Clinical and Radiological Examination of the Foot and Ankle

The Path to Definitive Diagnosis

Siddhartha Sharma
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Editors

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ISBN 978-981-97-4201-1 ISBN 978-981-97-4202-8 (eBook)
https://doi.org/10.1007/978-981-97-4202-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Dedicated to our families

Foreword

It is with great pleasure that I provide the foreword to this comprehensive volume titled *Clinical and Radiological Examination of the Foot and Ankle: The Path to Definitive Diagnosis*. This body of work is authored by a distinguished group of international surgeons and scientists associated with the Foot & Ankle Research and Innovation Lab (FARIL) at Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA, as well as the FARIL International Initiative that spans multiple continents.

Having dedicated almost three decades to the field of orthopedic surgery and to the intricate subspecialty of foot and ankle most specifically, I continue to be awed by the complexities involved in accurately diagnosing and managing many of the disorders affecting this part of our anatomy. This book arrives as an essential resource to help bridge the existing knowledge gaps and foster a deeper understanding of the current clinical and radiological perspectives impacting the care of challenging foot and ankle pathology.

The contributors to this volume are friends and colleagues from around the world who have shared their wealth of experience and specific areas of expertise to enrich the pages of this book. Their insights broach many of the disease states affecting the foot and ankle patients we collectively serve, rendering this an invaluable educational care tool and practical guide for musculoskeletal clinicians, radiologists, and researchers alike. Each chapter has been crafted to reflect the latest advancements and methodologies in the examination and treatment of specifically controversial or challenging foot and ankle problems.

This publication also serves as an up-to-date educational scaffold for those who are actively training in the fields of orthopedic or radiological medicine. It underscores the importance of a nuanced approach to patient care and emphasizes diagnostic techniques that are pivotal in developing effective treatment plans.

As we continue to make strides in medical and surgical sciences, the cross-specialty collaboration demonstrated by this book is evidence of the significant progress that can be achieved when working in unison. I am confident that *Clinical and Radiological Examination of the Foot and Ankle: The Path to Definitive Diagnosis* will prove to be a cornerstone text for the current and future generations of healthcare professionals dedicated to improving patient outcomes in musculoskeletal care.

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Preface

The examination of the foot and ankle represents a unique challenge in the field of orthopedic surgery and musculoskeletal medicine. This intricate region, with its delicate balance of bones, tendons, ligaments, and joints, is susceptible to a myriad of pathologies that can manifest as complex disorders affecting mobility and quality of life. Hence, the journey to achieving a definitive diagnosis demands a comprehensive understanding of both clinical assessment and radiological interpretation.

Clinical and Radiological Examination of the Foot and Ankle: The Path to Definitive Diagnosis is a pioneering text designed to bridge the gap in resources dedicated to the examination of foot and ankle pathologies. Within these pages, we explore every facet of clinical and radiological evaluation, from fundamental principles to advanced diagnostic techniques, offering a systematic approach to understanding and diagnosing a wide spectrum of conditions affecting this crucial anatomical region.

This book is meticulously crafted to serve as a comprehensive guide for orthopedic surgeons, podiatrists, fellows, residents, and medical students interested in mastering the intricacies of foot and ankle examination. It integrates the latest evidence-based practices, providing detailed insights into the biomechanics, anatomy, and radiology essentials for accurate diagnosis and appropriate decision-making. Each chapter delves into specific pathologies, offering a blend of clinical wisdom and cutting-edge diagnostic methods.

The key features of this book include:

- A detailed exploration of relevant biomechanics, anatomy, and radiology fundamentals.
- In-depth coverage of physical examination techniques for common foot and ankle pathologies.
- Extensive collection of clinical photographs and radiological images, enhancing understanding and aiding in diagnostic accuracy.
- Examination of emerging technologies shaping the future of foot and ankle diagnostics.

This book has come to life through the collaborative efforts of the FARIL International Initiative affiliated with Foot & Ankle Research and Innovation Lab (FARIL), Massachusetts General Hospital, Harvard Medical School. The contributors to this book are experts in the field from around the world, each sharing valuable insights gained through years of clinical practice and research. By combining their expertise, we have created a resource that not only elucidates the complexities of foot and ankle examination but also provides practical guidance for achieving definitive diagnoses.

We invite you to embark on this journey with us—to delve into the nuances of foot and ankle pathology and equip yourself with the knowledge and skills needed to navigate the path to definitive diagnosis. Whether you are a seasoned practitioner seeking to refine your diagnostic acumen or a trainee eager to explore this captivating specialty, *Clinical and Radiological Examination of the Foot and Ankle: The Path to Definitive Diagnosis* promises to be an indispensable companion on your professional voyage.

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About the Editors

Siddhartha Sharma is Additional Professor of Orthopedic Surgery at the Postgraduate Institute of Medical Education and Research, Chandigarh, India. He specializes in foot and ankle surgery and limb lengthening and deformity correction.

He completed his Ph.D. at PGIMER, Chandigarh, and pursued a postdoctoral fellowship at the Foot & Ankle Research and Innovation Lab (FARIL) at Massachusetts General Hospital, Harvard Medical School, USA. Currently, he serves as the FARIL International Ambassador from India. He is faculty for AO Trauma and AO Alliance, teaching on various AO basic, advances, and foot and ankle courses. He also holds the position of Secretary at the North Zone Orthopaedic Association (India) and Joint Editor for ASAMI India. He has received numerous research grants internationally and nationally and has authored over 100 publications. He serves as the Associate Editor of the *Journal of Foot and Ankle Surgery* (Asia Pacific) and reviewer for several journals of international repute.

Soheil Ashkani-Esfahani is Assistant Professor of Orthopedic Surgery and the Director of the Foot & Ankle Research and Innovation Lab (FARIL) at Massachusetts General Hospital, Harvard Medical School, USA.

He is a renowned clinician-scientist who has several highly cited publications in world-renowned journals, patents, techniques, and lectures published and presented at various international platforms and events. As the director of research and innovation, he focuses on developing more accurate, faster, and less invasive diagnostic technologies and treatment methods for orthopedic conditions. His work encompasses new imaging technologies such as portable handheld ultrasound, weight-bearing CT scan, needle arthroscopy, using artificial intelligence (AI) in orthopedics, 3D modeling, and device development, patient-centered decision support, and patient-specific management methods.

He has served as the reviewer for globally distinguished journals such as *Foot and Ankle International*, *The Spine Journal*, and Foot and Ankle Surgery. He has received various grants, awards, and accolades from national and international societies and institutions such as AOFAS, EFAS, AAOS, NSF, Harvard Medical School, MIT, and various orthopedic industries. Moreover, he has trained tens of medical students, fellows, residents, and scientists, some of whom are current leaders in the orthopedic world.

Bedri Karaismailoglu serves as a foot and ankle surgeon and Assistant Professor of Orthopedics and Traumatology at Istanbul University-Cerrahpasa. He is the Director of the Cerrahpasa Research, Design, and Simulation Laboratory (CAST), focusing on integrating 3D technologies into healthcare. Previously, he worked at the Foot & Ankle Research and Innovation Lab (FARIL) at Mass General Hospital—Harvard University, Boston, USA, and currently serves as its International Ambassador in Turkey.

He has authored numerous peer-reviewed publications, delivers lectures globally, and has received prestigious honors and grants from organizations such as EFAS, SICOT, ISAKOS, and AOFAS. Actively engaged in international orthopedic associations, he serves as the Vice-Chair of the Asia Pacific Orthopaedic Association Young Surgeon's Forum and contributes as a reviewer for esteemed orthopedic journals.

Check for updates

General Principles and Basics

1

Ankit Dadra, Mandeep S. Dhillon, and Siddhartha Sharma

1.1 Introduction

The foot and ankle serve as the fundamental support structure of the human body, playing a pivotal role in maintaining our characteristic upright posture, and acting as the central point for transmitting the entire body's weight during walking. Comprising 26 bones and encompassing 33 articulations, the foot is designed to offer flexibility on uneven surfaces and to absorb the shocks generated during movement [1].

The intricate workings of this remarkable mechanism often go unnoticed and unappreciated until a malfunction or issue arises. When faced with a foot and ankle pathology, conducting a thorough yet focused examination becomes imperative for attaining an accurate orthopedic diagnosis. It is crucial to understand that diagnostic tests and imaging techniques should act as supplementary tools, and not as replacements of clinical assessments. The clinician must delve into a detailed patient history and conduct a thorough examination, considering the patient's overall health rather than just concentrating on the affected anatomical site. While various methodologies for foot and ankle examination exist, it is essential for orthopedic surgeons to formulate their own approach, ensuring they do not overlook critical examination points. This chapter outlines the fundamental principles of orthopedic clinical examination and offers a general overview of the examination of the foot and ankle. Specific examinations focused on particular pathologies will be discussed in subsequent chapters.

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S. Sharma et al. (eds.), *Clinical and Radiological Examination of the Foot and Ankle*, https://doi.org/10.1007/978-981-97-4202-8_1

We also encourage our readers to develop personalized examination approaches that encompass all essential aspects. Diverse practitioners may approach patients with foot or ankle issues differently, but several key components should be an integral part of a comprehensive examination. These include, but are not limited to, assessment of gait, examination of footwear and any orthotic devices in use, and evaluation of the foot and ankle in both standing and sitting positions, following a systematic "look, feel, and move" schema.

1.2 Prerequisites

1.2.1 Consent, Rapport, and Other Important Aspects

Before commencing an examination, it is imperative for a clinician to obtain the patient's consent and the patient's right to decline the examination must be respected. Maintaining proper hand hygiene is of paramount importance both before and after examining each patient, serving as a crucial measure to prevent the transmission of infections.

Given that certain orthopedic tests may be provocative or uncomfortable, establishing a strong rapport with the patient becomes essential prior to the examination. Building rapport with the patient can be effectively nurtured during the process of gathering the patient's medical history. As a general rule, tests that may provoke discomfort should be conducted toward the latter part of the examination. In the case of pediatric patients or children, having their caregiver or parents present can create a more comfortable and cooperative examination setting.

When female patients are being examined by male examiners, it is essential to have a chaperone or a relative of the patient present during the examination. This practice ensures that a respectful and secure environment is maintained throughout the examination process.

1.2.2 Adequate Exposure

To conduct a thorough examination, it is essential that the patient is appropriately undressed. This involves removing socks and shoes from both feet. If the patient is wearing pants or trousers, they should either be entirely removed, taking due care to cover the genitalia, or rolled up to the mid-thighs to fully expose the knees, legs, ankles, and feet from all angles—front, back, and sides. This comprehensive exposure is particularly critical because certain deformities may be concealed if the area is inadequately exposed. For instance, an equinus contracture at the ankle may not be readily apparent if there is a recurvatum deformity at the knee, and the foot might appear to have a normal plantigrade position even in the presence of a significant deformity if proper exposure has not been achieved (Fig. 1.1).

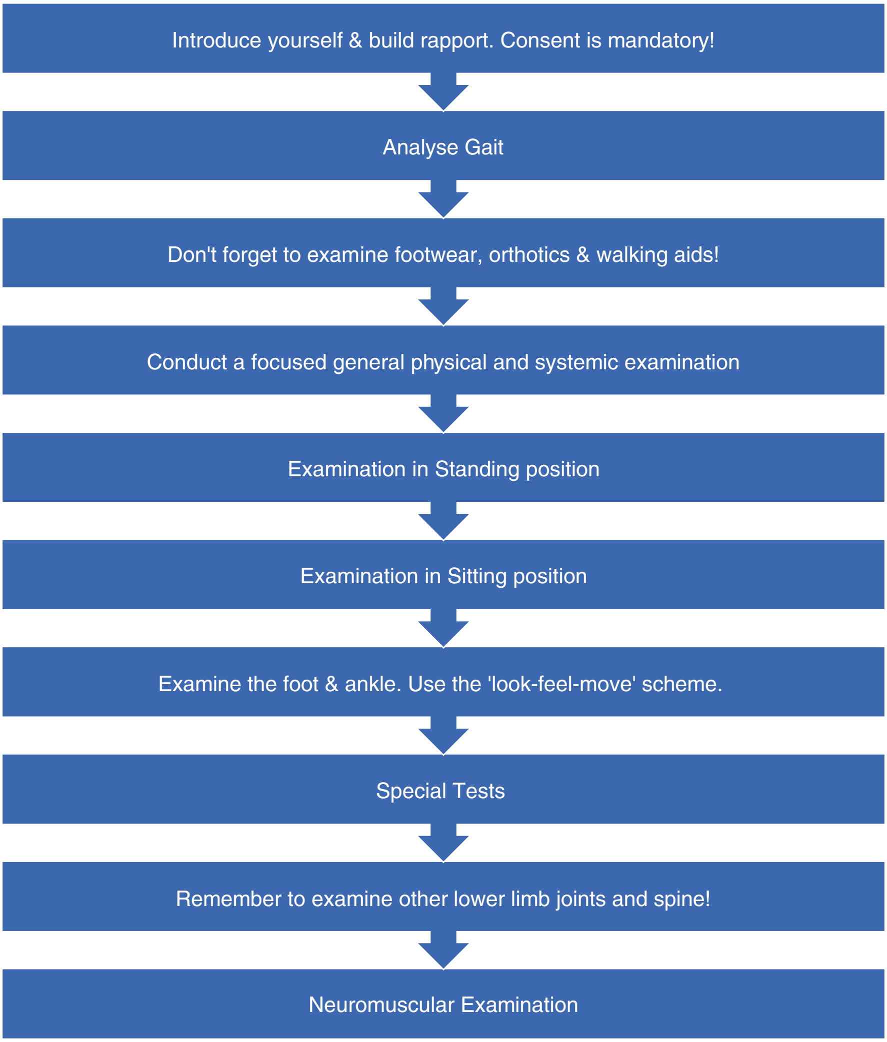

Fig. 1.1 The proposed scheme of foot and ankle examination

1.3 The Foot and Ankle Examination

After having obtained consent, as well as built a good rapport with the patient, we will now look at a general scheme of foot and ankle examination. As pointed out earlier, readers are encouraged to develop their own schemes, while ensuring that no important aspects are left out.

1.3.1 Analysis of Gait and Walking Aids

The authors like to begin the foot and ankle examination with a quick evaluation of the patient's gait. It is not within the scope of this chapter to discuss different gait types in detail. Nevertheless, it is essential to have the patient walk, as well as to record any unusual or pathological gait patterns.

Furthermore, it is of significance to take note of whether the patient is ambulating with a plantigrade foot or if there are any noticeable deformities affecting their walking pattern. Equally important is the evaluation of whether the patient relies on walking aids or assistive devices for support and whether they are capable of evenly bearing weight on both feet during the bipedal gait.

Any deviations or irregularities in the patient's gait should be subject to a more in-depth examination.

1.4 Analysis of Footwear

Examining the patient's choice of footwear is a frequently underestimated aspect of clinical assessment; however, it can yield valuable insights. A shoe is perhaps the most common orthotic devices, making it essential for a foot and ankle surgeon to possess familiarity with its components (Fig. 1.2). This knowledge also helps in recommending any necessary footwear modifications tailored to the patient's specific pathology.

Footwear may either be the source of a patient's complaints or hold important diagnostic clues. It is also imperative to take note of any atypical wear patterns on the shoes, as they may provide important information about the foot pathology in question. Wear patterns in common foot and ankle pathologies has been presented in Table 1.1. Furthermore, it is essential to observe specific shoe modifications, such

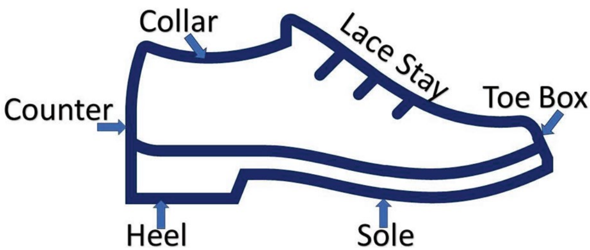

Fig. 1.2 Parts of a shoe

Table 1.1 Shoe wear patterns in different foot and ankle pathologies

Sr no.	Deformity	Wear patterns of shoe
1.	Cavovarus	Lateral border
2.	Flatfoot	Medial border
3.	Equinus	Front (toebox)
4.	Calcaneus	Heel

Table 1.2 Commonly used shoewear modifications

Shoewear modifications		
1.	Medial arch support	Pes planus
2.	Outer border raise	Cavo-varus deformity
3.	Metatarsal pads	Pes cavus/metatarsalgia
4.	Heel raise/sole lift	Limb length discrepancy/fixed equinus
5.	Rocker sole	Great toe arthritis/metatarsalgia, bursitis
6.	SACH (solid ankle cushion heel)	Hindfoot arthritis/ankle fusion, spurs
7.	Metatarsal bar	Metatarsalgia/Morton's neuroma/callosities/ plantar fasciitis

as lifts to address limb length discrepancies or accommodations for foot deformities. The examination should also encompass an evaluation of insoles or sole modifications when applicable (Table 1.2).

When assessing foot and ankle pathologies, it is also crucial to consider the use of any other orthotic devices by the patient. This includes items such as canes, axillary crutches, walkers, ankle–foot orthoses (AFOs), and foot inserts or insoles. These additional orthotic devices can have a significant impact on the patient's gait, stability, and overall orthopedic condition, and they may play a role in the diagnosis and treatment plan. Therefore, a comprehensive examination should encompass the evaluation of all relevant orthotic devices to ensure a thorough understanding of the patient's orthopedic needs.

1.5 General Physical Examination

A quick but focused general physical examination is invaluable and its importance cannot be overemphasized. Loss of eyebrows and typical facies in patient presenting with ulnar neuritis often bilateral and skin lesions is typical of leprosy [2]. "Moon" facies, protuberant abdomen, skin striae, and so on may well reveal chronic steroid intake as the etiology of avascular necrosis of the hip in a patient with hip pain [3]. Similarly, nicotine stains on the teeth and nails and atrophy of the nails indicate that the patient has been a chronic smoker and that his leg pain may be a result of vascular claudication due to Buerger's disease [4]. Bruising over the body, cigarette burn marks, and other "accidental" burn marks in a young child who presents with a history of multiple fractures may hint towards child abuse. Signs that may suggest spinal dysraphism such as the presence of a hairy patch, nevus (birthmark), lipoma (fatty mass), dimple, or sinus in the lumbar region should be looked for [5]. These physical findings might indicate underlying neurological issues that could contribute to foot and ankle problems. Beighton's scoring system should be employed to evaluate hyperlaxity of the joints in various parts of the body, which can provide valuable insights into the patient's condition and help guide the diagnosis and management of their foot and ankle deformities [6]. It is often helpful to revisit the general physical examination after examining the joint, in light of the etiological possibilities.

1.6 Systemic Examination

In addition to the musculoskeletal system, it is crucial to examine all other body systems. A routine and precise evaluation of the nervous, cardiovascular, respiratory, gastrointestinal, and urogenital systems should be developed. Referring to medical textbooks for detailed examination procedures of these systems is encouraged.

1.7 Examination of the Musculoskeletal System

In general, it is advisable to follow the *look-feel-move* scheme of examination for the musculoskeletal system.

1.7.1 Inspection (Look)

Adequate exposure of the area to be examined is essential to avoid missing critical information. It is essential to conduct a thorough inspection from multiple angles, encompassing views from the front, sides, and back in all cases. Specifically, when assessing the lower limbs, examinations should be performed both with the patient in a supine position and, whenever possible, in a standing position. This dual approach is vital as certain abnormalities become apparent only when the patient is bearing weight while standing. This should be standard practice whenever the patient's condition allows it, because weight-bearing assessments offer dynamic insights into joint function and can accentuate deformities, revealing their true extent and magnitude. This is particularly valuable when evaluating issues related to the lower limbs and their weight-bearing capacity (Fig. 1.3). Assessing the position of the heel with respect to the floor is best done from the back, allowing for the observation of any calf asymmetry as well as any swelling in the Achilles tendon or the posteromedial and posterolateral aspects of the ankle. Furthermore, from behind, it is possible to comment on the tibiocalcaneal angle, representing the alignment between the long axis of the tibia and the long axis of the os calcis. This angle is typically around 5° of valgus.

From behind, it is also feasible to evaluate the visibility of the forefoot, which is particularly relevant in cases of posterior tibial tendon disruption. This assessment includes checking for the "too-many-toes sign," where normally, about one and a half toes are visible [7]. If more toes are visible or there is an asymmetry between the two sides, it suggests a dropped arch or a varus/valgus deformity of the foot that requires attention. Detailed inspection of each joint will be covered in respective chapters.

Fig. 1.3 Examination of the foot and ankle from the front and back in a healthy subject. Note is made of the plantigrade position of both feet. The heels are in physiological valgus, as noted from the back

1.7.2 Palpation (Feel)

It is important to ensure that your hands are warm before making contact with the patient, especially in the case of pediatric patients. Palpation begins with assessing joint warmth, followed by tenderness evaluation. Given the complexity of the foot, which comprises 26 bones and numerous articulations, conducting a meticulous examination can indeed be overwhelming. To navigate this complexity effectively, it is valuable to engage the patient in the process by asking them to pinpoint the specific area of pain. This approach not only aids in identifying the exact location of tenderness but also provides valuable diagnostic clues. For example, tenderness in the sinus tarsi can be a significant clinical sign, as it often suggests injury or arthritis affecting the posterior facet of the subtalar joint. Detecting tenderness over the anterior process of the calcaneum is equally important, as fractures in this region can frequently go unnoticed in routine X-ray examinations. Palpation techniques for each joint are discussed in subsequent chapters with relevant pathologies.

1.7.3 Movements and Measurements (Move)

Active and passive movements of the joint under examination should be checked. Comparison with the normal side helps to determine the extent of movement. The “arc of movement” is the sum of movements in any plane, accounting for any deformities. Ankle movement, both active and passive, is assessed with the patient seated, knees flexed and extended, preferably with their legs hanging off the examination table. The typical ankle range of motion comprises around 20° dorsiflexion and 40° plantarflexion [8]. If the ankle cannot reach a neutral position during plantarflexion, it is termed a “calcaneus” position.

When an ankle cannot be dorsiflexed to a neutral position, it is described as being in equinus. In cases where the Achilles tendon complex appears to contribute to this deformity, it becomes crucial to identify whether the gastrocnemius or soleus muscle is responsible for the limited dorsiflexion. This differentiation can be achieved through the Silfverskiold test [9]. It involves assessing ankle dorsiflexion first with the hip and knee extended and then with the hip and knee flexed. If dorsiflexion improves with knee flexion, it suggests a gastrocnemius contracture.

When evaluating passive movement in the foot and ankle, it is important to position the forefoot in supination to rule out dorsiflexion at Chopart’s and the midtarsal joints. Additionally, inverting the heel to stabilize the subtalar joint helps ensure that the passive movement assessment is isolated to the ankle joint itself. This approach enhances the accuracy of the examination by focusing on the specific joint of interest and excluding movements from adjacent joints. Subtalar movement can be evaluated with the foot hanging off the edge of the examination table or with the patient lying face down. Specific joint movements are discussed in respective chapters.

1.7.4 Special Tests

Each joint or anatomical area has unique clinical tests for diagnosing various pathologies. The selection of relevant “special” tests depends on the differential diagnoses considered such as the Coleman block test for cavovarus foot, single heel raise test for tibialis posterior dysfunction, and Thompson test for Achilles tendon rupture. Specific tests for each joint are discussed in respective chapters.

1.7.5 Neuromuscular Examination, Vascular Status, and Regional Lymph Nodes

A detailed neuromuscular examination is crucial for assessing foot and ankle conditions. This assessment includes evaluating motor power and sensations using the MRC grading system, checking peripheral pulses, and examining regional lymph nodes. Assessing major muscle groups is critical, with a primary focus on ankle dorsiflexors, plantar flexors, foot evertors, invertors, and toe flexors and extensors. These muscle groups are integral to foot and ankle function, influencing stability, mobility, and balance, and it is essential to check for strength, coordination, and flexibility in these muscles. Any weakness, asymmetry, or limited range of motion may aid in guiding appropriate treatment and rehabilitation strategies for individuals with foot and ankle pathologies. When patients report neurological symptoms in the foot, it is vital to rule out lumbar nerve root tension. Assessing for clonus helps distinguish between upper and lower motor neuron lesions, and sensory evaluation aids in identifying patients at risk for ulceration and differentiating between conditions such as polio and spina bifida, both involving lower motor neuron lesions.

Besides considering the possibility of distant neurological diseases affecting the foot and ankle, it is also essential to be aware of specific entrapment neuropathies in this area that can cause symptoms such as numbness, tingling, and muscle wasting. Tarsal tunnel syndrome, resulting from posterior tibial nerve compression, causes plantar pain, paresthesia, and numbness. Deep peroneal nerve entrapment, often beneath the inferior extensor retinaculum, is linked to trauma and causes dorsum foot pain extending to the first web space. Superficial peroneal nerve entrapment occurs when the nerve exits the lateral compartment, leading to calf pain and numbness on the foot's dorsum. Palpating the common peroneal nerve around the fibula's neck is essential when deep or superficial peroneal nerve entrapment is suspected. Other entrapment neuropathies, such as sural nerve entrapment and lateral plantar nerve branch entrapment, should be considered if common causes are ruled out.

1.7.6 Examination of Adjacent Joints

It is imperative to examine joints neighboring the affected joint as part of a comprehensive evaluation. The primary pathology can either impact multiple joints or stem from an adjacent joint. For instance, hip pain can result in flexion deformities in the hip and knee, while pain in the knee may actually be referred from the hip and pain in the leg may originate from a prolapsed intervertebral disc. Rheumatoid arthritis may result in flexion deformities of the hip and knee, which can alter the foot and ankle biomechanics. In essence, examining adjacent joints is not merely a suggestion but a crucial component in ensuring precise diagnoses and formulating effective treatment strategies in orthopedic practice.

1.8 Conclusion

In conclusion, when faced with foot and ankle pathology, a thorough examination is imperative for accurate orthopedic diagnosis. While diagnostic tests and imaging techniques have their place, they should complement, not replace, clinical assessments. It is vital to engage patients in the examination process, considering their overall health and not just focusing on the affected area. The proposed scheme of examination, covering gait analysis, footwear assessment, general physical examination, systemic examination, and musculoskeletal examination, provides a comprehensive approach. Orthopedic surgeons must develop their own personalized examination methods while ensuring that they do not overlook essential examination points. Overall, a meticulous examination is essential to unravel the intricate complexities of foot and ankle pathologies and guide effective treatment strategies.

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Biomechanics of the Foot and Ankle

2

Bugra Gullu, Omer Subasi, and Lercan Aslan

2.1 Introduction

The foot and ankle play a crucial role in providing stability, adaptability, and efficient locomotion for the human body. This complex system is responsible for absorbing and translating forces while maintaining the whole-body stability. The complexity of these joints arises because their axes cannot be simply explained by coronal, sagittal, and axial movements. Nearly all joints in the foot and ankle have their own axis, thus resulting in the movements becoming combined. Understanding the biomechanics of the foot and ankle is essential for diagnosing and treating common pathologies and improving overall foot health. In this article, we will explore the structural organization and kinematics of the foot and ankle, as well as the passive stability and muscle control that contribute to its function.

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S. Sharma et al. (eds.), *Clinical and Radiological Examination of the Foot and Ankle*, https://doi.org/10.1007/978-981-97-4202-8_2

2.2 Functional Anatomy

2.2.1 Talocrural (Ankle) Joint

The talocrural (ankle) joint is a hinge-type joint between the dome of the talus, medial and lateral malleoli, and tibial plafond. The talus is shaped like a truncated cone, or frustum, with the apex directed medially [1]. The talus is 4.2 mm wider anteriorly than posteriorly (Fig. 2.1) [2].

Due to the greater width of the talus in its lateral portion, the diameters of the circles passing through the medial and lateral joint surfaces vary. Consequently, despite ankle joint movement primarily occurring in the sagittal plane, the axis of rotation is not fixed. There are variable rotation axes during plantar flexion and dorsiflexion of the ankle. During ankle dorsiflexion, the axis of rotation is inferior and lateral, whereas as the ankle moves into plantar flexion, it shifts medially [3].

The normal range of dorsiflexion (DF) at the ankle joint is approximately 10°–20°. The normal range of plantar flexion (PF) is around 45°–50°. Although clinically insignificant, there are ankle movements in the transverse and coronal

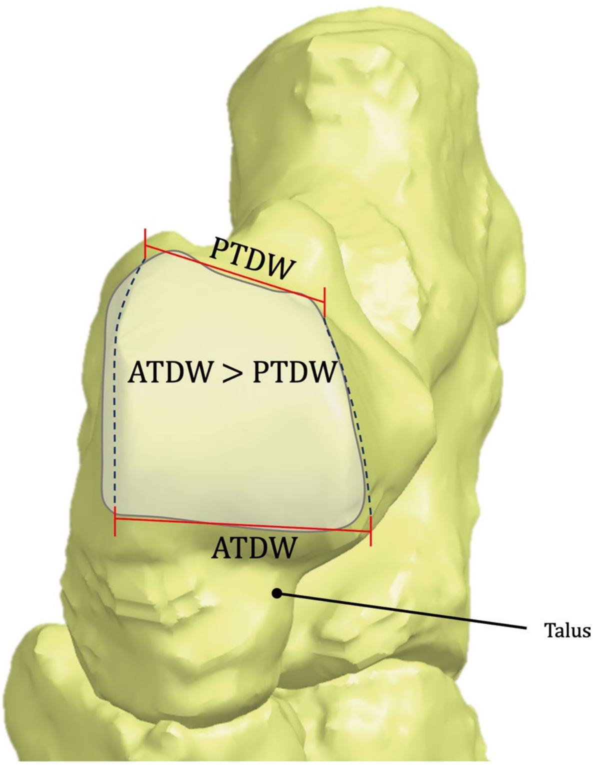

Fig. 2.1 The view of the talar dome that shows the anterior portion is wider than the posterior portion

planes as well. During ankle dorsiflexion, a 5°–6° external rotation is observed in the talus [4]. This rotation is reversed during plantar flexion. In the coronal plane, minimal inversion has been reported during both dorsiflexion and plantar flexion. In addition, the movement of the lateral malleolus also occurs, which is a result of the anterior portion of the talus dome being wider. With ankle dorsiflexion, the fibula translates laterally moving away from the tibia and maintaining the continuity of the mortise. Conversely, during plantar flexion, it moves medially toward the tibia.

2.2.2 Subtalar Joint

The subtalar joint is situated between the talus and the calcaneus: the anterior, middle, and posterior facets on the plantar surface of the talus and corresponding facets of the dorsal surface of the calcaneus make up the joint contact areas. Talus' convex head articulates with the concave surface of the calcaneus, allowing for complex multiplanar motion (Fig. 2.2).

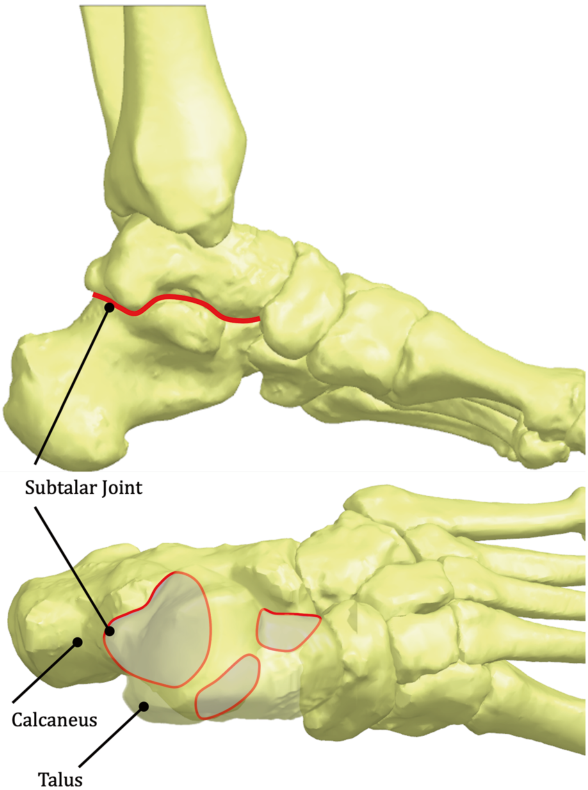

Fig. 2.2 Articulations between talus and calcaneus, consisting of anterior, middle, and posterior facets

The subtalar joint axis is often described as an "oblique axis" because it does not align with any one cardinal plane. Instead, it is an inclined axis that runs from posterior–superior to anterior–inferior through the talus. This axis is roughly oriented at an angle of 42° to the horizontal and about 16° to the sagittal plane [1, 5] (Fig. 2.3). This unique orientation facilitates motion in all three planes, with pronation, abduction, and extension occurring concurrently, just as supination, adduction, and flexion occur simultaneously. The range of motion of the subtalar joint is, approximately, 25°–30° for inversion and 5°–10° for eversion [5] (Fig. 2.4).

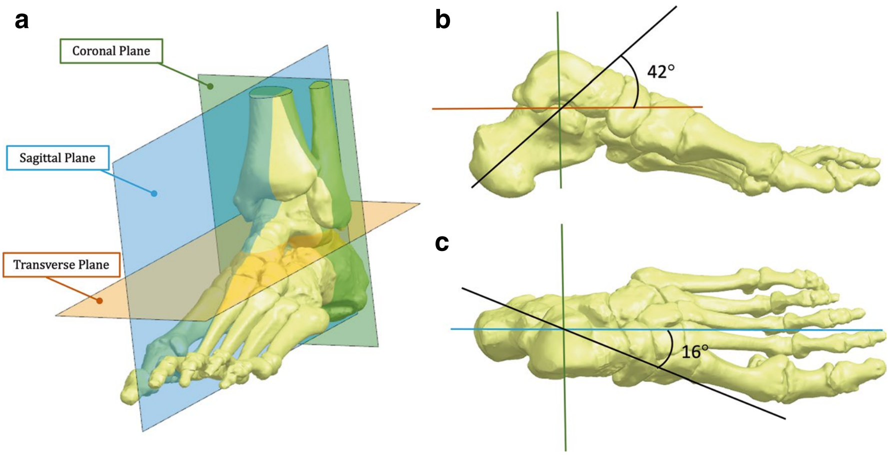

Fig. 2.3 (**a**) The standard planes of the foot. The subtalar joint's axis according to horizontal (**b**) and sagittal planes (**c**)

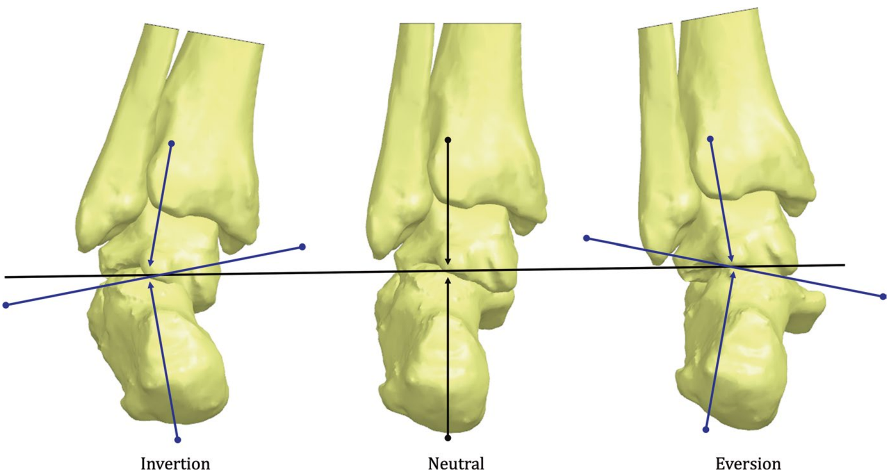

Fig. 2.4 Movement of the subtalar joint

2.2.3 Midtarsal Joint

The foot can be divided into three sections: hindfoot, midfoot, and forefoot (Fig. 2.5). The midtarsal joint, also known as Chopart's joint or transverse tarsal joint, is a complex articulation between hindfoot and midfoot. It consists of talonavicular and calcaneocuboid joints. The calcaneocuboid joint lies on the lateral side of the foot facilitates side-to-side movement and contributes to the transverse arch of the foot. The talonavicular joint is positioned on the medial side and assists in creating the medial longitudinal arch.

The midtarsal joint's movement is characterized by a combination of rotations around two primary axes: the longitudinal axis and the oblique axis. The longitudinal axis of the midtarsal joint runs from posterolateral to anteromedial. This axis slopes upward anteriorly 15° and is medially deviated by 9° [6]. The movement of the longitudinal axis is that of pronation–supination. Some abduction occurs in combination with pronation and, likewise, some adduction with supination. The oblique axis runs from posterolateral to anteromedial as well, more vertically with respect to the longitudinal axis. The axis is oriented at 52° in the sagittal plane and 57° in the coronal plane (Fig. 2.6) [6]. The movement created by the oblique axis is that of plantar flexion–adduction and dorsiflexion–abduction combinations. The range of motion of the midtarsal joint is 8° of rotation around the longitudinal axis and 22° around the oblique axis. The gross motion is 5°–10° for inversion to 10°–15° for eversion.

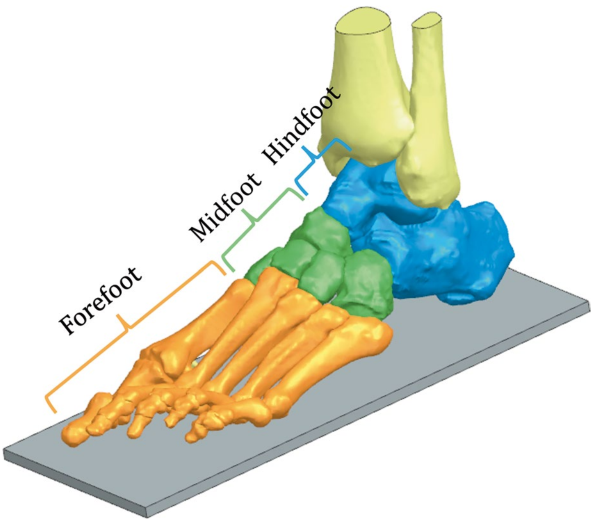

Fig. 2.5 The three sections of foot

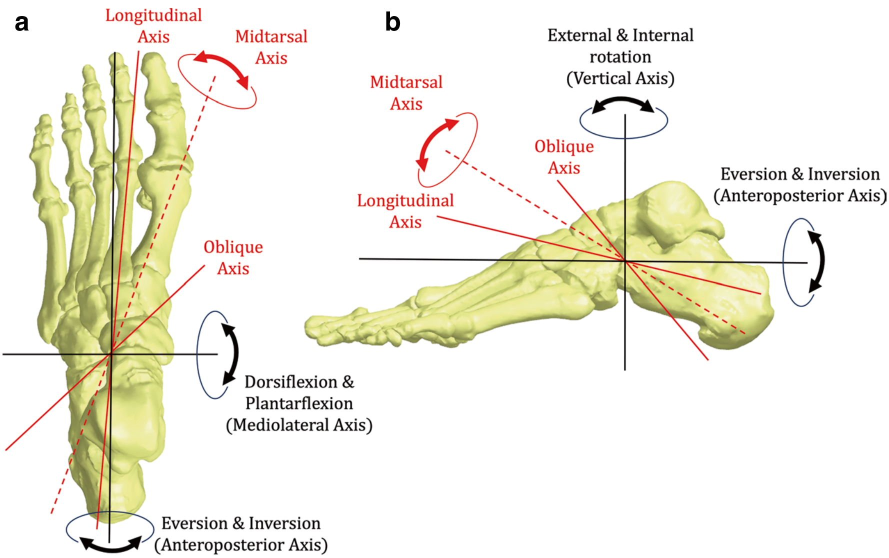

Fig. 2.6 Axes of the midtarsal joint on AP view (**a**) and lateral view (**b**)

2.2.4 Metatarsophalangeal and Interphalangeal Joints

The metatarsophalangeal (MTP) joints are located between the metatarsal bones and the proximal phalanges of the toes. The MTP joints are synovial hinge joints, allowing primarily flexion and extension. The interphalangeal (IP) joints are located between the phalanges of the toes. Each toe, except the hallux, possesses two IP joints: the proximal interphalangeal (PIP) joint and the distal interphalangeal (DIP) joint. Similar to the MTP joints, the IP joints are primarily synovial hinge joints, allowing flexion and extension movements.

At the MTP joints, the normal range of flexion is approximately 40°–60° and extension is 20°–30°. The normal range of flexion at the PIP joint is around 20°–70°, while the extension is usually around 0°. The normal range of flexion at the DIP joint is approximately 25° and extension is limited due to the shape of the joint surfaces [7]. For the hallux, the normal range of active MTP flexion is 23°, extension is 71°; active IP flexion is 46° and extension is 12° [8].

2.2.5 Arches of the Foot

The arches of the foot are formed by the arrangement of bones, ligaments, tendons, and muscles, collectively creating a dynamic and adaptable foundation. The human foot contains three main arches: the medial longitudinal arch, the lateral longitudinal arch, and the transverse arch (Fig. 2.7).

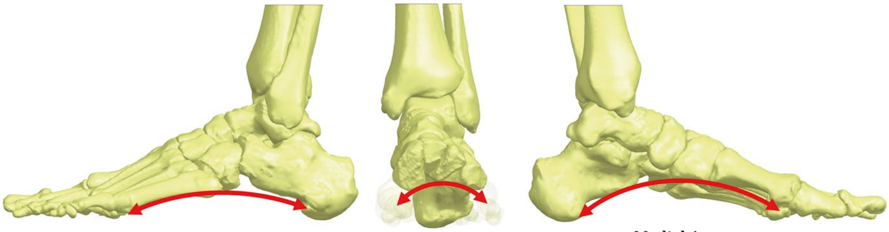

Fig. 2.7 Arches of the foot

The medial longitudinal arch is the most prominent and recognizable arch of the foot. It spans from the heel to the forefoot and consists of several key components. The calcaneus forms the posterior base of the arch, while the talus rests on the calcaneus and acts as the keystone; navicular, cuneiforms, and first, second, and third metatarsals form the rest of the arch. It is supported by the soft tissues of the spring ligament (plantar calcanea navicular ligament), deltoid ligament, posterior tibial tendon, plantar aponeurosis, and flexor hallucis longus and brevis muscles.

Two models have been proposed to explain the medial longitudinal arch's load-bearing mechanism: the Truss and Beam [9]. The Truss model suggests that the arch is a triangular structure, consisting of two columns and a cord at the base. The structure connecting the bottom two corners of the triangle is the plantar fascia, and the point at the top where the force originates from is the talus. When a force is applied, the load is distributed to the columns, causing them to separate. The tension in the plantar fascia prevents this separation and ensures an even distribution of the load. The Beam model, on the other hand, works like a classical Roman arch. With a vertical load, the convex side of the beam creates compressive forces, while on the concave side, tensile forces emerge, and the load is distributed across the beam.

The lateral longitudinal arch is located on the lateral side of the foot and is lower and flatter than the medial arch. It consists of the calcaneus, cuboid, and the fourth and fifth metatarsals. It is described as the only true Roman arch of the foot, the cuboid being the keystone [10].

The existence and nature of the transverse arch of the human foot are subjects of controversy. Some sources suggest that this arch runs horizontally across the midfoot, perpendicular to the longitudinal arch, and is formed by the tarsal bones, while others propose it is formed by the metatarsals [11–13]. Under non-weight-bearing conditions, the midfoot takes on an arcuate structure. However, in weight-bearing situations, this structure is not consistently observed [14]. As a result, the transverse arch of the foot and its functionality remain a subject of debate.