Original Article

Reliability of Range of Motion Assessment Using Universal Goniometer and Video Goniometer Application: A Comparative Study

Duane Tristan Jayubo, Phoebe Demegillo, Anthony Joy Ramas, Neo Eljan Apolonio, Kaizhi Makabenta, Meg Evicelle Aznar, Dianne Mae Legion, Erl John Manalo, Ma. Le Ann Canono, Jacob Rosales, Gwynth Kaye Sudario, Faivy Kristine Alcalde and Julienne Daffon

Department of Physical Therapy, College of Biomedical Sciences, Doña Remedios Trinidad Romualdez Educational Foundation Inc., Tacloban City, Leyte Philippines

ABSTRACT

Objectives: To compare the reliability of universal goniometer (UG) and video goniometer (VG) applications in assessing the range of motion of lower extremity involvement in patients with osteoarthritis during gait

Study design: A comparative study design

Setting: Department of Physical Therapy, Community-Based Rehabilitation of Doña Remedios Trinidad Romualdez Educational Foundation Inc., Tacloban City, Leyte, Philippines

Subjects: Forty-three participants with knee osteoarthritis

Methods: The research involved 43 participants aged 40 to 80 with persisting unilateral knee pain for at least 6 months and above who can perform independent walking activities recruited from Palo and Tacloban City, Leyte, Philippines, through a community-based program. Data collection included demographic information and range of motion (ROM) measurements during walking, which occurred over specific dates with a two-day gap between trials. Joint angles were measured using a universal goniometer and a video goniometer, with the universal goniometer attached to key joints like the knee, hip, and ankle during specific gait cycles. The video goniometer employed the Angles application to measure joint angles in the sagittal plane, using anatomical landmarks such as the greater trochanter, lateral epicondyle, and lateral malleolus. Measurements were adjusted to ensure consistency, with specific angles for hip flexion/extension, knee flexion/extension, and ankle dorsiflexion/plantarflexion recorded. To ensure impartiality, researchers randomized video sequences and restricted access to measurements. Reliability was assessed using the intraclass correlation coefficient (ICC) for inter and intra-rater assessments.

Results: The difference between the interrater reliability among UG and VG showed that UG (ICC = 0.536) is more reliable than VG (ICC = 0.318) in assessing hip, knee, and ankle range of motion (ROM). The difference between the intra-rater reliability among UG and VG, on the other hand, showed that VG (ICC = 0.714) is more reliable than UG (ICC = 0.611) in assessing hip, knee, and ankle ROM.

Conclusions: In conclusion, when assessing ROM in patients with arthritis with multiple assessors, the universal goniometer shows better consistency among assessors (interrater reliability), while the video goniometer demonstrates more consistent assessments by individual assessors across multiple trials (intra-rater reliability).

Keywords: universal goniometer, video goniometer, range of motion, knee osteoarthritis, reliability

ASEAN J Rehabil Med. 2025; 35(2): 67-75.

Introduction

Goniometers are crucial for measuring joint angles in various disciplines, but concerns exist regarding reliability and accessibility. Measuring range of motion (ROM) is vital for assessing joint function, diagnosing movement limitations, and tracking rehabilitation progress. Accurate ROM measurements help identify joint stiffness or asymmetry, guide treatment plans, and monitor recovery. In clinical and research contexts, reliable ROM data supports effective patient care and facilitates comparison across studies.

The traditional universal goniometer (UG) is a widely utilized instrument for measuring ROM. Research shows that a clinician's repeated use of the traditional goniometer on the same individual yields consistent measurements, indicating reliable ROM assessments with proper training and standardized protocols.[1] Key factors influencing reliability include clinician experience, as more experienced practitioners tend to demonstrate higher intra-rater reliability and adherence to standardized procedures for patient positioning and goniometer alignment.[2,3]

On the other hand, video goniometer (VG) applications have demonstrated high reliability, suggesting that consistent

Correspondence to: Duane Tristan Jayubo, Department of Physical Therapy, College of Biomedical Sciences, Doña Remedios Trinidad Romualdez Educational Foundation Inc., Tacloban City, Leyte Philippines; E-mail:jayubo.duanetristan.bspt@gmail.com

Received: Jul 14, 2024 Revised: Jan 10, 2025 Accepted: Jan 11, 2025

measurements can be obtained regardless of the assessor. This goniometer type offers several potential advantages, including increased objectivity, as the recorded movement can be reviewed multiple times, reducing the subjectivity inherent in manual measurements.[4] Additionally, it allows for a more detailed analysis of movement patterns, such as velocity, acceleration, and timing.[5] However, the reliability of video goniometry is influenced by several factors, including accurate camera calibration, the precision of the software used for analysis, and consistent camera angle and positioning, all of which are critical for ensuring reproducible and accurate results.[6]

Traditional UG remain popular despite drawbacks such as requiring two-handed operation. New technologies like the Angles Video-Goniometer app offer promising alternatives that are affordable and user-friendly alternatives for clinicians and researchers. The Angles Video-Goniometer application is both valid and reliable for assessing joint angles.[7] It can be used during static and dynamic activities for adults and children. While studies confirm the validity and reliability of the app, there is a lack of research comparing it to traditional goniometers, particularly in measuring functional activity among patient populations.

The Angles-Video Goniometer Application or the Angles App was developed to provide a modern, accessible tool for measuring joint angles using video technology. The development process involved designing a user-friendly interface allowing users to capture video recordings, mark anatomical landmarks and measure joint angles in static and dynamic positions.[8] The Angles App was meticulously designed to offer a cost-effective and efficient alternative to traditional goniometers. Its validation has been rigorously conducted, with research demonstrating that the App provides reliable and accurate measurements.[9] Studies comparing the application's measurements with those obtained from traditional goniometers have confirmed its accuracy.[10] Furthermore, the application's measurements have been tested against those of healthy subjects, showing consistency with established methods.[11] This validation supports the application's effectiveness and reliability for joint angle assessment in clinical and research settings.

Despite its promising capabilities, there is a notable gap in research comparing the Angles app to traditional goniometers, particularly in functional assessments for patients with knee osteoarthritis (OA). This gap highlights the need to evaluate whether the app can offer comparable or superior accuracy in measuring ROM during functional tasks such as gait, as this has already been used in assessing healthy individuals.[12] Furthermore, knee OA was chosen for this study due to its prevalence and the significant impact on gait and functional mobility. Precise measurement of ROM in this population is critical for assessing treatment efficacy and monitoring disease progression. However, limited research compares video goniometers to traditional methods, specifically in the context of knee OA. Focusing on knee OA patients, this study aims to determine the application's efficacy in a context where precise measurement is crucial for effective management and treatment planning. The findings will help address this gap and improve clinical practice for managing knee OA.

Methods

Research design

Approved by the Eastern Visayas Health Research and Development Consortium Committee on June 19, 2023 (protocol code 2023-010), this study was conducted at Palo and Tacloban City, Leyte, Philippines, through a community-based program under the facilitation of the Department of Physical Therapy, Community-Based Rehabilitation of Doña Remedios Trinidad Romualdez Educational Foundation Inc., Tacloban City, Leyte, Philippines. The research was designed as a comparative study to evaluate the range of motion (ROM) in the lower extremities—specifically the hip, knee, and ankle—in patients with knee osteoarthritis during gait. This evaluation utilized both a universal goniometer and a video goniometer.

Participants

The study included 43 patients from various communities in Palo and Tacloban City, Leyte, identified through the Remedios Trinidad Romualdez Community-Based Rehabilitation program. The sample size of 43 was calculated using a 95% confidence interval, a 5% margin of error, and a population proportion of 25%, with a total population size of 50. Eligible participants were males or females aged 40 to 80 with unilateral knee pain persisting for at least 6 months or diagnosed with knee osteoarthritis who could independently walk. Inclusion criteria were based on clinical signs and symptoms and classification criteria for knee osteoarthritis.[13] Participants with a medical history of joint arthroplasty in any lower extremity joint (hip, knee, or ankle) were excluded from the study.

Study procedure

Participants were recruited following protocols, ensuring confidentiality and obtaining informed consent through personal contact and signed consent forms. Initial contact was made with 50 potential participants, of whom 43 met the inclusion criteria and underwent assessment. The assessment process included administering a questionnaire gathering demographic information and ROM data.

Gait assessments were conducted in a controlled indoor environment with careful consideration for optimal camera positioning to capture the entire body during walking trials. An Apple iPhone 11 camera at high-definition video quality at 30 frames per second frame rate, mounted on a stabilizer, was used to record video footage by tracking the participant throughout their gait cycle. This approach ensured optimal distance from the participants while maintaining a full view of the reference limb. The entire data collection process took an average time of 15 minutes. Researchers were also individually assigned different roles, including the one who prepares the markers for the participants, the cameraman, and the respective assessors with physical therapists throughout the process. Participants were instructed to walk along a 20-feet predetermined pathway at their preferred speed with their painful leg as reference faced towards the single camera, recording them at the lateral aspect. Markers (cotton and tape) were also affixed to the reference leg's hip, knee, and ankle joints to ensure precise identification of the fulcrum for accurate placement during measurement.

Joint angles were measured using two distinct methods: a universal goniometer and a video goniometer. The universal goniometer was utilized to measure specific gait cycles, with the small goniometer attached to joints of interest, such as the knee, hip, and ankle. This measurement was synchronized with video footage to document joint angles at various points in the gait cycle, as shown in Figure 2 and elaborated further in Table 1.

The video goniometer method employed anatomical landmarks marked with the Angles application (Figure 3). Joint angles in the sagittal plane were measured for the hip, knee, and ankle. Anatomical landmarks included the greater trochanter, lateral epicondyle of the femur, and lateral malleolus. Specific joint angle measurements included hip flexion (0° to 180° anteriorly), hip extension (0° to 180° posteriorly), knee flexion (0° to 180°), knee extension (180° to 0°), ankle dorsiflexion (0° to 90°), and ankle plantarflexion (90° to 180°). The reference point of 180° represented the initial or starting position, subsequently interpreted as 0°. To ensure consistency across all video goniometer assessments for the hip, knee, and ankle, the researcher adjusted the data by subtracting 180° where applicable. Ankle joint angles below 90° were classified as dorsiflexion, while angles above 90° were identified as plantarflexion.

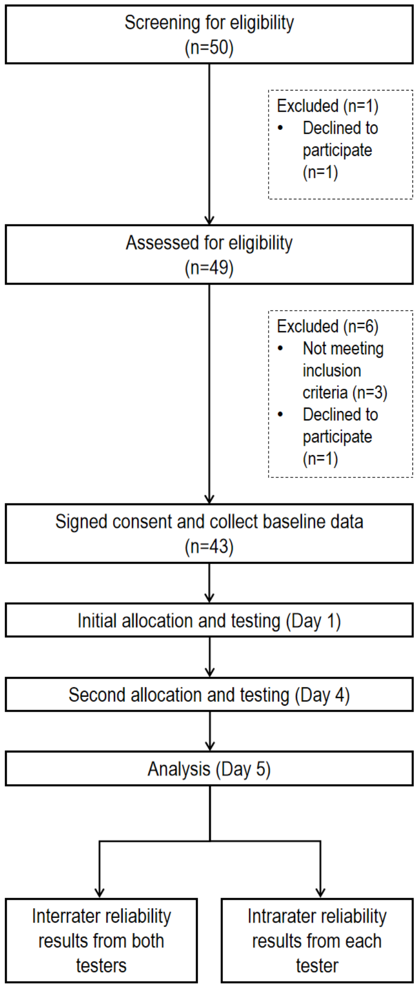

Figure 1. Data gathering procedure

Data collection occurred over specific dates with a two-day gap between trials to minimize fatigue and allow for recovery. All collected measurements were meticulously organized in a spreadsheet for subsequent statistical analysis, ensuring systematic data management and integrity throughout the study.

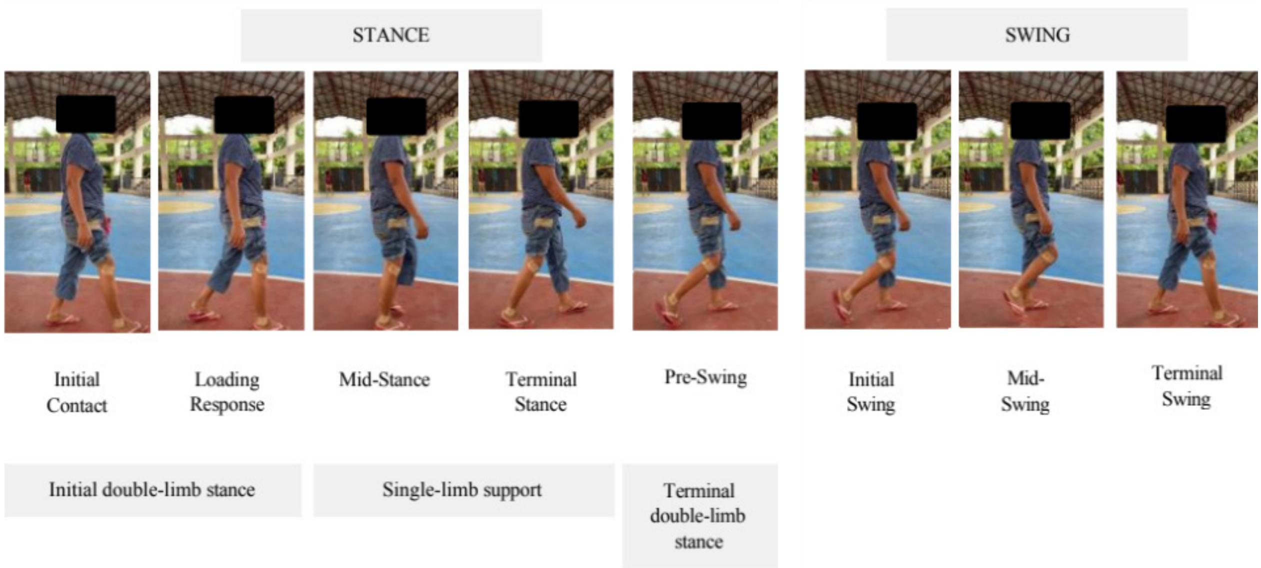

Figure 2. The phases and subphases of the gait cycle

Table 1.

The subphases of the Gait Cycle	Description
Initial contact	At the beginning of the stance, when the heel or some other portion of the foot contacts the ground.
Loading response	Body weight rapidly loads onto the lead limb from the trailing limb. The hip remains stable, the knee flexes to absorb shock, and the forefoot lowers to the ground. Immediately follows initial contact and ends when the opposite limb lifts from the ground for swing.
Mid-stance	The trunk progresses from behind to in front of the ankle over the single stable limb. It starts when the contralateral foot lifts from the ground for a swing.
Terminal stance	The trunk continues forward progression relative to the foot. The heel rises from the ground, and the limb achieves a trailing limb posture and ends with contralateral initial contact.
Pre-swing	Body weight rapidly unloads from the reference limb, and the reference limb prepares for swing. It starts with contralateral initial contact and ends at the ipsilateral limb toe-off.
Initial swing	It starts when the reference foot lifts from the ground. Hip, knee, and ankle rapidly flex for clearance and advancement.
Mid-swing	Thigh continues advancing, knee begins to extend, and ankle achieves neutral posture.
Terminal swing	The knee achieves maximal extension, and the ankle remains neutral in preparation for the heel's first initial contact. It ends when the foot contacts the ground.

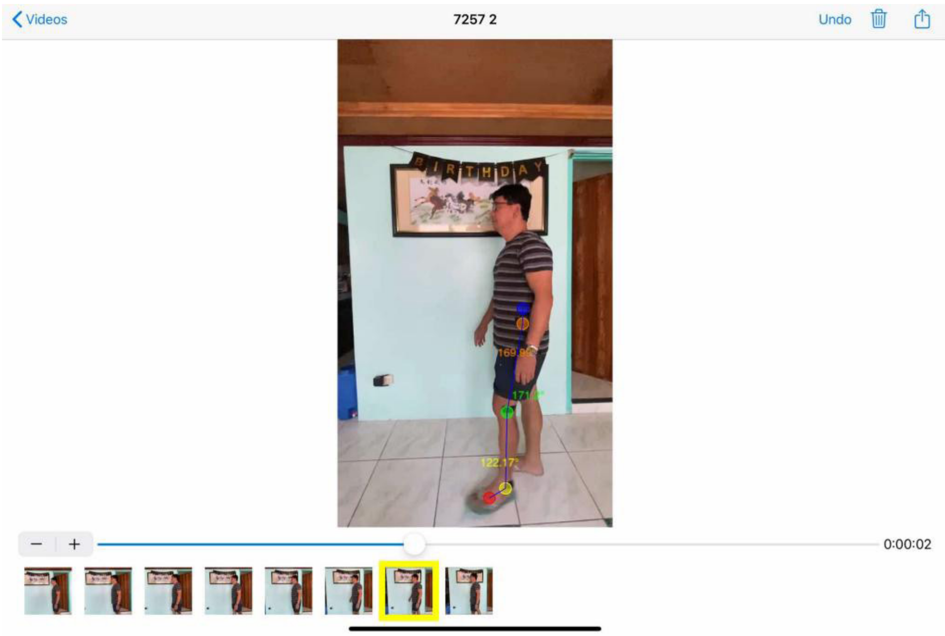

Figure 3. Data sample from the Angles-Video Goniometer Application

Statistical treatment of data

The intraclass correlation coefficient (ICC) formula was employed, utilizing SPSS statistical package version 26 to calculate ICC estimates and their 95% confidence intervals. For interrater reliability, a mean-rating (k = 2), consistency, and two-way mixed-effects model was applied, while for interrater reliability, an absolute-agreement, two-way mixed-effects model was used.

Results

General characteristics of the subjects

The demographic data of 43 participants (Table 2) revealed that the majority of participants were aged between 50-70 years (58.1%), with a smaller proportion under 50 years (30.2%) and over 70 years (11.7%). Females comprised 69.8% of the sample, while males accounted for 30.2%. Regarding disease onset, most participants (51.2%) reported onset between 1-4 years ago, with smaller percentages experiencing onset less than a year ago (25.6%), 5-8 years ago (13.9%), and over 8 years ago (9.3%).

Interrater reliability

The average interrater reliability measured by ICC for lower extremity motions during different subphases of gait using both UG and VG (Table 3) showed that the overall average reliability was higher for UG (ICC = 0.536, 95%CI [0.28, 0.72]) compared to VG (ICC = 0.318, 95%CI [0.02, 0.56]). Among the gait subphases, interrater reliability using UG was highest during the initial swing (Isw) with an ICC of 0.840 (95%CI [0.72, 0.91]). In contrast, VG reliability was consistently lower across all subphases, with the highest reliability also during the Isw at 0.547 (95%CI [0.30, 0.73]).

Table 2. Demographic data of 43 participants

Variables	Number (%)
Age	
< 50 years old	13 (30.2)
50-70 years old	25 (58.1)
> 70 years old	5 (11.7)
Gender	
Male	13 (30.2)
Female	30 (69.8)
Disease onset	
< 1 year ago	11 (25.6)
1-4 years ago	22 (51.2)
5-8 years ago	6 (13.9)
> 8 years ago	4 (9.3)

*Average ICC was obtained from the ICC values of hip, knee, and ankle joints

Table 3. The interrater reliability of the universal goniometer (UG) and video goniometer (VG) for measuring lower limb joint movements in gait cycle

Subphases of Gait Cycle	Average ICC of UG	Average ICC of VG
Initial contact	0.497	0.315
Loading response	0.506	0.415
Mid-stance	0.079	0.143
Terminal stance	0.501	0.249
Pre-swing	0.599	0.263
Initial swing	0.840	0.547
Mid-swing	0.725	0.398
Terminal swing	0.544	0.210
Average Reliability	0.536	0.318

*Average ICC was obtained from the ICC values of hip, knee, and ankle joints

Interrater reliability

The average interrater reliability (ICC) for lower extremity motions across different gait subphases using the UG and VG (Table 4) indicated that the overall average reliability was higher for VG (ICC = 0.714, 95%CI [0.53, 0.84]) compared to UG (ICC = 0.611, 95%CI [0.38, 0.77]). The highest reliability for UG was observed during terminal stance (Tst) with an ICC of 0.663 (95%CI [0.45, 0.80]). In comparison, VG showed its highest reliability during the Isw with an ICC of 0.814 (95%CI [0.68, 0.90]).

Discussion

Demographic data

This study provides valuable insights into the demographic and clinical characteristics of the participants, which are crucial for interpreting the findings and understanding their implications. The sample, consisting of 43 participants, showed that the majority were aged between 50 and 70 years (58.1%), reflecting the typical age range for knee OA, which is most prevalent among middle-aged and older adults.[15] A smaller proportion were under 50 (30.2%), and only 11.7% were over 70 years, consistent with epidemiological data.16 The gender distribution revealed a higher proportion of females (69.8%) compared to males (30.2%), aligning with the known higher prevalence of knee OA in women due to hormonal changes and more significant knee joint stress.[17,18] Additionally, the majority of participants reported disease onset between 1 and 4 years ago (51.2%), with fewer experiencing onset within the past year (25.6%) or beyond 8 years ago (9.3%). This distribution indicates that the sample includes individuals at various stages of disease progression, offering insights into both early and more established OA.[19,20] Overall, the demographic characteristics of the study sample reflect the typical profile of individuals with knee OA and provide context for the findings on joint angle measurements and their implications for diagnosis and treatment. Future research should continue to explore these variables to refine and enhance management strategies for knee OA.

Table 4. The intrarater reliability of the universal goniometer (UG) and video goniometer (VG) for measuring lower limb joint movements in gait cycle

Subphases of Gait Cycle	Average ICC of UG	Average ICC of VG
Initial contact	0.547	0.777
Loading response	0.624	0.766
Mid-stance	0.529	0.699
Terminal stance	0.663	0.488
Pre-swing	0.640	0.602
Initial swing	0.697	0.814
Mid-swing	0.664	0.783
Terminal swing	0.523	0.781
Average Reliability	0.611	0.714

*Average ICC was obtained from the ICC values of hip, knee, and ankle joints

Interrater reliabilities

A UG showed moderate interrater reliability for osteoarthritic patients' lower extremity (LE) motions. These findings are consistent with several studies that noted UG's consistent performance in measuring joint ROM, particularly for the knee.[21,22] The research conducted in 2003 provides additional evidence reinforcing the notion of moderate interrater reliability associated with using UG in measuring ankle range of motion.[23] Overall, UG remains a reliable tool for clinical evaluations, providing accurate joint ROM measurements due to its standardized positions and precise landmarks.

The interrater reliability of VG showed poor interrater reliability. A study in 2023 emphasized the moderate reliability of knee joint angle measurements during walking in neurological patients,[24] while another study in 2001 stressed the importance of precise and consistent measurements,[25] advocating for standardized methodologies. These findings highlight the low interrater reliability of VG for assessing hip, knee, and ankle ROM in arthritis patients, underscoring the importance of standardized measurement approaches.

Interrater reliabilities

The interrater reliability of using UG showed moderate interrater reliability for LE motions in osteoarthritic patients. Compared to studies reporting high reliability with alternative tools,[26,27] this review finds moderate interrater reliability with UG. Related studies also confirm the moderate reliability found here, stressing the importance of following specific protocols to ensure accuracy and dependability.[28,29]

The interrater reliability of using VG showed moderate interrater reliability. A similar study expressed good interrater reliability for hip, knee, and ankle joints, particularly at initial contact.[30] Emphasis should also be placed on the importance of design considerations in evaluating measurement changes applicable to VG reliability assessments.[31] These studies collectively validate VG as a reliable tool for clinical evaluations, emphasizing the need for consistent measurement practices.

Comparison of UG and VG reliabilities

As applied in this study, the universal goniometer is the traditional tool for measuring joint angles, typically requiring manual alignment of the device with anatomical landmarks at each subphase of gait. While familiar and commonly used, this method can introduce variability in measurements due to improper alignment with the necessary anatomical landmarks, leading to potential inconsistencies. On the other hand, the Angles video goniometer application streamlines the process by allowing clinicians to plot the joints directly within the specific gait subphase to obtain the joint angle. This process makes it more efficient, as the need to identify multiple landmarks is eliminated, with only the fulcrum of each joint needing attention. However, the VG can be somewhat confusing due to its use of a coordinate grid, which necessitates subtracting degree angles to calculate the correct joint angle, adding a layer of complexity to its interpretation.

In assessing hip ROM, UG demonstrated higher interrater reliability than VG, in contrast to previous findings that reported equal reliability between the two methods.[32] Discrepancies in this study may be attributed to human errors.[33] UG also demonstrated higher reliability in assessing knee ROM, echoing previous research findings that showed greater interrater reliability with UG than a smartphone goniometer application in dancers with knee osteoarthritis.[34] In evaluating ankle ROM, UG demonstrated more excellent reliability, which aligns with previous findings suggesting higher interrater consistency using a traditional universal goniometer over other measurement instruments.[35] In contrast, VG showed higher interrater reliability than UG in assessing hip, knee, and ankle ROM. In a study conducted by researchers in 2017, findings indicated that a goniometer app displayed high levels of intra- and interrater reliability, with minor differences noted between measurements taken by students and experienced physicians when compared to UG.[36]

Furthermore, the VG offers several distinct advantages over the UG, contributing to its increased reliability and utility. Firstly, the VG eliminates the need for physical contact and manual alignment, which can introduce variability and measurement errors with the UG. The UG relies on precise manual positioning and alignment by the examiner, which can be influenced by factors such as examiner experience and consistency.[37] In contrast, the VG uses video recordings to capture joint angles, allowing for more consistent and repeatable measurements by minimizing human error.[38] Secondly, the VG provides a more comprehensive analysis of joint motion. Analyzing video recordings enables detailed assessments of dynamic movements and multiple gait cycles, which is challenging with the UG due to its one-time measurement approach.[39] This capability allows for better capture of complex gait patterns and provides a more complete picture of joint kinematics during functional activities.[40] Additionally, the VG is more accessible and user-friendly. Traditional UG measurements often require two-handed operation and direct physical contact, which can be cumbersome and less practical in clinical settings.[41] The VG, however, simplifies the measurement process through an intuitive interface and does not require physical interaction, making it more suitable for both clinical and research applications.[42] Finally, the VG's digital format allows easy data storage, retrieval, and analysis. This digital advantage streamlines documentation and facilitates using advanced analytical tools and software for in-depth evaluation and comparison of joint angles.[43] In contrast, UG data is typically recorded manually, which can be time-consuming and prone to inaccuracies.[44] As for the limitations of this study, a small sample size may affect the generalizability of the findings to a broader population. Addi-tionally, the study focused on a specific group of osteoarthritic patients, was conducted in a controlled environment, and assessed short-term reliability, limiting the applicability of the results to other patient populations, real-world settings, and long-term measurements.

Conclusion

In conclusion, the universal and video goniometer are reliable tools for measuring joint ROM. However, the universal goniometer shows high interrater reliability, meaning assessments by different evaluators were highly consistent. Conversely, the video goniometer exhibits higher interrater reliability, indicating more consistent assessments by the same evaluator across different trials.

Future studies should assess the reliability of both goniometers in larger, more diverse populations. Additionally, the impact of training and standardized protocols on measurement consistency, especially with the video goniometer, should be explored. Lastly, future studies should ask participants for consent to wear fitted clothes or undergarments to ensure accurate landmark marking.

Conflict of interest declaration

The authors declare no conflicts of interest with any financial organizations about the materials presented in this manuscript.

Data availability

The authors confirm that the major data supporting the findings of this study are available within the article. However, other supporting data of this study are available from the corresponding author, DTJ, upon reasonable request.

References

1. Otter SJ, Agalliu B, Baer N, Hales G, Harvey K, James K, Keating R, McConnell W, Nelson R, Qureshi S, Ryan S. The reliability of a smartphone goniometer application compared with a traditional goniometer for measuring first metatarsophalangeal joint dorsiflexion. J Foot Ankle Res. 2015 Dec [cited 2025 Jan 9];8:1-7. Available from: https://link.springer.com/article/10.1186/s13047-015-0088-3. doi: 10.1186/s13047-015-0088-3
2. Keogh JW, Cox A, Anderson S, Liew B, Olsen A, Schram B, Furness J. Reliability and validity of clinically accessible smartphone applications to measure joint range of motion: A systematic review. PLoS One. 2019 May [cited 2025 Jan 9];14(5):e0215806. Available from: https://journals.plos.org/plosone/article?id = 10.1371/journal.pone.0215806. doi: 10.1371/journal.pone.0215806
3. Kiatkulanusorn S, Luangpon N, Srijunto W, Watechagit S, Pitchayadejanant K, Kuharat S, Bég OA, Suato BP. Analysis of the concurrent validity and reliability of five common clinical goniometric devices. Sci Rep. 2023 Nov [cited 2025 Jan 9];13(1):20931. Available from: https://www.nature.com/articles/s41598-023-48344-6 doi: 10.1038/s41598-023-48344-6.
4. Vijayan V, Connolly JP, Condell J, McKelvey N, Gardiner P. Review of wearable devices and data collection considerations for connected health. Sensors (Basel). 2021 Aug [cited 2025 Jan 9];21(16):5589. Available from: https://www.mdpi.com/1424-8220/21/16/5589 doi: 10.3390/s21165589.
5. Parks MT, Wang Z, Siu KC. Current low-cost video-based motion analysis options for clinical rehabilitation: a systematic review. Phys Ther. 2019 Oct [cited 2025 Jan 9];99(10):1405-25. Available from: https://academic.oup.com/ptj/article/99/10/1405/5531059 doi: 10.1093/ptj/pzz097.
6. McKinnon CD, Ehmke S, Kociolek AM, Callaghan JP, Keir PJ. Wrist posture estimation differences and reliability between video analysis and electrogoniometer methods. Hum Factors. 2021 Nov [cited 2025 Jan 9];63(7):1284-94. doi: 10.1177/0018720820923839.
7. Cunha AB, Babik I, Harbourne R, Cochran NJ, Stankus J, Szucs K, et al. Assessing the validity and reliability of a new video goniometer app for measuring joint angles in adults and children. Arch Phys Med Rehabil. 2020 Feb [cited 2023 Jun];101(2):275-82. doi: 10.1016/j.apmr.2019.07.008.
8. Edriss S, Romagnoli C, Caprioli L, Zanela A, Panichi E, Campoli F, Padua E, Annino G, Bonaiuto V. The role of emergent technologies in the dynamic and kinematic assessment of human movement in sport and clinical applications. Appl Sci. 2024 Jan [cited 2025 Jan 9];14(3):1012. Available from: https://www.mdpi.com/2076-3417/14/3/1012 doi: 10.3390/app14031012.
9. Huang J, Tian F, Zhang Z, Shi W, Lin J, Chen L, et al. Reliability and concurrent validity of angle measurements in lower limb: EOS 3D goniometer versus 2D manual goniometer. J Orthop Transl. 2020 Sep [cited 2023 Jun];24:96-102. Available from: https://www.sciencedirect.com/science/article/pii/S2214031X20300681 doi.org/10.1016/j.jot.2020.05.002.
10. Geneen LJ, Moore RA, Clarke C, Martin D, Colvin LA, Smith BH. Physical activity and exercise for chronic pain in adults: an overview of Cochrane Reviews. Cochrane Database Syst Rev. 2017 Apr [cited 2024 Jul];4(4):CD011279. doi: 10.1002/14651858.CD011279.pub3.
11. Epskamp S, Dibley H, Ray E, Bond N, White J, Wilkinson A, et al. Range of motion as an outcome measure for knee osteoarthritis interventions in clinical trials: an integrated review. Phys Ther Rev. 2020 [cited 2024 Jul];25(5–6):462–81. doi:10.1080/10833196.2020.1867393.
12. Aafreen A, Khan A, Khan AR, Ahmad A, Parween S, Maurya NK, Alshehri MM, Shaphe MA, Ahmed H, Mirza H. Reliability and validity of a smartphone goniometer application for measuring the quadriceps angle in healthy women: a cross-sectional study. Int J Ther Rehabil. 2024 Feb [cited 2025 Jan 9];31(2):1-0. doi: 10.12968/ijtr.2023.0048.
13. Al-Mahmood MR, Uddin MT, Islam MT, Fuad SM, Shah TR. Correlation between goniometric measurements of range of motion and radiographic scores in osteoarthritis knee: an observational study among females. Medicine (Baltimore). 2022 Aug [cited 2023 Jun];101(32):e29995. Available from: https://journals.lww.com/md-journal/fulltext/2022/08120/Correlation_between_goniometric_measurements_of.73.aspx?context = LatestArticles doi: 10.1097/MD.0000000000029995.
14. Perry J, Burnfield JM. Gait analysis: normal and pathological function. 2nd ed. Thorofare (NJ): SLACK Incorporated; 2010 [cited 2023 Jun].
15. Felson DT. Epidemiology of hip and knee osteoarthritis. Epidemiol Rev. 1988 [cited 2023 Jun];10:1-28. doi: 10.1093/oxfordjournals.epirev.a036019.
16. McAlindon TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, Bierma-Zeinstra SM, et al. OARSI guidelines for the non-surgical management of knee osteoarthritis. Osteoarthritis Cartilage. 2014 Mar [cited 2024 Jul];22(3):363-88. Available from: https://www.sciencedirect.com/science/article/pii/S1063458414000168 doi: 10.1016/j.joca.2014.01.003.
17. Szilagyi IA, Waarsing JH, van Meurs JBJ, Bierma-Zeinstra SMA, Schiphof D. A systematic review of the sex differences in risk factors for knee osteoarthritis. Rheumatology (Oxford). 2023 Jun [cited 2024 Jul];62(6):2037-2047. Available from: https://academic.oup.com/rheumatology/article/62/6/2037/6887132 doi: 10.1093/rheumatology/keac688.
18. Tschon M, Contartese D, Pagani S, Borsari V, Fini M. Gender and sex are key determinants in osteoarthritis not only confounding variables. A systematic review of clinical data. J Clin Med. 2021 Jul [cited 2024 Jul];10(14):3178. Available from: https://www.mdpi.com/2077-0383/10/14/3178 doi: 10.3390/jcm10143178.
19. Lopes DG, Costa D, Cruz EB, Mendonça N, Henriques AR, Branco J, et al. Association of physical activity with physical function and quality of life in people with hip and knee osteoarthritis: longitudinal analysis of a population-based cohort. Arthritis Res Ther. 2023 Jan [cited 2024 Jul];25(1):14. Available from: https://link.springer.com/article/10.1186/s13075-023-02996-x doi: 10.1186/s13075-023-02996-x.
20. Simic M, Harmer AR, Agaliotis M, Nairn L, Bridgett L, March L, et al. Clinical risk factors associated with radiographic osteoarthritis progression among people with knee pain: a longitudinal study. Arthritis Res Ther. 2021 Jun [cited 2024 Jul];23(1):160. Available from: https://link.springer.com/article/10.1186/s13075-021-02540-9 doi: 10.1186/s13075-021-02540-9.
21. Brosseau L, Balmer S, Tousignant M, O'Sullivan JP, Goudreault C, Goudreault M, et al. Intra-and intertester reliability and criterion validity of the parallelogram and universal goniometers for measuring maximum active knee flexion and extension of patients with knee restrictions. Arch Phys Med Rehabil. 2001 Mar [cited 2023 Jun];82(3):396-402. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0003999301234303 doi: 10.1053/apmr.2001.19250.
22. Takeda Y, Furukawa K. Clinical reliability and usability of smartphone goniometers for hip range of motion measurement. J Phys

Ther Sci. 2022 [cited 2023 Jun];34(6):433-9. Available from: https://www.jstage.jst.go.jp/article/jpts/34/6/34_2021-210/_article/-char/ja/ doi: 10.1589/jpts.34.433.
23. Rossettini G, Geri T, Polli A, Signori A, Testa M. Interrater reliability of procedures measuring the passive range of motion of lower extremity joints in healthy and symptomatic subjects. A systematic review. Ital J Physiother. 2012 Mar [cited 2024 Jul];2:12-31. Available from: https://www.sif-fisioterapia.it/media/24/IT-Journal-of-Physioyherapy-1-2012.pdf#page = 17
24. Parati M, Gallotta M, De Maria B, Pirola A, Morini M, Longoni L, et al. Video-based goniometer applications for measuring knee joint angles during walking in neurological patients: A validity, reliability and usability study. Sensors (Basel). 2023 Feb 16 [cited 2023 Jun];23(4):2232. Available from: https://www.mdpi.com/1424-8220/23/4/2232 doi: 10.3390/s23042232
25. Williams MA, McCarthy CJ, Chorti A, Cooke MW, Gates S. A systematic review of reliability and validity studies of methods for measuring active andPassive cervical range of motion. J Manipulative Physiol Ther. 2010 Feb [cited 2023 Jun];33(2):138-55. Available from: https://www.researchgate.net/profile/Christopher-Mccarthy-4/publication/41507566_A_Systematic_Review_of_Reliability_and_Validity_Studies_of_Methods_for_Measuring_Active_andPassive_Cervical_Range_of_Motion/links/604a008b92851c1bd4df22d5/A-Systematic-Review-of-Reliability-and-Validity-Studies-of-Methods-for-Measuring-Active-andPassive-Cervical-Range-of-Motion.pdf doi: 10.1016/j.jmpt.2009.12.009.
26. Alawna MA, Unver BH, Yuksel EO. The reliability of a smartphone goniometer application compared with a traditional goniometer for measuring ankle joint range of motion. J Am Podiatr Med Assoc. 2019 Jan [cited 2023 Jun];109(1):22-9. doi: 10.7547/16-128.
27. Shamsi M, Mirzaei M, Khabiri SS. Universal goniometer and electro-goniometer intra-examiner reliability in measuring the knee range of motion during active knee extension test in patients with chronic low back pain with short hamstring muscle. BMC Sports Sci Med Rehabil. 2019 Dec [cited 2023 Jun];11:1-5. Available from: https://link.springer.com/article/10.1186/s13102-019-0116-x doi: 10.1186/s13102-019-0116-x
28. Gajdosik RL, Bohannon RW. Clinical measurement of range of motion: review of goniometry emphasizing reliability and validity. Phys Ther. 1987 Dec [cited 2023 Jun];67(12):1867-72. Available from: https://www.researchgate.net/profile/Richard-Bohannon-2/publication/19477050_Clinical_Measurement_of_Range_of_Motion_Review_of_Goniometry_Emphasizing_Reliability_and_Validity/links/0c96051844b64e474d000000/Clinical-Measurement-of-Range-of-Motion-Review-of-Goniometry-Emphasizing-Reliability-and-Validity.pdf doi: 10.1093/ptj/67.12.1867.
29. Watkins MA, Riddle DL, Lamb RL, Personius WJ. Reliability of goniometric measurements and visual estimates of knee range of motion obtained in a clinical setting. Phys Ther. 1991 Feb [cited 2023 Jun];71(2):90-6. Available from: https://citeseerx.ist.psu.edu/document?repid = rep1&type = pdf&doi = ec07d3c06571530d5a-8306488baa6115f1b4ca0d doi: 10.1093/ptj/71.2.90.
30. Fernández-González P, Koutsou A, Cuesta-Gómez A, Carratalá-Tejada M, Miangolarra-Page JC, Molina-Rueda F. Reliability of kinovea® software and agreement with a three-dimensional motion system for gait analysis in healthy subjects. Sensors (Basel). 2020 Jun [cited 2023 Jun];20(11):3154. Available from: https://www.mdpi.com/1424-8220/20/11/3154 doi: 10.3390/s20113154.
31. Kamper SJ, Maher CG, Mackay G. Global rating of change scales: a review of strengths and weaknesses and considerations for design. J Man Manip Ther. 2009 Jul [cited 2023 Jun];17(3):163-70. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2762832/ doi: 10.1179/jmt.2009.17.3.163.
32. Mohsin F, McGarry A, Bowers R. The reliability of a video analysis system (PnO clinical movement data) and the universal goniometer in the measurement of hip, knee, and ankle sagittal plane motion among healthy subjects. J Prosthet Orthot. 2018 Jul [cited 2023 Jun];30(3):145-51. Available from: https://journals.lww.com/jpojournal/fulltext/2018/07000/the_reliability_of_a_video_analysis_system__pno.8.aspx doi: 10.1097/JPO.0000000000000201.
33. Kagee A. Addressing psychosocial problems among persons living with HIV. Afr J Psychiatry (Johannesbg). 2012 Nov [cited 2023 Jun];15(6):424-6. Available from: https://hdl.handle.net/10520/EJC127136
34. Beshara P, Anderson DB, Pelletier M, Walsh WR. The reliability of the microsoft kinect and ambulatory sensor-based motion tracking devices to measure shoulder range-of-motion: A systematic review and meta-analysis. Sensors (Basel). 2021 Dec [cited 2023 Jun];21(24):8186. Available from: https://www.mdpi.com/1424-8220/21/24/8186 doi: 10.3390/s21248186
35. Zheng H, Tulu B, Choi W, Franklin P. Using mHealth app to support treatment decision-making for knee arthritis: patient perspective. EGEMS (Wash DC). 2017 [cited 2023 Jun];5(2). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5994956/ doi: 10.13063/2327-9214.1284
36. Melián-Ortiz A, Varillas-Delgado D, Laguarta-Val S, Rodríguez-Aparicio I, Senent-Sansegundo N, Fernández-García M, Roger-de Oña I. Fiabilidad y validez concurrente de la app Goniometer Pro vs goniómetro universal en la determinación de la flexión pasiva de rodilla. Acta Ortop Mex. 2019 Feb [cited 2023 Jun];33(1):18-23. Available from: https://www.scielo.org.mx/scielo.php?pid = S2306-41022019000100018&script = sci_arttext
37. Felthun JZ, Taylor S, Shulruf B, Allen DW. Assessment methods and the validity and reliability of measurement tools in online objective structured clinical examinations: a systematic scoping review. J Educ Eval Health Prof. 2021 [cited 2024 Jul];18:11. Available from: https://synapse.koreamed.org/articles/1149208 doi: 10.3352/jeehp.2021.18.11.
38. Saiki Y, Kabata T, Ojima T, Kajino Y, Kubo N, Tsuchiya H. Reliability and validity of pose estimation algorithm for measurement of knee range of motion after total knee arthroplasty. Bone Joint Res. 2023 May [cited 2024 Jul];12(5):313-320. Available from: https://boneandjoint.org.uk/article/10.1302/2046-3758.125.BJR-2022-0257.R1 doi: 10.1302/2046-3758.125.BJR-2022-0257.R1.
39. Michelini A, Eshraghi A, Andrysek J. Two-dimensional video gait analysis: A systematic review of reliability, validity, and best practice considerations. Prosthet Orthot Int. 2020 Aug [cited 2024 Jul];44(4):245-262. Available from: https://journals.sagepub.com/doi/full/10.1177/0309364620921290. doi: 10.1177/0309364620921290.
40. Roggio F, Ravalli S, Maugeri G, Bianco A, Palma A, Di Rosa M, et al. Technological advancements in the analysis of human motion and posture management through digital devices. World J Orthop. 2021 Jul [cited 2024 Jul];12(7):467-484. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC8316840/ doi: 10.5312/wjo.v12.i7.467.
41. Soeters R, Damodar D, Borman N, Jacobson K, Shi J, Pillai R, Mehran N. Accuracy of a smartphone software application compared with a handheld goniometer for measuring shoulder range of motion in asymptomatic adults. Orthop J Sports Med. 2023 Jul [cited 2024 Jul];11(7):23259671231187297. Available from: https://journals.sagepub.com/doi/full/10.1177/23259671231187297 doi: 10.1177/23259671231187297.
42. Yaikwawongs N, Limpaphayom N, Wilairatana V. Reliability of digital compass goniometer in knee joint range of motion measurement. J Med Assoc Thai. 2009 Apr [cited 2024 Jul];92(4):517-22. Available from: https://www.thaiscience.info/Journals/Article/JMAT/10402800.pdf

43. Van Crombrugge I, Sels S, Ribbens B, Steenackers G, Penne R, Vanlanduit S. Accuracy assessment of joint angles estimated from 2d and 3d camera measurements. Sensors (Basel). 2022 Feb [cited 2024 Jul];22(5):1729. Available from: https://www.mdpi.com/1424-8220/22/5/1729 doi: 10.3390/s22051729.

44. Guerra E, Licciardi L, Van Veenendaal P, Robinson LS. Reliability and clinical utility of a novel telehealth-based goniometry approach to measure range of motion of the digits of the hand. J Hand Ther. 2024 Jan-Mar [cited 2024 Jul];37(1):83-93. doi: 10.1016/j.jht.2023.05.004.