection did not find shoe models meeting the search criteria.

11. Selection of a model for custom production: all lasts that meet the selection conditions are analyzed in the database. If any of the parameters does not fit into the range of acceptable values, then the last is not rejected and analysis continues. For each parameter of the last, the degree of its compliance/non-compliance is calculated. According to the degree of compliance with the parameters, a rating of the lasts is formed and a rational one is selected for modification. For each inappropriate parameter of the selected last, the sizes for the necessary modification are given. In this case, choosing a model is rational according to the last recommended for modification, that will allow preserving the aesthetic properties of the original design. However, this is not always possible, since there may not be models corresponding to deformations of the foot for the selected last. In this case, in accordance with the specified requirements for the design of the upper, a model is selected that has the mark “transformability” in the database — the ability of the model to retain its aesthetic and functional properties when designing on an alternative last.

## 5. CONCLUSION

The proposed concept is largely focused on the use of modern digital 3D-scanning devices, as well as special data processing programs, although it does not exclude

traditional manual methods for obtaining anthropometric data.

Taking into account the specifics of orthopedic shoes as a medical device, primary diagnosis of the feet condition is necessary. Depending on the degree and nature of the deformation, an independent remote selection is possible according to the feet parameters received and input into the database in advance, which will allow making a remote order for custom production.

The principles and remote selection algorithm considered are invariant to the conditions of remote selection of both orthopedic products and mass-produced products.

This study shows new approaches to ensuring the required parameters of orthopedic shoes, including when it is selected remotely based on foot data, as well as to customization and individual production of orthopedic shoes.

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