International Journal of Scientific Research and Management (IJSRM)
||Volume||13||Issue||06||Pages||2227-2236||2025||
Website: https://ijsrm.net ISSN (e): 2321-3418
DOI: 10.18535/ijsrm/v13i06.mp02

Evaluating the Reliability of Kinotek: An AI-Driven 3D Motion Capture Tool for Weight-Bearing Ankle Dorsiflexion Assessment.

Ofra A. Pottorf[1], Daniel Vapne[2], Jessie Hirsch[1], James Pierre-Glaude[3], Kaitlyn Haase[4]

[1] Department of Allied Health and Kinesiology, Hofstra University, Hempstead, NY, United States
[2] Advantage Physical Therapy, Woodmere, NY, United States
[3] Department of Physical Therapy, Stony Brook University, Stony Brook, NY, United States
[4] Kinotek Inc., Portland, ME, United States
Corresponding Author:
Ofra Pottorf, PT, PhD, DPT [1]
119 Hofstra University, Hagedorn Hall 222C, Hempstead, NY 11549, United States

Abstract

Background: The range of motion (ROM) in ankle dorsiflexion during weight-bearing activities has important functional implications, including an elevated risk of injury when ROM is restricted. The integration of advanced digital technologies, particularly those utilizing artificial intelligence (AI), is becoming increasingly prevalent across professional domains. These tools have demonstrated effectiveness in enhancing diagnostic accuracy and improving patient outcomes in physical rehabilitation. This study aimed to assess the reliability of a portable 3D motion capture platform incorporating AI (Kinotek) compared to a standard plastic goniometer in evaluating weight-bearing ankle dorsiflexion ROM.

Methods: Twenty-four healthy participants (mean age: 29 ± 12 years; height: 172.7 ± 10.2 cm; weight: 70.3 ± 15 kg) were recruited. Each participant completed two (test-retest) trials of weight-bearing ankle dorsiflexion during a forward lunge. Intertrial reliability was evaluated using the $ICC_{(2,k)}$ with a 95% CI, comparing measurements obtained from the Kinotek system and the goniometer.

Results: The mean ± standard deviation (standard error of the mean) ROM values were 18.8 ± 6.67 (0.99) degrees for Kinotek and 14.61 ± 5.72 (0.86) degrees for the goniometer. The ICC (95% CI) values were 0.90 (0.82–0.94) for Kinotek and 0.79 (0.65–0.89) for the goniometer. The Pearson correlation coefficient (r) was 0.55.

Conclusion: The findings indicate that the Kinotek system demonstrates good-to-excellent reliability, whereas the goniometer exhibits moderate-to-good reliability in assessing weight-bearing ankle dorsiflexion ROM. The strong association observed supports the potential utility of AI-driven motion capture systems as reliable tools in both clinical and research contexts for evaluating weight-bearing ankle dorsiflexion.

Keywords: 3D motion capture, reliability, range of motion, artificial intelligence, weight-bearing assessment

Introduction

Ankle dorsiflexion (ADF) range of motion (ROM) is essential for numerous daily activities, including gait, stair negotiation, and transitions between sitting and standing [1,2]. It also contributes to dynamic balance and athletic tasks such as jumping, landing mechanics [3,4], and arm swing coordination [5]. Restricted ADF ROM has been linked to various biomechanical alterations and clinical conditions, including an increased risk of both overuse and acute injuries, such as ankle sprains, Achilles and patellar tendinopathy [6–9], plantar fasciitis [10], patellofemoral pain syndrome [11,12], stress fractures [13–17], and anterior cruciate ligament (ACL) tears [3]. Consequently, exercises targeting improvements in ADF are commonly prescribed, necessitating accurate and reliable ROM assessments to guide and monitor intervention outcomes.

The anatomical design of the ankle enables it to withstand substantial compressive, shear, and rotational forces while adapting to variable surfaces and contributing to propulsion during gait [1]. During weight-bearing tasks, dorsiflexion positions the talocrural joint in a closed-packed configuration, promoting lower limb stability and efficient energy transfer throughout the stance phase of gait [1,18]. Conversely, restricted ADF ROM may alter the joint's axis of motion and lead to soft tissue adaptations, resulting in dysfunctional movement patterns. Insufficient ADF ROM during the mid-stance and push-off phases increases loading on the forefoot and midfoot, contributing to conditions such as metatarsalgia and neuropathic ulceration [19]. When ADF ROM is less than 10°, individuals often demonstrate altered pelvic and lower limb kinematics, including reduced step length, decreased hip and knee flexion during gait, and increased ipsilateral pelvic rotation [20]. Furthermore, individuals with ADF asymmetry ≥6.5° are at greater risk of musculoskeletal injuries, particularly those related to overuse [17].

Restrictions in ADF ROM also impact proximal joint mechanics and neuromuscular coordination [21,22]. As a compensatory strategy, individuals often exhibit increased femoral internal rotation and calcaneal eversion, which redistribute mechanical demands to surrounding musculature. These compensations can alter muscle recruitment patterns, such as elevated hip abductor activity relative to gluteal muscle engagement during single- and double-limb tasks [22–24]. These changes contribute to atypical movement patterns, such as dynamic knee valgus, frequently observed during squatting and landing tasks [4,25]. Limited sagittal plane motion may also prompt compensatory movements in the frontal and transverse planes, including increased subtalar pronation and tibial internal rotation [12,25–28]. Three-dimensional motion analysis has shown that restricted ADF is associated with reduced knee flexion, increased hip adduction, and elevated knee external rotation during dynamic activities [27]. These kinematic deviations are implicated in several lower extremity pathologies, including ACL rupture, patellar instability, anterior knee pain, and iliotibial band syndrome [3,12,27,29–31]. When left unaddressed, these biomechanical abnormalities can predispose individuals to cumulative stress and overuse injuries.

To better assess and address ADF limitations, recent technological advancements have led to the development of innovative tools capable of capturing joint ROM during functional tasks. One such tool is Kinotek, which utilizes a single tripod-mounted camera (weighing 0.44 kg; dimensions: 103 × 39 × 126 mm) to provide 3D motion analysis (Fig. 1). The system generates detailed kinematic analyses, including digital avatars, time-series graphs of joint angles throughout movement, and comprehensive reports highlighting side-to-side asymmetries (Figs. 2 and 3). Although artificial intelligence (AI)-driven technologies such as Kinotek hold promise for enhancing diagnostic specificity, prognostic accuracy, and assessment efficiency [32,33], further research is needed to establish their reliability and validity. The purpose of this study was to evaluate the reliability and validity of Kinotek for measuring weight-bearing ADF ROM during a forward lunge—a functional task relevant to identifying mobility impairments. Goniometric assessment, a standard method widely used in clinical practice, served as the comparative reference. Although non-weight-bearing exercises have demonstrated similar effectiveness [14], closed-chain movements more accurately reflect the biomechanical demands of daily functional tasks and were therefore emphasized in this analysis.

Fig. 1: Kinotek 3D motion analysis camera mounted on a tripod.

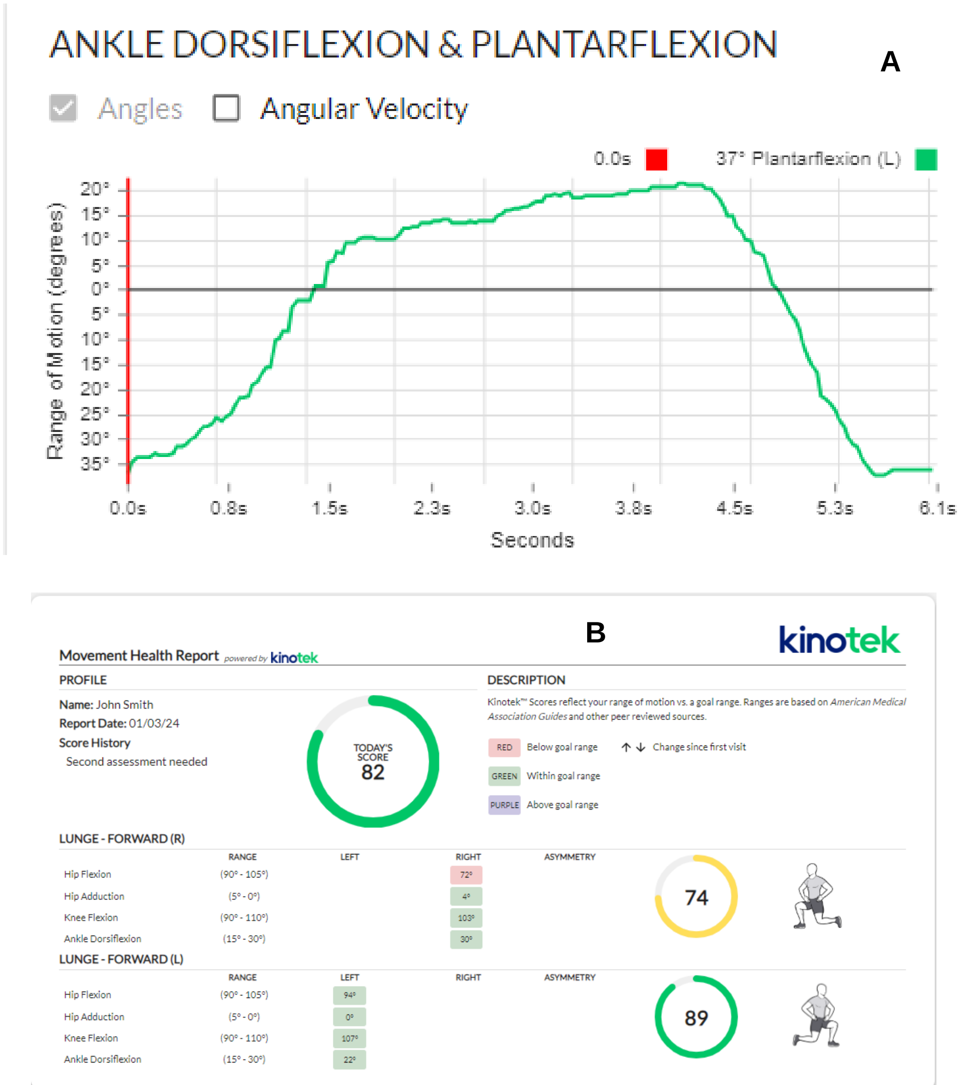


Fig. 2: Kinotek 3D motion tracking by A) time series and B) movement report.

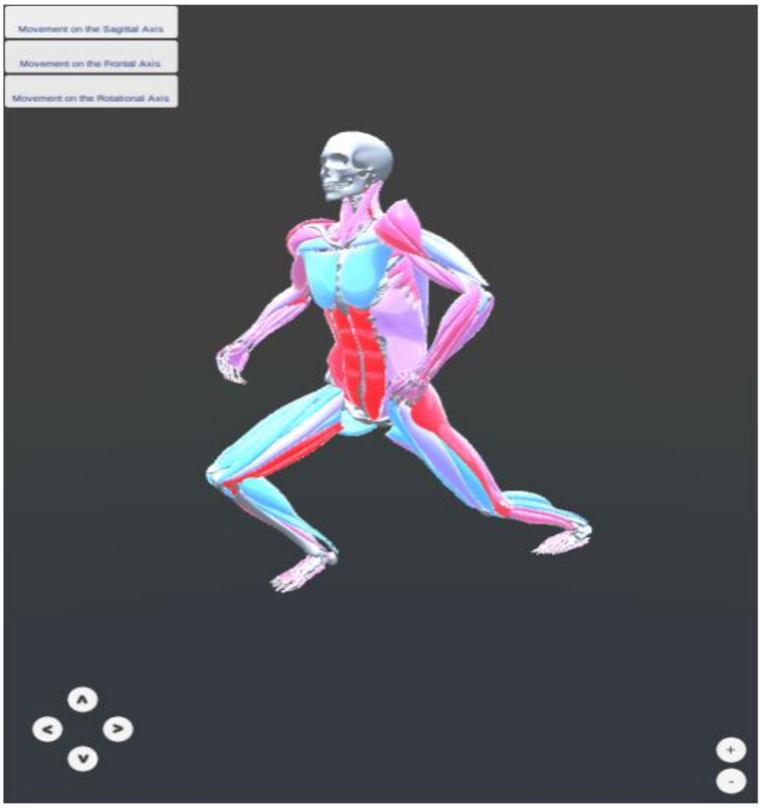


Fig. 3: Kinotek 3D motion analysis digital avatar.

Materials and Methods

Participants

Ethical approval for this study was granted by Hofstra University Institutional Review Board, and informed consent was granted by each participant. Participants were eligible to participate in the study if they were at least 18 years of age, had the ability to perform movements bilaterally and had the ability to demonstrate the specified movements without loss of balance. Participants were excluded from this study if they were taking any medications that impair balance or ability to think, had any recent injuries that are still being treated by a healthcare provider to the lower extremities, if they had active pain or tingling/numbness during the time of data collection, or were not able to provide consent.

Instruments

The instruments utilized for data collection are presented in Fig. 4 and include the following: 1) a standard 180° 8-inch plastic goniometer and 2) Kinotek 3D motion capture system (Fig. 4). The Kinotek camera employs Light Detection and Ranging (LiDAR) technology, which utilizes infrared light emitted from a pulsed laser to measure distances. This advanced depth-sensing technology, driven by AI, produces spatiotemporal representations of body movements. The platform incorporates Microsoft's Kinect camera, which processes 750 data points per visual analysis at a rate of 30 frames per second (fps). The camera is mounted on a tripod and operates via a WiFi connection. The goniometer is a tool widely used by healthcare providers to assess joint ROM and detect body asymmetries. Previous research has demonstrated that goniometers possess sufficient intra-rater reliability for measuring ROM across various joints of the body. [34-40] In this study, the goniometer was utilized as a reference standard to compare measurements obtained from the Kinotek camera with traditional goniometric assessments.

Fig 4.: Standard 180° 8-inch plastic goniometer and Kinotek camera.

Tester Selection and Procedure

For data collection, a single tester who is a physical therapist conducted all goniometric measurements. The tester was blinded to the displayed readings while positioning the goniometer on the participant and a second individual recorded the measurements. Weight-bearing ADF ROM at the talocrural joint was assessed as participants performed a forward lunge on a three-inch step, positioned seven feet away from the camera, as depicted in Fig. 5. The room setup included a floor marking at seven feet from the camera's center, with the camera oriented forward and tilted upward at a 6º angle. The camera's height was adjusted to align with the participants' mid-pelvic region at the level of the umbilicus.

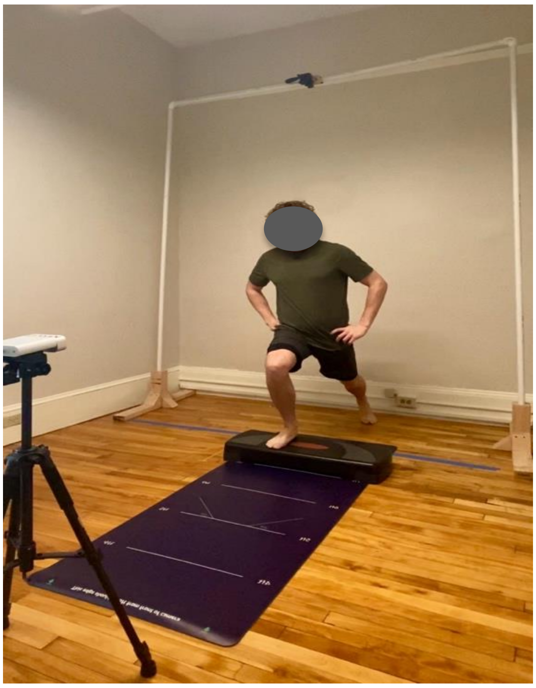


Fig 5.: Weight-bearing ankle dorsiflexion range of motion assessment.

During the recording, participants placed their foot on the step and, upon receiving a standardized verbal cue, initiated active ROM by lunging forward onto the step. Participants were instructed to stop at their maximum available range of motion and hold the position while the tester recorded the goniometric measurements for ADF. To ensure consistency, all participants received the same verbal instructions, were shown a visual demonstration of the movement, and were briefed on potential compensatory body movements. Each participant performed one practice trial, during which feedback was provided to address any extraneous variables, such as compensations or variations in movement speed. Following the practice trial, two additional trials (test-retest) were conducted for each lower extremity, which were used for data analysis.

Data Analysis

Data were analyzed using SPSS Statistics v29 (Armonk, NY). The mean (M), standard deviation (SD), and standard error of the mean (SEM) were calculated and reported. Intertrial reliability was assessed using the Intraclass Correlation Coefficient ($ICC_{2,k}$) with a 95% Confidence Interval (CI). Descriptive statistical analysis was conducted to summarize the demographic characteristics of the participant sample. The of reliability was rated poor for values less than 0.5, moderate for values between 0.5 and 0.75, good for values between 0.75 and 0.9, and excellent when greater than 0.90. [41] For validity, the Pearson correlation coefficient (*r*) was assessed. The strength of association was rated small for values between .10 and .30, medium for values between .3 and .5, and large for values between .5 and 1.0. [42]

Results

The total sample size of participants meeting the inclusion criteria was 24, comprising 15 individuals who identified as female and 9 who identified as male. The mean age of the participants was 29 ± 12 years, with an average height of 172.7 ± 10.2 cm and weight of 70.3 ± 15 kg. Of note, while the total sample consisted of 24 participants, the data analysis was performed using an n=48, as each participant was assessed bilaterally, contributing two independent data points (right and left). Of these 48 data points, four outliers were excluded due to errors in the data processing of the Kinotek software.

Table 1 presents the mean (M) and standard deviation (SD) for weight-bearing DF measurements recorded by both tools. The M ± SD (SEM) for the goniometer was 14.61 ± 5.72 (0.86), while the corresponding values for Kinotek were 18.8 ± 6.67 (0.99). The intertrial reliability and validity for weight-bearing ADF during the forward step lunge, measured with the goniometer and Kinotek, are detailed in Table 2 and illustrated in Fig. 6 as scatterplots. The ICC [95% CI)] was 0.90 (0.82–0.94) for Kinotek and 0.79 (0.65–0.89) for the goniometer, with a Pearson's correlation coefficient (*r*) = .55 ($p<0.001$).

Table 1: Weight-bearing ankle dorsiflexion range of motion during a forward step lunge measured with Kinotek and goniometer.

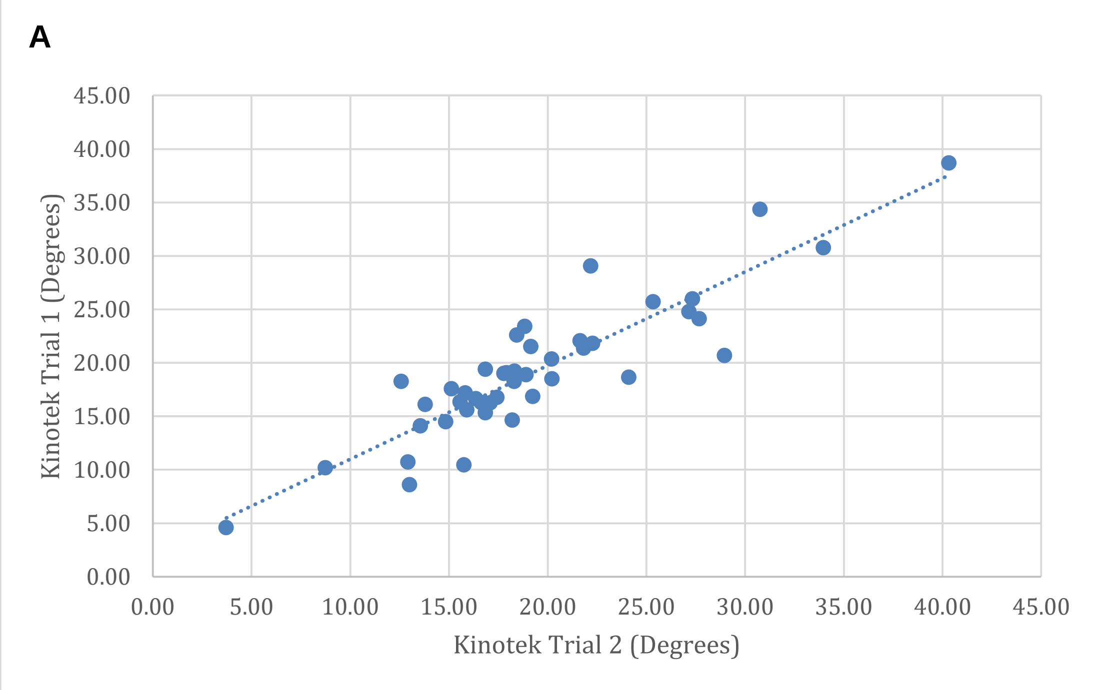
Instrument	Mean (°)	SD (°)	SEM (°)
Goniometer	14.61	5.72	0.86
Kinotek	18.80	6.67	0.99

Notes. Mean (M); standard deviation (SD); standard error of measure (SEM).

Table 2: Intertrial Reliability and Validity for weight-bearing ankle dorsiflexion range of motion during a forward step lunge for goniometer and Kinotek.

Instrument	ICC (95% CI)	*r*
Goniometer	0.79 (0.65-0.89)	0.55 ($p<0.001$)
Kinotek	0.90 (0.82-0.94)	0.55 ($p<0.001$)

Notes. Intraclass correlation coefficient (ICC); confidence interval (CI); Pearson correlation coefficient (*r*)



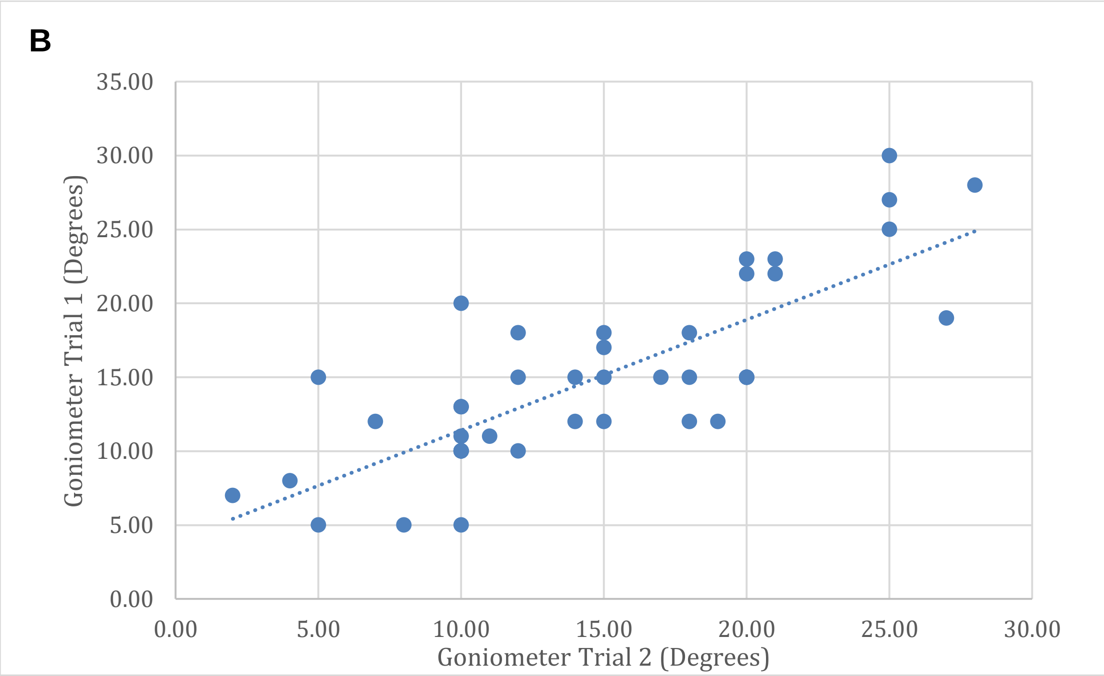


Figure 6.: Intertrial reliability for weight-bearing ankle dorsiflexion range of motion measurement with A) Kinotek and B) goniometer.

Discussion

This study found the intertrial reliability of Kinotek for measuring weight-bearing ADF ROM) to be good-to-excellent, with ICC values ranging from 0.65 to 0.94. The goniometer demonstrated moderate-to-good reliability, with ICC values ranging from 0.65 to 0.89. Pearson's correlation coefficient was $r = 0.55$ ($p < 0.001$). Overall, both tools demonstrated good reliability, with Kinotek slightly outperforming the goniometer, and a strong association observed between the two tools. These findings align with prior research supporting the reliability of markerless motion capture systems in assessing joint ROM. Specifically, studies investigating the concurrent validity of Microsoft's Kinect sensor compared to Vicon have reported good to excellent correlation [43]. Lempereur et al. [44] also emphasized the advantages of 3D motion analysis, particularly in capturing dynamic movements with high precision, which is consistent with the reliability demonstrated by the Kinotek system in this study.

Traditional tools for assessing ROM include inclinometers, goniometers, tape measures [2], and mobile phone applications [36]. The results of this study are consistent with earlier research examining the intrarater reliability of goniometric assessments. Konor et al. [45] investigated the reliability and validity of goniometers, inclinometers, and tape measures for assessing weight-bearing ADF ROM using a similar protocol and reported good reliability across all three tools. Conversely, Kim et al. [46] reported moderate to poor ICC values for ADF measurement using a goniometer, which contrasts with the current findings.

The Kinotek system's integration of AI and LiDAR technology offers several advantages over traditional tools. It enables continuous motion tracking throughout the range of movement, generates time-series data, and creates digital avatars for comprehensive kinematic analysis. These features allow clinicians to assess movement quality from multiple planes, extending beyond static end-range measurements, as noted by D'Antoni et al. [32] and Loria [33]. However, the software errors identified in this study emphasize the need for continued refinement to ensure reliability across diverse clinical and research settings.

This study had several limitations. First, the relatively small sample size (n = 24) limits the generalizability of the findings. Future studies should include larger, more diverse populations to improve external validity. Second, the current investigation focused exclusively on ADF ROM in the sagittal plane. Although a previous study examined the reliability and validity of Kinotek for shoulder mobility [47], additional research is needed to comprehensively evaluate its performance across multiple joints and movement planes. Despite these limitations, the capabilities of advanced algorithms, machine learning, and AI-driven technologies remain promising for the advancement of clinical assessment methods.

Conclusions

The objective of this study was to evaluate the reliability and validity of the Kinotek motion capture system for measuring weight-bearing ADF ROM, using goniometry as the reference standard. The results demonstrated good-to-excellent reliability, supporting the Kinotek platform as a dependable tool for both clinical and research applications in assessing weight-bearing ADF ROM. These findings are consistent with previous research highlighting the potential of AI-driven motion analysis technologies to improve diagnostic accuracy and functional assessment. Future studies should expand on these results by including larger and more diverse populations, examining additional joints, and evaluating a broader array of functional movement patterns.

References

1. Almansoof HS, Nuhmani S, Muaidi Q. Role of ankle dorsiflexion in sports performance and injury risk: A narrative review. *Electron J Gen Med.* 2023;20(5):em521. doi:10.29333/ejgm/13412
2. Zunko H, Vauhnik R. Reliability of the weight-bearing ankle dorsiflexion range of motion measurement using a smartphone goniometer application. *PeerJ.* 2021;9:e11977. doi:10.7717/peerj.11977
3. Malloy P, Morgan A, Meinerz C, Geiser C, Kipp K. The association of dorsiflexion flexibility on knee kinematics and kinetics during a drop vertical jump in healthy female athletes. *Knee Surg Sports Traumatol Arthrosc.* 2015;23(12):3550-3555. doi:10.1007/s00167-014-3222-z
4. Taylor JB, Wright ES, Waxman JP, Schmitz RJ, Groves JD, Shultz SJ. Ankle dorsiflexion affects hip and knee biomechanics during landing. *Sports Health.* 2022;14(3):328-335. doi:10.1177/19417381211019683
5. He Y, Fekete G, Sun D, et al. Lower limb biomechanics during the topspin forehand in table tennis: A systemic review. *Bioengineering (Basel).* 2022;9(8):336. doi:10.3390/bioengineering9080336
6. Baumbach SF, Braunstein M, Seeliger F, et al. Ankle dorsiflexion: What is normal? Development of a decision pathway for diagnosing impaired ankle dorsiflexion and gastrocnemius tightness. *Arch Orthop Trauma Surg.* 2016;136(9):1203-1211. doi:10.1007/s00402-016-2513-x
7. Johanson M, Baer J, Hovermale H, Phouthavong P. Subtalar joint position during gastrocnemius stretching and ankle dorsiflexion range of motion. *J Athl Train.* 2008;43(2):172-178. doi:10.4085/1062-6050-43.2.172
8. Mahieu NN, Witvrouw E, Stevens V, Van Tiggelen D, Roget P. Intrinsic risk factors for the development of Achilles tendon overuse injury: A prospective study. *Am J Sports Med.* 2006;34(2):226-235. doi:10.1177/0363546505279918

9. Backman LJ, Danielson P. Low range of ankle dorsiflexion predisposes for patellar tendinopathy in junior elite basketball players: A 1-year prospective study. *Am J Sports Med.* 2011;39(12):2626-2633. doi:10.1177/0363546511420552
10. Pascual Huerta J. The effect of the gastrocnemius on the plantar fascia. *Foot Ankle Clin.* 2014;19(4):701-718. doi:10.1016/j.fcl.2014.08.011
11. Hassan KA, Youssef RSE, Mahmoud NF, Eltagy H, El-Desouky MA. The relationship between ankle dorsiflexion range of motion, frontal plane projection angle, and patellofemoral pain syndrome. *Foot Ankle Surg*. 2022;28(8):1427-1432. doi:10.1016/j.fas.2022.08.003
12. Piva SR, Goodnite EA, Childs JD. Strength around the hip and flexibility of soft tissues in individuals with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 2005;35(12):793-801. doi:10.2519/jospt.2005.35.12.793
13. de la Motte SJ, Lisman P, Gribbin TC, et al. Systematic review of the association between physical fitness and musculoskeletal injury risk: Part 3—Flexibility, power, speed, balance, and agility. *J Strength Cond Res.* 2019;33(6):1723-1735. doi:10.1519/JSC.0000000000002382
14. Dinh NV, Freeman H, Granger J, et al. Calf stretching in non-weight bearing versus weight bearing. *Int J Sports Med.* 2011;32(3):205-210. doi:10.1055/s-0030-1268505
15. Moreno-Pérez V, Soler A, Ansa A, et al. Acute and chronic effects of competition on ankle dorsiflexion ROM in professional football players. *Eur J Sport Sci.* 2020;20(1):51-60.
16. Mourcou Q, Fleury A, Diot B, Franco C, Vuillerme N. Mobile phone-based joint angle measurement for functional assessment and rehabilitation of proprioception. *Biomed Res Int.* 2015;2015:328142. doi:10.1155/2015/328142
17. Teyhen DS, Shaffer SW, Butler RJ, et al. What risk factors are associated with musculoskeletal injury in US Army Rangers? A prospective prognostic study. *Clin Orthop Relat Res.* 2015;473(9):2948-2958. doi:10.1007/s11999-015-4342-6
18. Medina McKeon JM, Hoch MC. The Ankle-Joint Complex: A Kinesiologic Approach to Lateral Ankle Sprains. *J Athl Train*. 2019;54(6):589-602. doi:10.4085/1062-6050-472-17
19. Abdulmassih S, Phisitkul P, Femino JE, Amendola A. Triceps surae contracture: Implications for foot and ankle surgery. *J Am Acad Orthop Surg.* 2013;21(7):398-407. doi:10.5435/JAAOS-21-07-398
20. Aquino MRC, Resende RA, Kirkwood RN, et al. Spatial-temporal parameters, pelvic, and lower limb movements during gait in individuals with reduced passive ankle dorsiflexion. *Gait Posture.* 2022;93:32-38. doi:10.1016/j.gaitpost.2022.01.010
21. Howe LP. The acute effects of ankle mobilizations on lower extremity joint kinematics. *J Bodyw Mov Ther.* 2017;21(4):775-780. doi:10.1016/j.jbmt.2016.11.007
22. Lima YL, Ferreira VMLM, de Paula Lima PO, Bezerra MA, de Oliveira RR, Almeida GPL. The association of ankle dorsiflexion and dynamic knee valgus: A systematic review and meta-analysis. *Phys Ther Sport*. 2018;29:61-69. doi:10.1016/j.ptsp.2017.07.003
23. Nakagawa TH, Petersen RS. Relationship of hip and ankle range of motion, trunk muscle endurance with knee valgus and dynamic balance in males. *Physiother Sport.* 2018;34:174-179. doi:10.1016/j.ptsp.2018.10.006
24. Rabin A, Kozol Z, Spitzer E, Finestone A. Ankle dorsiflexion among healthy men with different qualities of lower extremity movement. *J Athl Train.* 2014;49(5):617-623. doi:10.4085/1062-6050-49.3.14
25. Macrum E, Bell DR, Boling M, Lewek M, Padua D. Effect of limiting ankle-dorsiflexion range of motion on lower extremity kinematics and muscle-activation patterns during a squat. *J Sport Rehabil*. 2012;21(2):144-150. doi:10.1123/jsr.21.2.144
26. Stanley LE, Harkey M, Luc-Harkey B, et al. Ankle dorsiflexion displacement is associated with hip and knee kinematics in females following anterior cruciate ligament reconstruction. *Res Sports Med.* 2019;27(1):21-33. doi:10.1080/15438627.2018.1502180
27. Rabin A, Portnoy S, Kozol Z. The association of ankle dorsiflexion range of motion with hip and knee kinematics during the lateral step-down test. *J Orthop Sports Phys Ther.* 2016;46(11):1002-1009. doi:10.2519/jospt.2016.6621

28. Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population: A two-year prospective study. *Am J Sports Med.* 2000;28(4):480-489. doi:10.1177/03635465000280040701
29. Noehren B, Hamill J, Davis I. Prospective evidence for a hip etiology in patellofemoral pain. *Med Sci Sports Exerc.* 2013;45(6):1120-1124. doi:10.1249/MSS.0b013e31828249d2
30. Greiwe RM, Saifi C, Ahmad CS, Gardner MJ. Anatomy and biomechanics of patellar instability. *Oper Tech Sports Med.* 2015;23(1):2-9. doi:10.1053/j.otsm.2014.10.001
31. Aderem J, Louw QA. Biomechanical risk factors associated with iliotibial band syndrome in runners: A systematic review. *BMC Musculoskelet Disord.* 2015;16:356. doi:10.1186/s12891-015-0808-7
32. D'Antoni F, Russo F, Ambrosio L, et al. Artificial intelligence and computer-aided diagnosis in chronic low back pain: A systematic review. *Int J Environ Res Public Health.* 2022;19(10):5971. doi:10.3390/ijerph19105971
33. Loria K. What's the impact of AI on physical therapy? How artificial intelligence can enhance physical therapist services—and when PTs should use caution. *APTA Mag.* 2023;15(11):34-42.
34. Furness J, Schram B, Cox AJ, et al. Reliability and concurrent validity of the iPhone® compass application to measure thoracic rotation range of motion in healthy participants. *PeerJ.* 2018;6:e4431. doi:10.7717/peerj.4431
35. Kolber MJ, Hanney WJ. The reliability and concurrent validity of shoulder mobility measurements using a digital inclinometer and goniometer: A technical report. *Int J Sports Phys Ther.* 2012;7(3):306-313
36. Pottorf OA, Lee DJ, Czujko PN. Reliability and concurrent validity of mobile health technology for patient self-monitoring in physical rehabilitation. *Shoulder Elbow Surg Int.* 2022;6(3):506-511. doi:10.1016/j.jseint.2022.02.002
37. Reid S, Egen B. The validity and reliability of DrGoniometer, a smartphone application for measuring forearm supination. *J Hand Ther.* 2019;32:110-117. doi:10.1016/j.jht.2018.03.003
38. Salamh PA, Kolber M. The reliability, minimal detectable change, and concurrent validity of a gravity-based bubble inclinometer and iPhone application for measuring standing lumbar lordosis. *Physiother Theory Pract.* 2014;1:2-7. doi:10.3109/09593985.2013.800174
39. Shin SH, Ro DH, Lee OS, Oh JH, Kim SH. Within-day reliability of shoulder range of motion measurement with a smartphone. *Man Ther.* 2012;17:298-304. doi:10.1016/j.math.2012.02.010
40. Tayfur I, Afacan MA. Reliability of smartphone measurements of vital parameters: A prospective study using a reference method. *Am J Emerg Med.* 2019;37:1527-1530. doi:10.1016/j.ajem.2019.03.021
41. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research [Published correction appears in *J Chiropr Med*, 2017, 16(4), 346]. *J Chiropr Med.* 2016;15(2):155-163. doi:10.1016/j.jcm.2016.02.012
42. Bosco FA, Aguinis H, Singh K, et al. Correlational effect size benchmarks. *J Appl Psychol.* 2015;100(2):431-449. doi:10.1037/a0038047
43. Chen B, Wang W, Hu G, et al. Concurrent validity of a markerless motion capture system for the assessment of shoulder functional movement. *Med Novel Technol Devices.* 2022;15:100131. doi:10.1016/j.medntd.2022.100131
44. Lempereur M, Brochard S, Leboeuf F, Rémy-Néris O. Validity and reliability of 3D marker-based scapular motion analysis: A systematic review. *J Biomech.* 2014;47(10):2219-2230. doi:10.1016/j.jbiomech.2014.04.028
45. Konor MM, Morton S, Eckerson JM, Grindstaff TL. Reliability of three measures of ankle dorsiflexion range of motion. *Int J Sports Phys Ther.* 2012;7(3):279-287.
46. Kim PJ, Peace R, Mieras J, Thoms T, Freeman D, Page J. Interrater and intrarater reliability in the measurement of ankle joint dorsiflexion is independent of examiner experience and technique used. *J Am Podiatr Med Assoc*. 2011;101(5):407-414. doi:10.7547/1010407
47. Pottorf O, Vapne D, Ghigiarelli J, Haase K. Reliability and concurrent validity of a markerless, single camera, portable 3D motion capture system for assessment of glenohumeral mobility. *Int J Sports Phys Ther.* 2023;18(5):1176-1185.