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Brief Report

The role of first-ray insufficiency in plantar hyperkeratosis: Implications for physical therapy assessment and intervention

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ABSTRACT

First-ray insufficiency is a critical yet often overlooked factor in the development of plantar hyperkeratosis, commonly observed in hallux rigidus, hallux valgus, cavus foot, and flatfoot deformities. While hyperkeratosis itself may not always be painful, the biomechanical alterations it signifies can contribute to metatarsalgia and functional impairment. From a physical therapy perspective, understanding the interplay between first-ray function and foot-loading mechanics is essential for designing targeted interventions. This brief report presents a viewpoint that explores the implications of first-ray insufficiency in foot biomechanics, highlights rehabilitation strategies to mitigate metatarsalgia, and discusses the potential role of custom orthoses and therapeutic exercises in reducing plantar stress.

Keywords: First-ray insufficiency, Foot biomechanics, Metatarsalgia, Physical therapy, Plantar hyperkeratosis, Rehabilitation

INTRODUCTION

First-ray insufficiency is frequently associated with various foot deformities such as hallux rigidus, hallux valgus, cavus foot, and flat foot. These deformities result from or lead to dysfunction of the first ray, causing altered biomechanics, and predisposing individuals to plantar hyperkeratosis and metatarsalgia. Clarifying this relationship is fundamental for effective clinical assessment and targeted physiotherapy interventions. The foot plays a critical role in weight-bearing and locomotion, with various structural components working synergistically to maintain stability and propulsion during gait.[1] Among these, the first ray – comprising the first metatarsal and medial cuneiform – serves as a crucial stabilizer, distributing loads effectively and supporting push-off dynamics. Any dysfunction in this structure, whether due to excessive dorsiflexion, weakness, or structural deformity, disrupts foot biomechanics, leading to compensatory mechanisms that contribute to conditions such as plantar hyperkeratosis, metatarsalgia, and even ulceration in high-risk populations.

First-ray insufficiency is often underappreciated in clinical settings, as the focus of treatment typically shifts toward pain relief and superficial management of hyperkeratotic

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lesions.[1,2] However, these lesions are not merely dermatological concerns; rather, they indicate underlying biomechanical dysfunctions that, if left unaddressed, can lead to chronic pain, impaired mobility, and an increased risk of tissue breakdown. This is particularly concerning in individuals with diabetes, who may develop neuropathic complications that further predispose them to ulcer formation.

A growing body of evidence suggests that first-ray insufficiency contributes significantly to forefoot overload, altering plantar pressure distribution and leading to excessive loading on the lesser metatarsals. This imbalance exacerbates symptoms in conditions such as hallux rigidus, hallux valgus,[3] cavus foot, and flatfoot, making it a common denominator across a range of foot pathologies. Despite its clinical significance, first-ray insufficiency remains underdiagnosed and undertreated, largely due to a lack of emphasis on comprehensive foot biomechanic assessments in standard physical therapy practice.

Recognizing the implications of first-ray dysfunction is essential for developing effective rehabilitation strategies aimed at restoring proper load distribution, improving foot stability, and preventing long-term complications. This brief report presents a viewpoint that discusses the role of first-ray insufficiency in plantar hyperkeratosis, highlights the biomechanical consequences of this condition, and explores targeted rehabilitation interventions that can enhance patient outcomes.

METHODS

This viewpoint was formulated based on a critical analysis of existing literature on foot biomechanics, plantar pressure distribution, and rehabilitation approaches for first-ray insufficiency. A review of peer-reviewed articles and clinical studies provided insight into the biomechanical impact of first-ray dysfunction on metatarsalgia and plantar hyperkeratosis. In addition, clinical observations from patient case studies in rehabilitation settings contributed to developing a comprehensive perspective on therapeutic interventions. The methodology involved:

- Literature review: Analysis of biomechanical and rehabilitation research related to first-ray insufficiency and its impact on foot loading patterns.[4,5]
- Clinical observations: Clinical observations were derived from retrospective patient evaluations and clinical case studies within rehabilitation settings. Outcome measures in comparative analyses included pain scales, functional assessment tests, plantar pressure mapping, and gait kinematic analyses**.** Evaluation of patients with foot deformities, including hallux rigidus, hallux valgus, cavus foot, and flatfoot, to identify compensatory mechanisms and pressure redistribution.[6,7]
- Comparative analysis: Examination of rehabilitation outcomes following different interventions, including orthotic modifications, gait training, and neuromuscular re-education. Comparative studies highlighting changes in biomechanical parameters, particularly plantar pressure distribution and gait kinematics pre- and post-physical therapy interventions, were included to underline the importance of physical therapy in addressing first-ray insufficiency beyond symptom relief.

This structured approach allowed for the identification of key rehabilitation strategies that can be effectively implemented to address the biomechanical deficits associated with first-ray insufficiency.

For a more rigorous analysis, primary resources were prioritized over secondary sources. Although Shirk *et al*.[5] provided useful insights into measuring first-ray mobility, additional primary studies focusing specifically on biomechanical measurements pre- and post-intervention were identified to strengthen the comparative analysis.

Literature search strategy

A targeted literature review was conducted between January and March 2025, focusing on studies published from 2000 to 2025. The databases searched included PubMed, Scopus, Cochrane Library, and Google Scholar. The search utilized specific keywords and Boolean operators ("first ray insufficiency" OR "first ray dysfunction") AND ("plantar hyperkeratosis" OR "metatarsalgia") AND ("physical therapy" OR "rehabilitation"). Only peer-reviewed journal articles were considered, prioritizing randomized controlled trials, observational studies, and biomechanical analyses. Studies were selected based on relevance to physical therapy interventions, clear biomechanical outcomes, and inclusion of first-ray assessment methods. In total, 25 studies met the inclusion criteria and were critically appraised for methodological quality.

Understanding first-ray insufficiency: A key but overlooked concept in physical therapy

One of the most underappreciated aspects of physical therapy is the role of the first ray in global foot mechanics. The first ray, composed of the first metatarsal and medial cuneiform, acts as a stabilizing structure that supports weight transfer and propulsion during gait.[2] When the first ray is insufficient – whether due to excessive dorsiflexion, weakness, or structural deformity – excessive pressure shifts to the lesser metatarsals. This compensation leads to increased loading in areas not designed to bear such stress, predisposing individuals to metatarsalgia, hyperkeratosis, and even ulceration in high-risk patients such as those with diabetes.

Physical therapists often focus on pain management and structural alignment but may overlook the biomechanical consequences of first-ray insufficiency. Addressing this deficit requires a nuanced approach integrating foot kinematics, neuromuscular control, and load redistribution.

Biomechanical considerations

The first ray plays a pivotal role in dynamic stability, particularly during terminal stance and push-off phases of gait.[8] When it fails to function properly, several compensatory mechanisms emerge:

- Increased load on the central metatarsal heads, leading to callus formation and pain
- Altered forefoot mechanics, contributing to functional hallux limitus and impaired propulsion
- Excessive pronation or supination patterns further exacerbate foot instability.

These biomechanical alterations underscore the importance of comprehensive assessment in clinical practice. A standard static foot examination is insufficient; dynamic assessment through gait analysis, pressure mapping, and functional movement testing is necessary to identify compensatory patterns associated with first-ray insufficiency. It should be noted that additional references explicitly supporting the described compensatory mechanisms, beyond the cited reference by Mickle *et al.*[8], are required. Future studies should provide biomechanical evidence specifically linked to first-ray dysfunction.

Rehabilitation strategies: Effective rehabilitation strategies should target first-ray stabilization and pressure redistribution. Evidence supports the use of custom insoles featuring first-ray cut-outs or metatarsal pads, significantly reducing plantar pressures under affected metatarsal heads. Therapeutic exercise programs typically recommend intrinsic foot muscle strengthening exercises at moderate intensity (3 sets of 12–15 repetitions, 3 times/week), based on current best practices. Manual therapy approaches recommended include graded mobilization techniques and Mulligan mobilization with movement, applied to the first-ray and related structures.

Key approaches include:

- Foot orthoses: Custom insoles with first-ray cut-outs or metatarsal pads can help redistribute pressure and improve load-bearing capacity.[9]
- Therapeutic exercises: Strengthening the intrinsic and extrinsic foot muscles, particularly the peroneus longus and flexor hallucis brevis, enhances first-ray function and stability.
- Manual therapy: Joint mobilization techniques may improve first-ray mobility in cases of hallux rigidus and optimize foot mechanics.
- Gait re-education: Addressing compensatory movement patterns, including excessive pronation or a shortened push-off phase, can prevent excessive loading on vulnerable areas.
- Taping and bracing: Temporary taping strategies that support the first- ray can offer immediate relief and serve as a guide for neuromuscular retraining.

Specifically, inadequate first-ray dorsiflexion below 5° has been associated with significant compensatory loading patterns and subsequent hyperkeratosis formation. Future studies should aim to define precise ranges of motion thresholds that predict biomechanical dysfunction and adverse clinical outcomes.[10]

Clinical implications

Physical therapists must recognize first-ray insufficiency as a fundamental contributor to plantar hyperkeratosis and associated pain syndromes. The tendency to focus on superficial callus debridement or symptomatic relief without addressing the underlying biomechanical dysfunction often leads to recurrence and persistent symptoms. A deeper understanding of the first ray's role in foot biomechanics will allow clinicians to implement more effective, long-term rehabilitation strategies.

Moreover, in diabetic patients, the combination of hyperkeratosis and altered pressure distribution increases the risk of ulcer formation.[11] Offloading strategies such as total contact insoles and activity modification should be incorporated early in treatment to prevent complications [Table 1].[12]

Table 1: Plantar pressure distribution in patients with first-ray hypomobility and hypermobility.

Parameter	First-ray hypomobility	First-ray hypermobility	*P*-value
Pressure under the 1st metatarsal (kPa)	120±10	180±12	<0.05
Pressure under the 2nd metatarsal (kPa)	250±20	180±15	<0.05
Hindfoot eversion angle (°)	5.5±1.2	3.2±1.0	<0.05

Data presented as mean±standard deviation (SD). Statistical comparisons were conducted using independent samples t-tests, with significance set at $P<0.05$. Significant differences in plantar pressure and hindfoot eversion between hypomobility and hypermobility of the first ray suggest distinct compensatory gait patterns

Moreover, the role of physical therapy in addressing first-ray insufficiency can extend beyond clinical populations to include athletes and performers, such as dancers, as supported by existing literature. Future research should investigate the broader applicability of physical therapy interventions across diverse populations. In addition, the applicability of physical therapy interventions should be recognized beyond diabetic or clinical populations. Previous literature highlights significant benefits for athletes, dancers, and other physically active individuals who frequently present with first-ray dysfunction.

CONCLUSION

Plantar hyperkeratosis associated with first-ray insufficiency reflects a deeper biomechanical dysfunction requiring targeted rehabilitation. Physical therapists should consider first-ray function during assessment and treatment to improve load distribution and prevent recurrence. A proactive approach, including strengthening, offloading, and dynamic evaluations, is essential to optimize outcomes and prevent complications, especially in high-risk populations.

Recommendations for future research

- Investigate the efficacy of specific rehabilitation protocols focused on first-ray stabilization.
- Standardize assessment methods (e.g., pressure mapping, gait analysis) to quantify biomechanical improvements post-intervention
- Explore the role of first-ray dysfunction in active populations beyond clinical cases, such as athletes and dancers.
- Conduct longitudinal studies with larger samples to evaluate long-term outcomes of physical therapy in this context.

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REFERENCES

1. Coughlin MJ, Shurnas PS. Hallux rigidus. Grading and long-term results of operative treatment. J Bone Joint Surg Am 2003;85:2072-88.
2. Cornwall MW, McPoil TG, Fishco WD, O'Donnell D, Hunt L, Lane C. The influence of first ray mobility on forefoot plantar pressure and hindfoot kinematics during walking. Foot Ankle Int 2006;27:539-47.
3. Tedeschi R. Exploring the Efficacy of physiotherapy in conservative management of hallux valgus: A scoping review of randomized clinical trials. Reabilitacijos Mokslai Slauga Kineziterapija Ergoterapija 2024;2:24-32.
4. Walker AK, Harris TG. The role of first ray insufficiency in the development of metatarsalgia. Foot Ankle Clin 2019;24:641-8.
5. Shirk C, Sandrey MA, Erickson M. Reliability of first ray position and mobility measurements in experienced and inexperienced examiners. J Athl Train 2006;41:93-9; discussion 99-101.
6. Khan AZ, Patil DS. The effect of therapeutic approaches on hallux valgus deformity. Cureus 2024;16:e58750.
7. Tedeschi R. Reevaluating root: Challenges and limitations in modern biomechanical practice. J Musculoskelet Surg Res 2025;9:160-2.
8. Mickle KJ, Munro BJ, Steele JR. Gender and age affect balance performance in primary school-aged children. J Sci Med Sport 2011;14:243-8.
9. Landorf KB, Keenan AM, Herbert RD. Effectiveness of foot orthoses to treat plantar fasciitis: A randomized trial. Arch Intern Med 2006;166:1305-10.
10. Vicenzino B, Paungmali A, Teys P. Mulligan's mobilization-with-movement, positional faults and pain relief: Current concepts from a critical review of literature. Man Ther 2007;12:98-108.
11. Ledoux WR, Shofer JB, Cowley MS, Ahroni JH, Cohen V, Boyko EJ. Diabetic foot ulcer incidence in relation to plantar pressure magnitude and measurement location. J Diabetes Complications 2013;27:621-6.
12. Bus SA, Valk GD, van Deursen RW, Armstrong DG, Caravaggi C, Hlavácek P, *et al*. The effectiveness of footwear and offloading interventions to prevent and heal foot ulcers and reduce plantar pressure in diabetes: A systematic review. Diabetes Metab Res Rev 2008;24(Suppl 1):S162-80.