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Foot Morphological Characteristics among Elite Male Kenyan Rugby Union Players: A Cross-Sectional Study

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Abstract

Purpose: Foot morphology refers to structural foot characteristics, including length, width, arch height, and posture, which directly govern biomechanical load distribution and dynamic stability during high-impact sports. Despite its relevance to athletic performance profiling and injury screening, anthropometric foot baselines for elite rugby union players remain heavily limited within African populations and the Kenyan context.

Methodology: A cross-sectional descriptive study voluntarily evaluated 846 feet across 423 elite male rugby union league players during the 2025–2026 competitive season. Structural parameters were collected via physical anthropometric screening alongside the standardized revised Foot Posture Index (FPI-6) tool to evaluate multi-position foot alignment.

Findings: The elite cohort demonstrated a mean foot length of 272.32 mm and a mean truncated foot length of 201.71 mm. Functional arch mobility during weight-bearing was observed through a reduction in mean dorsum height from 70.40 mm in the seated position to 66.31 mm in the standing position, with an overall mean navicular drop of 4.10 mm. Normal foot arch types were identified in 59.3% (n = 251) of the participants, while 52.2% (n = 221) exhibited neutral, normal foot alignment.

Unique Contribution to Theory, Practice and Policy: Elite Kenyan rugby union players possess predominantly normal foot morphological characteristics and structural dimensions that align cleanly with the high physical demands of elite rugby participation. These data establish essential regional anthropometric baselines for sports scientists, physiotherapists, and conditioning coaches to optimize talent profiling, construct field-specific injury prevention screenings, and guide custom athletic footwear development.

Keywords: *Foot Posture Index, Foot Arch Type, Truncated Foot, Navicular Drop, Rugby Union, Kenya*

JEL Classification: *I10, I15, J24*

INTRODUCTION

Foot morphology refers to the structural characteristics of the foot, including foot length, foot width, truncated foot length, dorsum height, arch height, navicular height, navicular drop, and overall foot posture, which collectively describe the size, shape, alignment, and structural configuration of the foot (Williams & McClay, 2000; Redmond et al., 2008; Mei et al., 2022). These structural characteristics influence plantar pressure distribution, shock absorption, balance, force transmission, gait mechanics, and lower limb biomechanics during weight-bearing and dynamic activities (Neal et al., 2014; Buldt et al., 2018; Mei et al., 2022). In rugby union, where athletes are routinely exposed to sprinting, tackling, scrummaging, jumping, cutting, and rapid changes of direction, optimal foot morphology is essential for efficient force production, movement control, and performance (Gurney et al., 2009; Mei et al., 2022).

Elite rugby union players exhibit distinctive anthropometric and musculoskeletal characteristics that reflect the physical demands of the sport and positional roles (Duthie et al., 2003; Till et al., 2020). While previous research has extensively described the body size, strength, power, and physiological profiles of rugby players, comparatively fewer studies have investigated foot morphology despite its recognised role in lower limb biomechanics and functional performance (Gurney et al., 2009; Mei et al., 2022). Available evidence suggests that rugby athletes generally possess larger feet, broader forefeet, and variations in arch morphology than non-athletic populations, adaptations that are thought to reflect prolonged exposure to repetitive mechanical loading and high-impact sporting activities (Gurney et al., 2009; Mei et al., 2022).

Evaluation of foot morphology has become increasingly important in sports medicine because structural variations of the foot influence plantar loading patterns, postural stability, lower limb alignment, and movement efficiency (Redmond et al., 2008; Buldt et al., 2018; Mei et al., 2022). Objective measurements including foot length, foot width, truncated foot length, dorsum height, navicular drop, and the Arch Height Index (AHI) provide reliable indicators of foot structure and are widely used in both clinical practice and biomechanical research (Williams & McClay, 2000; Williams et al., 2001; Butler et al., 2008). Advances in digital anthropometry and three-dimensional foot scanning have further improved the precision and reproducibility of foot measurements, facilitating more accurate assessment of foot morphology for clinical evaluation, footwear design, and sports performance applications (Redmond et al., 2008; Mei et al., 2022).

Assessment of foot morphology is particularly relevant in rugby because the foot serves as the primary interface between the athlete and the playing surface, transmitting substantial ground reaction forces during running, acceleration, deceleration, tackling, scrummaging, and jumping (Gurney et al., 2009; Mei et al., 2022). Structural variations in foot morphology may alter load distribution, plantar pressure patterns, postural control, and lower limb alignment, thereby influencing movement efficiency and potentially contributing to overuse or traumatic musculoskeletal injuries (Neal et al., 2014; Buldt et al., 2018; Mei et al., 2022). Consequently, evaluation of foot morphology has become an important component of athlete screening, footwear prescription, orthotic management, rehabilitation, and injury surveillance in elite sport (Redmond et al., 2008; Mei et al., 2022).

Among elite rugby players, assessment of foot posture and medial longitudinal arch characteristics has received increasing attention because of their influence on lower limb biomechanics during static and dynamic weight-bearing activities (Cornwall et al., 2008; Neal et al., 2014; Mei et al., 2022). Clinical tools such as the Foot Posture Index (FPI-6), Navicular Drop Test, and Arch Height Index are widely used owing to their acceptable reliability, validity, ease of administration, and applicability in both clinical and field settings (Cornwall et al., 2008; Redmond et al., 2006; Koo & Li, 2016). These assessments enable clinicians and researchers to identify variations in foot posture, establish normative values, monitor structural adaptations associated with sport participation, and support evidence-based clinical decision-making (Redmond et al., 2006; Cornwall et al., 2008; Mei et al., 2022).

Despite growing recognition of the importance of foot morphology in sports performance and injury prevention, published evidence describing the morphological characteristics of elite rugby players remains limited, particularly within African populations (Mei et al., 2022). Existing research has largely focused on non-African athletic populations, with limited information available regarding the structural foot characteristics of elite African rugby players. Previous studies have demonstrated variation in foot morphology and functional characteristics among athletic populations, highlighting the importance of population-specific data for footwear selection and clinical assessment (Gurney et al., 2009). However, population-specific reference data for elite Kenyan rugby union players remain scarce. Establishing such reference data is therefore important for understanding population-specific variations in foot structure and providing baseline information for athlete assessment, footwear selection, clinical management, and future biomechanical, epidemiological, and injury-prevention research. The findings may be useful to coaches, sports physiotherapists, sports medicine practitioners, footwear professionals, and rugby governing bodies. This study therefore sought to characterize the foot morphological characteristics of elite male Kenyan rugby union players.

METHODOLOGY

A descriptive, cross-sectional study was conducted among elite male athletes actively competing in the premier 15-a-side rugby union league during the 2025–2026 competitive season (n = 423). A purposive sampling approach was utilized to recruit participants based on strict, predefined eligibility criteria. To be included in the final analysis, players were required to be officially registered with their respective clubs and certified as physically fit for full training and match selection by their team's medical staff for the duration of the 2025/2026 season. All athletes participated on a completely voluntary basis and provided written informed consent prior to the commencement of data collection. Data was collected using a standardized revised Foot Posture Index (FPI-6) tool to evaluate bilateral feet of 423 elite rugby players while physical measurement of foot structures (Foot length, Arch height index, foot truncated length, foot dorsum height (standing), foot dorsum height (seated) and navicular drop) were measured by trained research assistants using ‘Takei Scientific Instrument’ below (Figure 3.11a & b) and data recorded in data capture sheet (APPENDIX A).

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(a) (b)

Figure: 1 a and b. Arch height instruments, (Takei Scientific Instruments Co. Ltd., Japan) (Images for evaluating foot structure by Miller et al., 2014).

Validity and reliability of the revised Foot Posture Index (FPI-6) standardized clinical instrument has been established before with studies showing excellent construct validity for assessing static foot posture across diverse populations (Cornwall et al., 2008; Yang et al., 2022). Similarly, the revised (FPI-6) has consistently demonstrated good to excellent reliability in assessing static foot posture across different populations. Cornwall et al. (2008) reported good inter-rater reliability of the FPI-6, while Yang et al. (2022) reported excellent inter-rater reliability, with an Intraclass Correlation Coefficient (ICC) of 0.97 and ICC values exceeding 0.75 for each of the six assessment criteria. Furthermore, significant positive correlations among the individual assessment items and the total FPI-6 score ($p < .01$) support the instrument's internal consistency. Based on this evidence, the FPI-6 was adopted in its original form for the present study. All research assistants underwent standardized training in the administration of the FPI-6 and anthropometric measurement procedures before data collection. A standardized measurement protocol and equipment were used throughout data collection to minimize measurement variation. Formal inter-rater and intra-rater reliability coefficients were not calculated during the study.

The study authorization was obtained from Kenyatta University Graduate School, while ethical approval was obtained from the Kenyatta University Ethics and Review Committee (KUERC) and the Research Permit was sought from the National Commission for Science, Technology, and Innovation (NACOSTI) and the Kenya Rugby Union (KRU). Data processing and statistical computations were executed utilizing SPSS (Version 26.0). Prior to primary analysis, the data were subjected to the Shapiro-Wilk test to assess the normality of distribution across all continuous anthropometric variables, including foot length, truncated foot length, dorsum height metrics, and navicular drop. Continuous data following a normal distribution are expressed as means, standard deviations (SD), and ranges, whereas non-parametric parameters are reported via medians and interquartile ranges (IQR). All statistical analyses were based on the right dominant foot per participant ($n = 423$), thereby avoiding potential violation of the independence assumption associated with correlated bilateral measurements. Categorical descriptives derived from the standardized Foot Posture Index (FPI-6), including foot alignment profiles and foot arch types, are presented as absolute frequencies and corresponding percentage distributions (n, %) in tables and graphs.

RESULTS

Foot Posture Structure Characteristics

Foot structure was assessed using five linear measures: foot length, truncated length, dorsum height (seated and standing), and navicular drop. The mean foot length was 272.32 mm with a range of 191 mm to 312 mm. The variation in foot size was large between players. Truncated length also showed moderate variability (mean=201.71 mm) suggesting differences in proportions of forefoot and foot. The foot height measurements were similar, with the dorsum height in the seated position (mean = 70.40 mm) and standing position (mean = 66.31 mm) being slightly lower in the standing position, as expected, due to load-bearing compression of the foot structure during standing. The mean navicular drop was 4.10 mm; range 0 to 13.32 mm. This means that most players have low to moderate navicular drop values, and a small subgroup has higher values, which may indicate excessive pronation tendencies as shown on Table 1.

Table 1: Summary of Static Foot Structure Characteristics of Elite Male Kenyan Rugby Players (N=423)

Variable	Mean (mm)	Median (mm)	Min (mm)	Max (mm)
Foot length	272.32	272.00	191	312
Truncated length	201.71	200.50	170	235
Dorsum height (seated)	70.40	70.76	47.11	88.81
Dorsum height (standing)	66.31	66.49	42.38	83.38
Navicular drop	4.10	3.74	0	13.32

Foot Length

Foot length averaged 272.32 mm (SD = 15.41), with a median of 272.00 mm indicating a roughly symmetric distribution (Figure 1). Values ranged from 191 mm to 312 mm with most players clustered close to the mean, with comparatively few cases at the extremes of the range.

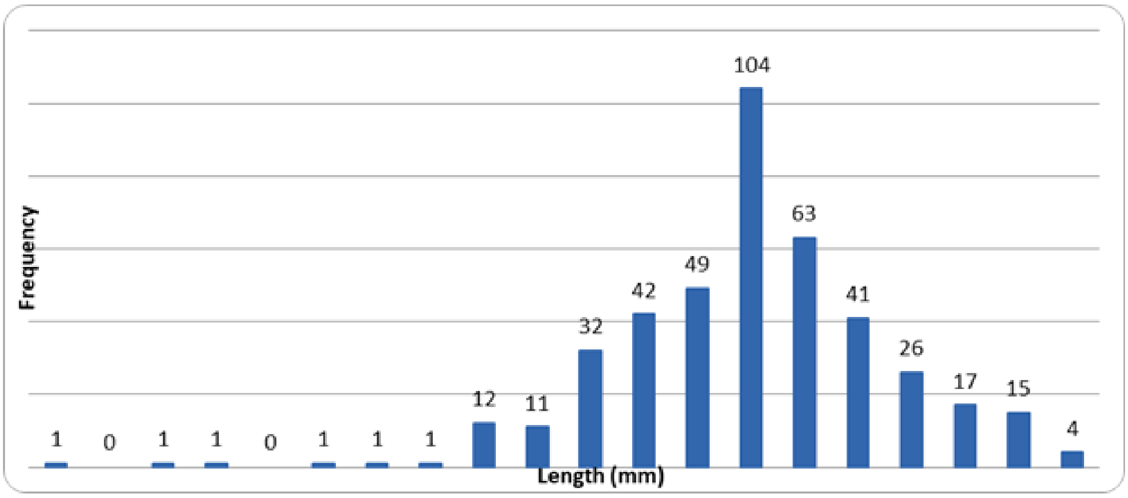

Figure 1: Foot Length Distribution

Truncated Foot Length

Truncated length averaged 201.71 mm (SD = 10.74), with a median of 200.50 mm and a range of 170 mm to 235 mm (Figure 2).

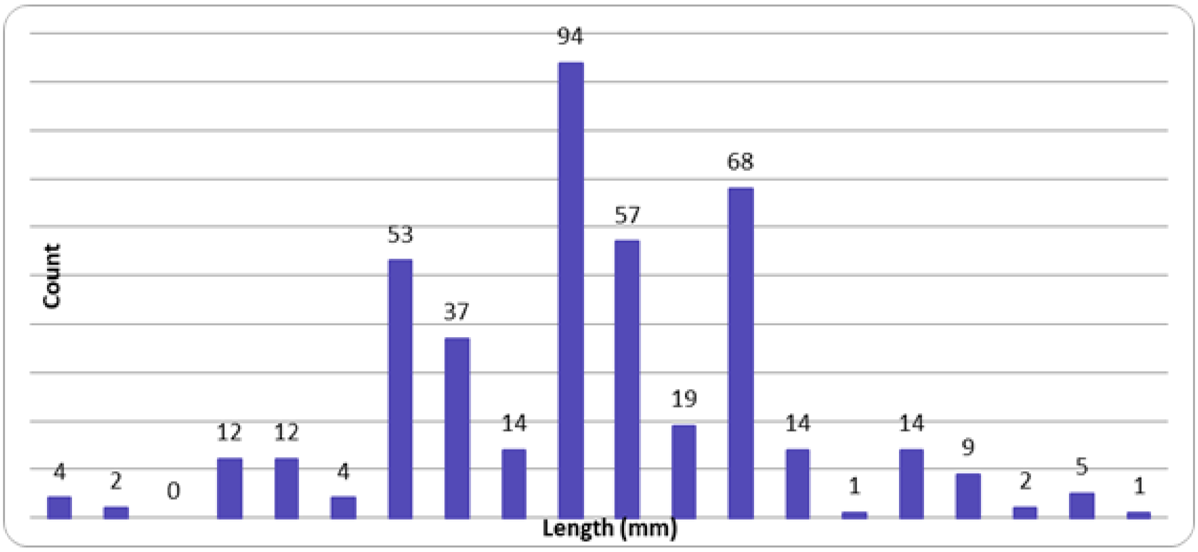

Figure 2: Truncated Foot Length Distribution

Dorsum Foot Height (Seated)

Dorsum height was measured in the seated, non-weight-bearing position averaged 70.40 mm (SD = 5.49), with a median of 70.76 mm and a range of 47.11 mm to 88.81 mm (Figure 3). The distribution was tight relative to its range, with most measurements falling within roughly one standard deviation of the mean.

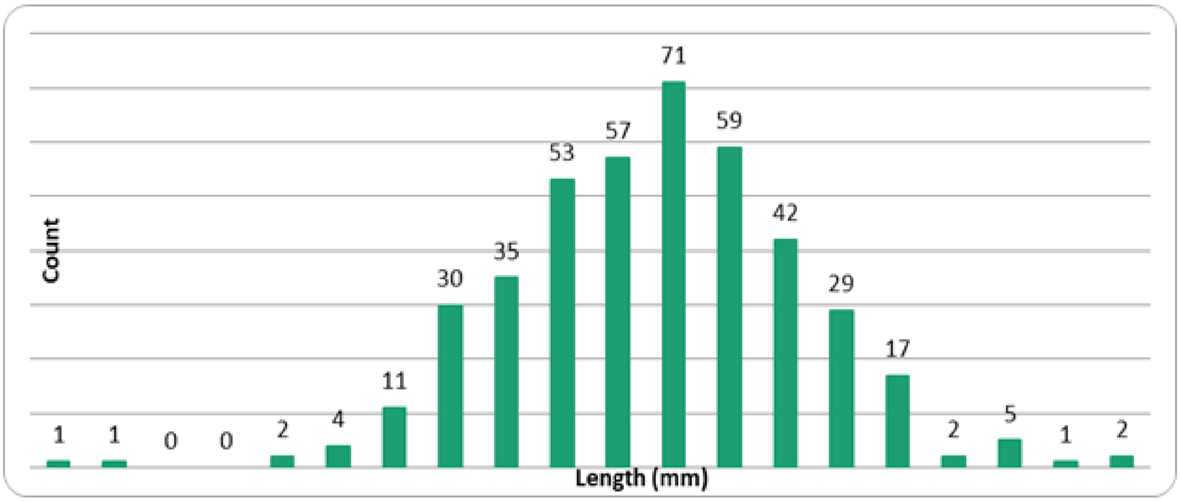

Figure 3: Dorsum Height (Seated)

Dorsum Foot Height Standing

The dorsum foot height was measured in standing, weight-bearing load. It averaged 66.31 mm (SD = 5.26), with a median of 66.49 mm and a range of 42.38 mm to 83.38 mm. This is roughly 4 mm lower than the seated values on average, consistent with the foot flattening slightly under body weight (Figure 4)

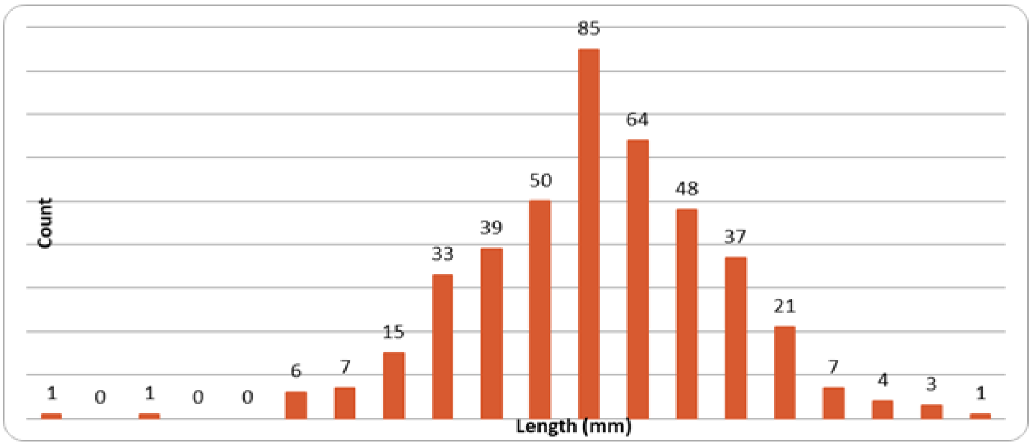

Figure 4: Dorsum foot height (Standing)

Navicular Drop

Navicular drop, the difference between seated and standing navicular height, averaged 4.10 mm (SD = 1.95), with a median of 3.74 mm and a range of 0 mm to 13.32 mm.

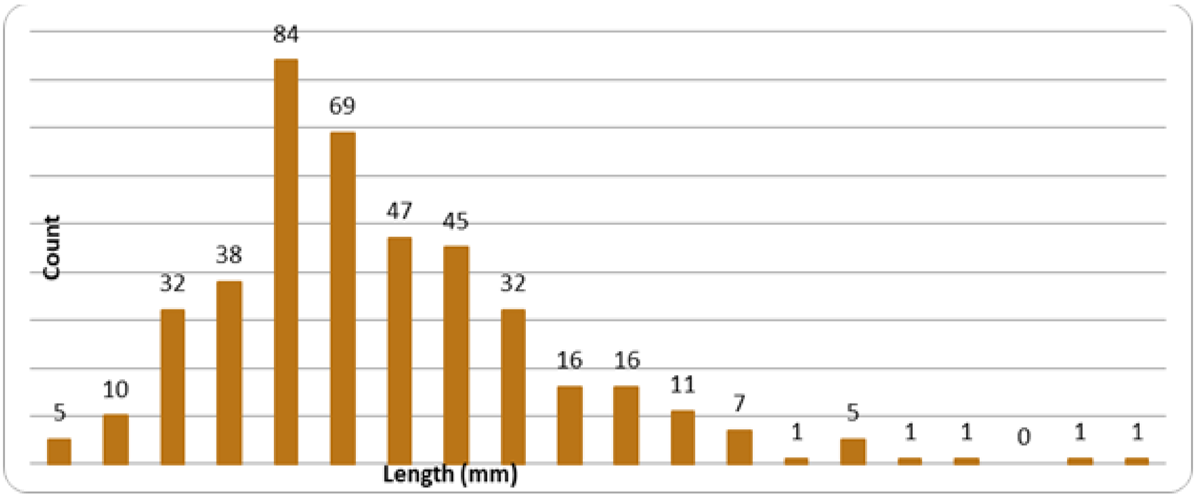

Figure 5: Navicular Drop

Foot Width

The foot width measurements of the 423 elite male Kenyan rugby players are presented in Table 2. The mean foot width was 117.81 mm (SD = 12.45), with a standard error of 0.61 mm. The measured foot widths ranged from 73 mm to 212 mm, indicating considerable variation in transverse foot dimensions among the participants. The variance was 155.01 mm², reflecting the dispersion of foot width measurements around the sample mean. All 423 participants had complete foot width measurements and were included in the analysis (n = 423).

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Table 2: Distribution of Foot Width

	Foot Width						
	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Foot_width_mm	423	73	212	117.81	.605	12.450	155.005

Foot Posture Type

The foot posture assessment of the 423 rugby players showed that 52.2% (n = 221) had normal foot alignment. However, a considerable combined proportion of 42.1% (n = 178) showed supinated foot posture, with 35.0% supinated and 7.1% highly supinated. Additional findings showed that only 5.6% (n = 24) were pronated or highly pronated feet.

Table 3: Distribution of the Foot Posture Type (FPI Score) (N = 423)

FPI Score Range	Category	Frequency	Percent
-12 to -5	Highly supinated	30	7.1
-4 to -1	Supinated	148	35.0
0 to +5	Normal	221	52.2
+6 to +9	Pronated	23	5.4
+10 and above	Highly pronated	1	0.2
	Total	**423**	**100.0**

Foot Arch Type (AHI)

Results showed that the most common foot arch type among the participants was normal foot arch accounting for 59.3% (n = 251) of the sample. This was followed by a high arch which was found in 40.0% (n=169) players. Low arch was the least common type of foot arch, with only 0.7% (n = 3) of the participants having this type of arch.

Table 4: Foot Arch Type using AHI

Category	Arch Height Index (AHI)	Frequency	Percent
High arch	Less than 0.21	169	40.0
Normal	0.21 to 0.28	251	59.3
Low arch (flat foot)	More than 0.28	3	0.7
Total		**423**	**100.0**

Discussion

The Foot Structure Characteristics

This study sought to determine the characteristics of foot structure among elite male Kenyan rugby players. Their bilateral static feet were assessed using physical measures of foot length, truncated length, dorsum height (seated and standing), foot width, navicular drop while the foot posture type was assessed using the revised Foot Posture Index (FPI-6) tool.

Foot Length

The mean foot length of 272.32 mm (Figure 1) observed among the elite Kenyan rugby players is consistent with the anthropometric characteristics reported among elite rugby populations internationally, where relatively larger foot dimensions are considered advantageous for maintaining postural stability, distributing plantar loads, and generating propulsive forces during high-intensity activities. Larger feet increase the base of support and may improve the efficiency of force transfer during sprinting, scrummaging, tackling, and rapid multidirectional movements, all of which are fundamental components of rugby performance (Gurney et al., 2009; Waithaka, 2013).

These findings are comparable with those reported by Gurney et al. (2009), who demonstrated that elite rugby players from New Zealand possessed relatively long and broad feet consistent with the substantial body size and musculoskeletal characteristics required for collision sports. Their study further identified morphological differences among Caucasian, Māori, and Pacific Island rugby players, suggesting that foot morphology is influenced by both body habitus and population-specific characteristics. In contrast, the present study involved a relatively homogeneous East African athletic population. Consequently, the relatively large foot dimensions observed among Kenyan rugby players are more likely to reflect adaptations associated with elite rugby participation and body size rather than marked ethnic heterogeneity alone.

Recent evidence further demonstrates that foot morphology varies considerably across populations owing to complex interactions among genetics, sex, habitual physical activity, environmental exposure, footwear practices, and developmental influences (Hoey et al., 2023). In their systematic review, Hoey et al. (2023) reported significant differences in foot length, width, arch morphology, and forefoot characteristics across different ethnic groups, emphasizing that normative foot measurements derived predominantly from European populations should not be universally applied to athletes from other geographical regions. Similarly, Hawes and Sovak (1994) demonstrated that long-term footwear habits and environmental influences contribute substantially to foot development and morphology. Collectively, these findings highlight the importance of establishing population-specific anthropometric reference values for athletes.

From a biomechanical perspective, larger foot dimensions may provide functional advantages by increasing the plantar contact area with the playing surface, thereby enhancing stability and promoting more effective distribution of plantar pressures during high-impact sporting activities (Chow, 2022). A larger base of support may improve postural control during scrummaging, tackling, landing, and rapid changes of direction, potentially reducing excessive localized loading within the lower extremity (Kozel et al., 2025). However, foot length alone should not be interpreted as an independent predictor of injury risk (Mei et al., 2022). Contemporary sports injury models recognize that lower extremity injuries arise from complex interactions among intrinsic factors, including foot morphology, muscle strength, neuromuscular control, previous injury history, and extrinsic factors such as training load, footwear, and playing surface (Bahr, 2016; Bittencourt et al., 2016). Consequently, foot length should be interpreted as one component of an athlete's overall biomechanical profile rather than an isolated determinant of injury susceptibility.

The present findings therefore provide valuable normative anthropometric data for elite Kenyan rugby players, a population that remains underrepresented in sports biomechanics research. Establishing these population-specific reference values contributes to improved clinical assessment, footwear prescription and design, injury surveillance, and future investigations exploring the relationships between foot morphology, functional foot stability, athletic performance, and lower extremity injury risk among African rugby populations.

Truncated Foot Length

The truncated mean foot length (201.71 mm) (Figure 2) observed among the elite Kenyan rugby players reflects forefoot dimensions that are consistent with the functional requirements of high-intensity collision sports (William & McClay, 2000). Truncated foot length represents the distance from the posterior aspect of the heel to the first metatarsophalangeal joint and provides a more functionally relevant measure of foot size than total foot length because it excludes the toes, whose length varies considerably between individuals and contributes minimally to weight-bearing and the calculation of structural foot indices (McPoil et al., 2008).

Although normative truncated foot length values have not been widely reported among elite rugby players, the relatively large measurements observed in the present study are consistent with the substantial body size and lower-limb anthropometric characteristics typically exhibited by elite rugby athletes (Till et al., 2020). During sprinting, acceleration, scrummaging, tackling, and rapid changes of direction, the forefoot functions as the primary lever for propulsion, transmitting forces generated by the plantar flexor musculature through the metatarsal heads to the playing surface. Efficient forefoot loading is therefore essential for force production, propulsion, and dynamic stability during rugby-specific movements (Nigg et al., 2017; Williams & McClay, 2000).

From a biomechanical perspective, truncated foot length is particularly important because it serves as the reference measurement for calculating normalized indices of foot structure, including the Arch Height Index (AHI) (Williams & McClay, 2000). This truncated foot length played a key role to calculate the Arch Height Index (AHI) to determine the foot arch type in the current study. The results from the current study showed that the most common foot arch type among the participants was normal foot arch 59.3% (n = 251), high arch 40.0% (n=169) low arch type 0.7% (n = 3) respectively (Table 4).

Normalizing dorsum height to truncated foot length minimizes the influence of overall body size, improves the reliability and validity of arch measurements, and facilitates meaningful comparisons of foot morphology between individuals and populations (Williams & McClay, 2000; McPoil et al., 2008). Consequently, truncated foot length has become the preferred anthropometric measure for clinical and research assessment of foot posture and medial longitudinal arch characteristics.

Despite its clinical importance, limited research has investigated the independent relationship between truncated foot length and sports injury risk (Fallon et al., 2023; Wang et al., 2025). Contemporary evidence indicates that lower-extremity injuries cannot be attributed to a single anatomical characteristic but instead arise from complex interactions among intrinsic factors including foot morphology, intrinsic foot muscle function, neuromuscular control, previous injury history, and anatomical alignment and extrinsic factors such as training load, footwear, playing surface, and sport-specific mechanical demands (Bittencourt et al., 2016; Bahr, 2016). Therefore, truncated foot length should be interpreted primarily as a standardized anthropometric reference measure that facilitates accurate assessment of foot structure rather than as an independent predictor of injury susceptibility.

The present findings therefore provide valuable baseline anthropometric data for elite Kenyan rugby players; a population for whom published foot morphology data remain scarce. Establishing these population-specific reference values contributes to improved clinical assessment, footwear design, and future investigations examining the relationships between normalized foot structure, functional foot stability, athletic performance, and lower-extremity injury risk in African rugby populations (Hoey et al., 2023).

Foot Dorsum Height (Sitting to Standing)

The foot dorsum height (66.31 mm (SD = 5.26) (Figure 3 & 4) reduced by 4mm when changing position from sitting to standing among the elite Kenyan rugby players demonstrates the normal deformation of the medial longitudinal arch during weight-bearing (William & McClay, 2000). This reduction reflects the physiological lowering of the arch as body weight is transferred through the foot and is considered an important indicator of normal foot function and load accommodation (Williams & McClay, 2000; McPoil et al., 2008). Furthermore, moderate deformation of the medial longitudinal arch allows the foot to absorb impact forces during initial contact while retaining sufficient stiffness to provide an effective propulsive lever during the terminal stance phase of gait (Hicks, 1954; McKeon et al., 2015).

Rugby union places exceptionally high mechanical demands on the foot owing to repeated sprinting, jumping, scrummaging, tackling, rapid acceleration, deceleration, and multidirectional changes of direction. These activities expose the lower extremities to substantial ground reaction forces and require the foot to function efficiently as both a mobile adaptor during impact absorption and a rigid lever during propulsion (Nigg et al., 2017; Hendricks et al., 2020). Consequently, maintaining an appropriate balance between arch flexibility and structural stiffness is fundamental to efficient movement performance and lower-limb load distribution in elite rugby players (McKeon et al., 2015).

The relatively small reduction in dorsum height observed in the present study suggests that the medial longitudinal arch remained structurally stable during loading while preserving the normal flexibility required for shock attenuation. This finding is consistent with the concept of the Foot Core System, which proposes that coordinated interaction among the passive ligamentous structures, intrinsic foot muscles, and neural control mechanisms maintains dynamic arch stability during functional activities (McKeon et al., 2015). Appropriate regulation of arch deformation enables efficient storage and release of elastic energy while minimizing excessive mechanical stress on the plantar fascia and other supporting soft tissues (Hicks, 1954).

Although few studies have specifically evaluated dorsum height changes in elite rugby players, previous research has demonstrated that foot morphology and arch characteristics vary according to population, sporting discipline, and habitual loading patterns (Hoey et al., 2023; Bargeman 2025). The relatively stable arch profile observed among the present participants may therefore reflect long-term adaptation to the multidirectional loading characteristics of rugby union. In contrast, endurance runners are predominantly exposed to repetitive sagittal-plane loading over prolonged distances, whereas rugby players experience frequent multidirectional movements, collisions, and rapid changes of direction that impose different mechanical demands on the foot (Dimundo et al., 2021; Hendricks et al., 2020). Such sport-specific loading patterns may contribute to differences in foot morphology and functional arch behavior between athletic populations.

Direct comparison with other studies should nevertheless be interpreted cautiously because assessment techniques differ considerably across investigations. Whereas some studies quantify foot morphology using three-dimensional digital foot scanning and imaging technologies, the present study employed direct anthropometric measurements of dorsum height together with the Foot Posture Index (FPI-6) and navicular drop assessments. Differences in measurement methodology may influence reported values and limit direct comparisons across populations (Redmond et al., 2006; McPoil et al., 2008). Nevertheless, the observed dorsum height characteristics provide important baseline data describing foot structure among elite Kenyan rugby players and contribute to the limited evidence available on foot morphology in African collision-sport athletes.

Navicular Drop

The mean navicular drop of 4.10 mm represents one of the most clinically important findings of the present study (Figure 5). This value falls within the range generally regarded as normal medial longitudinal arch mobility and is substantially lower than values commonly associated with excessive foot pronation or hypermobility (Brody, 1982; Redmond et al., 2006). Moderate navicular displacement reflects the normal deformation of the medial longitudinal arch during weight-bearing and is considered essential for efficient shock absorption while preserving the structural stiffness required for propulsion during dynamic activities (McKeon et al., 2015; Hicks, 1954).

The relatively small navicular drop observed among the elite Kenyan rugby players suggests that the medial longitudinal arch remained mechanically stable during loading while maintaining sufficient flexibility to attenuate impact forces. Rugby union imposes exceptionally high mechanical demands on the lower extremities through repeated sprinting, tackling, jumping, scrummaging, acceleration, deceleration, and multidirectional changes of direction, all of which require efficient regulation of arch deformation to optimize force transfer and dynamic stability (Dimundo et al., 2021; Hendricks et al., 2020). Maintenance of normal arch mobility may therefore represent a favorable biomechanical characteristic that supports both athletic performance and efficient lower-limb load distribution.

Previous investigations have shown that excessive navicular displacement is associated with increased foot mobility, greater pronation, and altered lower-limb biomechanics, which may contribute to abnormal loading patterns during functional activities (Brody, 1982; Buldt et al., 2018). Conversely, excessively rigid arches may reduce the foot's capacity to absorb impact forces, potentially increasing stress transmission to more proximal joints. Consequently, the moderate navicular drop observed in the present study may indicate an appropriate balance between flexibility and structural stability, characteristics considered desirable for high-performance athletes (McKeon et al., 2015).

The relatively stable arch characteristics observed in this study may also reflect long-term neuromuscular adaptations associated with elite rugby participation. Repeated exposure to high-intensity loading is thought to enhance the coordinated function of the intrinsic foot muscles, extrinsic musculature, plantar fascia, and passive ligamentous structures responsible for maintaining dynamic arch stability (McKeon et al., 2015). However, it should be recognized that these adaptations have not been directly measured in the present study and therefore should be interpreted cautiously.

Population-specific differences in foot morphology may provide an additional explanation for the findings. Hoey et al. (2023), in a systematic review of foot morphology, demonstrated that foot dimensions and arch characteristics vary according to ethnicity, sex, habitual footwear use, and environmental exposure. Anthropological evidence further suggests that populations with greater exposure to barefoot locomotion or minimal footwear during growth often demonstrate stronger intrinsic foot musculature, wider forefeet, and more robust arch function than predominantly shod populations (Hollander et al., 2017; Hoey et al., 2023). Although barefoot history was not assessed in the present study, this remains a plausible explanation for the moderate navicular displacement observed among the Kenyan rugby players and warrants investigation in future research.

Comparison of the present findings with previous studies should nevertheless be undertaken cautiously because considerable methodological heterogeneity exists in the assessment of foot structure. Because navicular mobility has been evaluated using manual anthropometric techniques, the Navicular Drop Test, digital calipers, radiographic methods, three-dimensional foot scanning, and imaging technologies, each demonstrating different levels of reliability and measurement precision (Brody, 1982; McPoil et al., 2008; Redmond et al., 2006). Such methodological variation has been recognized as a major limitation when comparing foot morphology across studies and populations (Hoey et al., 2023). Nevertheless, the present findings provide valuable normative data describing dynamic arch behavior among elite Kenyan rugby players and contribute to the limited evidence available on foot biomechanics in African collision-sport athletes.

Finally, although normal navicular drop may reflect favorable foot function, it should not be interpreted as an independent predictor of injury risk. Contemporary sports injury models recognize that lower-extremity injuries result from complex interactions among anatomical characteristics, neuromuscular control, intrinsic foot muscle function, training load, previous injury, footwear, playing surface, and sport-specific mechanical demands rather than any single biomechanical variable (Bahr, 2016; Bittencourt et al., 2016). Accordingly, navicular drop should be interpreted as one component of a comprehensive assessment of foot structure and functional foot stability rather than an isolated determinant of injury susceptibility.

Foot Posture Type

Foot posture was evaluated using the revised Foot Posture Index (FPI-6), a validated multidimensional clinical assessment tool that classifies foot posture into highly supinated, supinated, normal, pronated and highly pronated categories based on six observations of rearfoot and forefoot alignment (Appendix B) (Redmond et al., 2006). These revised FPI-6 is widely regarded as one of the most reliable and clinically applicable methods for assessing static foot posture because it incorporates multiple anatomical features rather than relying on a single measurement. These has been demonstrated in previous studies having possed good inter-rater and intra-rater reliability and is applicable across athletic and non-athletic populations (Redmond et al., 2006; Keenan et al., 2007; Buldt et al., 2018).

The present study found that 52.2% of the elite Kenyan rugby players exhibited normal foot posture, while 35.0% had supinated feet, 7.1% were highly supinated, 5.4% demonstrated pronated feet, and only 0.2% exhibited highly pronated foot posture. Overall, approximately 42.1% of the participants demonstrated some degree of supination, whereas only 5.6% exhibited pronation (Table 6). These findings indicate that the majority of elite Kenyan rugby players possess either normal or mildly supinated foot posture, with relatively few players demonstrating excessive pronation. The predominance of supination is clinically relevant because supinated (high-arched) feet are biomechanically rigid, with decreased shock absorption, impaired force dissipation, and increased lateral ankle instability (Neal et al., 2014). These features directly increase the risk of lateral ankle sprains, stress fractures, and plantar fasciitis, all consistent with the study's finding that the ankle was the most frequently injured location (46.5%) (Tong & Kong 2014).

The predominance of normal foot posture is biomechanically advantageous because it provides an appropriate balance between flexibility for shock absorption and rigidity for efficient propulsion (Hicks, 1954). These has been applicable during gait and athletic movements, where the foot must function initially as a flexible structure to accommodate ground reaction forces and subsequently transform into a rigid lever during push-off to facilitate efficient force transmission (Hicks, 1954; McKeon et al., 2015). In rugby union, where players repeatedly sprint, accelerate, decelerate, jump, tackle, scrummage and rapidly change direction under substantial external loads, maintaining this balance between mobility and stability is essential for both performance and efficient lower-limb biomechanics (World Rugby, 2023; Hendricks et al., 2020).

The predominance of normal foot posture observed in the present study is consistent with current understanding that healthy athletic populations generally demonstrate neutral foot alignment rather than extreme pronation or supination (Buldt et al., 2018; Neal et al., 2014). Although relatively few studies have specifically described Foot Posture Index classifications among elite rugby players, the observed distribution suggests that normal foot posture may represent a favorable structural characteristic for accommodating the multidirectional loading demands imposed by rugby union.

An important finding was the relatively high proportion of players exhibiting supinated (35.0%) and highly supinated (7.1%) feet. Supinated foot posture is typically characterized by a relatively high medial longitudinal arch, increased rearfoot inversion and reduced midfoot mobility (Redmond et al., 2006; Buldt et al., 2018). From a biomechanical perspective, a moderately supinated foot may function as a relatively rigid lever during propulsion, potentially improving mechanical efficiency during sprint acceleration, jumping and explosive changes of direction by reducing excessive deformation of the medial longitudinal arch (McKeon et al., 2015). Such characteristics may be advantageous during many rugby-specific movements that require rapid force production (Hicks, 1954).

However, excessive supination should not be interpreted as universally beneficial. A highly supinated foot demonstrates reduced capacity for shock absorption because limited pronation decreases the foot's ability to dissipate impact forces during weight-bearing (Neal et al., 2014). Consequently, greater mechanical loading may be transmitted to the ankle, tibia and knee, potentially increasing susceptibility to impact-related conditions such as lateral ankle sprains and stress injuries. Nevertheless, the evidence supporting these relationships remains inconsistent, and recent systematic reviews indicate that static foot posture alone demonstrates only weak associations with lower-limb musculoskeletal injuries (Neal et al., 2014; Buldt et al., 2018).

The predominance of supinated feet observed in the present study differs from findings reported in many recreational and general populations, where neutral and mildly pronated foot postures are generally more common (Buldt et al., 2018; Hoey et al., 2023). One possible explanation is that elite rugby players are exposed to unique mechanical demands characterized by repeated acceleration, deceleration, multidirectional cutting, scrummaging and high-impact collisions (Preatoni, 2015). These demands require efficient force transfer and dynamic stability, characteristics that may favour individuals with relatively stiffer foot mechanics.

However, current evidence remains insufficient to conclude that rugby participation itself produces a more supinated foot posture, and longitudinal studies are required to determine whether these findings reflect sport-specific adaptation or selection of athletes with favorable biomechanical characteristics (Gurney et al.,2009).

Population-specific morphological characteristics may also contribute to the findings. Hoey et al. (2023) demonstrated that foot morphology differs significantly across ethnic groups owing to interactions among genetics, sex, environmental influences, habitual footwear use and physical activity. Furthermore, habitual barefoot locomotion during childhood has been associated with stronger intrinsic foot musculature, better-developed medial longitudinal arches and altered foot morphology compared with predominantly shod populations (Hollander et al., 2017). Although barefoot history was not evaluated in the present study, these developmental and environmental factors may partly explain the relatively high prevalence of normal and mildly supinated foot posture observed among the Kenyan rugby players.

Only 5.4% of participants demonstrated pronated feet, while a single player (0.2%) exhibited highly pronated foot posture. This relatively low prevalence is clinically important because excessive pronation has historically been considered a potential contributor to altered lower-limb biomechanics. Excessive pronation may prolong foot mobility during stance, increase tibial internal rotation and alter lower-limb kinematics; however, contemporary evidence indicates that these biomechanical alterations demonstrate only modest associations with overuse injuries and should not be interpreted as direct causes of injury (Neal et al., 2014). Injury development is now recognized as multifactorial, involving interactions among foot posture, muscle function, neuromuscular control, training load, previous injury, footwear and playing surface (Bahr, 2016; Bittencourt et al., 2016).

The relatively low prevalence of pronated foot posture observed in the present study complements the low mean navicular drop previously reported, suggesting that the participants generally possessed structurally stable medial longitudinal arches (Neal et al., 2014). Nevertheless, static foot posture should not be interpreted in isolation. Functional characteristics, including intrinsic foot muscle strength, dynamic balance, neuromuscular control and movement quality, provide additional information regarding foot function and may be more clinically relevant when evaluating injury risk than static alignment alone (McKeon et al., 2015; Bahr, 2016).

Conclusion

This study demonstrates that elite Kenyan rugby union players exhibit a distinct distribution of static foot morphology, characterized by a high prevalence of supinated foot profiles, which diverges noticeably from the neutral or mildly pronated trends typically observed in general and recreational cohorts. Evaluated through a morpho functional lens, this relatively stiff and stable architectural profile appears to match the heavy, multidirectional physical demands of elite rugby match play, providing a rigid structural framework optimized for effective force transfer during high-velocity cutting, tackling, and scrummaging.

Crucially, while extremes in static alignment alter localized structural load-bearing capacity along the lower limb kinetic chain, our findings reinforce the contemporary consensus that musculoskeletal injury development is a complex, multifactorial web. Static foot posture or isolated foot dimensions like truncated foot length do not act as independent, linear predictors of musculoskeletal breakdown. Instead, structural alignment forms a baseline interface that interacts dynamically with intrinsic muscle function, historic structural damage, daily training workloads, and varying playing surfaces.

Clinical implications and future directions

- **Integrated pre-season screening**: Sports physiotherapists and technical team staff should transition away from using the Foot Posture Index (FPI-6) as an isolated, exclusionary risk predictor. It should instead be embedded within comprehensive pre-season screens that capture individual movement quality and neuromuscular control.
- **Proactive workload management**: Team coaches and, strength and conditioning trainers should carefully balance external training volumes when exposing athletes with rigid, supinated foot structures to hard pitches or aggressive contact drills, as their reduced shock-absorption capacity can route unattenuated ground reaction forces up the leg.
- **Sport-Specific Footwear Design**: Commercial rugby boot manufacturers should utilize local anthropometric data such as the robust midfoot and wide forefoot profiles seen in barefoot-adapted populations to design wider, more accommodating toe boxes that reduce artificial structural constraint and mitigate lateral tissue strain.
- **Longitudinal Tracking**: Because this study's cross-sectional design cannot establish direct causality, future prospective tracking over multiple competitive seasons is needed. Longitudinal data will ultimately determine whether these rigid foot characteristics reflect progressive, sport-specific musculoskeletal remodeling or the natural athletic selection of individuals with robust baseline biomechanical phenotypes.

Ethics Approval and Consent to Participate

This study was approved by the Kenyatta University Graduate School / Ethics Committee of Kenyatta University Ethics and Review Committee (KUERC)] (Approval Number: KU/ERC/COND.APPROVAL/VOL.1). And the Research Permit was sought from the National Commission for Science, Technology and Innovation (NACOSTI) (Approval no: 327356) and the Kenya Rugby Union (KRU). Informed written consent was obtained from all individual elite league players prior to physical screening.

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Conflict of Interest

The authors declare that they have no competing interests, either financial or personal, that could have inappropriately influenced or biased the conduct, analysis, or presentation of this research.

Authors' Contributions

All authors contributed equally to this work. Mr. Lamech Francis designed the study methodology and supervised data collection and FPI-6, Physical foot measurements. While Dr.

Boit and Dr. Mundia assisted in data analysis and manuscript drafting. All authors have reviewed and approved the final submitted version.

Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available due to institutional confidentiality agreements safeguarding the identities of elite league athletes. However, anonymized physical measurement data are available from the corresponding author upon reasonable academic request.

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Appendix A:

FPI 6 Assessment Tool

Date	Factor	Plane	Score 1 Type........		Score 2 Type........		Score 3 Type........	
			Left -2 to +2	Right -2 to +2	left -2 to +2	Right -2 to +2	Left -2 to +2	Right -2 to +2
Rearfoot	Tala head position/ palpation	Transverse						
	Curves Supra and infra lateral malleolus	Frontal/ Transverse						
	Inversion/ eversion of the calcaneus	Frontal						
Forefoot	Prominence in the region of the TNJ	Transverse						
	Congruence of the medial longitudinal arch	Sagittal						
	Abduction/ Adduction forefoot on rearfoot	Transverse						
	TOTAL							
	Interpretation	Normal Pronated Highly pronated Supinated Highly supinated	0 to +5 +6 to +9 10+ -1 to -4 -5 to -12					

Appendix B: Foot Morphological Definitions

Variables	Definition	Source
Foot length (cm)	Measured from the most posterior point of the calcaneus to the distal end of the longest toe	Butler et al., 2008
Foot width (cm)	Measured from the first metatarsophalangeal joint to the fifth metatarsophalangeal joint	Zhao, X., Tsujimoto, T., Kim, B., Katayama, Y., & Tanaka, K. (2017).
Truncated foot length (cm)	Measured from the most posterior point of the calcaneus to the first metatarsophalangeal joint	Butler et al., 2008
Navicular height (cm)	Measured from the ground to the tuberosity of navicular bone	Mulligan, E. P., & Cook, P. G. (2013).
Dorsum height at 50% of the foot length (cm)	Obtained at 50% of foot length with a vertical caliper measured from the ground to the top of the dorsum	Mulligan, E. P., & Cook, P. G. (2013).
Arch height index (AHI)	Calculated as the dorsum height at 50% of the total foot length divided by truncated foot length	Williams, D. S., & McClay, I. S. (2000)