Original article
UDC 616.7+617.586-007.5-07+004.89
https://doi.org/10.56871/RBR.2025.92.13.008

Foot examination methods: traditional and digital technologies (literature review)

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For citation: Cherepovsky K.Yu. Foot examination methods: traditional and digital technologies (literature review). *Russian Biomedical Research*. 2025;10(4):116–124. https://doi.org/10.56871/RBR.2025.92.13.008.

Received: 03.09.2025 **Revised: 03.11.2025** **Accepted: 15.12.2025**

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ABSTRACT. Diagnosis of foot conditions requires integration of traditional and digital methods to ensure a comprehensive assessment of anatomical and functional parameters. Classical techniques (clinical examination, morphometry, plantography, radiography) remain relevant for initial evaluation but are limited by subjectivity and static nature. Digital technologies — computerized plantography, weight-bearing computed tomography (WBCT) and 3D scanning — provide high accuracy, objectivity, and the capacity for dynamic assessment. Their combination enhances diagnostic precision, reveals biomechanical dysfunctions, supports the design of personalized orthotic devices, and enables the creation of standardized databases. Literature analysis confirms that synergistic integration of methods, supplemented by ultrasound and magnetic resonance imaging for tissue assessment, represents the optimal diagnostic strategy. The incorporation of digital technologies with artificial intelligence tools opens new prospects for deformation prediction and treatment personalization.

Keywords: foot, podiatry, plantography, radiography, computerized plantography, 3D scanning, morphometry

Funding. The author claims no external funding for the study.

Оригинальная статья
https://doi.org/10.56871/RBR.2025.92.13.008

Методы исследования стопы: традиционные и цифровые технологии (обзор литературы)

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Для цитирования: Череповский К.Ю. Методы исследования стопы: традиционные и цифровые технологии (обзор литературы). *Российские биомедицинские исследования.* 2025;10(4):116–124. https://doi.org/10.56871/RBR.2025.92.13.008.

Поступила: 03.09.2025 **Одобрена: 03.11.2025** **Принята к печати: 15.12.2025**

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РЕЗЮМЕ. Диагностика состояния стопы требует интеграции традиционных и цифровых методов, обеспечивающих комплексную оценку анатомо-функционального состояния. Классические подходы (клинический осмотр, морфометрия, плантография, рентгенография) сохраняют значение для первичной диагностики, однако их точность ограничена субъективностью и статичностью. Цифровые технологии — компьютерная плантография, нагрузочная компьютерная томография (weight-bearing computed tomography, WBCT) и 3D-сканирование — обеспечивают высокую точность, объективность и возможность динамического анализа. Их сочетание повышает диагностическую информативность, позволяет выявлять нарушения биомеханики, проектировать индивидуальные ортопедические изделия и формировать стандартизированные базы данных. Анализ литературы подтверждает, что синергия методов, дополненная ультразвуковыми исследованиями и магнитно-резонансной томографией для оценки мягких тканей, является оптимальной стратегией диагностики. Интеграция цифровых технологий с инструментами искусственного интеллекта открывает перспективы прогнозирования деформаций и персонализации лечения.

Ключевые слова: стопа, подиатрия, плантография, рентгенография, компьютерная плантография, 3D-сканирование, морфометрия

Источник финансирования. Автор заявляет об отсутствии внешнего финансирования при проведении исследования.

The study of the morphofunctional characteristics of the foot, both normal and pathological, remains one of the key tasks of modern medicine [1]. Podiatry, which specializes in congenital, acquired, and post-traumatic changes in the foot and ankle joint, covers a wide range of clinical issues — from prevention and selection of orthopedic footwear to the development of surgical treatment algorithms [2]. Despite the variety of existing methods (visual examination, podometry, plantography, radiography, etc.), none of them can provide a comprehensive picture of the anatomical and functional state of the foot [3, 4]. This circumstance necessitates a critical analysis of the capabilities of individual approaches and their rational combination.

Clinical examination is used at the stage of primary diagnosis and provides a general idea of the morphology and function of the foot. It includes a questionnaire (complaints, medical history, footwear/load characteristics) and a direct examination of the patient [5, 6]. The examination is carried out both without load in a sitting position and under physiological load; the shape of the foot, the condition of the skin, the axis of the limb are assessed, and local structural changes in different regions of the foot are identified [2, 6, 7]. For functional assessment of the arches of the foot, tests are used (lever test of the first toe, active plantar flexion test of the toes, Stritter's test, “peeking toes” symptom, etc.) [8, 9].

Despite the importance of clinical assessment, its results largely depend on subjective factors — the patient's sensations and the doctor's interpretation [4, 6]. In order to improve data reproducibility, structured examination protocols have been proposed to improve data reproducibility (Papaliodis D.N. et al., 2014), including sequential assessment of the skin, structural abnormalities and deformities, foot sensitivity, the range of active and passive movements in the foot joints, and comprehensive palpation analysis [10]. However, even standardized schemes do not allow for an objective quantitative assessment of load parameters and functional dynamics, which makes it necessary to confirm clinical observations with instrumental methods.

One of the most common traditional approaches remains the morphometric method, based on direct measurements (length, width, height of the foot, calculation of indices) using a tape measure, podoscope, and compass. Its simplicity, accessibility, and speed make it convenient in clinical practice, but the method reflects mainly static anatomical parameters and is subject to measurement errors [11].

Podometry, which involves the use of a podoscope or caliper to determine linear, angular, and volumetric characteristics, expands the capabilities of morphometric analysis. It allows for the detection of early stages of flat feet and the assessment of foot symmetry and shape [2]. However, like morphometry, podometry does not provide information about the functional state of the foot and remains dependent on subjective interpretation of measurements.

Plantography, a method of recording impressions of the plantar surface of the foot, has become an important step towards objectivity and effectiveness in assessing the condition of the foot. Analysis of plantograms (visual and calculated) using the Clark angle, Weissflog index, Chippaux–Smirak index, and other indicators allows for a comprehensive characterization of the condition of the foot arches and is a recognized method for detecting flat feet [2, 11–13]. The advantages of the method remain its accessibility and simplicity of measurement. However, the quality of the impressions obtained depends on many factors (technique, material, foot position), and low resolution and manual data processing reduce the accuracy and reproducibility of the results [14, 15]. Attempts at automation, such as devices like the Foot Imprinter (Orlin M.N., 2000), simplified the process but did not eliminate methodological limitations [16].

The transition to digital technologies has led to the emergence of a new field — computer plantography, which is an automated system for recording, analyzing, and storing data on the plantar surface of the foot [17]. Unlike traditional methods, computer plantography provides high measurement accuracy, eliminating the influence of subjective factors [3, 7, 18, 19]. A key advantage is the ability to quantitatively assess the distribution of load on the feet, which is particularly important in the diagnosis of musculoskeletal disorders (e.g., flat feet) and the selection of individual orthopedic devices. An additional advantage is the ability to repeat measurements multiple times, which allows tracking changes over time, for example, during rehabilitation or correction of flat feet in children [20, 21].

The development of the method is accompanied by the creation of specialized hardware and software complexes. For example, a computerized plantar complex developed in Volgograd in 2005, based on a flatbed scanner and specialized software, automated the calculation of morphometric parameters (length, width, angles of deviation of the first and fifth toes, Weisflog index, etc.) and provided a qualitative assessment of the foot's support surface, including dynamic functional tests [22].

The “DiaSled” (footprint) complex allows for both static and dynamic analysis of the foot, assessing the duration and force of pressure on different parts of the foot, step parameters, and visualizing the results in the form of podograms, which makes it a sought-after tool for clinical assessment [23].

Modern automated podometry and plantography systems cover a wide range of devices, from domestic plantoscopes (GREENFOOT, PODOSKAN-MBN) [24], which record only the plantar surface, to multifunctional complexes such as BODYTRONIC 600 (Germany) [25] and domestic DiaSled-Scan and Scan [26], which allow additional visualization of the rear and lateral surfaces of the foot. Such an expansion of the diagnostic field increases the accuracy of the assessment of deformities and asymmetries. An important practical advantage of all digital systems is the high speed of examination, which makes them particularly useful for mass screening and in conditions of intensive clinical flow.

Thus, despite the relatively high cost of equipment and software, computer plantography has taken a firm place in modern foot diagnostics. Its main advantages — objectivity, high accuracy, and the ability to dynamically analyze load distribution — make the method optimal for specialized centers and, in the future, the basis for integrated digital systems for assessing the condition of the musculoskeletal system [3, 12].

Verification of foot pathologies and the choice of treatment tactics in many cases rely on radiological diagnostic methods. Among them, the most common is flat X-ray imaging, which still retains its status as the “gold standard” for visualizing bone structures. It allows for a detailed assessment of the anatomical structures of the foot both without load and under physiological load, which is especially important when analyzing biomechanics and planning the correction of deformities [26, 27].

A standard X-ray examination of the foot is performed in several projections. Direct and lateral X-rays in a standing position (with and without load) are used to assess the configuration of the tarsal and metatarsal bones, the transverse tarsal joint (Chopart joint), the metatarsophalangeal joints (Lisfranc joint), and the phalanges of the toes [28]. A direct plantar projection is used to determine angular characteristics and interosseous relationships [29, 30]. The lateral projection allows measurement of the navicular angle, heel angle, height of the longitudinal arch, and angle of inclination of the forefoot, displaying the tarsal bones, calcaneus, and joints of the first toe [29, 30]. The oblique internal projection supplements the data, detailing the anatomy of the tarsus and metatarsus [29, 30]. Thus, radiography remains the main method of morphometric analysis of the skeletal skeleton of the foot, necessary for the diagnosis of deformities and evaluation of the effectiveness of surgical treatment [31, 32].

However, the methodological limitations of radiography — two-dimensionality and static images — do not allow for a complete analysis of spatial and functional characteristics. These shortcomings are partially compensated for by X-ray computed tomography (XCT), including weight-bearing computed tomography (WBCT), which has been in use since 2012 [27, 33]. WBCT provides three-dimensional reconstruction and layer-by-layer imaging of bone structures under physiological load, which significantly increases the accuracy of spatial measurements. The method is indispensable for assessing complex multiplanar deformities, but, like radiography, it remains static and is accompanied by exposure to ionizing radiation, which limits its use, especially in dynamic observation [33].

Magnetic resonance imaging (MRI) is preferred for studying soft tissue components. It provides high spatial resolution in the visualization of tendons, ligaments, fasciae, vessels, and nerves, and allows for the diagnosis of inflammatory and degenerative changes without radiation exposure. MRI is especially valuable in cases of combined injuries and chronic pain syndromes. The main limitations of the method are its high cost, the duration of the examination, and the presence of contraindications (metal implants, claustrophobia, etc.) [34, 35].

Ultrasound examination (US) plays an important role in functional foot diagnostics due to its non-invasive nature, the possibility of dynamic scanning in real time, and the ability to perform interventional procedures. The method is informative in assessing the condition of soft tissue structures — tendons, fascia, and ligaments. Its main limitation is its high operator dependence, i.e., the subjectivity of interpretation, which directly depends on the specialist's qualifications, reducing the reproducibility and objectivity of the results. It is a factor that stimulates the development of automated imaging systems and the search for more standardized alternatives [36–38].

Against this backdrop, non-contact digital technologies are actively developing, in particular 3D scanning, which is considered an accurate and reproducible method for obtaining morphometric data on the foot. Unlike traditional contact methods, 3D scanning allows the foot to be examined both statically and dynamically, providing a three-dimensional representation of shape, volume, and load distribution [39, 40]. The debate in the scientific community about its advantages over classical methods has stimulated a number of comparative studies.

The work of C.P. Witana et al. (2006) demonstrated statistically significant discrepancies between the results of manual measurements and 3D scanning: differences in 8 out of 18 spatial parameters of the foot indicated the greater accuracy of digital technologies [41].

A study by J. Zhao and S. Xiong (2008), focused on applied footwear design tasks, revealed minimal discrepancies (<5 mm) between 3D scanning and traditional methods, which became important evidence of the practical applicability of the technology in mass footwear production [42].

By 2010, the accumulated data set allowed a group of foreign researchers to conduct a review assessing the potential of 3D foot scanning for use in orthopedics, the footwear industry, and other ergonomic purposes. Based on a meta-analysis of 38 scientific articles, it was found that 3D scanning provides more accurate and rapid morphometric data on the foot compared to traditional methods, and also allows for the study of dynamic changes in the shape of the foot under load. The researchers also noted the practical effectiveness of 3D scanning for the personalized manufacture of footwear and orthopedic products, which reduces production times [43]. Further studies have reinforced these conclusions.

For example, L.K. Noldner and H.J.H. Edgar (2013), comparing 2D scanning, 3D scanning, and manual measurements, clearly identified 3D scanning as the method that minimizes measurement error and provides the highest accuracy in studying foot morphology [44]. The work of Yu-Chi Lee et al. (2014) expanded on this conclusion, proving that 3D scanning provides the most complete and informative set of foot morphometric data not only in comparison with the method using a digital caliper, but also with digital and ink footprint methods [45]. Recent studies continue to demonstrate the reliability of the technology even in complex cases. A study by J. Mueller et al. (2023), focused on pediatric practice (277 children), confirmed the higher accuracy of 3D scanning for assessing anatomical parameters of the foot compared to 2D scanning and manual measurements, emphasizing its validity for clinical application [46].

The analysis of modern foot examination methods allows us to draw the following conclusions, which are of significant importance for science and clinical practice.

1. *Synergy of methods.* No single method provides comprehensive diagnostic information. The future of diagnostics lies in the strategic combination of traditional and digital technologies. Clinical examination remains the starting point, but requires further structuring to reduce subjectivity. X-ray imaging retains a key role in the assessment of bone pathology, but should be supplemented by CT for complex cases and 3D reconstruction. Functional assessment increasingly relies on computerized plantography and 3D scanning. MRI and ultrasound are the methods of choice for soft tissue pathology.

2. *Advantages of digitization.* Computer plantography and 3D scanning provide unprecedented accuracy, objectivity, and speed in obtaining morphometric and functional data, minimizing the human factor. They form the basis for the creation of extensive standardized databases necessary for scientific research and the development of standards.

3. *Personalization. 3D technology* opens up new horizons in personalized medicine, making it economically and technically feasible to manufacture individual orthoses, insoles, and shoes that precisely match the anatomy and biomechanics of a specific patient. This directly increases the effectiveness of conservative treatment and rehabilitation.

4. *Prospects.* The integration of data from various methods (e.g., combining load data from computer plantography with 3D scanning or WBCT) using artificial intelligence technologies for analysis is the most promising direction. This will not only improve diagnosis, but also predict the development of pathologies and optimize treatment strategies. Reducing the cost and increasing the accessibility of digital systems is a key task for their widespread implementation in routine clinical practice.

Thus, the future of foot diagnostics is determined not by replacement, but by the synergy of traditional and digital methods within a unified diagnostic ecosystem. This approach provides a comprehensive, objective, and personalized assessment of the condition of the foot, contributing to the effectiveness of prevention, treatment, and rehabilitation of patients.

ADDITIONAL INFORMATION

The author read and approved the final version before publication.

Competing interests. The author declares no obvious and potential conflicts of interest related to the publication of this article.

ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

Автор прочитал и одобрил финальную версию перед публикацией.

Конфликт интересов. Автор декларирует отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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