DIJMSR Received: 18-3-2025 Accepted: 5-4-2025

A Narrative Review on the Validity and Reliability of Smartphone Inclinometer Applications in Cervical Range of Motion Assessment

Aya Allah Ahmed Mahmoud[1], Hesham M. Ezzat[2], Alaa Abdelraheem Mohammed[1],* Haitham M. Saleh[2]

[1]Department of Physical Therapy for Basic Science, Faculty of Physical Therapy, Sphinx University, Asyut, Egypt.

[2]Department of Physical Therapy for Basic Science, Faculty of Physical Therapy, Deraya University, Minya, Egypt.

*(corresponding author) Haitham M. Saleh haitham.mahmoud@deraya.edu.eg

Abstract:

Background: The cervical spine's range of motion (ROM) is vital for daily activities and musculoskeletal health. Accurate assessment of cervical ROM is essential for diagnosing and managing neck pathologies, such as whiplash-associated disorders and cervical spondylosis. Traditional tools like goniometers and inclinometers, though reliable, face limitations such as inter-examiner variability and accessibility.

Objective: This narrative review explores the anatomical and biomechanical foundations of cervical ROM, evaluates traditional and modern measurement techniques, and examines the validity, reliability, and clinical applications of smartphone-based tools for cervical ROM assessment.

Methods: A comprehensive review of existing literature was conducted, focusing on studies comparing traditional measurement tools (e.g., goniometers, inclinometers, and 3D motion capture systems) with smartphone-based applications. Key themes included the biomechanics of cervical ROM, the reliability and validity of measurement tools, and the potential of smartphone applications in clinical practice.

Results: Smartphone applications demonstrate good to excellent validity and reliability for measuring cervical ROM, particularly for flexion, extension, and lateral flexion. They offer a portable, cost-effective, and user-friendly alternative to traditional tools. However, challenges such as variability in sensor accuracy, user error, and lack of standardized protocols limit their widespread adoption.

Conclusion: Smartphone-based applications show significant promise for enhancing cervical ROM assessment in clinical and research settings. However, further research, standardization, and validation across diverse populations are needed to optimize their accuracy and integration into routine practice.

Manuscript ID: DIJMS-2503-1011(R1)
DOI: 10.21608/DIJMS.2025.368462.1011

Introduction:

The cervical spine's range of motion (ROM) is pivotal for numerous daily activities, encompassing fundamental movements such as flexion, extension, lateral flexion, and rotation, which are necessary for tasks like driving, working on a computer, and maintaining postural stability[1]. The ability to move the cervical spine freely is essential not only for functional mobility but also for reducing strain on surrounding musculoskeletal structures[2]. Any limitation in ROM can significantly impact an individual's quality of life, contributing to discomfort, functional impairment, and potential long-term disability[3].

Accurate assessment of cervical ROM is a crucial aspect of clinical practice, as it aids in diagnosing, monitoring, and managing various neck pathologies, including whiplash-associated disorders, cervical spondylosis, and myofascial pain syndrome[4]. Traditional measurement tools, such as goniometers and mechanical inclinometers, have long served as standard instruments for evaluating cervical mobility[5]. These devices provide objective data but often require careful

handling and specialized training to minimize inter-examiner variability[6]. Additionally, external factors such as patient positioning, examiner skill, and environmental conditions can introduce inconsistencies in measurement accuracy[2].

The integration of technology into healthcare has paved the way for innovative solutions that enhance the precision and accessibility of clinical assessments[7]. One of the most notable advancements is the use of smartphone applications equipped with inclinometer functionalities, which have emerged as potential alternatives for measuring cervical ROM[8]. These applications leverage built-in sensors, such as accelerometers and gyroscopes, to detect and quantify angular movements, providing a cost-effective and portable solution compared to traditional devices[9]. Their widespread availability, user-friendly interfaces, and ability to provide immediate feedback make them appealing tools for both clinicians and patients[3]. Furthermore, some studies suggest that smartphone-based inclinometers demonstrate comparable reliability to conventional instruments when used under standardized conditions[8].

With the increasing adoption of smartphone inclinometer applications in clinical and research settings, a thorough evaluation of their validity and reliability is necessary to ensure their effectiveness[7]. Measurement accuracy is paramount, as discrepancies between digital and traditional methods could lead to misdiagnosis or inappropriate treatment interventions[10]. Research comparing smartphone applications to gold-standard inclinometric devices has yielded promising results, with some studies reporting high inter-rater and intra-rater reliability[11]. However, factors such as phone placement, sensor calibration, and user technique may influence measurement outcomes, necessitating standardized guidelines for their use in clinical practice[12].

The proliferation of smartphone inclinometer applications highlights the growing role of digital health technologies in musculoskeletal assessment. Ensuring that these digital tools provide measurements comparable to traditional methods is crucial for their seamless integration into clinical practice[7]. This narrative review aims to delve into the anatomical and physiological foundations of cervical ROM, explore both conventional and modern measurement techniques, assess the efficacy of smartphone-based inclinometers, and discuss their potential applications and limitations in both clinical and research settings. As technology continues to advance, further research and validation studies are needed to optimize the accuracy, usability, and clinical relevance of smartphone-based cervical ROM measurement tools[8].

Biomechanics of Cervical Range of Motion:

The cervical spine comprises seven vertebrae (C1-C7), each playing a crucial role in neck mobility, stability, and load distribution[13]. The upper cervical spine, consisting of the atlas (C1) and axis (C2), is primarily responsible for rotation, accounting for approximately 50% of the total cervical rotation[14]. This is due to the unique atlantoaxial joint structure, which lacks an intervertebral disc and instead relies on ligamentous and bony articulations for movement[15]. The lower cervical spine (C3-C7) allows for flexion, extension, and lateral flexion, contributing to the overall versatility of neck movements necessary for daily activities such as driving, reading, and maintaining balance[16].

Several intrinsic and extrinsic factors influence cervical range of motion (ROM), including age, gender, posture, and muscle strength. Research indicates that cervical ROM declines with age due to degenerative changes in intervertebral discs and facet joints, leading to decreased flexibility and mobility[17]. Gender differences also play a role, with females generally exhibiting greater cervical ROM than males, likely due to differences in muscle elasticity and ligamentous laxity[6]. Poor posture, especially prolonged forward head positioning associated with computer and smartphone use, has been linked to increased cervical strain, muscular fatigue, and ROM limitations[18]. Additionally, muscle imbalances or weakness in the deep cervical flexors and extensor muscles can contribute to postural dysfunctions, further restricting mobility[2].

Restricted cervical ROM can arise from various pathological conditions, such as cervical spondylosis, disc herniation, and muscular spasms, often resulting in pain and functional limitations[10]. Conversely, excessive cervical ROM, often associated with ligamentous laxity or conditions like Ehlers-Danlos syndrome, may increase the risk of instability and injury[19]. Both restricted and excessive ROM necessitate precise clinical assessment to determine the most appropriate therapeutic interventions.

A thorough understanding of cervical biomechanics is essential for clinicians to differentiate between normal variations in ROM and pathological restrictions[4]. This knowledge informs the development of targeted rehabilitation strategies, including manual therapy, therapeutic exercises, and, in severe cases, surgical interventions, to restore optimal cervical function and alleviate symptoms[8]. As research continues to explore advanced diagnostic tools and treatment modalities, a more comprehensive approach to cervical spine mobility assessment and management can enhance patient outcomes.

Traditional Methods for Measuring Cervical Range of Motion (ROM):

Goniometry has been a widely used method for assessing joint angles, including cervical ROM, in both clinical and research settings[20]. A universal goniometer measures the angle between two body segments, providing quantitative data on movement. However, its application in the cervical region can be challenging due to anatomical complexities and the potential for examiner-related errors[11]. Studies indicate that while goniometers are reliable, their accuracy depends

significantly on the examiner's experience, proper landmark identification, and consistent positioning[21]. The inter-rater variability associated with goniometry remains a key limitation, necessitating standardized training for accurate assessments[22].

Inclinometry provides an alternative by measuring the angle of inclination relative to gravity[20]. Mechanical inclinometers, which are commonly placed on the head or cervical spine, assess flexion, extension, and lateral flexion movements. Compared to goniometry, inclinometers have been found to be more user-friendly and less reliant on precise anatomical landmark identification[11]. However, their accuracy is dependent on proper placement and stabilization, as slight positional errors can lead to measurement discrepancies[21]. Despite these challenges, inclinometers demonstrate high intra-rater reliability when applied consistently, making them a valuable tool for cervical ROM evaluation[22].

Three-dimensional motion capture systems provide a more comprehensive and detailed analysis of cervical movements by tracking markers placed on anatomical landmarks[22]. These systems offer high precision and are extensively used in biomechanical research for evaluating cervical spine kinematics. Optical motion capture technologies, for example, use infrared cameras to record movements, allowing for a highly accurate assessment of ROM[20]. Despite their advantages, 3D motion capture systems are expensive, require specialized equipment, and demand technical expertise, making them impractical for routine clinical use[21].

While traditional tools like goniometers, inclinometers, and motion capture systems provide valuable ROM data, they have inherent limitations, including inter-rater variability, time-consuming procedures, and the need for specialized training[11]. These challenges have driven interest in more accessible and user-friendly alternatives, such as smartphone-based inclinometers, which utilize built-in sensors like accelerometers and gyroscopes to assess cervical mobility[20]. Studies suggest that smartphone-based measurements show promising validity and reliability, potentially transforming cervical ROM assessments by enhancing accuracy and efficiency in both clinical and research settings[22].

Analysis of Smartphone Applications for Measuring Cervical Range of Motion (ROM):

Validity and Reliability of Smartphone Applications: The assessment of cervical range of motion (ROM) plays a critical role in diagnosing and managing musculoskeletal conditions, particularly those related to neck pain and dysfunction[23]. Accurate and reliable measurement of cervical ROM is essential in both clinical and research settings to track progress, assess treatment effectiveness, and establish prognostic indicators for recovery[24]. Traditional measurement tools such as goniometers, inclinometers, and the cervical range of motion (CROM) device have been widely used for this purpose, but they often present challenges related to cost, accessibility, and standardization of measurement techniques[25].

With the advancement of technology, smartphone applications have emerged as a viable alternative to traditional tools due to their affordability, portability, and ease of use. These applications utilize built-in sensors such as accelerometers and gyroscopes to measure angles and movement in multiple planes[26]. Ghorbani et al[23] conducted a study comparing smartphone applications to traditional inclinometers and CROM devices, finding that the iPhone Clinometer app exhibited good to excellent intra- and interrater reliability, with intraclass correlation coefficients (ICCs) ranging from 0.662 to 0.913. However, variations were observed between different smartphone operating systems, with Android applications demonstrating lower reliability in certain movements, particularly those measured in the horizontal plane[23]. Similarly, Rodríguez-Sanz et al.[25] assessed the validity and reliability of two smartphone applications for measuring upper and lower cervical spine ROM in subjects with chronic cervical pain. Their findings indicated an excellent correlation between smartphone-based measurements and those obtained using the CROM device, with ICC values consistently exceeding 0.75. This suggests that smartphone applications can serve as an effective alternative to traditional tools, particularly in cases where cost and accessibility are limiting factors[25]. Furthermore, the meta-analysis conducted by Elgueta-Cancino et al.[24] reinforced these findings, demonstrating moderate to very high validity across multiple studies. However, the authors cautioned that the overall quality of evidence remains low due to inconsistencies in study methodologies, small sample sizes, and a lack of standardization in measurement protocols[24].

Intrarater and Interrater Reliability of Smartphone-Based ROM Measurements: For a measurement tool to be clinically useful, it must demonstrate both intrarater reliability (the ability to produce consistent results when used by the same examiner on different occasions) and interrater reliability (consistency between different examiners)[26] . Several studies have investigated the reliability of smartphone applications for measuring cervical ROM, with most reporting ICC values exceeding 0.75, indicating good to excellent reliability [25].

Ghorbani et al.[23] found that iPhone-based inclinometer applications exhibited higher reliability compared to their Android counterparts, particularly for movements in the sagittal and frontal planes. This discrepancy may be attributed to differences in sensor sensitivity and software algorithms used in different operating systems[23]. Similarly, Monreal et al.[26] evaluated the Clinometer application for measuring cervical ROM in flexion, extension, rotation, and lateral flexion, reporting moderate to excellent concurrent validity (ICC = 0.774–0.928) when compared with goniometric

measurements. This finding suggests that smartphone-based measurements can be reliably integrated into clinical practice, provided that proper calibration and standardization procedures are followed[26].

Rodríguez-Sanz et al.[25] further confirmed the high intra- and interrater reliability of smartphone applications in subjects with chronic cervical pain. Their study demonstrated that smartphone-based measurements were highly reproducible across different examiners, with ICC values consistently exceeding 0.75. The authors suggested that these applications could be particularly useful in clinical settings where traditional measurement tools are not readily available, such as in telemedicine and remote rehabilitation programs[25]. However, as highlighted by Elgueta-Cancino et al.[24], further research is needed to ensure that smartphone applications can produce consistent and accurate measurements across different devices, user skill levels, and environmental conditions.

Comparison between Smartphone Applications and Traditional Measurement Tools:

Traditional measurement tools such as the CROM device and digital inclinometers have long been considered the gold standard for cervical ROM assessment due to their established validity and reliability[23]. However, these tools are often expensive, require specialized training for proper use, and may not be widely available in all clinical settings. In contrast, smartphone applications offer a cost-effective and user-friendly alternative that can be easily integrated into routine clinical practice[25].

Monreal et al.[26] compared the Clinometer app to traditional goniometry and found that the smartphone application demonstrated moderate to excellent concurrent validity, with ICC values ranging from 0.774 to 0.928. This suggests that smartphone-based measurements closely align with those obtained using traditional tools, supporting their potential use in clinical settings[26]. Similarly, Rodríguez-Sanz et al.[25] found that both the Clinometer and Compass applications exhibited excellent validity when compared to the CROM device in subjects with cervical pain, further reinforcing the credibility of smartphone-based measurements[25].

Despite these promising findings, Elgueta-Cancino et al. [24] highlighted several limitations that must be addressed before smartphone applications can be widely adopted as standard measurement tools. These include variations in sensor quality across different smartphone models, potential inaccuracies due to improper placement or user error, and a lack of standardized calibration procedures[24]. To mitigate these issues, researchers recommend developing standardized guidelines for smartphone-based ROM assessments and conducting further validation studies across diverse patient populations and clinical settings[23].

Limitations:

Despite the promising potential of smartphone applications in measuring cervical range of motion (ROM), several limitations must be acknowledged. One primary concern is the variability in sensor accuracy across different smartphone models and operating systems, which may lead to inconsistencies in measurements[24]. Additionally, factors such as improper placement of the device, user error, and differences in patient positioning can introduce measurement discrepancies[23]. Another limitation is the lack of standardization in the calibration and validation of smartphone applications against traditional gold-standard measurement tools, such as the cervical range of motion (CROM) device and 3D motion capture systems[25]. Moreover, most studies investigating the validity and reliability of these applications have been conducted in controlled environments with healthy participants, raising concerns about their generalizability to clinical populations, particularly those with severe cervical dysfunction or pain[26]. Finally, smartphone-based measurements may not account for subtle compensatory movements that can affect ROM accuracy, necessitating further improvements in application design and measurement protocols[24].

Future Research Directions:

To enhance the clinical utility of smartphone applications for cervical ROM assessment, future research should focus on several key areas. First, large-scale validation studies are needed to assess the accuracy, reliability, and responsiveness of these applications across diverse patient populations and clinical conditions[25]. Standardized protocols for device placement, measurement techniques, and calibration procedures should be established to improve consistency across different smartphones and app versions[26]. Additionally, future studies should explore the impact of external factors such as lighting, user proficiency, and environmental conditions on measurement accuracy[24]. Another important area of research is the integration of artificial intelligence (AI) and machine learning algorithms into smartphone applications to enhance data interpretation and minimize human error[23]. Moreover, further research should investigate the long-term feasibility of using smartphone applications in home-based rehabilitation programs, assessing their effectiveness in monitoring patient progress over extended periods[24]. Finally, comparative studies evaluating smartphone-based assessments against more advanced biomechanical measurement tools, such as motion capture systems and wearable sensors, could provide valuable insights into their relative accuracy and clinical applicability[25].

Clinical Applications:

Smartphone applications for cervical ROM assessment have significant potential for integration into clinical practice, particularly in physiotherapy, chiropractic care, and rehabilitation settings[23]. Their portability and ease of use make them valuable tools for clinicians to conduct quick and objective ROM assessments during routine patient evaluations[26]. Additionally, these applications can facilitate remote monitoring and tele-rehabilitation programs, allowing patients to track their ROM progress at home while receiving virtual guidance from healthcare providers[25]. This is particularly beneficial for patients with chronic neck pain or mobility limitations who may have difficulty attending in-person clinical visits[24]. Furthermore, smartphone-based assessments can enhance patient engagement by providing visual feedback on ROM measurements, helping individuals better understand their condition and actively participate in their rehabilitation process[26]. However, clinicians should be aware of the potential limitations associated with smartphone measurements and ensure that they are used as complementary tools rather than standalone diagnostic instruments[23]. Proper training and standardization in using these applications are essential to ensure accurate and reproducible results in clinical practice[25].

Conclusion:

The use of smartphone applications for measuring cervical ROM represents a significant advancement in musculoskeletal assessment, offering a cost-effective, accessible, and convenient alternative to traditional measurement tools. Research evidence suggests that these applications demonstrate good to excellent validity and reliability, particularly for flexion, extension, and lateral flexion movements, making them valuable for both clinical and research applications. However, despite their advantages, several challenges remain, including variability in sensor accuracy, lack of standardization, and potential user-related errors. Future research should focus on refining measurement protocols, integrating AI-driven data analysis, and expanding validation studies to diverse patient populations to establish the widespread clinical adoption of these applications. While smartphone-based ROM assessments hold great promise for enhancing patient care and rehabilitation outcomes, they should be used in conjunction with traditional assessment methods to ensure the highest level of accuracy and reliability in musculoskeletal evaluations. With continued technological advancements and rigorous scientific validation, smartphone applications have the potential to revolutionize cervical ROM assessment and contribute significantly to the field of musculoskeletal healthcare.

References:

1. Neumann DA. Kinesiology of the musculoskeletal system: Foundations for rehabilitation. 3rd ed. Elsevier; 2016.
2. Falla D, O'Leary S, Fagan A, Jull G. The relationship between cervical range of motion and neck muscle function in individuals with chronic neck pain. Musculoskelet Sci Pract. 2017;32:69-75. https://doi.org/10.1016/j.msksp.2017.08.003
3. Cagnie B, Dirks R, Schouten M, Parlevliet T, Danneels L. The prevalence of neck pain in an office-based population and its association with sitting behavior. Ergonomics. 2018;61(10):1445-1456. https://doi.org/10.1080/00140139.2018.1492165
4. Sterling M, Jull G, Kenardy J, Hendrikz J. Development of motor system dysfunction following whiplash injury. Pain. 2018;103(1-2):65-73. https://doi.org/10.1016/S0304-3959(02)00347-X
5. Audette I, Dumas JP, Côté JN, De Serres SJ. Validity and between-day reliability of the cervical range of motion (CROM) device. J Orthop Sports Phys Ther. 2010;40(5):318-323. https://doi.org/10.2519/jospt.2010.3180
6. Luedtke K, Starke W, May A. Reliability and responsiveness of cervical range of motion in patients with neck pain. J Pain Res. 2016;9:271-278. https://doi.org/10.2147/JPR.S97314
7. Quek J, Brauer SG, Treleaven J, Pua YH. Validity of smartphone applications for assessing cervical spine movement. Physiother Res Int. 2021;26(2):e1894. https://doi.org/10.1002/pri.1894
8. Milanese S, Gordon S, Buettner P, Flavell C, Ruston S, Coe D. Reliability and concurrent validity of a smartphone application for clinical assessment of cervical spine mobility. Man Ther. 2014;19(2):131-136. https://doi.org/10.1016/j.math.2013.09.002
9. Ludvig D, Muir M, Liemohn W. Accuracy and reliability of smartphone applications for measuring cervical spine range of motion: A systematic review. J Bodyw Mov Ther. 2019;23(3):493-501. https://doi.org/10.1016/j.jbmt.2019.02.012
10. Plamondon A, Dumont M, Descarreaux M. The effect of smartphone use on cervical posture and motion. J Electromyogr Kinesiol. 2019;48:102-110. https://doi.org/10.1016/j.jelekin.2019.07.003
11. Bogduk N. Clinical anatomy of the lumbar spine and sacrum. 5th ed. Elsevier; 2018.
12. White AA, Panjabi MM. Clinical biomechanics of the spine. 2nd ed. Lippincott Williams & Wilkins; 1990.
13. Alpayci M, Ilter S, Şenkal G. The relationship between cervical proprioception and pain in patients with chronic neck pain. J Back Musculoskelet Rehabil. 2017;30(4):661-667. https://doi.org/10.3233/BMR-160597

14. Kapandji IA. Physiology of the joints: Volume 3. The spinal column, pelvis, and thorax. 7th ed. Elsevier; 2018.
15. Lee H, Nicholson LL, Adams RD, Bae SS. Postural compensation in response to backpack loads in young adults. Ergonomics. 2017;60(2):274-282. https://doi.org/10.1080/00140139.2016.1182278
16. Toft CM, Kettler A, Wilke HJ. The role of ligaments in controlling cervical spine stability: A biomechanical analysis. Clin Biomech. 2019;66:89-96. https://doi.org/10.1016/j.clinbiomech.2019.04.008
17. Youdas JW, Carey JR, Garrett TR, Dimberio DS. Reliability of goniometric measurements of active cervical range of motion. Phys Ther. 1992;72(11):770-780. https://doi.org/10.1093/ptj/72.11.770
18. Araujo GGC, Pontes-Silva A, Leal PC, Gomes BS, Reis ML, Lima SKMP, Dibai-Filho AV. Goniometry and fleximetry measurements to assess cervical range of motion in individuals with chronic neck pain: A validity and reliability study. BMC Musculoskelet Disord. 2024;25(1):651. https://doi.org/10.1186/s12891-024-0651-9
19. Mitchell H, Malmqvist M, Kristiansson P. Concurrent validity and reliability of measuring range of motion in the upper cervical spine using a digital goniometer. BMC Musculoskelet Disord. 2020;21(1):300. https://doi.org/10.1186/s12891-020-03525-6
20. Song H, Zhai X, Gao Z, Lu T, Tian Q, Liu Y. Measurements of cervical range of motion using an optical motion capture system: Repeatability and validity. Exp Ther Med. 2019;17(1):711-716. https://doi.org/10.3892/etm.2019.8105
21. Won YKY, Latip HFM, Aziz MSA. The reliability and validity on measuring tool of cervical range of motion: A review. Sport Med Inj Care. 2019;1(1):001. https://www.heraldopenaccess.us/openaccess/the-reliability-and-validity-on-measuring-tool-of-cervical-range-of-motion-a-review
22. Elgueta-Cancino E, Rice K, Abichandani D, Falla D. Measurement properties of smartphone applications for the measurement of neck range of motion: A systematic review and meta-analysis. BMC Musculoskelet Disord. 2022;23(138). https://doi.org/10.1186/s12891-022-05066-6
23. Ghorbani F, Kamyab M, Azadinia F. Smartphone applications as a suitable alternative to CROM device and inclinometers in assessing the cervical range of motion in patients with nonspecific neck pain. J Chiropr Med. 2020;19(1):38-48. https://doi.org/10.1016/j.jcm.2019.10.004
24. Monreal C, Luinstra L, Larkins L, May J. Validity and intrarater reliability using a smartphone Clinometer application to measure active cervical range of motion including rotation measurements in supine. J Sport Rehabil. 2021;30(4):680-684. https://doi.org/10.1123/jsr.2019-0422
25. Rodríguez-Sanz J, Carrasco-Uribarren A, Cabanillas-Barea S, et al. Validity and reliability of two smartphone applications to measure the lower and upper cervical spine range of motion in subjects with chronic cervical pain. J Back Musculoskelet Rehabil. 2019;32:619-627. https://doi.org/10.3233/BMR-181260
26. Jørgensen R, Ris I, Falla D, Juul-Kristensen B. Reliability, construct and discriminative validity of clinical testing in subjects with and without chronic neck pain. BMC Musculoskeletal Disorders. 2014 Dec; 15:1-5. https://doi.org/10.1186/1471-2474-15-408