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Original Article

Smartphone Video-Based Cervical Range of Motion Assessment in Pediatric Torticollis: A Validity and Reliability Study

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ABSTRACT\

Background: Accurate cervical range-of-motion assessment is important for diagnosing torticollis, planning rehabilitation, and monitoring clinical change. Smartphone video analysis may provide an accessible alternative to conventional measurement, but its measurement properties require evaluation. Objective: To determine the concurrent validity, intra-rater reliability, inter-rater reliability, and measurement error of smartphone video-based cervical range-of-motion assessment in children with torticollis. Methods: This cross-sectional measurement-property study included 30 children aged 6 months to 5 years with congenital or acquired torticollis. Cervical rotation, lateral flexion, flexion, and extension were assessed using smartphone-recorded video analysis and conventional goniometry. Pearson correlation coefficients evaluated associations between methods. Two assessors analysed the recordings for inter-rater reliability, and one assessor repeated the analysis after one week for intra-rater reliability. Intraclass correlation coefficients, standard errors of measurement, and 95% minimal detectable changes were calculated. Results: Smartphone measurements were 0.7°–0.8° lower than goniometric measurements, with no reported significant differences between methods. Correlations ranged from 0.88 to 0.95 (all $p<0.001$). Intra-rater ICCs ranged from 0.92 to 0.96 and inter-rater ICCs from 0.90 to 0.94. SEM values ranged from 2.1° to 2.5°, and MDC95 values ranged from 5.8° to 6.9°. Conclusion: Smartphone video analysis demonstrated strong associations with goniometry and high reliability for repeated analysis of stored recordings, although formal agreement analysis remains necessary before clinical interchangeability can be assumed. Keywords: Smartphone video analysis; Cervical range of motion; Pediatric torticollis; Congenital muscular torticollis; Concurrent validity; Inter-rater reliability; Intra-rater reliability; Measurement error.

INTRODUCTION

Pediatric torticollis is a musculoskeletal condition characterized by an abnormal head posture associated with restricted cervical mobility and muscular imbalance (1). Congenital muscular torticollis is the most frequently recognized form and commonly results from shortening or fibrosis of the sternocleidomastoid muscle, producing ipsilateral cervical lateral flexion and restricted contralateral rotation. Acquired torticollis may arise from several musculoskeletal, neurological, ocular, or inflammatory causes. Irrespective of aetiology, delayed recognition and management may contribute to persistent postural asymmetry, craniofacial deformity, restricted cervical movement, and functional limitations (2-4).

Accurate assessment of cervical range of motion is central to the clinical evaluation of children with torticollis. Objective measurements help establish the severity and direction of movement restriction, guide treatment planning, monitor rehabilitation progress, and determine whether observed changes exceed expected measurement variability. Conventional approaches include visual estimation, manual goniometry, and other clinician-administered measurements. Although these methods are widely used, their accuracy and repeatability may be influenced by assessor experience, anatomical landmark identification, participant positioning, movement compensation, and the child's age and cooperation. Instrumented three-dimensional motion-analysis systems can provide detailed movement measurements but may be costly, technically demanding, and unavailable in routine paediatric rehabilitation practice (5-7).

The increasing availability of high-resolution smartphone cameras has created opportunities for low-cost digital movement assessment. Smartphone-recorded videos can be reviewed frame by frame and analysed using digital motion-analysis software to quantify joint or segmental angles. Unlike direct clinical measurements, stored recordings may permit repeated assessment by different clinicians, facilitate documentation of rehabilitation progress, and reduce dependence on measurements obtained during a single clinical observation. These characteristics may be particularly useful in young children, whose attention, cooperation, and movement consistency can vary during assessment (8-10).

Nevertheless, the use of smartphone video analysis for cervical range-of-motion measurement requires formal evaluation before it can be incorporated into clinical practice. A method may demonstrate a strong statistical association with conventional measurement without showing sufficient agreement for the two methods to be used interchangeably. Its clinical usefulness also depends on the repeatability of video interpretation between assessors and within the same assessor, as well as the magnitude of measurement error. Evidence concerning these measurement properties in children with torticollis remains limited (11-13).

Therefore, this study aimed to determine the concurrent validity and intra-rater and inter-rater reliability of smartphone video-based cervical range-of-motion measurements compared with conventional clinical goniometry in children with torticollis. The study also quantified the standard error of measurement and 95% minimal detectable change for cervical rotation, lateral flexion, flexion, and extension.

MATERIALS AND METHODS

A cross-sectional observational measurement-property study with a repeated video-analysis component was conducted among children receiving assessment in paediatric rehabilitation settings. The study evaluated the concurrent validity of smartphone video-based cervical range-of-motion measurements against conventional clinical goniometry and examined the repeatability of angle extraction from stored smartphone recordings. Thirty children clinically diagnosed with torticollis were included. Eligible participants were aged between 6 months and 5 years, had congenital muscular torticollis or acquired torticollis, and were able to undergo assisted cervical movement assessment. Children with cervical fractures, neurological disorders, previous cervical surgery, or severe developmental limitations that prevented completion of the assessment were excluded (13-15).

Demographic and clinical information was recorded for each participant, including age, sex, classification of torticollis, and side of involvement. Cervical range of motion was evaluated for rotation, lateral flexion, flexion, and extension. Each movement was assessed using conventional clinical goniometry and smartphone video-based analysis. The assessments were performed under standardized clinical conditions, with the child positioned and supported to permit the required cervical movement while limiting avoidable compensatory movement. Assisted movements were used where necessary according to the child's age and ability to cooperate (16).

For the conventional assessment, cervical angles were measured in degrees by an experienced physiotherapist using clinical goniometry. The participant was stabilized during each movement, and the goniometric measurement was obtained at the available end range. The same four cervical movements assessed by goniometry were recorded using a smartphone camera. The smartphone was maintained at a fixed height and distance relative to the participant, and recordings were obtained from the viewing plane appropriate to the movement being assessed. The recorded videos were subsequently reviewed using digital motion-analysis software, through which cervical angles were determined from the relevant anatomical alignment at the available end range (17).

Two assessors independently analysed the smartphone recordings to determine inter-rater reliability. Each assessor evaluated the stored recordings without altering the original video files. For intra-rater video-analysis reliability, the same assessor repeated the measurements after an interval of one week. The repeat assessment was therefore designed to determine the stability of angle extraction from the stored recordings rather than test–retest reliability of the entire recording procedure or the child's repeated physical performance.

The smartphone-derived measurements were compared with the corresponding goniometric measurements for each cervical movement. Continuous variables were summarized using means and standard deviations, whereas categorical variables were presented as frequencies and percentages. Differences between smartphone video-based and goniometric measurements were examined using paired comparisons. Concurrent validity was evaluated using Pearson correlation coefficients to quantify the strength and direction of the linear association between the two measurement methods. Correlation coefficients were interpreted as measures of association and not as direct evidence that the methods were interchangeable.

Intra-rater and inter-rater reliability were evaluated using intraclass correlation coefficients. Reliability estimates were interpreted according to the magnitude of the coefficients, with values above 0.75 indicating acceptable reliability and values of 0.90 or greater indicating excellent reliability. Measurement error was quantified using the standard error of measurement. The 95% minimal detectable change was calculated from the standard error of measurement using the formula $MDC95 = SEM \times 1.96 \times \sqrt{2}$. Statistical significance was established at $p<0.05$.

RESULTS

Thirty children with torticollis were included in the analysis. Their mean age was 24.6 ± 10.8 months. Seventeen participants were male (56.7%) and 13 were female (43.3%). Congenital muscular torticollis was present in 26 children (86.7%), whereas four children (13.3%) had acquired torticollis. Right-sided involvement was reported in 18 participants (60.0%) and left-sided involvement in 12 (40.0%).

Smartphone video-based measurements were numerically close to the corresponding goniometric measurements across all four cervical movements. Smartphone-derived measurements were lower than goniometric measurements by 0.7° for rotation, 0.7° for lateral flexion, 0.8° for flexion, and 0.7° for extension. The reported comparisons did not identify statistically significant differences between the two methods for any movement (all $p>0.05$). However, the absence of exact p-values, confidence intervals for paired differences, and limits of agreement prevented direct assessment of equivalence or interchangeability.

Strong positive correlations were observed between smartphone video-based and goniometric measurements. Rotation demonstrated the highest correlation ($r=0.95$; 95% CI: 0.90–0.98; $p<0.001$), followed by flexion ($r=0.92$; 95% CI: 0.84–0.96; $p<0.001$), extension ($r=0.90$; 95% CI: 0.80–0.95; $p<0.001$), and lateral flexion ($r=0.88$; 95% CI: 0.76–0.94; $p<0.001$). These findings indicated consistently strong linear associations between the two measurement approaches, although correlation alone did not establish agreement at the individual-participant level.

Table 1. Demographic and Clinical Characteristics of Children With Torticollis

Characteristic	n (%) or Mean ± SD
Total participants	30
Age, months	24.6 ± 10.8
Male	17 (56.7)
Female	13 (43.3)
Congenital muscular torticollis	26 (86.7)
Acquired torticollis	4 (13.3)
Right-sided involvement	18 (60.0)
Left-sided involvement	12 (40.0)

SD: standard deviation.

Table 2. Comparison of Smartphone Video-Based and Goniometric Cervical Range-of-Motion Measurements

Cervical movement	Smartphone video, Mean ± SD (°)	Goniometry, Mean ± SD (°)	Mean difference (°)	p-value
Rotation	52.4 ± 10.6	53.1 ± 10.8	−0.7	>0.05
Lateral flexion	31.6 ± 8.2	32.3 ± 8.5	−0.7	>0.05
Flexion	43.8 ± 9.4	44.6 ± 9.2	−0.8	>0.05
Extension	38.7 ± 8.9	39.4 ± 9.1	−0.7	>0.05

Mean difference was calculated as smartphone video measurement minus goniometric measurement. SD: standard deviation. Exact p-values, paired-difference standard deviations, confidence intervals, and test statistics were unavailable.

Table 3. Correlation Between Smartphone Video-Based and Goniometric Cervical Range-of-Motion Measurements

Cervical movement	Pearson's r	95% CI	p-value
Rotation	0.95	0.90–0.98	<0.001
Lateral flexion	0.88	0.76–0.94	<0.001
Flexion	0.92	0.84–0.96	<0.001
Extension	0.90	0.80–0.95	<0.001

CI: confidence interval. Confidence intervals were derived from the reported correlation coefficients and sample size using Fisher's z transformation. Pearson's r represents linear association and does not independently establish agreement or interchangeability between measurement methods.

Table 4. Reliability and Measurement Error of Smartphone Video-Based Cervical Range-of-Motion Analysis

Cervical movement	Intra-rater ICC	Inter-rater ICC	SEM (°)	MDC95 (°)
Rotation	0.96	0.94	2.1	5.8
Lateral flexion	0.93	0.91	2.4	6.6
Flexion	0.94	0.92	2.2	6.1
Extension	0.92	0.90	2.5	6.9

ICC: intraclass correlation coefficient; SEM: standard error of measurement; MDC95: 95% minimal detectable change. Intra-rater reliability represents repeated analysis of the same stored recordings after one week rather than repeat recording of the participants. MDC95 was calculated as SEM × 1.96 × $\sqrt{2}$. Confidence intervals could not be calculated because the ICC model and underlying variance components were unavailable. Repeated analysis of the stored smartphone recordings demonstrated high intra-rater and inter-rater reliability. Intra-rater ICCs ranged from 0.92 for extension to 0.96 for rotation, whereas inter-rater ICCs ranged from 0.90 for extension to 0.94 for rotation. Rotation showed the highest intra-rater and inter-rater reliability, while extension produced the lowest coefficients; nevertheless, all reported point estimates were at least 0.90. The SEM ranged from 2.1° for rotation to 2.5° for extension. Corresponding MDC95 values ranged from 5.8° to 6.9°, including 5.8° for rotation, 6.6° for lateral flexion, 6.1° for flexion, and 6.9° for extension. Under the reported assessment conditions, an observed change exceeding approximately 6°–7° would therefore be more likely to represent change beyond measurement error, depending on the cervical movement evaluated.

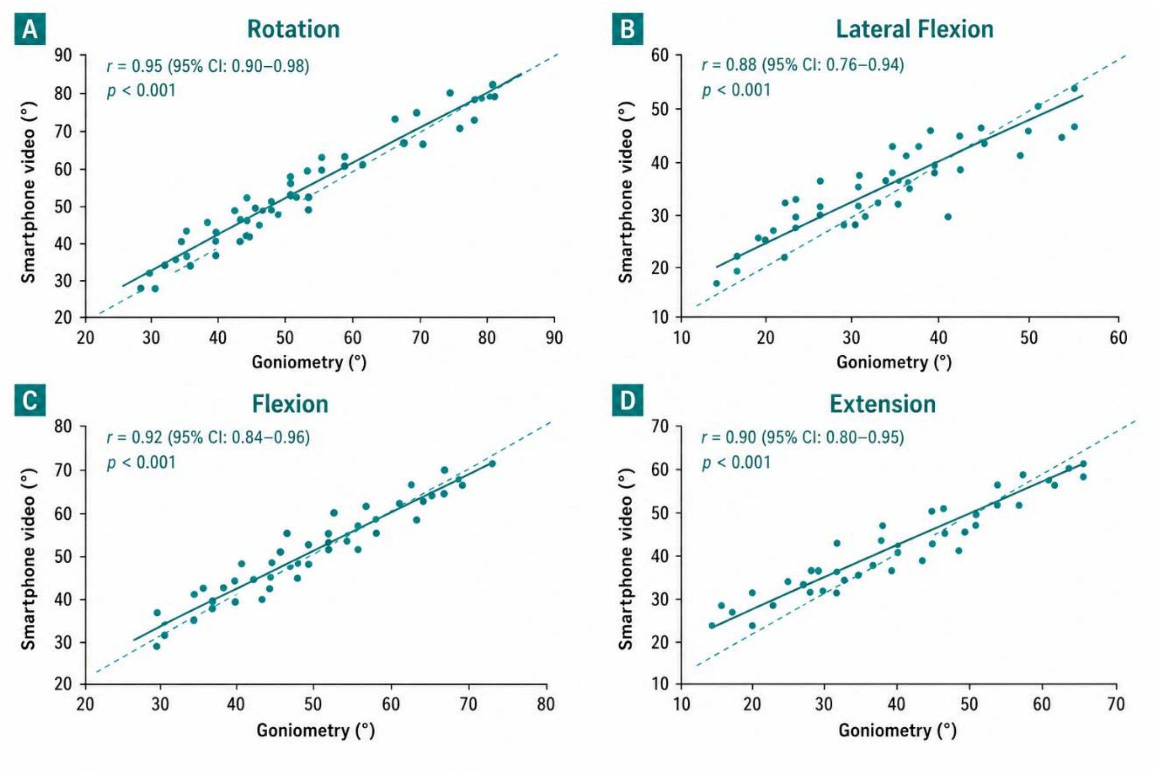

Figure 1 demonstrates strong positive correlations between smartphone video-based and goniometric cervical range-of-motion measurements for rotation (r=0.95), lateral flexion (r=0.88), flexion (r=0.92), and extension (r=0.90), with all associations statistically significant at p<0.001; the regression lines closely follow the lines of equality, indicating consistently similar measurements across the four cervical movements.

DISCUSSION

This study evaluated the concurrent validity, intra-rater reliability, inter-rater reliability, and measurement error of smartphone video-based cervical range-of-motion assessment in children with torticollis. Smartphone-derived measurements were numerically close to conventional goniometric measurements across cervical rotation, lateral flexion, flexion, and extension, with mean differences ranging from −0.7° to −0.8°. Strong positive correlations were observed for all four movements, and repeated analysis of the stored recordings produced high intra-rater and inter-rater intraclass correlation coefficients. These findings indicate that smartphone video analysis consistently tracked variation in cervical mobility and that trained assessors could reproduce angle measurements from the same recordings with limited measurement error (11-13).

Rotation demonstrated the strongest relationship between the two measurement approaches, with a correlation coefficient of 0.95, followed by flexion, extension, and lateral flexion. The comparatively lower correlation for lateral flexion may reflect the greater difficulty of maintaining movement within a single frontal plane. In young children, shoulder elevation, trunk displacement, head rotation, inconsistent stabilization, and variable cooperation may influence the apparent angle captured by a two-dimensional camera. Rotation may be easier to standardize when the camera, child, and movement plane remain appropriately aligned, although out-of-plane movement can still introduce measurement error. The observed differences between movements therefore suggest that the performance of smartphone assessment may depend not only on image quality but also on movement-specific positioning and stabilization requirements (14-16).

The mean smartphone measurements were consistently 0.7°–0.8° lower than the corresponding goniometric measurements. This small systematic pattern may have resulted from differences in landmark identification, camera alignment, frame selection, participant positioning, or determination of the available end range. However, the absence of statistically significant paired differences did not establish equivalence or interchangeability between the methods. Pearson correlation coefficients quantified the strength of linear association but did not determine whether individual smartphone measurements agreed sufficiently with goniometric values across the complete measurement range. Formal agreement analysis using participant-level paired measurements would therefore be required before the two approaches could be considered clinically interchangeable (17).

The intra-rater ICCs ranged from 0.92 to 0.96, while the inter-rater ICCs ranged from 0.90 to 0.94. Rotation showed the highest intra-rater and inter-rater coefficients, whereas extension showed the lowest. Nevertheless, all reported point estimates were at least 0.90, indicating highly consistent angle extraction from the stored recordings. These findings primarily represented reliability of video interpretation rather than test–retest reliability of the complete assessment procedure. Because the same recordings were reanalysed, the estimates did not incorporate variability arising from repeat camera placement, participant repositioning, movement performance, child behaviour, or a second clinical session. Reliability of the entire smartphone-based procedure may therefore be lower than the reported video-analysis reliability.

The SEM values ranged from 2.1° to 2.5°, indicating relatively limited random measurement error during repeated analysis of the stored videos. The corresponding MDC95 values ranged from 5.8° for rotation to 6.9° for extension. These values suggest that an observed change of approximately 6°–7°, depending on the cervical movement, would be more likely to exceed measurement error under the conditions of this study. The MDC95 should not, however, be interpreted automatically as the minimum clinically important difference. Measurement error and clinical importance are distinct concepts, and the magnitude of cervical ROM change that is meaningful to children, caregivers, and clinicians requires separate investigation (18).

Smartphone video analysis may offer practical advantages in paediatric rehabilitation. Recordings can be reviewed frame by frame, retained for longitudinal comparison, and analysed by more than one assessor. The approach may also reduce dependence on specialized motion-analysis systems and allow clinicians to document changes in cervical movement visually and quantitatively. Its affordability and portability may be especially relevant in clinical environments where advanced biomechanical equipment is unavailable. Nevertheless, clinical implementation requires standardized recording procedures, clearly defined anatomical landmarks, assessor training, secure storage of identifiable paediatric videos, and confirmation that measurements remain reliable when recordings are obtained by different clinicians or caregivers.

Several strengths were evident in the study. Four clinically relevant cervical movements were assessed, smartphone measurements were compared with an established clinical measurement approach, two assessors participated in the reliability analysis, and both relative reliability and absolute measurement error were reported. The consistency of the correlation and ICC estimates across movements also supported the internal coherence of the reported findings.

The findings should be interpreted in view of important limitations. The sample included only 30 children and combined congenital muscular torticollis with acquired torticollis, despite possible differences in aetiology, severity, age distribution, and movement behaviour. The broad age range from 6 months to 5 years may also have introduced variation in motor control, cooperation, and the need for assisted movement. The study did not report a sample-size calculation, participant recruitment flow, assessor blinding, measurement order, exact smartphone and software specifications, anatomical landmark procedures, or the ICC model. Confidence intervals for ICC estimates and paired mean differences were unavailable. Conventional goniometry was used as the comparator, but it may itself be affected by positioning and assessor-related error. In addition, the use of two-dimensional video could not fully account for three-dimensional cervical movement, parallax, or movement outside the intended recording plane. Most importantly, correlation analysis did not establish individual-level agreement, and repeat analysis of stored recordings did not evaluate the reproducibility of the full recording procedure (20).

Future investigations should use larger and diagnostically homogeneous samples, prespecified sample-size calculations, standardized movement and camera protocols, assessor blinding, and complete reporting of ICC models and confidence intervals. Participant-level data should be analysed using Bland–Altman methods or another appropriate agreement framework. Repeat recordings obtained during separate sessions would permit evaluation of test–retest reliability of the complete procedure. Studies should also examine responsiveness to rehabilitation, age-specific feasibility, automated landmark tracking, caregiver-recorded videos, and the relationship between MDC95 values and clinically important improvement.

CONCLUSION

Smartphone video-based cervical range-of-motion measurements demonstrated strong positive correlations with conventional goniometry and high intra-rater and inter-rater reliability during repeated analysis of stored recordings in children with torticollis. Measurement error was limited, with MDC95 values ranging from 5.8° to 6.9° across the assessed cervical movements. These findings support smartphone video analysis as a promising method for quantifying paediatric cervical mobility under standardized assessment conditions; however, formal agreement analysis and evaluation of the complete recording procedure are required before clinical interchangeability with goniometry can be established.

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