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Research on the Foot and Ankle Health Auxiliary Diagnosis and Treatment Driven by Knowledge and Data

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Abstract

This study aims to address the two major industry pain points in the research and development of ankle health products, namely "shoemakers have no basis for making shoes" and "doctors have no shoes to use", and builds a knowledge- and data-driven ankle health assistant diagnosis and treatment system. By developing an ankle data acquisition system with medical image acquisition and multi-source data fusion functions, 1,820 cases of data acquisition were conducted among the target population, resulting in 640 cases of pathological foot conditions. A clinical medical database covering patients' biomechanical characteristics, pathological data, and diagnosis and treatment needs was established. On this basis, a parametric modeling method for shoe lasts based on modular design and differentiation strategy was proposed to complete the development of 22 healthy shoes in 4 categories, and establish a knowledge base for shoe design corresponding to typical foot deformities. Experiments have shown that the system can significantly improve the biomechanical fit of customized shoes and shorten the response time of clinical diagnosis and treatment. The research results provide data support and intelligent decision-making paradigm for the development of medical-grade ankle health products.

Keywords

Ankle health, Assisted diagnosis, Data acquisition.

1. Introduction

The foot serves as the foundation of the human body, with the normal ankle-foot complex being fundamental to overall health. Despite its critical biomechanical role in daily locomotion, the importance of ankle-foot health remains significantly underrecognized in both clinical practice and public awareness, including among medical professionals[1-2]. Anatomically, the foot comprises 26 bones, 19 muscles, over 100 ligaments, and intricate neurovascular networks, all subjected to sustained mechanical stress (Figure 1). Clinically divided into forefoot, midfoot, and hindfoot regions, the ankle-foot complex bears the entire body weight during standing, redistributed between the forefoot and heel. During ambulation, localized forces exceed 10 times body weight, subjecting the structure to cumulative stress over decades. Compounded by overuse injuries, trauma, and congenital abnormalities, this mechanical overload predisposes the ankle-foot complex to degenerative pathologies.

Post-injury biomechanical alterations often induce structural changes in lower limb kinematics, manifesting as traumatic arthritis (e.g., ankle, knee, or hip osteoarthritis) due to asymmetrical joint loading. Chronic lower limb pain further propagates spinal disorders, including lumbar disc herniation, scoliosis, and chronic low back pain. Common ankle-foot pathologies encompass hallux valgus, flatfoot, pes cavus, plantar fasciitis, chronic ankle instability, and tibial stress syndrome[3-5] (Figure 2). Secondary conditions such as foot drop and equinovarus deformities frequently arise from neurological disorders (e.g., stroke, spastic cerebral palsy).

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Post-traumatic complications include chronic regional pain syndrome, traumatic arthritis, motor dysfunction, muscular atrophy, joint stiffness, and malunion/nonunion fractures.

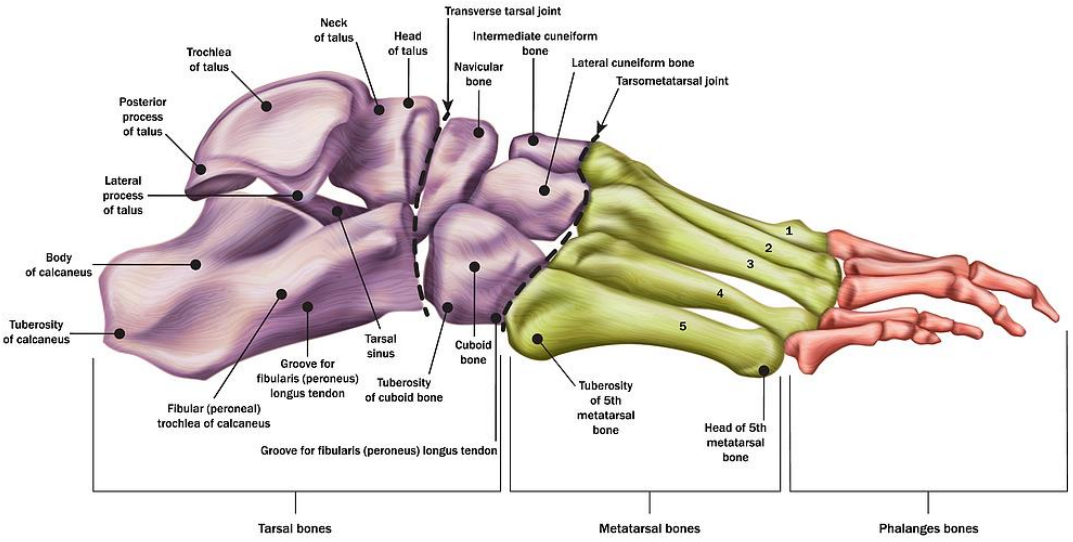

Figure 1: Anatomical structure of foot

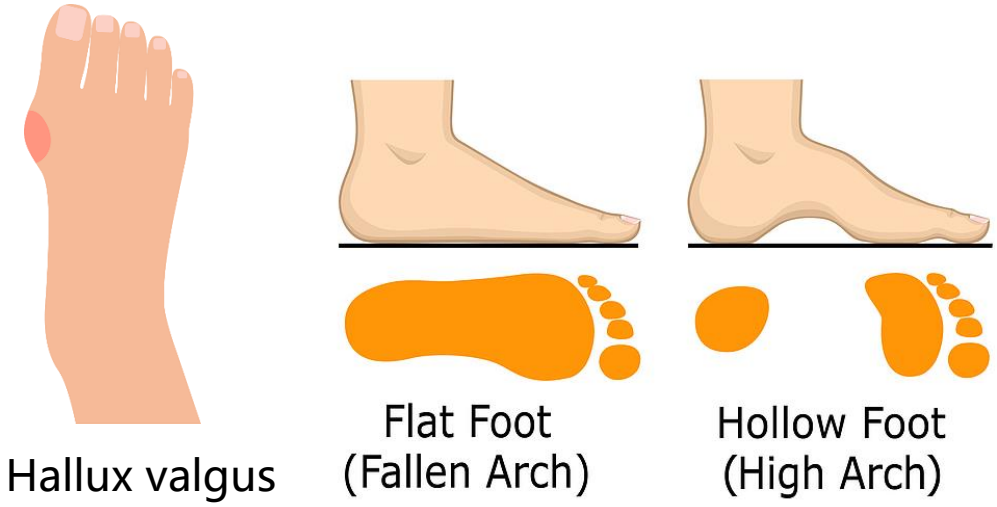

Figure 2: Pathological foot

Therefore, in response to the mechanisms and hazards of ankle health injuries mentioned above, the design of existing footwear products and accessories should fully consider the impact of human movement on the ankle, develop products and treatment equipment that can effectively inhibit ankle injuries, promote the health of human wearing shoes, and have profound social significance.

2. Research status

The development of existing ankle health products generally includes five categories: shoes, insoles, socks, accessories, and professional corrective equipment. Different products are suitable for the protection and treatment of ankle health problems[6-7]. Due to the limitations of domestic consumer attitudes and medical systems, the current emphasis on ankle health products by domestic consumers is far from sufficient, which seriously restricts the design and research and development efforts of enterprises and medical institutions on ankle health products. Especially for footwear products and their accessories, the design often only

considers the product style, and the protective and therapeutic effects of wearing them on ankle health problems are minimal.

The current research and development of ankle health products in China mainly focuses on two aspects: one is personalized ankle health equipment (ankle correction) tested, analyzed, and manufactured by professional medical institutions, which is a correction product specifically designed for ankle health problems[8-9]. Due to the fact that ankle health problems often do not endanger the body's health functions in the early stages and are not taken seriously, it is difficult for professional medical institutions' correction products to be effectively promoted in the market, which limits the development and maturity of the industry[10]. The other research and development of ankle health products is mainly focused on research institutes or shoe-making enterprises. Due to the lack of professional medical knowledge and testing equipment, there is a lack of relevant supporting data for the research and development of ankle health products, which seriously weakens the effectiveness of the products. At the same time, due to the lack of a professional image of professional medical institutions in the minds of consumers, it is also difficult to promote products in this field.

3. Innovative design

The research and development of foot and ankle clinical medical information collection system for medical terminals focuses on building a new paradigm of digital diagnosis and treatment. The system integrates multimodal data acquisition modules such as three-dimensional foot scanning, dynamic gait analysis and pressure distribution detection, and generates standardized clinical reports including biomechanical characteristics, pathological parameters and functional evaluation through intelligent algorithms. The platform supports interactive data annotation and cloud collaboration between doctors and patients, realizes structured storage and cross agency sharing of foot and ankle disease diagnosis and treatment data, provides accurate and quantitative basis for orthopedic footwear design, and effectively solves the problem of insufficient adaptability caused by the traditional footwear customization relying on empirical judgment.

The customized design database of health shoes based on clinical medical big data adopts a three-level mapping architecture of "pathological characteristics - functional requirements - design elements". The database integrates the foot and ankle disease model, foot shape parameters and biomechanical characteristics of patients, and uses parametric modeling technology to establish the association rules of foot support, pressure buffering, motion correction and other functional modules. Through the modular configuration system, the intelligent combination of sole curvature, midsole density, collar structure and other design parameters is realized to form a standardized design template library covering common diseases such as diabetic foot, flatfoot, heel tendinitis, and provide clinicians with a shoe prescription solution with both medical accuracy and production feasibility.

4. Research content and results

This study focuses on the collection of clinical medical data (including medical diagnoses, X-rays/CT scans, etc.) pertaining to diseased feet, and aims to develop a foot and ankle data collection system. This system integrates various multimodal data acquisition modules, such as high-precision 3D foot scanning, dynamic gait analysis, and pressure distribution detection (Figure 3). Leveraging a doctor-patient collaborative touch interaction platform, it enables gait video recording and pain area identification. The generated standardized medical report encompasses crucial clinical indicators like the foot arch index, joint mobility, and peak pressure. By constructing a digital solution encompassing screening, diagnosis, and therapeutic efficacy evaluation, this study provides a traceable quantitative basis for orthopedic footwear

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design, effectively addressing the adaptability blind spots inherent in traditional empirical customization methods.

Figure 3: Clinical medical data collection for pathological foot

In response to the technological upgrading needs in the field of foot and ankle orthopedics, we are committed to building a deep integration architecture between an intelligent IoT detection system and a multi-source medical database. By developing data interfaces for testing equipment, we have achieved standardized access for devices such as three-dimensional gait analyzers and dynamic plantar pressure plates, establishing a distributed IoT for foot and ankle detection. The system employs a time series database for millisecond-level data collection and integrates clinical diagnosis information to construct a multi-dimensional data cube encompassing biomechanical characteristics, pathological images, disease progression, and so on (Figure 4). Through the aforementioned research, we have established a foot and ankle clinical medical database focusing on sick feet, integrating clinical medical demand information with detection and analysis data, aiming to address the challenge of "shoemakers making shoes without evidence".

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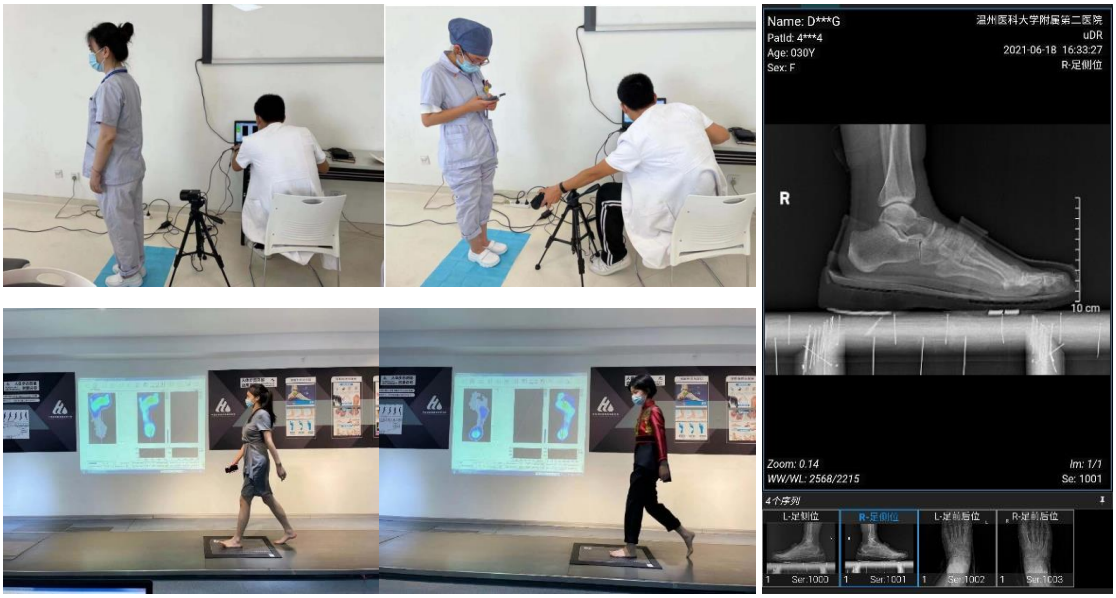

Figure 4: Real-time collection database for patients with foot condition

Figure 5: Basic database sample for customized design of ankle health shoes

Taking the sick foot as the logical main line, based on the clinical medical data, combined with the design elements such as style, the differentiated design strategy was studied, and the basic

database of customized design of foot and ankle health shoes composed of core modules such as shoe last was constructed to solve the dilemma of doctors without shoes. Figure 5 shows the customized design sample of foot and ankle health shoes.

5. Conclusion

This study successfully constructed an ankle health auxiliary diagnosis and treatment system based on multi-source medical data fusion, which effectively solved the industry dilemma of medical information separation in the field of traditional orthopedic shoes and appliances customization. Through the innovative intelligent data acquisition system, the multimodal data capture of 1820 clinical samples was realized. The medical database of sick foot was established, which integrated three-dimensional biomechanical characteristics, pathological images and diagnosis and treatment demand data, and built a digital closed loop covering screening diagnosis treatment. The parametric shoe last knowledge base developed based on the modular design strategy, through the clinical verification of 4 types and 22 types of customized shoes, confirmed that it can improve the biomechanical adaptation accuracy, shorten the diagnosis and treatment cycle, provide quantifiable engineering transformation path and intelligent decision support for the research and development of medical grade health shoes, and promote the transformation of the orthopedic industry from experience driven to data driven paradigm.

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